Intrinsic Object Centred Reference

Employing Object Structure to Define Space for Memory and Language

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Employing Object Structure to Define Space for Memory and Language

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In dem körperlichen Raume lassen sich wegen seiner drei Abmessungen drei Flächen denken, die einander insgesamt rechtwinklicht schneiden. Da wir alles, was außer uns ist, durch die Sinnen nur in so fern kennen, als es in Beziehung auf uns selbst steht, so ist kein Wunder, daß wir von dem Verhältniß dieser Durchschnittsflächen zu unserem Körper den ersten Grund hernehmen, den Begriff der Gegenden im Raume zu erzeugen. Die Fläche, worauf die Länge unseres Körpers senkrecht steht, heißt in Ansehung unser horizontal; und diese Horizontalfläche giebt Anlaß zu dem Unterschiede der Gegenden, die wir durch oben und unten bezeichnen. Auf dieser Fläche können zwei andere senkrecht stehen und sich zugleich rechtwinklicht durchkreuzen, so daß die Länge des menschlichen Körpers in der Linie des Durchschnitts gedacht wird. Die eine dieser Vertikalflächen theilt den Körper in zwei äußerlich ähnliche Hälften und giebt den Grund des Unterschiedes der rechten und der linken Seite ab, die andere, welche auf ihr perpendicular steht, macht, daß wir den Begriff der vorderen und hinteren Seite haben können.

> Kant, I. (1768). Von dem ersten Grunde des Unterschiedes der Gegenden im Raume (pp. 378-379).

Because of its three dimensions, three planes are conceivable in physical space that intersect one another in total at right angles. Because we know all that is outside of us through the senses to that extent only as it is with respect to ourselves, it comes as no surprise that we take from the relation of these cross-sections to our body the first ground to bring forth the concept of regions in space. That plane, to which the length of our body stands perpendicular, is called in our observation horizontal; and this horizontal plane provides the occasion for the distinction between the regions that we denote with above and below. On this plane, two others can stand perpendicular and at the same time intersect one another at a right angle such that the length of the human body is conceived in the line of the cross-section. One of those vertical planes divides the body in two exteriorly similar halves and delivers the ground for the distinction between the right and the left side; the other oriented perpendicular to it causes that we can have the concept of front and back.

> Kant, I. (1768). On the First Ground of the Distinction of Regions in Space (pp. 378-379). Translation by the present author.

Abstract

The thesis discusses the use of Intrinsic Object Centred Frames of Reference in defining and categorising the location, direction, and/or region of one object (the Figure) in the space surrounding another object (the Referent). It is considered how it is possible to define an intrinsic location (e.g., for use in memory) and to describe the location by means of a Directional Preposition (i.e., *above*, *below*, *in front of*, *behind*, *to the left of*, and *to the right of*) within such Frames of Reference. To this end, the research integrates and builds upon investigations on intrinsic descriptions of objects, object recognition, spatial language, spatial memory, and the connection between spatial language and spatial memory.

The thesis specifies how a Referent is assigned an intrinsic description in terms of *top-bottom*, *front-back* and *left-right* distinctions and how such a description can be used to define as well as describe the location of a Figure. To this end, it is discussed how the spatial structure of an object may hinder or facilitate its use as a Referent. Likewise, the information associated with the object category that influences the definition and labelling of dimensions and directions is considered. The processing required to produce a Directional Preposition (used in an Intrinsic Object Centred Frame of Reference) from viewing an object constellation is sketched. Findings from spatial memory research are reviewed with a special focus on effects of categories on reports from memory.

An experiment is presented that addresses several aspects of the developed theory by employing a spatial memory task for locations relative to a Referent whereby locations are exclusively defined in an Intrinsic Object Centred Frame of Reference. Both reaction time and the bias and accuracy of reports from memory are obtained simultaneously. This experimental procedure leads to several original findings. Reaction

time data is obtained in an experimental task that does not explicitly require the linguistic labelling of directions, but is still found to resemble data obtained with tasks in which labelling is an integral part of the experimental task. Data on the bias and accuracy of memory reports is gathered in an exclusively Intrinsic Frame of Reference. Considerable proportions of direction errors are observed in the spatial memory task.

The conclusion is drawn that an underlying intrinsic description of a Referent can be invoked to explain results on spatial memory as well as spatial language tasks. A relation between data from language and memory tasks can be inferred from such an underlying description if the respective task demands are kept into account.

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Was kann wohl meiner Hand oder meinem Ohr ähnlicher, und in allen Stücken gleicher sein, als ihr Bild im Spiegel? Und dennoch kann ich eine solche Hand, als im Spiegel gesehen wird, nicht an die Stelle ihres Urbildes setzen; denn wenn dieses eine rechte Hand war, so ist jene im Spiegel eine linke, und das Bild des rechten Ohres ist ein linkes, das nimmermehr die Stelle des ersteren vertreten kann. Nun sind hier keine innre Unterschiede, die irgendein Verstand nur denken könnte; und dennoch sind die Unterschiede innerlich, soweit die Sinne lehren, denn die linke Hand kann mit der rechten, ohnerachtet aller beiderseitigen Gleichheit und Ähnlichkeit, doch nicht zwischen denselben Grenzen eingeschlossen sein, (sie können nicht kongruieren) der Handschuh der einen Hand kann nicht auf der andern gebraucht werden. Was ist nun die Auflösung? Diese Gegenstände sind nicht etwa Vorstellungen der Dinge, wie sie an sich selbst sind, und wie sie der pure Verstand erkennen würde, sondern es sind sinnliche Anschauungen, d. i. Erscheinungen, deren Möglichkeit auf dem Verhältnisse gewisser an sich unbekannten Dinge zu etwas anderem, nämlich unserer Sinnlichkeit beruht. Von dieser ist nun der Raum die Form der äußern Anschauung, und die innere Bestimmung eines jeden Raumes ist nur durch die Bestimmung des äußeren Verhältnisses zu dem ganzen Raume, davon jener ein Teil ist, (dem Verhältnisse zum äußeren Sinne) d. i. der Teil ist nur durchs Ganze möglich, welches bei Dingen an sich selbst, als Gegenständen des bloßen Verstandes niemals, wohl aber bei bloßen Erscheinungen stattfindet. Wir können daher auch den Unterschied ähnlicher und gleicher, aber doch inkongruenter Dinge (z. B. widersinnig gewundener Schnecken) durch keinen einzigen Begriff verständlich machen, sondern nur durch das Verhältnis zur rechten und linken Hand, welches unmittelbar auf Anschauung geht.

Kant, I. (1783). Prolegomena zu einer jeden künftigen Metaphysik, die als Wissenschaft wird auftreten können (pp. 58-59).

What can be more similar to my hand or my ear, and in all parts more alike, than their image in the mirror? And still I cannot put such a hand, as it is seen in the mirror, in the place of its original; for if this was a right hand, then the one in the mirror is a left one, and the image of the right ear is a left one, which can never again take the place of the first. In this case there are no internal differences, that some mind could understand by thought only; and still the differences are inner, as far as the senses tell, because the left hand cannot be enclosed with the right within the same bounds, irrespective of their mutual sameness and similarity, (they cannot be congruent) the glove of one hand cannot be used for the other. What then is the solution? These objects are not just appearances of things as they are by themselves, and how the pure intellect would recognise them; instead, they are sensory notions, i.e., appearances, whose eventuality rests on the relations of certain things unknown in themselves to something else, viz., our sensuality. Of these then, the space is the form of the exterior notion, and the internal determination of every space is possible only through the determination of the external relations to the whole of space, of which it is a part, (the relations to the exterior sense) i.e., the part is only possible through the whole, which never takes place with things in themselves as objects of the intellect alone, however does so with appearances alone. That is why we cannot make the difference between similar and same, but still incongruent things (e.g., contrary wound snails) comprehensible by a single concept, but only by the relation to the right and left hand, which directly refers to point of view.

Kant, I. (1783). Prolegomena to any future metaphysics, which shall lay claim to being a science (pp. 58-59). Translation by the present author.

Preface

This piece of work has cost me a few years of my life. So do not misunderstand it. It has become quite extensive due to an over-ambitious quest for a relatively complete description of the subject. Good luck in working through it (do not despair). Thanks to all persons involved in the project one way or another and also to those that need to be thanked for drawing my mind away from the project now and then. Among these, special thanks to Appelhof, Dr. Death, Eshuis, Freksa, Habel, Rhenius, Rill, Steffens, Van der Zee, and Von Wolff. Have fun reading!

Hamburg, June 2005

Chapter 1.Spatial Relations and Expressing Directions

The location of an object can be defined relative to another object. Such a relative definition of location constitutes a relation between the objects. Within languages, there are means to communicate such relations. In English, and other languages such as Dutch and German, the location of an object may be expressed and comprehended by means of the prepositional phrases illustrated in Table 1.1.

English	Dutch	German
IN FRONT OF	VOOR	VOR
BEHIND	ACHTER	HINTER
ABOVE	BOVEN	ÜBER
BELOW	ONDER	UNTER
TO THE LEFT OF	LINKS VAN	LINKS VON
TO THE RIGHT OF	RECHTS VAN	RECHTS VON

Table 1.1. Directional Prepositions in English, Dutch, and German.

The prepositional phrases are typically used to define the direction in which a particular object can be found with respect to another object. In this thesis, I consider the spatial information that is characterised by such prepositions and prepositional phrases. Suppose somebody tells you:

(1) YOU CAN FIND THE BALL TO THE LEFT OF THE HOUSE.

Upon hearing (1), you know that the location of ‘the ball’ is defined relative to ‘the house’. Based on ‘the house’ (or ‘*the left side* of the house’), a direction (*to the left of*) is specified in which ‘the ball’ can be found. ‘The house’ (or any object in the same syntactic position) will be called the REFERENT and ‘the ball’ (or any other object) will be called the FIGURE. Between Referent and Figure, there exists a SPATIAL RELATION. The Spatial Relations denoted by the above-mentioned prepositions (and by prepositions such as *over*, *under*, *before*, *in back of*, *beside*, *to the north of*, and *to the east of*) will be called DIRECTIONAL RELATIONS. The prepositions themselves will be referred to as DIRECTIONAL PREPOSITIONS. There are also other spatial prepositions such as *in*, *at*, *near*, and *on* which are often called topological prepositions.[1] In this thesis, primarily Directional Relations associated with the meaning of Directional Prepositions are considered. The spatial information that I investigate can thus be characterised as the Spatial Relation between two objects in which the location of one object (the Figure) is defined by means of a Directional Relation relative to another object (the Referent).

After hearing (1), it looks like you have all the information you need in order to find the ball. This is not necessarily the case, though. By itself sentence (1) is ambiguous about the source of information upon which the direction ‘to the left of the house’ is based. ‘To the left of the house’ can be defined from the viewpoint of the speaker, it can be defined from the viewpoint from which you normally encounter the house (i.e. seen from the street) or it can be defined from the viewpoint of the person living in the house (i.e. a viewpoint facing the street). This ambiguity in (1) is caused by the so-called different FRAMES OF REFERENCE used to describe Directional Relations. Directions and locations can only be defined by means of a Frame of Reference. The commonalties and differences between Frames of Reference are considered in some detail in Section 1.3. Each of these Reference Frames is interesting

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[1] The terminology used in the literature varies. The Referent has also been called the reference object, the ground, or the landmark. The Figure has also been denoted as the located object or the trajector. Spatial prepositions have been referred to as relational prepositions as well. Directional Prepositions are sometimes called projective prepositions. Topological prepositions may be specified as proximity prepositions. See, e.g., Retz-Schmidt (1988) for an overview.

in its own right. In the present thesis, however, only one class of Reference Frames is considered. I will concentrate on INTRINSIC OBJECT CENTRED Frames of Reference. Other Frames of Reference are mainly considered for reasons of comparison and control.

To refer in an Intrinsic Object Centred manner is to specify a Figure's location with a direction based on inherent features of the Referent. A viewpoint-invariant direction must be defined by some intrinsic aspect of the Referent's structure that does not depend upon any other perspective. Therefore, one way or another, the Directional Relations must be attached to the Referent's structure. Supposedly, particular parts of a Referent can be distinguished by their spatial distribution within the Referent's structure. Such object-part distinctions are then extended into the space surrounding the Referent. Objects with inherent properties that are suited as a Referent are objects that have a *top* and a *bottom*, a *front* and a *back*, and/or a *left side* and a *right side* (this class of terms will be referred to as DIRECTIONAL NOUNS; Dutch: *bovenkant*, *onderkant*, *voorkant*, *achterkant*, *linkerkant*, and *rechterkant*; German: *Oberseite*, *Unterseite*, *Vorderseite*, *Rückseite*, *linke Seite*, and *rechte Seite*). In Chapter 2 Intrinsic Object Centred Frames of Reference are considered in more detail. Some structural and categorical features of objects are considered which make it possible or impossible to define DIRECTIONAL PARTS on and Directional Relations relative to the objects and, if possible, which may or may not allow the expression of such parts and relations through Directional Nouns and Directional Prepositions respectively.

Even when the Frame of Reference is clear with which to interpret a sentence such as (1), this does not mean that Directional Prepositions refer to precisely defined Directional Relations. In particular, Directional Prepositions do not differentiate between possible Figure locations within a part of space adjacent to the Referent. 'The ball' in the above example might be located at various distances from 'the house' and closer to the *front* than to the *back* of the house or vice versa. A relation expressed by *to* *the left of* is applicable to various Figure positions in a region defined relative to the Referent. A region associated with the meaning of Directional Prepositions will be called a DIRECTIONAL REGION. Directional Relations thus need to be characterised with a directional aspect as well as a regional aspect. See also Figure 1.1.

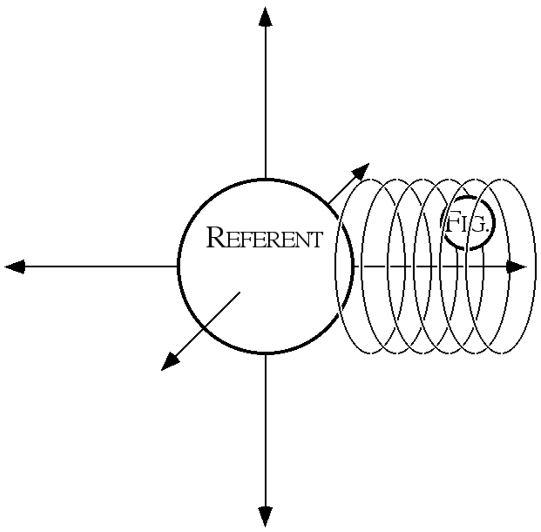

Figure 1.1. A Referent with a Frame of Reference imposed on it. The Frame of Reference is shown as an axial system defining six directions (*above*, *below, in front of, behind, to the left of,* and *to the right of*). At this point, the axial system serves illustrative purposes only and does not signal a theoretical commitment. The Figure (Fig.) is inside a region imposed together with the Frame of Reference.

Each Figure position can be defined as having a specific Spatial Relation relative to the Referent. Such a specific Spatial Relation can be CATEGORIZED as one Directional Relation or another. The sum of all locations that the Figure may occupy while its relation to the Referent may be categorised as the same Directional Relation will be called the Directional Region for the relevant Directional Preposition. Thus, the Directional Region for *to the left of* comprises all locations whose Spatial Relation relative to the Referent may be categorised as the Directional Relation that can be expressed through the Directional Preposition *to the left of*. Directional Relations are thus categorical in that they treat many specific Figure positions equally (Landau and

Jackendoff, 1993; Talmy, 1983). This does not mean that a particular preposition is always used indifferently for each Figure position within a Directional Region: A speaker may sometimes use a combination of Directional Prepositions and the applicability of a given preposition may vary over the region (Hayward and Tarr, 1995; Logan and Sadler, 1996).

Another aspect treated in this thesis concerns memory for spatial location. It is quite generally assumed that the spatial distinctions one refers to with spatial language (e.g., the Directional Relations one refers to with Directional Prepositions) have to be present in non-linguistic spatial representations as well (see, e.g., Clark, 1973; Hayward and Tarr, 1995; Landau and Jackendoff, 1993). In line with the subject of Intrinsic Object Centred Frames of Reference for language involving categorisation of spatial Figure-Referent relations in terms of inherent features of the Referent, an experiment on memory for INTRINSIC LOCATION will be presented, that is, memory for location relative to objects whereby the relative location needs to be defined in terms of inherent features of the Referent as well. The rationale behind this strategy is that insight in how Spatial Relations are defined in supposedly non-linguistic spatial tasks may be of help in understanding how Spatial Relations are defined and categorised in order to refer to them with Directional Prepositions. It is therefore necessary to discuss the relevance of memory experiments for the subject of Intrinsic Directional Relations.

It will be shown that the relation between spatial representations employed in memory for Intrinsic Location and the linguistic reference to Intrinsic Location is far from clear. However, evident from the start is that both the linguistic description of location and the coding of location in memory are based on some Frame of Reference. Moreover, in both the linguistic description of Intrinsic Location and the coding of Intrinsic Location for memory, this Frame of Reference depends on intrinsic aspects of the Referent. It is thus discussed if the Frame of Reference attached to the Referent is the same for both kinds of behaviour and, if not, how and why they differ. It is also considered if the categorisation observed for language is also employed in the coding of Intrinsic Location for memory. Last, but not least, the question is addressed which aspects of reports from memory for Intrinsic Location reveal something about which aspects of linguistic spatial reference to intrinsic Directional Relations.

1.1. Questions discussed in the Thesis

The questions that this thesis focuses upon may be clarified somewhat by listing them one after the other. First, consider the questions regarding language, that is, the categorisation of a Spatial Relation as a Directional Relation within an Intrinsic Object Centred Frame of Reference.

1.1.1. Relevant Questions regarding Language

One of the more general questions is the following:

(A) How is a Frame of Reference for language defined and applied to a Referent?

Regarding the mentioned focus on Intrinsic Object Centred Frames of Reference the more detailed question is:

(A1) How can a Frame of Reference for language be defined from the Referent's structure?

Although the focus will thus be on Intrinsic Object Centred Frames of Reference, one may consider whether –if the developed characterisations can be kept unspecific enough– the made distinctions can be generalised to other Frames of Reference for language.

Intrinsic Object Centred Frames of Reference are used to categorise Spatial Relations with. Therefore, another question is:

(B) How is a Spatial Relation defined with respect to a Referent?

Now note that many different Frames of Reference or co-ordinate systems (that may or may not be suited to play a role in language) can define Spatial Relations. It is therefore possible that a Spatial Relation is defined in terms that are not comparable at all to the Intrinsic Object Centred Frame of Reference for language. In such a case, the Spatial Relation must be redefined in order to become –at least partially– comparable. Such possible redefinition is ignored, as only the resulting definition of the Spatial Relation is important for categorisation as a Directional Relation. It is thus considered:

(B1) How are Spatial Relations defined with respect to a Referent so that (aspects of) the definitions are comparable to the Intrinsic Object Centred Frame of Reference for language?

The reason that I stress the comparability of the definition of the Spatial Relation with the definition of the Frame of Reference is categorisation. Categorisation requires that Spatial Relations allow evaluation against the Frame of Reference. Evaluation requires some shared aspect in their respective definition. Given that there is a shared aspect and comparison is possible, the next question concerns the rules governing categorisation:

(C1) How is a Spatial Relation (defined relative to a Referent) categorised as a Directional Relation in terms of the Intrinsic Object Centred Frame of Reference for language?

Related is the question regarding Directional Regions, or:

(C2) Which Spatial Relations (defined relative to a Referent) can be categorised as the same Directional Relation in the Intrinsic Object Centred Frame of Reference for language?

One may wonder if questions (A1) to (C2) really need to be split up like this. Indeed, the most straightforward definition of the Spatial Relation ((B1)) would be precisely in terms of the Intrinsic Object Centred Frame of Reference of language ((A1)). As an example Figure 1.2.A shows a reference direction (**0°**) and a counter clockwise aspect (**+/-**) that define the Frame of Reference. This co-ordinate system defines a Spatial Relation with an angular value (α) and a distance (**d**) from the Referent. This would make things quite convenient from a theoretical point of view, because for the questions regarding categorisation and Directional Regions only a specification of ranges of angular values is needed. The Spatial Relation is defined through the Frame of Reference and necessarily comparable with it, and categorisation could occur by defining ranges of Spatial Relations. For instance, *in front of* applies if the Spatial Relation is in the region **[-45, 45]**, *to the left of* if it is in the region **[45, 90]**, and so on. The ranges simultaneously define Directional Regions.

The previous example shows that it may not always be necessary to differentiate that stringently between questions (A) to (C2), as they appear somewhat redundant. Things are not always that simple however. For instance, one has to take into account that a Referent has an extension and a shape. Figure 1.2.B illustrates a different way to define a Spatial Relation. One of the shown vectors is defined from an origin in the Referent (β) while the other is defined based on the proximal distance to the Referent (α). Each of these two possible angular values allows comparison with the reference value. Categorisation therefore also depends on how the Spatial Relation is defined. Note that in the case of proximal distance, the Spatial Relation is defined from a different origin than the reference value. Note also that it is not possible to define the same Directional Regions for each way to define a Spatial Relation. One cannot adjust the categorisation procedures posited for both the α and β definitions such that the same Directional Regions result if one assumes that categorisation occurs by comparison of angular values with the reference value only. Those locations that have the same angular value (vectors of different lengths) from the origin in the Referent (β), may have varying angular values if defined by proximal distance from the Referent (α). Locations differentiated within one way to define Spatial Relations are not necessarily differentiated in another way to define Spatial Relations.

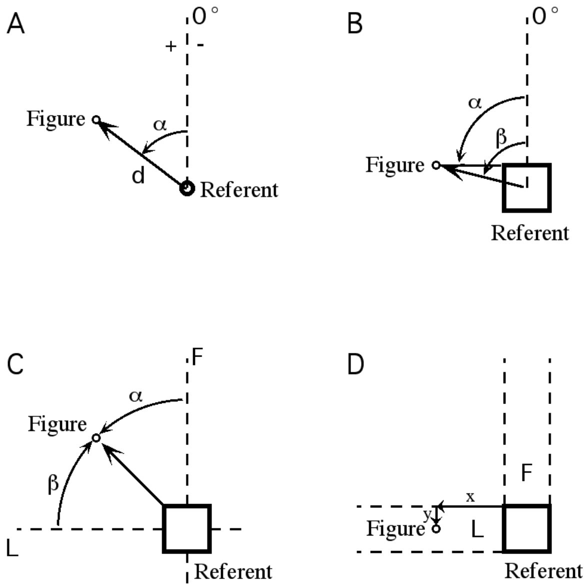

Figure 1.2. The definition of the Frame of Reference and the coding of the Spatial Relation may need to be separated. See text for details.

Additionally, the definition of the Frame of Reference may be more complicated than through one reference direction. In Figure 1.2.C, not only a single reference direction is used but one for each Directional Relation. Thus, the Spatial Relation can be defined in more than a single way: From one of the reference directions (α), from the other (β), from both, and/or from any of the other two (not shown). Following, the way the categorisation is accomplished may become more complicated as well. Is categorisation possible based on α alone, and therefore on β alone as well, or does it need to be based on α and β simultaneously, e.g., on their ratio?

Figure 1.2.D shows a final example. The location of the Figure is defined by **x** and **y**. Contrary to the previous examples, in this case regions are defined from the Referent first, and the location of the Figure is defined relative to these regions. Thus, **y** defines the Figure as being in the Directional Region for *to the left of*.

1.1.2. Relevant Questions regarding Memory

Next, consider the questions regarding memory for location. There are many different ways to define the location of an object. However, regarding this thesis, the general question concerning the coding of location for memory is:

(D) How is the location of the Figure coded relative to the Referent for memory?

A location is always defined in terms of some Frame of Reference or co-ordinate system. Regarding memory for Intrinsic Location, the more detailed question is:

(D1) How is the location of the Figure defined relative to the Referent's intrinsic structure?

Now note that while locations may be defined with respect to a Referent's intrinsic structure, that this definition does not necessarily involve the same inherent features of the Referent that are used for the Intrinsic Object Centred Frame of Reference for language. Thus, the Frame of Reference (or co-ordinate system) used to code an Intrinsic Location for memory is not necessarily the Frame of Reference used to categorise a Spatial Relation as a Directional Relation for language. Notwithstanding this possible complicating factor, it may further be the case that the co-ordinate system (Frame of Reference) used to define an Intrinsic Location with is also used to build spatial categories. It is of course advantageous if such spatial categories are the same as those used for language, but it is thinkable that they are construed at an ad hoc basis and unsuited to be referred to with Directional Prepositions.

(E1) Are Intrinsic Locations categorised in memory?

If so, in analogy to Directional Regions it is possible to ask:

(E2) Which Intrinsic Locations are categorised within the same spatial region?

1.1.3. Relevant Questions regarding Memory and Language

Now considering (A) to (C) and (D) to (E), one may consider the ideal situation in which the categorisation of Spatial Relations for language is comparable to the coding of Intrinsic Location for memory. This would be the case in which, on the one hand, Intrinsic Location for memory is categorised (at least spatially) within the same Frame of Reference used to categorise Spatial Relations for language. On the other hand, the coding of Intrinsic Location for memory would ideally be similar to the to definition of a Spatial Relation for language. Thus, the general question is:

(F) Under what circumstances does the coding of Intrinsic Location for memory and the definition of Directional Relations for language share most aspects?

While the more specific questions are:

(F1) When is the same Intrinsic Object Centred Frame of Reference used to categorise Spatial Relations for language and to code location for memory?

(F2) When is the coding of Intrinsic Location for memory (in part) the same as the definition of intrinsic Spatial Relations for language?

(F3) When is the categorisation employed for language similar to categorisation employed for memory?

Given that some answer can be given for (F) to (F3), there still remains one important question to be answered, and this concerns how the coding of an Intrinsic Location and the categorisation of these locations into regions are expressed in reports from memory. Therefore:

(G) How does one infer from reports from memory for Intrinsic Location how locations were coded (the co-ordinates) and if locations were categorised (the regions).

1.1.4. Structure of the Thesis

The questions listed above are the main topics of this thesis, although it will not be possible to give precise answers to all these questions. In order to shed some light on the topics it will be necessary to consider the information structures and the operations performed on these structures that are involved in establishing and using Intrinsic

Object Centred Frames of Reference. In Chapter 2 Intrinsic Object Centred Frames of Reference are considered in more detail. Not only is it considered how such a Frame of Reference may be used for language, but also how Intrinsic Locations may be defined for used in memory. Some similarities and some differences are encountered. Chapter 3 considers some of the operations (processes) involved in talking about the location of an object in an Intrinsic Object Centred Frame of Reference for language based on perceptual (notably visual) information. Then, in Chapter 4, the influences of categorisation on memory for location are considered, and it is there where the spatial information structures that code locations are discussed. If it can be argued that similar structures are used for intrinsic spatial reference in language, then the same structures might be used to define Spatial Relations. In Chapter 5, the findings of the first chapters are accumulated into a model of intrinsic spatial reference for language and its relation to spatial memory. Chapter 6 will describe an experiment on memory for location relative to a Referent and discuss the results in relation to the model. Chapter 7 will conclude on the project.

The subject of this thesis as outlined on the previous pages is a part of cognitive science. Therefore, the remainder of this chapter first -globally- considers some principles of cognitive science (Section 1.2) and how these are applied regarding Spatial Relations and Frames of Reference for language (Section 1.3).

1.2. Cognitive Science

The perception of a situation, the recollection of a configuration, the apprehension of a Spatial Relation, the production of speech (that is, the co-ordination of the movements of the articulatory apparatus necessary for verbal behaviour), the interpretation of sentences, the comparison between a visual image and the meaning of an utterance, are all a consequence of brain activity. All of these abilities, found together in a single system in human beings only (as far as I know), are studied within cognitive science. Cognitive science can be (broadly) characterised as the study of information-processing. When studying information-processing in human beings, one studies cognitive psychology. Cognitive psychology considers the human mind as a computational process. A computational process can be understood as the correspondence between the input in the human information-processing system and its output. The human information-processing system is the brain, input is obtained through the sensory organs, and output is human behaviour.

1.2.1. Levels of Description

There are different ways in which the brain and its functioning may be understood. Marr (1982) proposed that there are three levels of description in understanding complex information-processing systems. These are the computational, the algorithmic, and the implementational level. To avoid confusion with other uses of the word computational, I will –following Palmer and Kimchi (1986)– refer to the computational level of description as the informational level of description. The informational level of description of a certain information-processing task is concerned with the goal of the task, that is, with defining exactly what is being computed. It comprises of a well-defined description of input-output correspondences, without necessarily bothering much about how this correspondence comes about. It thus provides a (usually formal or even mathematical) characterisation of the information-processing task in terms of the available input information, the desired output information, rules stating which input should lead to what output, as well as the additional information that is required to obtain the desired output from the available input. In Diagram 1.1 a computational problem is illustrated.

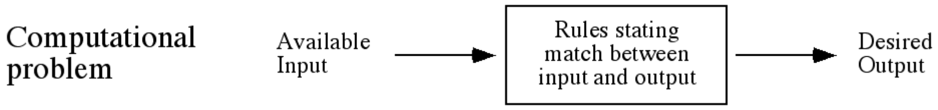

Diagram 1.1. The informational level of description. This level of description characterises the available input, the desired output, and the rules stating which input goes together with what output.

The algorithmic level of description on the other hand is explicitly concerned with how something is computed, how input-output correspondences may actually come about. It thus characterises the information-processing task by means of a specific way in which the available input is transformed into the desired output. Theories at this level of description typically deal with information structures (representations) and operations (processes) that transform these structures. The implementational level deals with how the computational algorithms are physically instantiated. It thus characterises the information-processing task in terms of the physical mechanisms actually used to transform the available input information into the desired output information. Diagram 1.2 shows an algorithmic description. The processes used in arriving from the input to the output each deliver a so-called representation (about which more below).

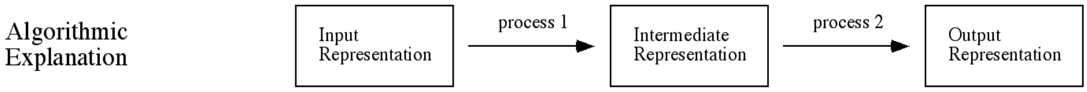

Diagram 1.2. The algorithmic level of description. This level defines how something is computed: Which stages information-processing passes in arriving at the output from the input.

Although it is clear that the information-processing task with which I am concerned has to be instantiated in the brain, I will not have much to say about the implementational level. On the one hand, I am primarily interested in providing a functional description (that is, a description in terms of information structures and processing thereof and not whether chips or neurones accomplish this). On the other hand, not enough is known about the workings of the brain in enough detail with respect to the present subject.

Moreover, what is known about the workings of the billions of neurones found in the brain, would make a (more or less) detailed implementational account of the present subject with its broad domain (from perception to language) though narrow theme (Intrinsic Object Centred Directional Relations) unfeasible.

The informational and algorithmic levels of description cannot be treated completely separate. As proposed by Palmer and Kimchi (1986), if an information-processing task (i.e., the well-defined scientific problem) characterised by an informational description is also given an algorithmic description (i.e., a theory is formulated on how the computational problem is performed), then this algorithmic description can be considered as a collection of smaller information-processing tasks each of which can be characterised through an informational description. They called this ‘recursive decomposition’: An iterative process of increasingly finer input-output operations. A process between two (hypothesised) representations (e.g., the processes illustrated in Diagram 1.2) can thus be considered as a (smaller) information-processing task and so again an algorithm may be proposed for the internal structure of this process as illustrated in Diagram 1.3. A computational problem may thus be decomposed into smaller computational problems and this decomposition may (recursively) be applied to obtain even smaller computational problems, and so on. A major branch of cognitive science characterises mental processing as the interplay of represented information and processes working on and changing these representations.

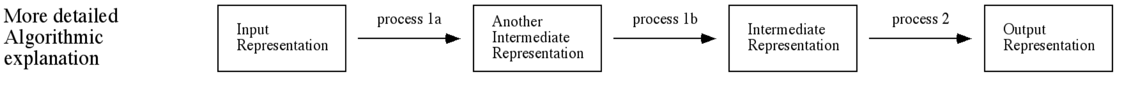

Diagram 1.3. Recursive decomposition. Each of the processes in an algorithmic description may be considered as an information-processing task for which again an algorithmic description can be defined.

The general principles just described will be exemplified in Section 1.2.2 by characterising in a coarse-grained manner what goes on inside someone’s head (i.e., the brain activity from a computational point of view) when she/he visually perceives a spatial configuration of objects and utters a sentence in which an object's location is specified with a Directional Preposition. The resulting sketch has to be seen as the general background against which the remainder of this thesis has to be interpreted. Some assumptions regarding input and output are made that are thought to be relevant for the computational problem (the present subject). In Chapter 2 the possible input, the (unfortunately not-that-well-defined) desired output, and how they may relate will be characterised in more detail. The focus will thus be to give merely an informational description though not necessarily very formal. It is thought that by stating with some precision the information that is thought to be available, the information that is thought to be desirable, and the information that is thought to be necessary to attain the desired from the available, that the representations and processes needed for this can be sketched more efficiently. Chapter 3 and Chapter 4 will more or less consider the algorithmic level of description for Intrinsic Object Centred Frame of Reference for language and the coding of (intrinsic) location for memory respectively. Thereby I will try to corroborate the developing theory by experimental evidence from the literature.

1.2.2. Global Sketch of the Mental Machinery

Spatial language behaviour is often observed in a communicative context in which one person (the speaker) explains the location of a Figure to another person (the addressee). The goal of the communicative act is to narrow down the search domain for the addressee for locating the Figure (see, e.g., Miller and Johnson-Laird, 1976). Information concerning the location of the Figure is communicated by relating the Figure's location to a Referent. In order to do this, the speaker has to analyse the spatial scheme (i.e. the array of objects in a perceptual scene obtained from vision or memory), identify a suitable Referent[2], and relate the Figure's position to the Referent's position and –in case of Intrinsic Object Centred Reference– orientation. The Spatial Relation thus has to be computed and, finally, the relation has to be expressed in language. Diagram 1.4 sketches the most general information-processing situation for the speaker.

Diagram 1.4. Wavelengths to sound waves. Light reflected from objects enters the eyes. It falls on the retinae and stimulates receptor cells there. Stimulation of the receptor cells provides the initial visual input for the brain. In the brain the input is transformed into stimulation of the articulatory apparatus, thus producing sound waves.

The computational problem in Diagram 1.4 is the processing that takes place between the light entering the eye and falling on the retinae (the input) and the sound waves produced by the articulatory apparatus (the output, i.e., behaviour).

1.2.2.1. Visual Perception

Visual processing starts when light arrives at the eyes. The first thing to be noticed is that when light reflected from objects in the world hits the eyes a projective transformation takes places. Only 2-dimensional (2D) images project upon the retinae. One of the main questions in visual perception is therefore how 3-dimensional (3D) information is derived from these 2D projections. Somehow, from 2D input, information concerning the factual 3D situation in the external world has to be calculated, i.e. a model of the world has to be built. Therefore, one speaks of a representation whereby this term is more generally used to refer to any information structure in the brain, regardless if it truly presents something again or if it actually

[2] What comprises a suitable Referent depends on various factors. E.g., a suitable Referent typically is a salient object, which is often bigger than the Figure (Talmy, 1983). If the Referent is salient within the perceptual scene, then the addressee will easily detect it and so a common ground between speaker and addressee is established based on which the addressee may actually locate the Figure.

stands for something. Within the brain (the information-processing system) an internal representation of the world is constructed which ideally reflects the actual situation in the external world. If perception leads to representations that truly match the environment (i.e. if perception is *veridical*), one may speak of a *homomorphism* between the structure of the environment and the structure of the representation. Homomorphic mapping between world and representation is to some extent necessary because a representation about the world will only be useful when the representation preserves information on the structure of the environment. The retinal image by itself, that is the activity of neural receptor cells in the retinae whose activity level depends on light intensity as well as wavelength to which different kinds of receptor cells are differently sensitive, is quite useless as a representation of the external world. Therefore, it is generally assumed that processes operate on the input, transforming it into different representations. The goal of this processing is to make information explicit which is only implicit in the input. Processing thus takes place between representations whereby this processing accomplishes the transference of information structured in one way in one representation (e.g., the input) into information structured in another way in another representation whereby information may be added. Representations are operated upon to build other representations with a different informational content. This idea can be illustrated as follows:

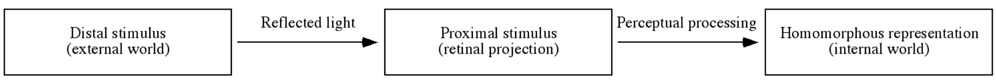

Diagram 1.5. Veridical perception. Through reflected light, a projection of the external world (distal stimulus) is cast upon the retinae. This retinal 'picture' (proximal stimulus) is transformed through perceptual processes into a representation that ideally reflects the structure of the external world.

Once an internal representation is constructed, further processing is required to obtain the speech output. The situation of input to output can thus be illustrated as follows:

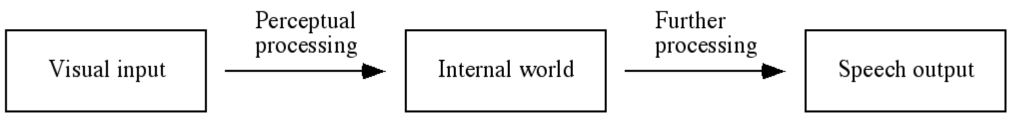

Diagram 1.6. Voicing the world obtained through vision. To obtain speech output from visual input, it is assumed that first the situation in the world is reconstructed through visual processing.

The construction of a homomorphous representation reflecting the structure of the external world from visual input is generally not thought to occur in a single step. Usually it is assumed that this transformation of the retinal image into meaningful facts about the environment takes place into different stages. One well-known approach is Marr's theory on object recognition (Marr, 1982), in which from the retinal image respectively an image-based (primal sketch), surface-based (2.5D model), and object-based (3D model) representation is derived. However, the processes and representations used for the recognition and/or identification of objects are not exactly uncontroversial. For a recent review of computational approaches to object recognition, see Edelman (1997); for a review that explicitly cuts across levels of description, see Vecera (1998). One important issue to which I will return in Chapter 3 is the viewpoint (in-) variance of object recognition as it is discussed between, for instance, Tarr and colleagues (Tarr and Bülthoff, 1995; Hayward and Tarr, 1997) and Biederman and colleagues (Biederman, 1987; Biederman and Gerhardstein, 1993, 1995). Whatever the outcome of this and other disputes, for the moment the major point is that visual input is transformed into a representation with what will be called perceptual objects in a perceptual scene (i.e., the internal world).

Here it suffices to assume that the perceptual representation (be it in 2D, 2.5D or 3D format) consists of a collection of spatially distributed objects that is automatically computed when the eyes open (see also Logan, 1995; Logan and Sadler, 1996). An additional assumption that has to be made is that this representation can be used to identify objects and to establish Spatial Relations between them. The perceptual representation needs to contain enough information (at least implicitly) to allow objects to be categorised and/or identified, and to allow Spatial Relations to be build between objects (explicitly, for which further processing may be needed). This latter assumption is necessary because the perceptual representation must support object categorisation and identification in order to access stored knowledge about the function of and possible interaction with the object. Furthermore, Spatial Relations must be derivable from the representation in order to enable meaningful spatial action (as navigation or grasping) and, of course, to explain spatial expressions such as Sentence (1) that are sometimes uttered based on visual information alone.

1.2.2.2. Linguistic Processing

The present thesis is not only concerned with visual perception, but also with the linguistic faculty. If a speaker intends to direct the attention of an addressee to the location of a Figure by uttering a sentence containing a Directional Preposition, then it may be required that the addressee interprets the sentence if the intention is to be met. It is assumed that sentence interpretation is accomplished through the construction of a conceptual representation, which is derived from the auditory input representation and possible intermediate linguistic representations. Ideally, if the meaning is derived (a conceptual representation has been built), the addressee may then compare this meaning with his/her perceptual representation. If the speaker chose a suited Referent, then the addressee might identify this Referent without much effort. The Directional Relation to which the Directional Preposition refers may then be applied to this Referent whereupon the addressee can direct his/her attention accordingly and may thus find and identify the Figure. Restricting the search domain to a specific region adjacent to the Referent thus facilitates the addressee’s search for the Figure.

Often, in linguistics, a broad segmentation of the linguistic competence in phonological, syntactic, and semantic and/or conceptual sub-processing is assumed in order to explain the understanding of linguistic expressions (see, e.g., Jackendoff, 1983). Phonological processing is used to identify the morpho-lexical constituents of a sentence, while syntactic processing helps building the meaning of a sentence from these constituents and their order. Details of phonological and syntactic processing are of little importance to the present thesis. The primary subject is the correspondence between perceptual representations arising from vision and conceptual representations arising from (when hearing) or responsible for (when expressing) language. The picture that results when perceptual and linguistic processing is combined is sketched in Diagram 1.7. With this mental machinery as the theoretical background, the questions of this thesis are approached.

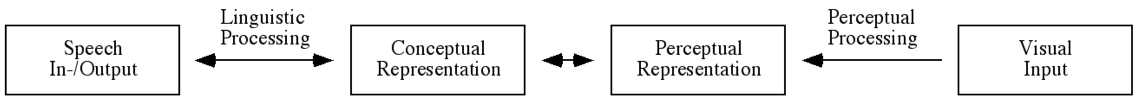

Diagram 1.7. A crude division of the information-processing route from vision to language. Visual input is transformed into a perceptual representation. From the perceptual representation, a conceptual representation is derived which can then be transferred into verbal output. The focus in the present thesis is mainly on the processing (steps) between the perceptual and the conceptual representation.

It is assumed here that conceptual representations are built from arguments and functions. As an example, consider a conceptual interpretation of sentence (1) according to 'Conceptual Semantics'. Jackendoff (1983, 1992) developed this research program out of the linguistic study of the meaning of sentences and words. In this research program, spatial language plays a special role. The premise is developed that it contains clues on how the structure of spatial representations[3] is organised. It thus becomes possible to

[3] Spatial representation according to Jackendoff refers to a representation that is more a-modal than a perceptual representation based on vision alone. It supposedly only represents spatial information and thereby integrates information from other modalities, such as hearing and touch as well. I will not clearly differentiate between spatial representations and (visual) perceptual representations, and use these terms somewhat sloppy. Instead it will be assumed that there is some spatially structured representation (2D, 2.5D, or 3D; see Section 1.2.3) and focus on how one may arrive from such a representation to a conceptual representation without bothering that much about whether some of its aspects are visual or if they are actually spatial.

investigate spatial representations by studying spatial language (Jackendoff, 1987; Landau and Jackendoff, 1993; Van der Zee, 1996). The basic assumptions, in this respect, are that spatial language is dependent on representations of spatial structure and that for a given language "[...] any aspect of space that can be expressed in language must also be present in nonlinguist spatial representations" (Not necessarily the other way around; Landau and Jackendoff, 1993, p. 217; see also Clark, 1973). This means that the distinctions made when uttering a sentence such as (1) refer to spatial representations. Thus, different ways of using Directional Prepositions (the Frames of Reference) as well as regions associated with the prepositions must somehow be distinguishable in the spatial representation.

In Jackendoff’s Conceptual Semantics (Jackendoff, 1983; 1992), the conceptual structure of a sentence as (1) is defined by a STATE, which is composed of a MATERIAL ENTITY (the Figure, i.e. ‘the ball’) that is mapped (‘is’) onto a PLACE (I will refer to this as the MappingFunction). This PLACE is construed of a PlaceFunction (‘to the left of’) applied to another MATERIAL ENTITY (the Referent, i.e. ‘the house’). Figure 1.3 illustrates the conceptual structure of sentence (1).

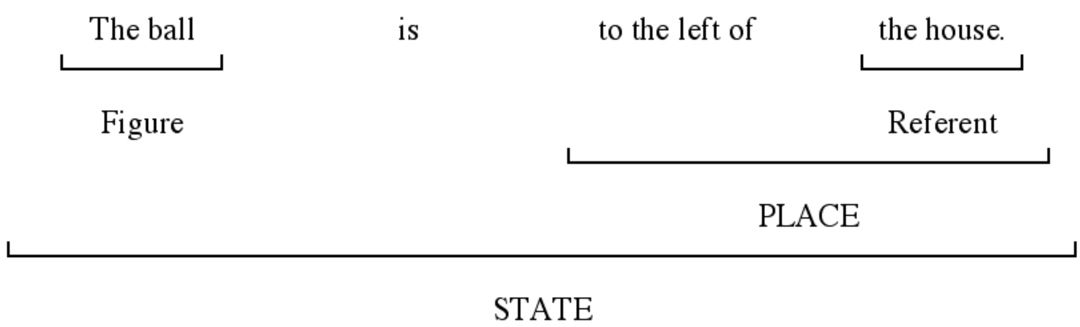

Figure 1.3. Conceptual structure of sentence (1).

Note that the distinctions made in Conceptual Semantics are only that, conceptual distinctions, and that the conceptual Mapping of the conceptual Figure on the conceptual Place construed by the conceptual PlaceFunction applied to the conceptual

Referent must not be confused with the categorisation of a specific Spatial Relation between Figure and Referent as a Directional Relation within a Frame of Reference applied to the Referent. To be clear, categorisation of a Spatial Relation is required to derive from a perceptual representation a conceptual representation that, according to Conceptual Semantics, includes such conceptual distinctions. Moreover, the result of the categorisation process (that is, the decided-upon spatial category or Directional Relation) is reflected in the conceptual structure. Thus upon seeing a constellation of Figure and Referent (which implies a perceptual representation), one may categorise a Spatial Relation as a Directional Relation (which implies building a conceptual structure), and express the relation by means of a sentence such as (1). However, the conceptual structure is not assumed to refer to any specific Spatial Relation. This is assumed here to allow that a sentence containing a Directional Preposition can be understood without a specific perceptual instantiation of the conceptual distinctions. Thus upon hearing and interpreting a sentence such as (1) (which implies building conceptual structure), one may, e.g., take its meaning for granted, search for a perceptual instantiation, imagine some (maybe prototypic) suited configuration, or recollect the intended situation from memory.

In the remainder of this chapter the different Frames of Reference for language will be characterised in more detail. I will mostly consider observations regarding directional Spatial Relations and Frames of Reference while assuming perceptual and conceptual representations as just described.

1.3. Frames of Reference for Language

In this section, different ways of defining Directional Relations are considered. This issue concerns the used viewpoint or the adopted Frame of Reference when defining a

Directional Relation. After considering general characteristics of Directional Relation building, a possible taxonomy of Frames of Reference is discussed.

1.3.1. Directional Spatial Relations

Sentence (1) denoted the location of ‘the ball’ (or Figure) by referring to a spatial area (direction and/or region) relative to ‘the house’ (or Referent). Generally, this is thought to occur by imposing a Frame of Reference on the Referent with which such spatial areas are specified (see, e.g., Clark, 1973; Levelt, 1984; Levinson, 1996; Miller and Johnson-Laird, 1976; Talmy, 1983). Reference frames assign directionality to the (perceptual) space surrounding the Referent. Frames of Reference are a prerequisite for any measurement, understanding, or interpretation of space to occur (be it real or perceptual). It is known for a long time that no location can be described unless some defining system is used (e.g., Levinson (1996) mentions Aristotle, while Vorwerg (2003) mentions Galilei). An easy way to see this is that from one person’s viewpoint the location of, say, the bags changed whereas for another person’s viewpoint it did not, while they are –to this person– still where they were, namely in the *back* of the car. If the defining system (viewpoint) is different, then questions concerning location may be answered differently. The important point is that spatial distinctions such as directions or locations have to be explicitly interpreted through some kind of space defining device. Exactly such a device is a Frame of Reference.

Different parameters of Frames of Reference can be defined. For instance, Logan and Sadler (1996) define origin, orientation, direction, and scale. In order not to use the word direction too much, I will use (assigned) directionality instead in the context of reference frame parameters. If, in 3D space, a location has to be determined, one first needs an origin from which the location can be defined (similar to an **origin** in a 3D graph). Orientation is needed to specify the dimensions of space (defining the **[X]**, **[Y]**, and **[Z] axes** in the graph). Directionality specifies order within dimensions by discriminating between half dimensions (or poles) at either side of the origin (specifying **[+]** and **[-]** sign on each of the axes). Finally, scale defines distance along directed dimensions (specifying the unit of measurement along the axes). Together these parameters can determine an exact location (in this Cartesian co-ordinate system, signed unit values on each of the axes define a precise location). To define a precise direction, one needs origin, orientation, assigned directionality and relative values, but not necessarily exact scale values (while, e.g., the **co-ordinates (1, -2, 3)** define the same direction as the **co-ordinates (2, -4, 6)**).

Note that if a Frame of Reference is defined in such terms, that the parameters are somehow used to categorise a Spatial Relation as a Directional Relation for language, but that it appears straightforward to code a location with those parameters. The location of a Figure can simply be coded by **(x, y, z)**. If the Spatial Relation of a Figure needs to be categorised as a Directional Relation, however, the Figure's location **(x, y, z)** or direction **(x: y: z)** needs to be categorised with respect to the directed dimensions **[±X, ±Y, ±Z]**. The location of a Figure defined by **(x, y, z)** actually defines three distances, from the **[Y, Z]**, **[X, Z]**, and **[X, Y]** planes respectively. The origin is the intersection point of these axial planes, while dimensions and directions are defined perpendicular to the planes, whereby directions require differentiation between either side of the plane (see, e.g., Clark, 1973; Kant, 1768). The **[+X]** direction is thus defined by orthogonality relative to the **[Y, Z]** plane and a means to differentiate **[+X]** from **[-X]**. If a Figure is categorised as, say, *in front of*, this may mean that *in front of* (**[+X]**) is differentiated from *behind* (**[-X]**), and that the location of the Figure on the *top-bottom*, *front-back*, and *left-right* dimensions (**(x, y, z)**) is characterised through membership of *in front of*. Categorisation may thus involve ignoring the Figure's position on other dimensions, and the question is what rules govern this (as an example, the highest value in **(x: y: z)** may define the categorisation). Both aspects, that a dimension is defined against an orthogonal plane, and that linguistic categorisation may involve ignoring values on other dimensions, is shown to be important.

The parameters of a Frame of Reference are applied to a Referent in order to define the spatial area in which the Figure is located. The origin is thus at the Referent. However, the other parameters of the Frame of Reference still need to be defined somehow. Some source of information is needed to set the Reference Frame parameters used to categorise a Spatial Relation as a Directional Relation (as the speaker does). Similarly, for an addressee, a Directional Preposition has to be interpreted relative to some set of directional distinctions defined from some viewpoint. I will call the entity (e.g., an object or some other source of information, see Section 1.3.2) where directions are derived from the PERSPECTIVE (also called secondary reference object (Talmy, 1983), viewpoint (Levinson, 1996), or origin (Bryant and Tversky, 1999; not to be confused with present use of **origin**)). Thus, the origin is set at the Referent, and directionality is assigned to space surrounding the Referent according to the Perspective. The specific Spatial Relation between Figure and Referent is categorised in terms of this assigned directionality.

Given that the Directional Relations I am concerned with can be captured by three pairs of opposing directions, it will be assumed that the Frames of Reference needed for this can be captured by an origin ((at) the Referent), (up to) three orthogonal oriented dimensions and directionality assigned to each of the dimensions (defined from a Perspective and applied to space surrounding the Referent). It is important to clearly differentiate between dimensions and directionality. The first part of the reasoning is that a particular Perspective does not necessarily define all six Directional Prepositional phrases mentioned in the introduction. For instance, a gravitational Perspective defines only the *above* and *below* directions, that is, only the opposing directions within the vertical dimension. Other dimensions are not defined from this Perspective nor are their pairs of opposing directions. However, when one direction is defined, the same

Perspective defines the opposite direction as well (at least I know of no counter-examples).[4] This exemplifies that one needs to differentiate either between dimensions (i.e., between the *top-bottom*, *front-back*, and *left-right* axes) where directionality may be assigned to, or between pairs of opposing directions (i.e., between the *top-bottom*, *front-back* and *left-right* directed axes) in which case directionality and dimensionality go together. The choice to take the first of these options and thus to differentiate between dimensions and dissociate these from the directionality assigned to them is motivated by the other part of the reasoning which is the meaning of the Directional Preposition *beside*:

(2) THE FIGURE IS BESIDE THE REFERENT.

In (2), the preposition refers to a specific dimensional arrangement of the Figure and the Referent, but does not indicate whether the Figure is to be found in one dimensional direction (*to the left of*) or in the opposite dimensional direction (*to the right of*). It thus is possible to refer to a dimension while not referring to directionality.[5] In addition, it is also possible to refer to dimensional parts, such as *ends* and *sides* (see Landau and Jackendoff, 1993).

1.3.1.1. Percepts, Concepts, and the Frame of Reference

The general notion of a Frame of Reference as sketched above (while ignoring questions relating to Perspectives which will be considered in Section 1.3.2) can be

[4] This at least seems to apply to Dutch, English, German, and related languages. Levinson (1996) mentions regarding intrinsic Frame of Reference that some other languages employ directional definitions by object parts that do not seem to involve the simultaneous definition of the opposed direction (p. 141). As the focus of the present thesis is on Dutch, English, and German, such possibilities are ignored.

[5] Therefore, *beside* and probably *next to* as well may be more accurately described as Dimensional Prepositions. The example refers only to the *left-right* dimension and no prepositions are known to me which refer to other dimensions. One may also argue that the Nouns *end* and *side* refer to dimensionality as in 'at the end of the table' (see also Landau and Jackendoff, 1993). Regarding Directional Prepositions, the possibility however remains that a differentiation is required between directed *top-bottom* and *front-back* dimensions and a *left-right* dimension with optionally assigned directionality.

tentatively linked to the mental machinery sketched in Section 1.2. It was assumed there that the perceptual representation simply consists out of a collection of spatially distributed objects. It is not assumed that all Spatial Relations between all possible combinations of objects are explicitly defined in the perceptual representation. Neither is it assumed that assigned directionality of space surrounding all possible Referents according to all possible Frames of Reference given all possible Perspectives is available there. No explicit Spatial Relation is assumed to be defined in the perceptual representation, at least initially. The Frame of Reference is required to make Spatial Relations explicit, which might then be expressed verbally. The perceptual representation thus defines the (implicit, un-interpreted) Spatial Relation between the Figure and Referent, while the conceptual representation defines the (explicit, categorised) Directional Relation between them.

The perceptual Spatial Relation between the Figure and Referent is given by different locations in the perceptual field.[6] To make the relation explicit and categorise it as a Directional Relation, it is required that directionality is given to perceptual space surrounding the Referent but also that the specific Spatial Relation between Figure and Referent is defined in similar terms (i.e., the Spatial Relation needs to be defined from the Referent in such a way that it is comparable to the Reference Frame distinctions). This latter requirement assures that the categorisation process can be based on similar kinds of information, which is a requirement for any categorisation. A specific Spatial Relation needs to be categorised as, e.g., Directional Relation 'A' rather than Directional

[6] Locations in a perceptual representation might be defined retinotopic, possibly added with depth information (i.e., relative distance from the viewer). If the origin of a retinotopic co-ordinate system would be at point of focus and the viewer focuses on the Referent, then the Figure-Referent relation is naturally defined in perceptual co-ordinates (say, the Figure is defined polar at **+10°** from the **0°** (upright) direction). Reference frame parameters can also be defined in such perceptual values (say, intrinsic *above* equals retinotopic **20°**). Categorization is based on a comparison between values. The difference between the values is the same in retinotopic or intrinsic co-ordinates (if intrinsic *above* is re-defined to be **0°**, then the perceptual relation is at **-10°**). It will be argued elsewhere that –in addition to specifying the Intrinsic Object Centred Frame of Reference itself– a full appreciation of Intrinsic Object Centred Reference requires that the relation between this frame and some other frame (Ego Centred or Environment Centred) is made explicit. See Hinton and Parsons (1981, 1988).

Relation 'B' which presupposes that the specific Spatial Relation is comparable to the reference frame distinctions for both Directional Relations in order to determine which is appropriate. Some shared aspect in the way that both the specific relation and the Reference Frame distinctions are coded accomplishes comparability. The categorisation process compares the shared aspect to determine (relative) goodness-of-fit for Directional Relation 'A' and for Directional Relation 'B'.

In order for directional Spatial Relations to be perceived and spoken about, the Figure and the Referent need to be marked in the perceptual representation and to correspond to arguments in the conceptual representation.[7] Correspondence obtained between a marked object in the perceptual representation and an argument in the conceptual representation equals identification (that is, if the correspondence is correct and the object is not categorised as 'unknown') while such perceptual-conceptual correspondence allows naming and access to stored information about the perceptual object. Perceptual-conceptual correspondence must be mediated by some object memory store. To obtain the link to a conceptual argument, the perceptual representation of an object must be compared with object representations in long-term memory. Here a categorisation process is assumed as well, which in the present case compares the structure of the perceptual object with stored representations in memory. The representation of objects in memory is considered in Chapter 3 regarding its relevance to Intrinsic Object Centred Frames of Reference. In all other cases, object recognition will be taken for granted.[8]

The establishing of correspondence between the relative position of two objects in the perceptual representation and a STATE in the conceptual representation (see Figure 1.2) equals the apprehension of Spatial Relations. One marked object in the perceptual

[7] Here, 'marked' simply refers to the selection –one way or another– of Figure and Referent among other perceptual objects. 'Correspond to' refers to some linking or binding between perceptual object and conceptual argument such that conceptual information about the argument can be said to be pertaining to or to refer to the perceptual object.
[8] It is thus assumed that each perceptual object is recognized. This is not necessarily the case. Perceptual-conceptual correspondence may occur without recognition: 'What is that thing that I see over there?'

representation corresponds to the conceptual argument to which the conceptual PlaceFunction is applied, and therefore functions as the Referent. A second marked perceptual object corresponds to the conceptual argument that is (conceptually) mapped onto the PLACE, and therefore functions as the Figure. The Frame of Reference mediates the correspondence between the relative position of Figure and Referent in the perceptual representation (the perceptual relation) and the STATE in the conceptual representation (the conceptual relation).

The Frame of Reference thus needs to define the directional information in perceptual space surrounding the Referent. Additionally, the perceptual spatial relation must be defined from the Referent. Finally, some categorising process is needed which interprets the spatial relation in terms of the Frame of Reference. In addition to Sentence (1), consider the following example sentences:

(3) THE BALL IS TO THE LEFT AND IN FRONT OF THE HOUSE.

(4) THE BALL IS NOT TO THE RIGHT OF THE HOUSE.

Sentences (3) and (4) illustrate that the categorisation process needs not only to be able to define which spatial area applies best, but also which of several spatial areas apply, and which spatial areas do not apply.[9]

Consider first the case in which a perceptual relation corresponds to a conceptual relation that is described with a single Directional Preposition as in Sentence (1). The mediating Frame of Reference is actually postulated to account for the meaning of a set of Directional Prepositions (i.e., at least 1 dimension with 2 opposing directions). The Reference Frame parameters (supplied by the Perspective) are applied around the

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[9] One might argue that when a Figure is categorized as *to the left of* a Referent, that it is possible to obtain *not to the right of* the Referent by logical inference and that there is no need to invoke the Frame of Reference for this assertion. This is true. However, when a Figure is categorized as *in front of* a Referent, *not to the right of* the Referent does not necessarily follow from inference alone, as the Figure may also be *to the right of* the Referent, or be *neither to the left nor to the right of* the Referent.

Referent. This means that two, four, or six directionality parameters of the Frame of Reference are defined in perceptual space. Thus, from a gravitational Perspective, a Figure is categorised either as *above* or as *below* the Referent. From another Perspective the Figure may be categorised as either *above, below, in front of, behind, to the left of*, or *to the right of* the Referent. From the available directionality parameters, only one is chosen to describe the location of the Figure relative to the Referent. This choice is the result of the categorisation process. The perceptual relation thus corresponds to the conceptual relation through the Frame of Reference and a categorisation process. The reference frame provides up to six directionality parameters in terms of which the position of the Figure relative to the Referent in the perceptual representation is categorised. Categorisation involves determining the goodness-of-fit of the Spatial Relation with the directionality parameters whereby the 'best fit' is chosen.

Next, consider the case in which a perceptual relation corresponds to a conceptual relation that is described with two Directional Prepositions simultaneously as in Sentence (3) (see also findings by Hayward and Tarr, 1995; Munnich, Landau, and Dosher, 2001; Zimmer, Speiser, and Baus, 2001). In this case, the perceptual relation has been categorised on two dimensions. This implies that the Frame of Reference defines two or three directed dimensions in perceptual space to begin with. If more than one Directional Preposition is used to describe a Directional Relation, the Prepositions must refer to different dimensions, as illustrated by the next Sentence.

(5) *THE FIGURE IS ABOVE AND BELOW THE REFERENT,

Sentence (5) makes no sense (if one assumes that the same Perspective is used to define *above* and *below* and ignores the hypothetical possibility that they are defined from different Perspectives). In Sentence (3), the perceptual relation has thus been categorised by making a choice between directional oppositions on two dimensions each. It may thus be the case that a perceptual relation can be categorised on all available directed dimensions (defining for each dimension which of the opposite directionality parameters applies). It can also be the case that a Spatial Relation can be categorised on one or a sub-set of the applicable directionality parameters (defining which spatial area applies best or which spatial areas apply best, if more than one happens to be applicable). Finally, it is possibly the case that a Spatial Relation is categorised by exclusion of directional parameters (defining which spatial area does not apply or which spatial areas do not apply).

Frames of Reference are assumed to function between the perceptual and conceptual representation. An interesting question is if the Reference Frame parameters are actually imposed within or upon the perceptual representation or if the Reference Frame is actually extra-perceptually defined, for example in a truly spatial representation. In any case, however, the Frame of Reference can be said to be intermediate in that sense that the directional parameters provided by the Perspective express their function during the information-processing route between perceptual and conceptual representation. See Diagram 1.8.

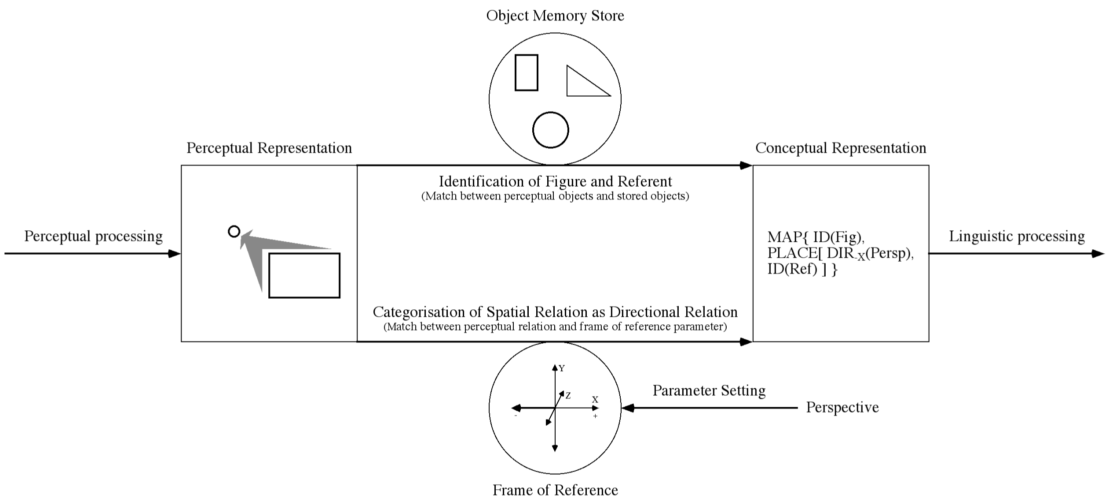

Diagram 1.8. The identification of Figure and Referent, and the categorisation of a Spatial Relation. Obtaining a conceptual representation from a perceptual Figure-Referent configuration involves identification of the Figure and the Referent and categorisation of the Spatial Relation in terms of the reference parameters supplied by the Perspective.

The need to posit that the Frame of Reference is intermediate in this sense is suggested, on the one hand, by the fact that Frames of Reference can be defined on the basis of different informational sources (i.e., Perspectives; see section 1.3.2). Different Perspectives may lead to a description of a Spatial Relation with different Directional Prepositions even when the perceptual representation is the same. On the other hand, different Frames of Reference may lead to a description of a Spatial Relation with the same Directional Preposition although the perceptual representation is different. Thus, the same perceptual representation may be described differently depending on the Perspective while the same description may suit different perceptual representations depending on the Perspective. If one would assume direct (one-to-one) correspondence between Directional Prepositions and meaning, that is, the conceptual representation, it would follow immediately that the Frame of Reference is intermediate between the perceptual representation and the conceptual representation. However, this is not necessarily so, because it may be the case that there is always some Perspective argument represented in the conceptual representation even when it is not always expressed. Considering that the conceptual structure is the result of categorisation involving the choice between at least two directionality parameters, it does follow that Frame of Reference and categorisation process are intermediate between perceptual representation and conceptual representation.

Although the Perspective provides the directional distinctions, it will be assumed that the Frame of Reference parameters are independent from the Perspective in the sense that the parameters are assumed to be similar across Perspectives. It is thus assumed that different Perspectives define the same kind of distinctions, i.e. one, two, or three pairs of directional oppositions. If this assumption is correct is an empirical question; it does appear most parsimonious to assume similar distinctions across different Perspectives and the number of dimensions they provide. The Perspective does define the orientation and the number of directed dimensions, the labelling of the dimensions (e.g., if a dimension is the *front-back* or the *top-bottom* dimension), and the labelling of the assigned directionality (e.g., given that a dimension is the *front-back* dimension, which part is labelled *front* and which part is labelled *back*).

Reference frames thus assign directionality to perceptual space on the basis of which a directional spatial argument structure can be built. When trying to explain the location of some Figure, a Referent is chosen, a Perspective is adopted and accordingly the dimension and directionality parameters are applied to space surrounding the Referent. The so-applied Frame of Reference is used to categorise the perceptual Spatial Relation. Some 'goodness-of-fit' measure of the perceptual Spatial Relation in terms of Reference Frame distinctions gives rise to a correspondence with a conceptual mapping of the argument Figure onto a certain PLACE defined by the MappingFunction applied to the argument Referent.

1.3.2. Different Frames of Reference

Many authors distinguish between different Frames of Reference for Language. See, for instance, Clark (1973), Garnham (1989), Levelt (1984, 1996), Miller and Johnson-Laird (1976), Retz-Schmidt (1988), Talmy (1983), and Tversky (1996). For one particular interesting taxonomy that ranges over various languages, see Levinson (1996). Here, I will simply consider a few aspects to differentiate between the Frames of Reference that need to be taken into account for reasons of comparison.

1.3.2.1. Intrinsic versus Relative Reference

Consider the following examples:

(6) THE BALL IS TO THE LEFT OF ME.

(7) THE BALL IS TO THE LEFT OF THE TREE [from my Perspective].

In both sentences, there is a Referent (‘me’ respectively ‘tree’) and a Figure (‘ball’), whose relation is specified through a direction (*to the left of*) relative to the Referent in about which the Figure can be found. The position of the Figure is thus defined with a Directional Relation from the Referent. The first question one may ask is: From which source of information are these directions defined? Here, there are two possibilities. On the one hand, the directions can be defined from the Referent itself. In sentence (6), the Referent is ‘me’ and the Perspective is defined by ‘me’ as well. The alternative possibility is that the directions are defined from another source of information than the Referent. In sentence (7), the Referent is ‘the tree’ while ‘me’ defines the Perspective. Two classes of Reference Frames can thus be distinguished depending upon whether the Frame of Reference is *extracted from* the Referent or if the Frame of Reference is *projected upon* the Referent. These different kinds of Frames of Reference will be referred to as INTRINSIC and RELATIVE reference respectively.

In the relative cases, the projection is from the Perspective upon the Referent. Three different kinds of projection have been observed. Here, they are classified as reflection, translation, and rotation (although, actually, in all cases there is also translation from the Perspective to the Referent). See Figure 1.4.[10]

[10] The illustration in Figure 1.4 suggests that the Frame of Reference is translated, reflected, and/or rotated as a whole, that is, simultaneously for all dimensions and directions. This is not necessarily the case. In particular, projections might have to be considered for each dimension separately. Thus in the reflection (P/m) frame, one might also assume that only the directionality of the *front-back* dimension is reflected, while the directionality of the other dimensions is only translated. This possibility requires an independent representation of dimensions. It will be argued in Section 2.4 that such independence is the case for Intrinsic Object Centred Frames of Reference.

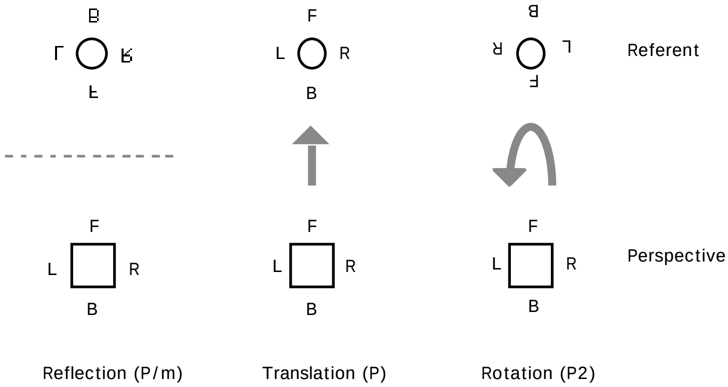

Figure 1.4. Three different ways of projecting a Frame of Reference. Translation (P, simple projection), Reflection (P/m, projection with a mirror (m) perpendicular to (/) the translation direction), and Rotation (P2, projection with 180° (2-fold) rotation) are shown. The notational convention is adapted from the international notation regarding space groups in grid translations. See any handbook on crystallography such as Borchardt-Ott (1993).

Languages that use reflection projection are, among others, Dutch, German, and English (relative P/m-frame). A well-known example of a language using translation projection is Hausa (Hill, 1982; relative P-frame). Rotation projection is found in Tamil (see Levinson, 1996; relative P2-frame). The three different ways of projection have in common that the projection is always performed forward, that dimensional orientations remain unchanged, and that *top-bottom* directionality is never reversed.

1.3.2.2. Egocentric versus Allocentric Reference

Another question, which leads to differentiation among Frames of Reference, concerns the kind of entity that functions as the Perspective and from which the directional distinctions are taken (independent of the above-mentioned distinction). Consider the next examples.

(8) THE BALL IS TO THE LEFT OF THE CAR [from the car's Perspective].

(9) THE BALL IS TO THE LEFT OF THE TREE (a) [when seen from the car],

(b) [from your Perspective].

As opposed to Sentences (6) and (7), Sentences (8) and (9) do not involve ‘me’ as the Perspective. Sentence (8) uses the car as Referent and the car defines the Perspective as well. Sentence (9) illustrates that a ‘not-me’ Perspective may also be used for relative reference. Reference in which ‘me’ determines the Perspective will be called EGOCENTRIC reference while reference in which ‘not-me’ functions as Perspective will be called ALLOCENTRIC reference. In egocentric reference, ego refers to the entity having the spatial representation upon which its use or comprehension of Directional Prepositions is based. Using my own Perspective (assigning directionality to my perceptual space from my viewpoint) is thus given a special status as opposed to me taking directional definitions from something or someone else (assigning direction to my perceptual space from someone else's or some other thing's viewpoint). Other persons are treated as any other object in this classification notwithstanding the special status addressees may have in communicative situations. If I (i.e., the entity bearing the relevant representation) take the Perspective of ‘you’ or if I take the Perspective of ‘the car’ both involves –for the representation-bearing entity– taking an imaginary viewpoint. In both cases, I have to take the orientation of the Perspective into account.

1.3.2.3. Envirocentric Reference

A final kind of directional reference could be treated in one of two ways (or even both ways). Consider the following examples.

(10) THE BALL IS TO THE NORTH OF THE TREE.

(11) MY LUNGS ARE ABOVE MY DIAPHRAGM [independent of my orientation].

(12) THERE IS A BIRTHMARK TO THE LEFT OF THE TATTOO.

(13) MY OFFICE IS RIGHT BEHIND THE LOBBY [from the Perspective of the building].

(14) THE SCRATCH TO THE LEFT OF THE STICKER ON THE BUMPER.

Sentence (10) may be interpreted as an envirocentric (or absolute; see Levinson, 1996) Frame of Reference where geographical distinctions specify the Perspective. Similarly, sentence (11) may be considered envirocentric as well, but with the ego serving as the environmental Perspective. Sentence (12) illustrates that this kind of Reference Frame can be applied to the outer surface of an object while (13) and (14) show that it need not be ‘me’. In this interpretation, there is an environment, absolute as in (10) or restricted to some entity as in (11) to (14), whereby directionality parameters (geographical or intrinsic to the restricted environment) are applied to space surrounding the Referent *within* this environment.

Alternatively, sentence (11) may be considered egocentric and relative whereby the Reference Frame directions are projected ‘inward’ upon the Referent (in Section 1.3.2.1 projections were ‘forward’). Sentence (13) would then have to be considered allocentric with inward projection. Finally, under this interpretation, sentence (10) may also be considered as relative reference with a kind of allocentric Perspective argument *ad infinitum* or absolute.

The question, which of these alternatives is more appropriate, is an interesting one. However, it could also be a question of taste. The difference between both the envirocentric and the absolute Frames of Reference on the one hand, and the intrinsic and relative Frames of Reference on the other, is that the former seem to imply an absolute (Newtonian) conception of space and the latter a relative (Leibnizian) conception of space. In absolute space relations are based on fixed bearings within the respective environment whereas in relative space relations are based on the orientation of the intrinsic Referent or the orientation of the Perspective in Relative frames (see also Levinson, 1996). If it happens to be the case that absolute Frames of Reference behave differently in terms of the categorisation of Spatial Relations than non-absolute Frames of Reference (as was assumed not to be the case for reasons of parsimony in Section

1.3.1.1), then one might consider if the Frames of Reference in Sentences (11) to (14) follow similar rules as those in Sentence (10) or in any other absolute reference system.

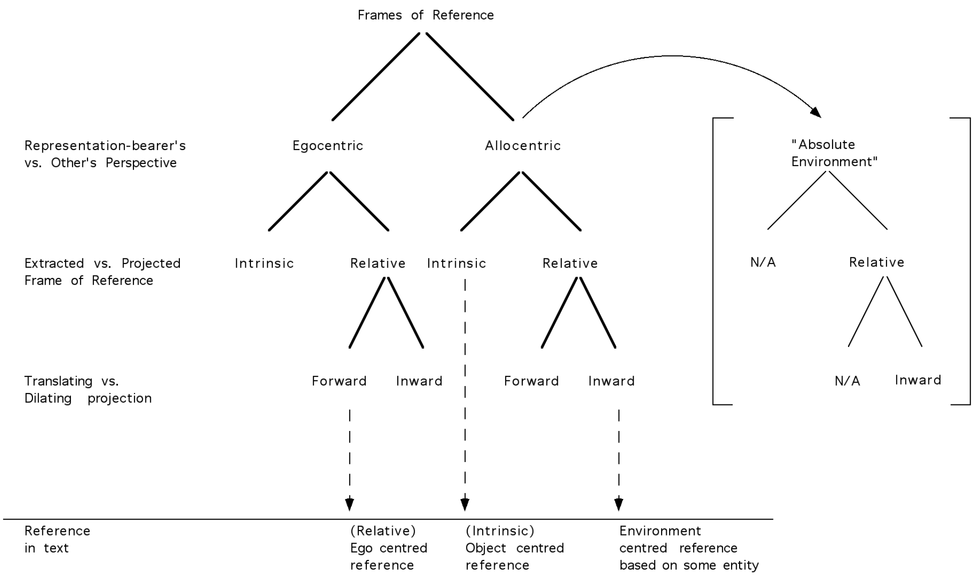

Figure 1.5. Schematic overview of the distinguished Frames of Reference.

Figure 1.5 illustrates one way of schematising the different Frames of Reference.[11] The tree-structure between brackets at the right illustrates the 'special' case of allocentric reference where an 'absolute environment' (e.g. geographical directions) determines the Perspective. An absolute environment Perspective cannot be used for intrinsic reference while the absolute environment cannot be used as a Referent. Described spatial situations are always inside an absolute environment and, thus, a direction cannot be defined relative to an absolute environment in an intrinsic sense (otherwise it would not be an absolute environment anymore). Similarly, an absolute environment Perspective cannot be projected forward.

[11] Instead of bi-partitioning into intrinsic and relative reference and bi-partitioning relative reference, it is also possible to tri-partition in relative (forward), intrinsic, and absolute (relative inward) reference.

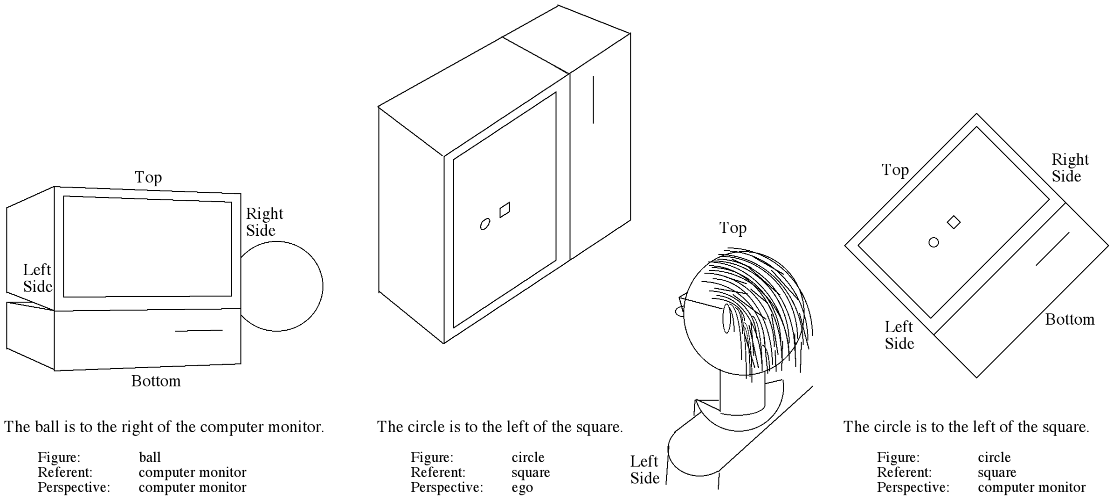

Figure 1.6. Illustration of three different Frames of Reference. Left: Intrinsic Object Centred Reference: The Perspective of the Referent is used to define the location of the Figure with respect to the Referent. Middle: Relative Ego Centred Reference: The Perspective of the ego is projected (forward) on the Referent to define the location of the Figure relative to the Referent. One has to consider the observer in the picture to be ego. If the observer is considered to be someone else, the sentence can be considered an example of relative allocentric reference. Right: Environment Centred Reference based on the computer monitor: The Reference Frame is defined by the surrounding Perspective and projected (inward) on the Referent to define the Figure's location.

In the remainder of this thesis, mainly three of the Frames of Reference will be encountered. The intrinsic allocentric Frame of Reference, which is the primary subject of the thesis, will be called (INTRINSIC) OBJECT CENTRED REFERENCE.[12] Relative egocentric reference will be referred to as (RELATIVE) EGO CENTRED REFERENCE and envirocentric or inward relative allocentric reference as ENVIRONMENT CENTRED REFERENCE with specification of the Reference Frame defining source. Figure 1.6 illustrates these Frames of Reference.

1.3.3. A Note on when Intrinsic Object Centred Reference is used

Given that in some languages different Frames of Reference may be in use, it is possible to ask which Frames of Reference are used predominantly. In languages as Dutch,

[12] It is called Object Centred to clearly differentiate it from other possible allocentric Perspectives that are not single objects (e.g., parades, or herds), and to differentiate from an addressee's Perspective, with respect to which intrinsic reference is also possible.

English, and German it is possibility to use some different Frames of Reference. In these languages (on which this thesis focuses) it is quite clear that Intrinsic Object Centred Reference is not always the first choice.

One important observation has been made regarding the vertical Directional Prepositions (*above* and *below*) when they can be defined from the Intrinsic Object Centred Perspective. If the intrinsic directions are not aligned with the environmental vertical, then the direction terms defined from the Intrinsic Object Centred Perspective are usually not used. A similar observation is made regarding the horizontal Directional Prepositions (*in front of*, *behind*, *to the left of*, and *to the right of*) when they can be defined from the Intrinsic Object Centred Perspective. If the intrinsic directions are aligned with the environmental vertical, then the direction terms defined from the Intrinsic Object Centred Perspective are usually not used ("Principle of canonical orientation", see Levelt, 1984; 1996; see also Garnham, 1989). It thus seems that the environmental vertical (i.e., the gravitational Perspective) is a dominant Frame of Reference overruling others.

Carlson-Radvansky and Irwin (1993; 1994) however show by aligning and misaligning the gravitational Environment Centred, Relative Ego Centred, and Intrinsic Object Centred Frames of Reference systematically, that the Intrinsic Object Centred Frame of Reference is still used in a minor portion in describing Spatial Relations. They also find that all three Frames of Reference seem to have an effect as evidenced by the influence of alignment versus misalignment of Frames of Reference on reaction times in judging Spatial Relations. Thus, while the intrinsic Frame of Reference may not always be the preferred Frame of Reference with which to express Spatial Relations between objects, it does seem to exert an effect.

Another reason to suspect that Intrinsic Object Centred Frames of Reference are not simply unavailable when conflicting with perceived verticality, even when they are not used to describe a Spatial Relation in, is the definition of Directional Parts on objects and reference to these through Directional Nouns. It is perfectly well possible to refer to the *top* of say, the car, even if this car happens to be 'upside-down'. In addition, it is possible to refer to 'a dent in the *front* of the car'. Moreover, it possible to use the car's Intrinsic Perspective and use it in a relative sense by means of projecting it on some Referent, as in Sentence (14), even when this conflicts with the gravitational vertical. Thus, whereas the Intrinsic Object Centred Frame of Reference may not be used equally often in all circumstances to describe Spatial Relations between Figure and Referent, there seems to be no problem in using the same Intrinsic Frame of Reference to define the Directional Parts of the Referent (as has also been noted by Clark, 1973; Miller and Johnson-Laird, 1976). Similarly, there seems to be no problem in using an object as an environmental Perspective and to project its Frame of Reference to some other Referent in its interior or on its outer surface.

Therefore, in what follows, I will ignore the questions of interaction with other Frames of Reference for a substantial part. Instead, I will proceed to characterise Intrinsic Object Centred Frames of Reference without bothering if (or when) they are used or not. Additionally, it is assumed that if someone tries to investigate the interactive and/or overruling aspects of different kinds of Frames of Reference, then it will be helpful to have a theory for each of the Frames of Reference to begin with. There also seems to be no problem in asking participants to define Spatial Relations from the Intrinsic Object Centred Perspective and to ignore all other ones that might be available. Furthermore, the experiments described on memory for Intrinsic Locations forced participants to use intrinsic characteristics of objects in spatial memory. No participant had any problems with understanding the task.

Chapter 2.Intrinsic Object Centred Reference Frames

In this Chapter, it will be assumed that there is a homomorphism between the structure of objects in the world and the structure of the intrinsic representation of objects. The reason for this is as follows. Directional definitions around Referents are not defined in the real world but only in the visual perceptual representation (or in a spatial representation). The Directional Relations to whom Directional Preposition phrases refer are usually defined in order to use them in communication. A communicative situation involves more than one perceptual representation (i.e., each participant is assumed to have one). Each of these perceptual representations could be construed from visual input obtained from different views upon the spatial situation. Therefore, the retinal projection and (following) the position, orientation, slant and/or tilt of the Referent as it appears to the addressee may be dramatically different from how it appears to the speaker. To obtain a link between real objects, directional definitions, and communicative useful Directional Prepositions despite possible differences in appearance, it is assumed here that the structure of objects in a perceptual representation is similar to the structure of objects in the actual world, and that a similar represented structure is obtained from different views. Assuming this assures that relevant distinctions in object structure (i.e., those that may be used to define Directional Parts) are available to all participants in the communicative situation and may be used to define intrinsic Directional Relations expressible by Directional Prepositions. For simplicity, I will therefore continue as if a 3D structure of objects in 3D space (or 2D structure in 2D space when considering 2D objects) is represented that complies with the structure of the actual world.

This assumption may not necessarily be true for actual representations. It is possible that the perceptual representation has less dimensionality. If that would be the case however, then probably one would have to assume some additional spatial processing and/or spatial inference to be able to explain the 3D character of directional definitions (i.e. a Frame of Reference with 3 directed dimensions). The fact that Intrinsic Object Centred Frames of Reference may be used in communicative situations makes it plausible that there is at minimum some kind of 'indirect' homomorphism between real-world objects on the one hand and the perceptual representation of these objects combined with additional processing on the other. When it is not the represented structure that defines 3D-ity, then at least the perceptual representation must allow valid inferences about actual object structure currently not in sight if communication is to be effective between speaker and addressee with different views on the Referent. It is possible to express or to understand Intrinsic Object Centred Directional Prepositions that refer to Directional Relations that are out of view. One of the advantages of using Intrinsic Object Centred Reference in some circumstances is exactly that it possible to describe Spatial Relations independent from the viewpoint of both speaker and addressee. It follows that the definition of the Spatial Relation should be independent of perceptual differences between speaker and addressee.

Once the assumption regarding homomorphism is made, it is possible to consider what makes the objects themselves suited and what makes them unsuited for use as a Referent in Intrinsic Object Centred Reference. That is, what intrinsic properties (structural and categorical) must be available to afford an object to be used as a Referent in intrinsic reference while ignoring all other aspects of the situation that have nothing to do with the (intrinsic aspects of) objects themselves. In Section 2.2, I will consider with which objects structured in what way intrinsic reference can be performed essentially. The spatial characteristics are important for intrinsic reference for language as well as for the coding of Intrinsic Location in memory. Thereafter, Section 2.3 considers how category membership restricts an object’s use as an intrinsic Referent for language. It is shown that both the possibility to refer to an intrinsic Spatial

Relation with a Directional Preposition and the coding of an Intrinsic Location for memory depend on spatial characteristics, but that linguistic reference depends on the object category of the Referent as well. However, there is no one-to-one correspondence between the Referent's spatial structure and the Referent's category. Then, Section 2.4 considers why the object category of the Referent comes with a specific labelling of intrinsic directions. Finally, Section 2.5 considers what can be said about Directional Regions, that is, which Spatial Relations may be categorised as a certain Directional Preposition. Also here, some differences between the categorisation of Spatial Relations for language and the coding of Intrinsic Location for memory are observed. At first, however, I will elaborate on the concept of structural (intrinsic) descriptions.

2.1. Intrinsic Descriptions

When considering Intrinsic Object Centred Frames of Reference it should first be stated what ‘intrinsic’ means. An intrinsic or structural description (or representation) of an object means that the structure of the object is defined relative to itself (Hinton, 1979; Hinton and Parsons, 1981, 1988; Marr and Nishihara, 1978; Palmer, 1983; Rock, 1973). Such a description of an object is independent of things as orientation, position, size, and parity (and therefore viewpoint), or put differently the description is invariant over rotation, translation, dilation, and reflection. Object features are defined relative to an object’s own origin and dimensions. Therefore, the intrinsic representation of a real car and a toy car may be more or less the same. In both cases, e.g., the height may be defined relative to the length with a similar aspect ratio, while the relative position of doors, wheels, and seats may be the same as well. Each is alike with respect to its own Frame of Reference.

Whereas an intrinsic description of an object is defined in terms of its own structure, it is assumed here that Intrinsic Object Centred Reference somehow extends this own structure beyond the object's exterior bounds in order to assign directionality to surrounding space with which Spatial Relations can be categorised. Therefore, it is considered to what extent intrinsic descriptions of objects may support the construction of intrinsic Directional Relations and intrinsic coded locations. The structural description of an object must thus support the definition of Directional Parts as well as Directional Regions. Therefore, what is needed, and following actively sought, are structural descriptions of objects (in particular: Referents) in three orthogonal directed dimensions, that is, in terms of *top-bottom*, *front-back*, and *left-right* distinctions, or in terms of features[13] that are able to support *top-bottom*, *front-back*, and *left-right* distinctions. As a word of warning note that, although intrinsic descriptions of object structure and Intrinsic Object Centred Frames of Reference for Language both carry the word 'intrinsic', this may be coincidental and that it first needs to be established if there is more than a superficial similarity. In any case, I will try to account for Intrinsic Object Centred Frames of Reference by means of structural descriptions of objects (Referents).

2.1.1. Enantiomorphs and Descriptions with Independent Dimensions

Consider the case of two objects that are symmetric counterparts or enantiomorphs as illustrated in Figure 2.1.A and B. For each of these objects one may define an intrinsic description, which may refer to the (relative) length of their parts (the lines **p** and **q**) and the relation between them (the angle α). However, contrary to what one may expect it is not possible to differentiate between these enantiomorphs by means of their respective intrinsic descriptions (see Corballis, 1988; Hinton, 1979; Hinton and Parsons, 1988;

[13] The term ‚feature’ is used from here on to refer to any aspect of an object that can be defined spatially, that is, components, features, parts, etc. that have a spatial distribution in the object’s structure.

Kant, 1783; Van Cleve and Frederick, 1991). The reason for this is that enantiomorphs have similar parts and similar relations between parts. They have the same shape except for parity. An intrinsic description would mention the parts and the relation between the parts; such a description fits each of the enantiomorphs as well as the other.

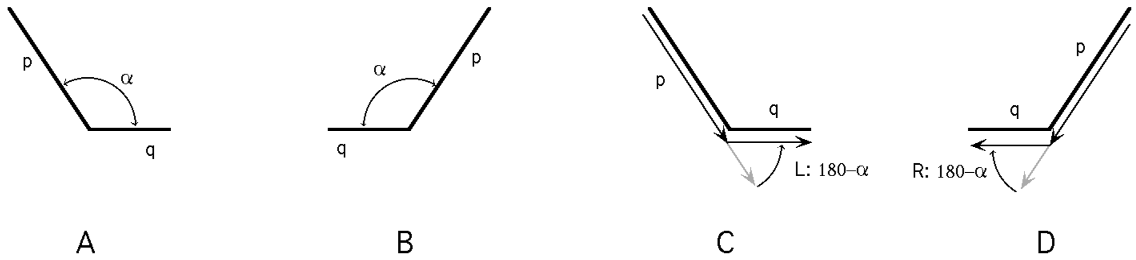

Figure 2.1. Intrinsic differentiation of enantiomorphs is not possible. Intrinsic description of the objects in A and B both mention line p, line q, and angle α. Discrimination of the objects requires at least one non-intrinsic element. C and D show that when line p is seen as a route, that upon arriving at angle α one object can be –conventionally– characterised with a *left* turn and the other with a *right* turn. Although such a description is not purely intrinsic, it can be used independent of the object's orientation.

2.1.1.1. Adding a Non-intrinsic Component to Differentiate Enantiomorphs

Enantiomorphs are different though. If one rotates one of them (mentally or actually), then it becomes clear that complete overlap with the other is not possible. This illustrates that the objects can be discriminated. The only way to differentiate between the symmetric counterparts in their respective descriptions is to make use of some non-intrinsic information.[14] Figure 2.1.C and D illustrate one possible, but arbitrary, way in which this may be done. When one of the lines, say **p**, is considered to be a route and/or a Perspective[15] then arriving at the angle at which line **q** is attached, one of the enantiomorphs is characterised by a *left* turn, while the other is characterised by a *right*

[14] A pictorial manipulation (mental or actual rotation) might be enough to determine whether the objects are the same or different. However, this procedure employs no explicit description of the objects so by rotation alone one is still unable to *communicate* which is which. For the definition of Directional Parts and Intrinsic Directional Relations, an explicit identification of parts is necessary as well. Pictures, mental images, templates, and the like do not support decomposition into parts unless it is assumed that they are generated by an underlying structure.

[15] As mentioned before, no definition of direction is possible without some kind of Frame of Reference. Also in this case, an –imposed– Perspective defines the Reference Frame.

turn. Such a description combines intrinsic and non-intrinsic information. The difference between **p** and **q** (the parts) and where they are attached to one another (their relation) functions as the intrinsic basis upon which the arbitrary Perspective and/or route Direction is applied. *Left* and *right* turns however are defined by virtue of an analogy to the human body, how we use these terms, or how we describe routes. Importantly, based on intrinsic information alone one is unable to tell symmetric counterparts apart; for this one needs to use some kind of non-intrinsic information.

The above example used an intrinsic description based on the identification (at least differentiation) of features and the relation between them. This kind of structural description will be referred to as the 'intrinsic features description'. No matter how much more complex the object is, what the orientation is in which the object appears, and whether it is a 2D or 3D object, the intrinsic features description does not differentiate between enantiomorphs (of course, for orthomorphic objects, that is objects without enantiomorphs, this is irrelevant). All that is required is the coding of the features and the relations between them. If such a description is used for recognition, then it is required that the features and the relations between them have been coded before, and that a further encounter with the object elicits this fact (which presupposes that some memory trace has been built). To determine if an object is the same as or a mirror image of a previously seen one, it is required that conventional information is added to the intrinsic description in both cases. If non-intrinsic information were not coded, then structural object descriptions in terms of intrinsic features would conclude that an object and its mirror image are the same.

2.1.1.2. Independent Dimensional Directionality

Intrinsic features descriptions are not necessarily suited for Intrinsic Object Centred Reference for language though. For this, descriptions of objects in orthogonal dimensions are needed. So, as an example, consider an intrinsic description along these lines of an object consisting out of similar parts as the previous example, but with a slightly different relation between the parts: the letter ‘L’. See Figure 2.2.

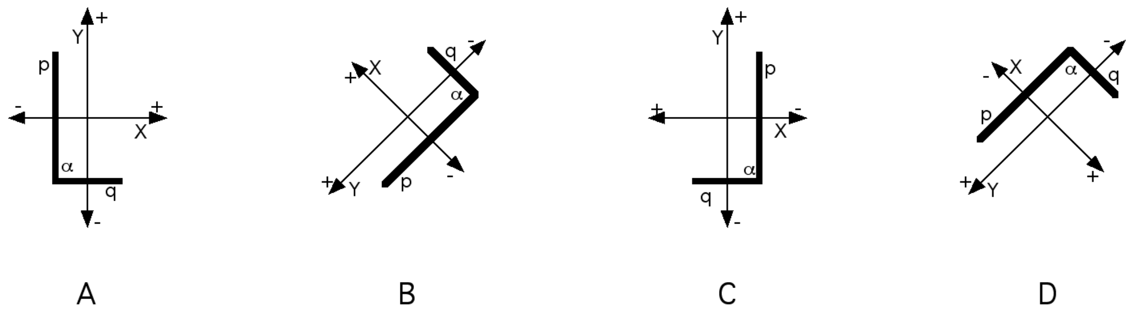

Figure 2.2. Intrinsic description in terms of orthogonal dimensions of the letter ‘L’ and its mirror image.

Independent of seeing that the object could be recognised as an ‘L’, it is possible to define dimensions along the parts of the object and to assign directionality according to where the other part can be found. Thus, in Figure 2.2.A-D, the **[Y]** dimension is aligned along part **p** and the **[-]** sign is attached where **q** is. Similarly, the **[X]** dimension is along part **q** and the **[-]** sign is attached where **p** is. As can be seen in the Figure, such a directional description can be applied over rotations and reflections of the object without any problem. Again, only differentiation between **p** and **q** and the determination of their relation is needed. The parts and their relation determine the orientation and (spatial) directionality of the dimensions with respect to the page. The dimensions and their directionality can be set independently of one another (see Hinton and Parsons, 1988). Therefore, a structural description such as this one will be referred to as an intrinsic description with 'independent dimensional directionality'.

It will now be assumed that the object is recognised as being an ‘L’, and that the whereabouts of the Directional Parts of an ‘L’ are known. Note that it need be the object's parts and their relation (that is, **p**, **q**, and α; perhaps by some perceptual, identity-independent intrinsic features description) that allow recognition of the ‘L’.[16] The established identity allows the identification of Directional Parts on the perceptual exemplar in its particular orientation (that is, orthogonal intrinsic directed dimensions can be established with respect to the perceptual parts and their interrelations). A linguistic directional description may replace the spatial directional description used above. The **[Y]** dimension becomes the *top-bottom* dimension where **[+]** is replaced by *top*. Similarly, the **[X]** dimension is the *left-right* dimension and its **[+]** denotes the *right side*. In fact, nothing else changes, except that the identity ‘L’ refers to only one of the reflection variants.[17] Given that it is possible to give all examples the same description, how is one to tell which of the objects are 'normal L' and which are 'reflected L'? Again, one needs to invoke non-intrinsic information. For reasons discussed in Chapter 3, an illustration of the involvement of non-intrinsic information is easiest with a comparison of the objects of Figure 2.2.A and C. The non-intrinsic information involves conventional linguistic labelling; spatial distinctions may however be used instead. Regarding Figure 2.2.A the object can be identified as a 'normal L' because the object complies with what is known about an ‘L’. For an ‘L’ that is upright (i.e., **[+Y]** is aligned with Ego or Environment Centred *above*), **[+X]** (or the direction in which part **q** 'points' as seen from part **p**) is aligned with Ego Centred *right*. Regarding Figure 2.2.C the object can be identified as a 'reflected L' because the object does not comply with what is known about an ‘L’. That is, although **[+Y]** is aligned correctly with Ego or Environment Centred *above*, **[+X]** is aligned with Ego Centred *left*. What 'we' call *left* and *right* given *top-bottom* directionality, and a specification of what is the normal version, thus differentiates normal from reversed versions. For Figure 2.2.B and D the procedure has to be analogous; there however needs to be a correction for the objects' orientation (why this is so and how this may be done is also discussed in the Chapter 3).

[16] It could also be assumed that holistic aspects perform recognition, that is, recognition without a decomposition of the perceptual object. However, for the definition of Directional Parts it is required that the perceptual object is decomposable.

[17] It is thus implied that both normal and mirror image versions of ‘L’ are recognized as an ‘L’.

As an example of an enantiomorphic object in 3D, which is perhaps more 'familiar' than an object consisting of two attached lines, consider intrinsic descriptions of shoes. Intrinsic descriptions of shoe structure cannot define the difference between a left shoe and a right shoe. All have noses, heels, soles, laces, and other parts that have the same relation with respect to one another for left shoes as well as right shoes. The structure of both kinds of shoes can be described (represented) along the 'nose-heel' dimension, the 'big-small toe' dimension, and the 'sole-lace' dimension. Note that again parts may define the perceptual description in this example, whereby the parts need not be identified as a 'nose' or 'heel'; the terms are used for convenience here. Thus, a (perceptual) intrinsic structural description of a shoe may order all the parts of a shoe along these dimensions. The same description would result for left shoes as well as right shoes. Without non-intrinsic information, it is impossible to differentiate left shoes from right shoes. The perceptual description does allow identification (as a shoe), and identity allows definition of Directional Parts and intrinsic directed dimensions with respect to the perceptual instance of the shoe. To determine whether the shoe is a left shoe or a right shoe, it is the *top-bottom* and *front-back* directed dimensions that have to be taken into account (or have to be taken as a reference), while left shoes and right shoes differ in part structure only along the *left-right* directed dimension, but not along the other directed dimensions. It requires knowledge on the general part structure of shoes to know which parts are associated with, e.g., the *top* of the shoe and which parts with other Directional Parts. In any case, the *top-bottom* and *front-back* directed dimensions can usually be defined easily on any shoe, for which it is required that the 'sole-lace' and 'nose-heel' dimensions of the shoe's description are defined as the respective directed dimensions. If it is determined what is the *top*, *bottom*, *front*, and *back* of the shoe, it is possible to apply what *we* –that is, not intrinsic to the shoe– call *left* and what we call *right*. Thus, given the *top-bottom* and *front-back* Perspective of the shoe, one may assign *left* and *right* Directional Parts to the shoe. Only after this is established it is possible to identify the shoe as a left shoe or a right shoe. Depending upon, e.g., if the 'big toe' part happens to be the *left* Directional Part or the *right* Directional Part, the shoe can be identified as a right respectively left shoe.

This example is interesting enough to extend it to the definition of Directional Relations. If one knows that some shoe is actually a left shoe, it is possible to define *left* and *right sides* –and, by extension, *left* and *right* intrinsic directional information– by means of the intrinsic structure of the shoe. The *right side* of a left shoe is where the 'big toe' would be and intrinsic 'to the right of the left shoe' is adjacent to that part of the shoe. However, intrinsic structure as such does not define *to the right of* with respect to any shoe (while the *right side* of a left shoe and the *left side* of a right shoe have the same structure and description). Moreover, if one wants to define 'to the right of the shoe' it is not even necessary to consider if it is a left shoe or a right shoe. All that is necessary is to take the *top-bottom* and *front-back* directed dimensions into account and apply what we call *left* and *right*.

The last part of the shoe example shows that sometimes non-intrinsic information is needed to explain how Directional Relations are defined that are –commonly and currently– classified as Intrinsic Object Centred Reference. 'To the left of the shoe' may be defined by considering if it is a left or a right shoe (which involves non-intrinsic information) and use the intrinsic structure of the respective shoe to define *to the left of*. Alternatively (and more efficiently), it is possible to use non-intrinsic information right away to define *to the left of* once the *top-bottom* and *front-back* directed dimensions are established. The *top-bottom* and *front-back* directed dimensions are similar for any shoe.

2.1.2. Non-intrinsic Descriptions are Rotation Variant

As a comparison, consider how it is possible to define an object non-intrinsic. For instance, one may define some object independent axial system (e.g. orthogonal dimensions based on the ego or the environment) and describe an object in terms of it. I will refer to such a description as an 'extrinsic directional description'. Figure 2.3 shows examples of ‘L’ with a superimposed extrinsic axial system. In Figure 2.3.A the ‘L’ is in its upright position and 'normal' version. The description of the object is about the same as the 'intrinsic directional description'. It is easy to see that the enantiomorph of the object (Figure 2.3.C) produces a different description. While the axes are signed from fixed bearings based on the ego or on the environment, and do not depend on the structure of the object, enantiomorphs produce different descriptions (such a description thus has an 'absolute, Newtonian flavour'). However, such object descriptions are not only reflection variant. In Figure 2.3.B, the orientation of the ‘L’ is no longer upright. As a result, the description of the object would change as well. Part **q**, for instance, is now at **[+X]** and **[+Y]** (or at the *top right side*). Therefore, descriptions of object structure defined non-intrinsic (by some external defining system) change with the orientation of the object (i.e. the description is rotation variant).

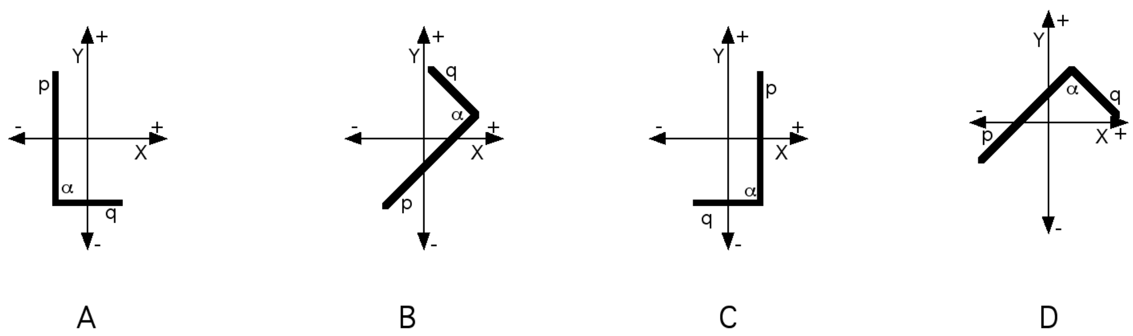

Figure 2.3. An extrinsic description of an object is rotation and reflection variant.

2.1.2.1. Non-intrinsic Descriptions and Correcting for Orientation

A solution to rotation variance (ignoring other variances) would be to attach the extrinsic co-ordinate system to particular aspects of the object. For instance, it is possible to align the **[Y]** dimension along part **p** so that part **q** is at **[-Y]**, as illustrated in

Figure 2.4. The description has become partially intrinsic as a result however because the co-ordinate system is attached and oriented according to intrinsic aspects of the object. In order to produce the same description for each orientation and location of the object, knowledge is thus required on how to attach the axial system to the object. Thus, if the object is recognised as an ‘L’ (again, the perceptual description must allow this), it requires knowing at which perceptual features of the ‘L’, e.g., the *top* directionality of the extrinsic reference frame needs to be attached. If the object is not identified as a known object, but is familiar (seen before), then it requires that the extrinsic frame be attached in the same way to obtain the same description in terms of Directional Parts (see also Rock, 1973). The use of knowledge associated with the object's identity is not different from an intrinsic description with independent dimensional directionality. Both cases require that the object's perceptual structure (parts plus relation) is used to identify it (or to recognise it as familiar) and identity is used to identify the Directional Part(s) among the perceptual features.

There is one obvious drawback to this procedure. Given some object at some orientation, either the extrinsic co-ordinate system needs to be rotated to attach it to the object or (the image of) the object needs to be rotated to match the co-ordinate system. An advantage of this drawback may however be that, by means of what will be called *normalisation* (see, e.g., McMullen and Jolicoeur, 1992), the orientation of the object is explicitly determined with respect to the extrinsic Frame of Reference. Determining the orientation of an object means determining the orientation of intrinsic directed dimensions with respect to Ego Centred or Environment Centred space (see Hinton and Parsons, 1981). Attaching an extrinsic Frame of Reference to intrinsic aspects of an object exactly establishes this. The issue of normalisation, that is the orientation of the intrinsic Frame of Reference with respect to upright, will be encountered again in Chapter 3.

Anyway, with a non-intrinsic description of the object corrected for intrinsic orientation by a 'normalisation procedure' (i.e., to overcome rotation variance of the description), it is perfectly well possible to tell the enantiomorphs apart. Figure 2.4 clearly shows that normal versions of ‘L’ have part **p** at **[-X]**, while reflected versions have part **p** at **[+X]**. For the objects in Figure 2.4.A and C, this is clear immediately while the objects happen to be upright. For the objects in Figure 2.4.B and D correction for the *top-bottom* orientation, that is deviation from upright, has to be performed first. Once the *top-bottom* directed dimension is normalised with respect to Ego or Environment Centred upright however, the difference between normal and reflected versions is clear right away as well. If attaching the Frame of Reference to the perceptual objects' top-bottom orientation performs the correction for object orientation, then, once the correction is completed, it can be directly accessed if part **q** points to the *left* or the *right*, and if the ‘L’ is normal or reflected.

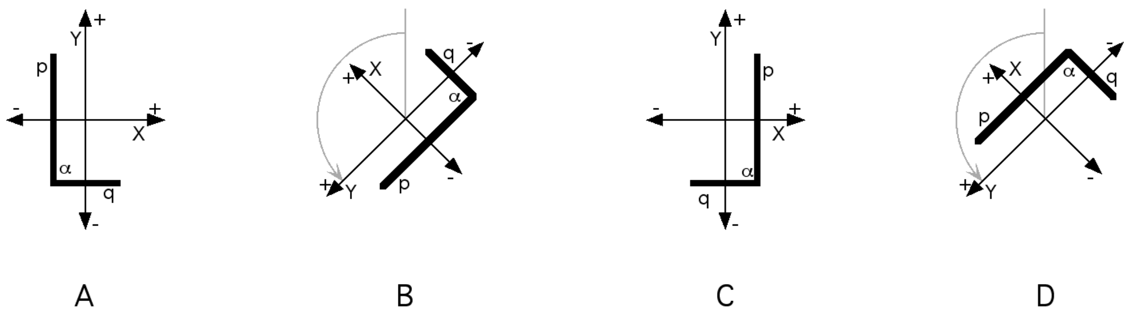

Figure 2.4. Attaching an extrinsic frame to intrinsic aspects. Normalisation (grey arc) may determine the orientation of the object.

There is one important aspect that differentiates the extrinsic orthogonal dimension attached to intrinsic aspects description from the intrinsic orthogonal dimension description. If extrinsic orthogonal dimensions are used, then the orientation and directionality of the second dimension is fixed relative to the orientation and directionality of the first dimension. Thus, the structure of the object does not define the directionality of the second axis, but fixed directionality defining bearings are rotated to match some single-dimensional aspects of the object. Thus, if, as in the example above, the extrinsic frame is rotated such that extrinsic *top* is aligned with intrinsic *top*, then *left* and *right* are rotated along and could not be reversed relative to the *top-bottom* directed dimension. The conventional definition previously used to differentiate left shoes from right shoes (or normal from reflected 'L') in the examples with independent dimensional directionality is therefore not necessary because an extrinsic frame is used. It is possible to argue that a conventional *left-right* definition is also used in the present case however while the convention is already pre-defined in the axial, dimensional system that is used to describe the object with. Instead of the signed **[X]** and **[Y]** axes shown in Figure 2.4, assume that the co-ordinate system employs Directional Prepositions. *Above-below* and *left-right* thus replace the **[Y]** and **[X]** axes respectively. If corrected for the *above-below* orientation, *left* and *right* are defined conventionally. The objects are evaluated with respect to extrinsic defined directionality.

2.1.3. Intrinsic Descriptions with Dependent Dimensional Directionality

It may not even be necessary to have a fixed set of directed dimensions derived from an extrinsic Perspective. That is, it might be possible to use the intrinsic structure of an object to extract one signed axis of a pre-defined co-ordinate system, whereby the orientation of the axis simultaneously defines the orientation *and sign* of a second axis (in 3D this requires that two axes are oriented, whereby the orientation and sign of the third axis is fixed). It could be the case that such a set of directed dimensions is available and that only intrinsic aspects (features) of the object regarding one dimension is used to set two directed axes, while the directionality on the other dimension is only allowed to be set in a single way. This is illustrated in Figure 2.5 where again examples of 'L' are shown. As a variation, this time the directed dimension is set along the *left-right* directionality. In contrast to setting the frame along the *top-bottom* features as was done with the corrected extrinsic frame above, this results in interpretations that may sound strange, but are computationally similar.

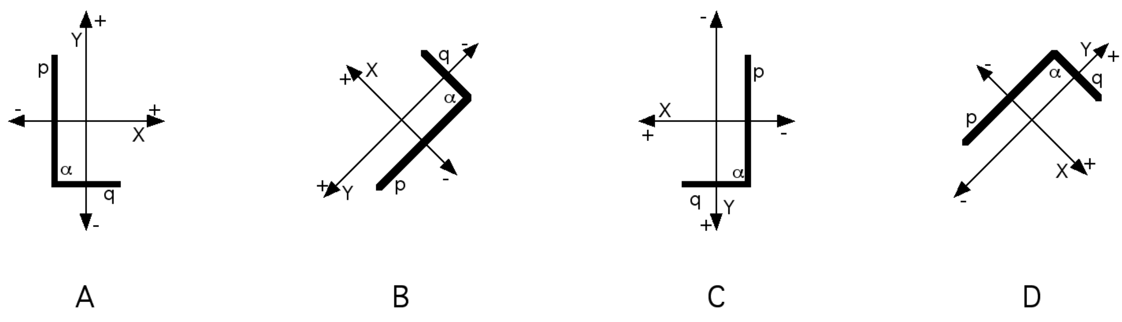

Figure 2.5. An intrinsic description with dependent dimensional directionality attached to the *left-right* dimension.

Most importantly, it is the *top-bottom* structure that is reversed in Figure 2.5.C and D, and which allows differentiating normal and mirror image versions. For instance, Figure 2.5.C has to be considered as an 'L' that is rotated 180° and that has its *top* and *bottom* features reversed. Because the frame is set according to the *left-right* structure, the *left-right* dimension is set at an orientation that deviates 180° from the normal orientation. Therefore the object in Figure 2.5.C should be considered a 'right-side-to-left' oriented object.[18] However, because part **q** is found at the *top* directionality of the frame (i.e. **[+Y]**), it has to be concluded that the object is *top-bottom* reversed. This may sound odd, but that would be the correct interpretation given that an intrinsic description with 'dependent dimensional directionality' is applied according to the object's *left* and *right* features. Computationally spoken there is not much of a difference to interpreting Figure 2.4.D as (almost) upside-down with *left* and *right* reversed, and interpreting Figure 2.5.C as (completely) right-side-to-left with *top* and *bottom* reversed (see also Corballis, 1988). The object in Figure 2.5.D would only deviate 45° from the normal

[18] The normal orientation of the object would usually be denoted by upright, while a 180° deviation from the normal orientation is normally referred to as upside-down. 'Upright' and 'upside-down' already show the bias that exists in interpreting orientation as deviation from the vertical, even for reflected objects. See also Chapter 3.

orientation of an ‘L’, but have *top* and *bottom* reversed. Again, one may argue that non-intrinsic information is defined within the frame used to describe the object and therefore enantiomorphs can be distinguished. Once one directed dimension is established, the other directed dimension is set as well.

The example of the shoe can be involved here as well. It is possible to distinguish left from right shoes by means of some non-intrinsic description corrected for the shoe's orientation or by means of an intrinsic description with dependent dimensional directionality. With 3D objects, the orientation of two dimensions needs to be corrected for, or the fixed-sign co-ordinate system must be set according to two intrinsic dimensions. Regarding differentiation of left and right shoes, the *left-right* directed dimension would be the dependent one and the frame is set according to the *top-bottom* and *front-back* features of the shoe. Given that there is only one way in which *left* and *right* are set, it would not be necessary anymore to consider what 'we' call *left* and *right*, given that this is thus incorporated within the frame. With the shoe structure found at the *left* and/or *right* directionality, it is possible to determine if it is a left or a right shoe. Similarly, once the other directed dimensions are set, *left* and *right* directionality can be applied directly for Directional Relations independent of the kind of shoe.

2.1.4. Intrinsic Descriptions of Spatial Relations and Extrinsic Conventions

In what follows, non-intrinsic information will usually not be involved to differentiate between enantiomorphic objects as in the shoe examples, but merely to distinguish between enantiomorphic (mirror symmetric) Directional Parts of an object. Non-intrinsic information will only be added to intrinsic descriptions as a last resort. It will only be used for the definition of directional information when there are no intrinsic characteristics that can do the job. It is required that the added non-intrinsic information can be used independent of the orientation of the reference object and the view on the object. If this requirement is not met, the directional information cannot be classified as being Intrinsic Object Centred anymore. Additionally, if the resulting description of directional information is to be any good in a communicative situation, better base it on some convention that is agreed upon between the participants in a conversation, that is, between the speakers of a language. It is possible to argue that the definition of *to the left of* and *to the right of* in the shoe example (independent dimensional directionality) is such a convention. Thus, that which is normally classified as Intrinsic Object Centred Reference may not have all of its aspects defined in a purely intrinsic sense.

The strategy pursued below will involve relying on aspects of objects defined intrinsic. Extrinsic descriptions corrected for intrinsic orientation are ignored completely, but note that such descriptions are similar to intrinsic descriptions with dependent dimensional directionality. Non-intrinsic aspects will only be involved if not possible otherwise (thus intrinsic independent directional descriptions to which conventional labelling may be added). I will thus try to explain Intrinsic Object Centred Reference for language and the coding of Intrinsic Location for memory by using the intrinsic structure of a Referent. The possibility of defining intrinsic directional information with some pre-defined co-ordinate system attached to some intrinsic aspects (intrinsic descriptions with dependent dimensional directionality) will only be invoked when relevant. Note that usually both description variants can be used, if one of them can. When considering possible spatial structure of Referents, however, some structures will be encountered with respect to which dependent dimensional directionality could be applied, while independent dimensional directionality fails. When considering the category characteristics of objects that determine if and why Directional Parts can be defined on objects, it will however be shown that objects with such spatial structures are not suited to define Directional Parts on them. It will be argued that intrinsic descriptions with independent dimensional directionality are more plausible. Experimental evidence discussed in Chapter 3 will be interpreted as corroborating this view. It does appear possible though to use both strategies in defining or remembering the Intrinsic Location of a Figure with respect to a Referent and that it is an empirical question to determine which of these is used (if any).

Thus, intrinsic aspects of a Referent will be used in attempts to define a co-ordinate system, which might be used for the categorisation of Spatial Relations as Directional Relations for Intrinsic Object Centred Reference for language. The structural intrinsic description strategy seems naturally in line with Intrinsic Object Centred Reference for language because, apart from the shared word, it establishes orientation invariance by itself. Orientation invariance is, among other invariants such as translation (location), dilation (size) and reflection (parity) variance, important to establish communication between speaker and addressee on Intrinsic Object Centred Frames of Reference when different views on the Referent are involved.

2.2. The Spatial Structure of a Referent

This section considers one important input characteristic when defining an Intrinsic Directional Relation on the basis of a perceptual representation: The spatial structure of the Referent. Spatial structure is considered to determine, on the one hand, which Intrinsic Locations relative to an object can be defined and, on the other, the *potential* of the object to support an Intrinsic Object Centred Frame of Reference for Language.

In order to define an Intrinsic Object Centred Frame of Reference on the basis of an object's intrinsic spatial structure, at least three aspects are thought to be important: The structural complexity of the object, possible rotation and reflection invariance transformations of the object, and the regularity of the object. As will be shown, these aspects are only partially independent. It will further be shown, that parameters of spatial Frames of Reference, such as origin, dimension, directionality, and scale (see

Logan and Sadler, 1996), may or may not be easily accommodated by intrinsic descriptions of objects with a given spatial structure. The origin could be some suitable point of the object, although it appears difficult, if not impossible, to give a definition, which can be applied to all objects.[19] The scale probably depends on the spatial extendedness of the Referent, which however may be ambiguous as the extendedness may not be constant over dimensions and directions (therefore one could ask if there is only one scale used for all dimensions or if scale is defined for each dimension). However, scale is not important in the present context, because it does not affect directionality. Scale will therefore mostly be ignored. Not all objects are suited to define three dimensions. Some objects only allow fewer dimensions, while others may even allow more (more than three dimensions however imply that they are not in an orthogonal orientation anymore). Finally, directionality can be assigned only when dimensions are available, but dimensionality does not imply assigned directionality.

2.2.1. Rotation Invariance

To assure that information concerning the location of the Figure is communicated successfully, the transferred information not only needs to be viewpoint independent, it also needs to be unambiguous. Regarding Intrinsic Object Centred Reference Frames, this means that the specified direction must have a unique definition relative to the Referent. Thus, an *a priori* requirement for intrinsic reference is that the intrinsic description of a Referent allows a unique definition of directions. Directions may not be indistinguishable from other directions. If an object is invariant under some rotation (rotation < 360°), then an intrinsic structural description of the object is unable to

[19] If objects lack natural origins for the definition of Intrinsic Locations and Directions, then it can be argued that the whole object needs to function as the origin of the Intrinsic Object Centred Frame of Reference for language. Whereas the intrinsic description of object structure may not allow a clear definition of all reference frame parameters, these might still need to be defined for intrinsic Frame of Reference for Language. Regarding coding of Intrinsic Location for memory, however, some origin must be used and any *ad hoc* origin could be used.

distinguish between some parts of the object. Similarly, the intrinsic directions that would change their orientation (i.e., within Environment or Ego Centred space) under the same rotation cannot be told apart either. To see this, consider a rectangular shaped table as a potential intrinsic Referent. Because this table is invariant when rotated 180° about the vertical axis, the table’s structure allows no intrinsic differentiation between horizontal directions. Therefore, it is not possible to uniquely define horizontal directions without adding non-intrinsic information as in, e.g., ‘at the farther end of the table’. This latter possibility (i.e., 'farther' defined from some external non-intrinsic Perspective and projected upon the Referent) is however dependent on the orientation of the table as well as on the viewpoint of the speaker and addressee. It is not possible to classify it as an example of Intrinsic Object Centred Reference (although part of the description refers to the intrinsic *dimensional* part ‘end’).

The structure of an object must thus allow a unique definition of one or more pairs of directions in order to be suited as an intrinsic Referent. Possible rotational invariance transformations of an object therefore strongly restrict its use as an intrinsic Referent. It can be shown that a Referent suited for Intrinsic Object Centred Reference does not have any rotational invariance transformations at all (2D and 3D objects) or only rotational invariance transformations about a single axis (3D objects). Before considering this closer, note first that in this section only the principal possibilities of defining Intrinsic Locations and Spatial Relations given some spatial structure of the Referent are considered. Categorisation of Spatial Relations is not considered yet nor therefore is it considered if Directional Prepositions could actually be used with respect to the objects. Categorisation of Spatial Relations as Directional Relations also depends on other object factors, in particular the object's category membership and the functional characteristics of object categories as discussed in Sections 2.3, and 2.4. It will however be considered to what extent an intrinsic Frame of Reference *may* be defined given an object's spatial structure. The extent to which a specific structure allows the definition of Intrinsic Locations and Directions is directly relevant to the coding of Intrinsic Location for memory, and partly relevant to the categorisation of Spatial Relations for language. Importantly, categorisation of Spatial Relations as Directional Relations is only possible if intrinsic directionality can be defined to begin with. However, the extent to which a spatial structure *could* support an intrinsic Frame of Reference does not determine the extent to which spatial structure *is* actually used to categorise Spatial Relations as Directional Relations for language. All directionality expressed by Directional Prepositions involves knowledge about the Referent's object category (see Section 2.4).

Thus, I proceed to consider which Frame of Reference parameters may be defined given an object's (Referent) spatial structure. This affects the possibility to define Intrinsic Locations and Directions directly, and definable locations may be used in memory for Intrinsic Locations. Not determined yet is if these definable Frame of Reference parameters are actually used to categorise Spatial Relations as this depends on category characteristics. The extent to which Frame of Reference parameters may be defined does however define the extent to which a spatial structure can potentially support Frames of Reference for categorisation. It thus defines the maximum number of intrinsic dimensions a spatial structure may have to categorise a Spatial Relation as an Intrinsic Directional Relation.

The set of all symmetries (transformational invariance) and their combinations forms a mathematical entity called a group. Objects can be assigned to symmetry groups. The symmetry group is itself a subgroup of the Euclidean congruencies (including translations), which is a subgroup of the Euclidean similarities (including dilations), which is a subgroup of the projective group (including projective transformations). The latter two groups are the basis of Euclidean and projective geometry respectively (see Palmer, 1983). Usually, e.g., within crystallography, reflection and inversion symmetry are included in the classification of objects (the *point* groups, i.e., the smallest crystal units) within possible subgroups of the symmetry group. Reflection and inversion are no operations that are spontaneously performed in the external world (turning a bag, jacket, or glove inside out probably comes closest to this) and a difference in viewpoint does not produce an inversed or reflected image of an object (except of course when looking at something through a mirror). Note here that a difference in viewpoint produces a difference in the perceived image of an object that could also have been produced by a rotation of the object. Therefore, at first, the rotational symmetry operations (that is, the rotation subgroups) will be considered whereby reflection and inversion point groups of relevant rotation groups will be considered when these are important regarding intrinsic descriptions for other reasons. An infinite number of rotation symmetry groups exist, but their classification is simple. I will treat this subject not exhaustively but quite extensively while to my knowledge this has not been done before with respect to the present subject. Symmetry groups have however been used in other psychological research. See, e.g., Chen and Chen (1999), Palmer (1983; 1991), or Pani (1994).

2.2.1.1. 2D Rotation Symmetry Groups

As the easier case, I will consider the 2D symmetry groups first. Figure 2.6 shows a few examples. The illustrations are mostly shape examples. However, it is not shape as such that determines the symmetry group, but the spatial organisation of the object. Other object features, such as colour, texture, or patterns, are capable to define a similar spatial organisation.

All the 2D rotational symmetry subgroups except for the C_1 group (C = Cyclic) are unsuited for intrinsic reference, because no unique intrinsic definition of location and direction is possible.[20] The C_1 *rotation* symmetry subgroup includes the asymmetric

[20] The notational convention that is used here and for 3D objects (Section 2.2.1.2) is the Schoenflies notation. See any handbook on crystallography, such as Borchardt-Ott (1993). 2D objects are sometimes classified differently, *viz.*, as Dihedral subgroups. If so, then it is implied that 2D objects can be rotated in 3D space. This possibility is excluded; the objects are not allowed to flip out of the plane of the page.

object (what will be called the C_1 *point* group) and the bilateral symmetric object (the C_{1s} point group). In all other cases, Intrinsic Locations cannot be defined for use in a memory task, nor can Spatial Relations be categorised for language. For instance, the circle (R_2 or C_∞) allows neither dimensions nor directionality to be imposed on it that is defined intrinsic. It does allow an origin however, which is the midpoint, the only intrinsic unambiguous location of a circle. Scale may be defined as well, be it diameter or radius. In fact, all intrinsic spatial information that can be defined is a distance from the midpoint (or from the circumference). Such a description applies equally well to a circular array of locations. No intrinsic directional information can be defined.

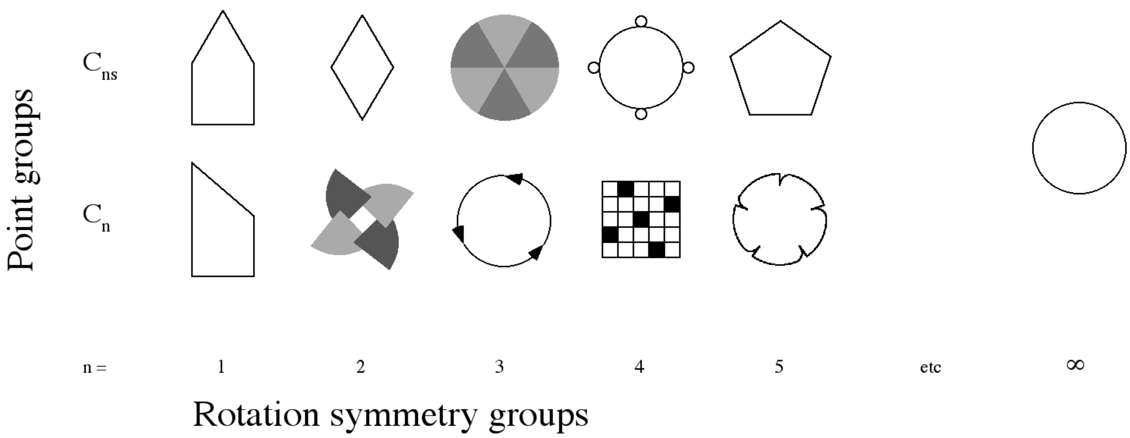

Figure 2.6. 2D objects that are not suited for intrinsic reference because of n-fold rotational invariance around the centre (except for the leftmost objects). Every location and direction around the objects and every point of the objects, except for the rotational centre, is –when defined from a purely intrinsic description of the objects– indistinguishable from n - 1 other locations and directions in the C_n case and in the C_{ns} case as well when locations are on or directions coincide with an axis of symmetry, but indistinguishable from 2n - 1 other locations and directions for all other locations and directions in the C_{ns} case. In the latter case however, combining the intrinsic description with some non-intrinsic directional information reduces indistinguishability from other locations and/or directions to n – 1 as well.

2.2.1.1.1. Two-fold Rotation Invariance

As another example, the C_2 rotation symmetry subgroup allows two dimensions to be defined, but it does not allow that directionality is assigned to them. Origin is still naturally defined: each 2D object with rotational invariance characteristics (i.e., rotation symmetry subgroups $C_{n;\, n\geq 2}$) has a natural mid-point, which is the point around which it can be rotated by 360°/n (or a multitude of this) without any apparent orientation change. The origin is the only unambiguous location of objects from these groups. Within the C_2 rotation symmetry subgroup, one may differentiate the C_{2s} point group, which has two axes of (reflection) symmetry, and the C_2 point group with no mirror symmetry. Both happen to be inversion symmetric about the origin as well; this has no relevance in the 2D case, though.

In the C_{2s} point group (e.g., a rectangle), the dimensions are naturally aligned with the symmetry axes while an intrinsic description with independent dimensional directionality only defines these axes unambiguously (see Figure 2.7.A). Each other thinkable orientation of orthogonal dimensions would not have an intrinsic description that may allow its discrimination from a mirror symmetric oriented pair of orthogonal axes (I will call this ‘enantiomorpic dimension setting’; see Figure 2.7.B and C). By implication, from the fact that two enantiomorphic objects allow no intrinsic discrimination, it follows that these dimension settings cannot be distinguished by intrinsic aspects either.

No directionality can be assigned to the dimensions because the object part along one half-axis is the same as the object part along the complementary half-axis. Locations on axes cannot be unambiguously defined, while locations on the axis at one side of the origin cannot be distinguished from locations on the axis at the other side of the origin. Descriptions of other points of the object are even less definite. When one uses Cartesian co-ordinates (**x** from the origin along one dimension, and **y** from the origin along the other dimension) to define such locations, it becomes apparent that each pair of co-ordinates actually describes four locations. What goes for locations on the object may be extended to locations around the object. See Figure 2.7.D. The same ambiguities hold for directional information. If directional information is based on intrinsic structure alone, a direction is indistinguishable from one other direction (the opposed) if the direction happens to coincide with an axis of symmetry and indistinguishable from three other directions otherwise.

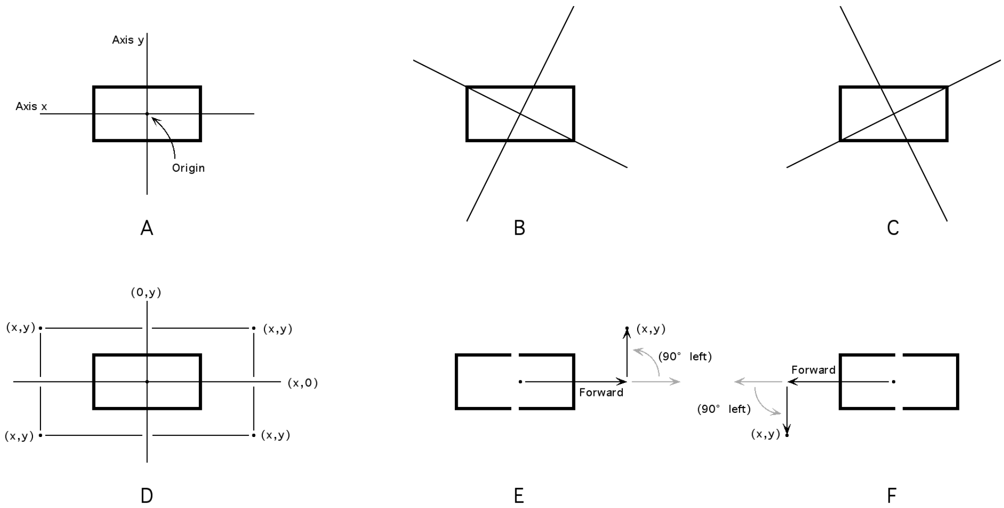

Figure 2.7. The C_{2s} point group and the definition of Intrinsic Location. See text for details.

While an intrinsic description of location with independent dimensional directionality may apply to four locations, it is also the case that with a rotation of 180° (the two-fold rotational invariance) only pairs of the four **(x, y)** locations of Figure 2.7.D happen to exchange places. Only these pairs are therefore indistinguishable (i.e., those that are at opposing corners). It is thus possible to differentiate between some of the locations. This differentiation cannot be based on intrinsic information alone, but instead requires some within-object Perspective supplemented with non-intrinsic information. In Figure 2.7.E and F one possible way is illustrated in which one pair of the locations may be differentiated from the other pair of locations with the same intrinsic description. A location may be defined by starting from the origin and defining distance along one dimension first (along the 'longest' dimension in this case), thereby establishing a particular Perspective (or route direction, say going ‘forward’) which can be defined in two directions. At the appropriate distance along the dimension, one may define one pair of locations by making a ‘*left* turn’ (as shown) and the other pair of locations by making a ‘*right* turn’ (not shown). Note that this strategy makes use of the intrinsic defined difference between dimensions. Any *left* and *right* turns (or any other convention such as clockwise and counter clockwise) are not defined by the object itself, because the object –and therefore intrinsic description– is the same regardless of the direction in which the turn is made. Labelling turns as *left* and *right* is possible by virtue of an analogy to the human body, the convention of using these terms, or how we describe routes.

It is, mildly spoken, questionable if there actually is such a convention in describing locations around rectangles or around other members of the same point group that is agreed-upon in a language community. For defining locations unambiguously, it makes no sense anyway, because there are no intrinsic unambiguous locations except for the centre of the rectangle. The example does however show that it is possible to differentiate between '*left* turn' and '*right* turn' pairs even when they have no intrinsic distinction. This non-intrinsic differentiation may require additional processing. The present analysis regarding this point group may thus have consequences in other domains but not regarding the subject of unambiguous intrinsic directional definitions. If non-intrinsic information is added it becomes clear that each defined direction is indistinguishable from one other direction as could be expected because of the point group's two-fold rotational invariance.

In the C_2 point group (e.g., a parallelogram), the structure of the object’s symmetry subgroup does not restrict the orientation of the dimensions. If dimensionality is assigned to a C_2 object, the dimensionality needs to depend on some characteristics of the object that are not shared by the point group as a whole. As illustrated with the parallelogram in Figure 2.8.A1 to A4, orthogonal dimensions may be defined, for example, relative to parallel sides, or relative to opposing corners. In fact, any other orientation of two orthogonal axes through the rotational centre (the origin) would do.

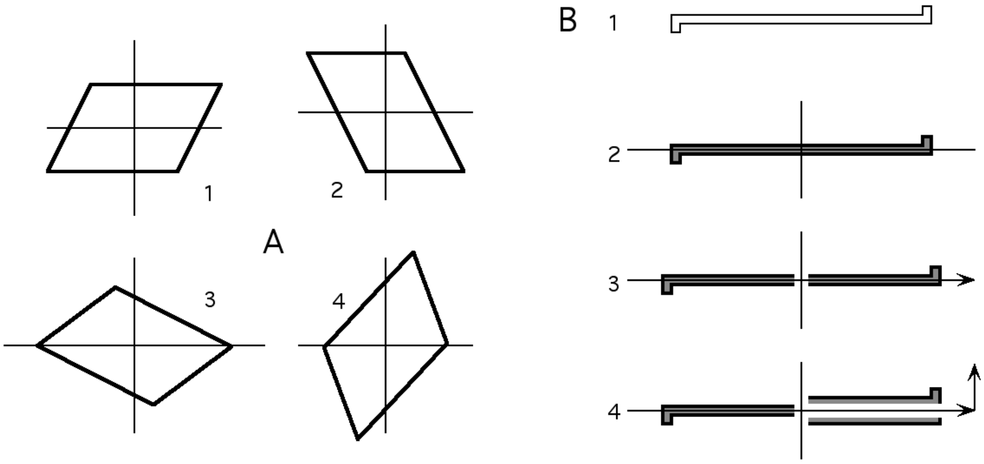

Figure 2.8. The C_2 point group and the definition of Intrinsic Location. See text for details.

If somehow a choice for a particular dimensional orientation is made, then it becomes possible to consider other Reference Frame parameters. With an object as illustrated in Figure 2.8.B1 it may be assumed –intuitively, but arbitrarily– that the dimensions (exemplified by an axial system) are aligned with the clearly longer extension and orthogonal to it, whereby the intuition is strengthened by the parallelism of sides with dimensional orientation (see Figure 2.8.B2). However, also with this point group it is not possible to assign directionality to the dimensions, because the object part along one half-axis is the same as along the other half-axis (however, rotated by 180°, but this actually equals the difference in orientation directed poles of a dimension have). See Figure 2.8.B3. In this case –contrary to the C_{2s}-case– this does not mean that an intrinsic description of location actually defines four locations. Again, a Perspective may be adopted on the object, but this time there is no need to define non-intrinsic turns. For instance, one may take the route ‘outward’ from the origin (point of rotation) along the longer dimension for some specified distance, and then define a turn in the direction with the small part attached (when the object is understood as being mainly rectangular with two small parts attached). See Figure 2.8.B4. Thus although one may define two different ‘outward directions’, the 'turn' one needs to make can be defined in the object structure. Therefore, an intrinsic description may define only two locations. Again, extension to directional information is straightforward.

2.2.1.1.2. No Rotation Invariance

Notwithstanding the interesting observations that are made with regard to Reference Frame aspects supported by rotational invariant objects, objects upon which dimensions and assigned directionality may actually be defined unambiguously are of more relevance to the present thesis. The C_1 rotation symmetry subgroup has no rotational invariance. Again, two point groups may be defined: Objects with bilateral symmetry (the C_{1s} point group) and objects without bilateral symmetry (the C_1 point group).

A bilateral symmetric 2D object allows dimensions and directionality to be defined in an intrinsic manner. The C_{1s} example of Figure 2.6 is shown with its axis of symmetry in Figure 2.9.A. If one dimension is set vertically along the axis of symmetry, then directionality can be defined along this dimension as well. This is illustrated in Figure 2.9.B where the object is separated at the point halfway along the axis of symmetry (this point is set arbitrarily while there is no natural origin with this object). From the clear difference between these separated parts it is possible to infer that an intrinsic description of the object includes the difference between these parts (or similarly defined parts) and therefore that directionality may be assigned to the dimension.[21] A bilateral symmetric 2D object always allows an intrinsic directed dimension along the axis of symmetry.

The intrinsic structure upon which directionality should be assigned to the second –orthogonal– dimension is illustrated in Figure 2.9.C by separating dimensional object parts at the point where this dimension crosses the axis of symmetry. The resulting parts are symmetric counterparts or enantiomorphs. It is not possible to

[21] The example only serves to illustrate how dimensional and Directional Parts (and by implication directionality parameters that are used to categorize a Spatial Relation as a Directional Relation) that may be defined need to be *oriented* in order to be unambiguous. The actual way in which Directional Parts are defined may be different from the way suggested in the Figure.

distinguish these enantiomorphs by means of an intrinsic description with independent dimensional directionality alone. If values along each of the dimensions define a location, then the definition applies to another location as well (see Figure 2.9.D). However, directionality can be assigned to the second dimension by making use of the first dimension and adding information that is not intrinsic. When the directionality of the first dimension is taken into account, directionality can be assigned to the second dimension through some act of labelling or marking.[22] In this way, one may tell apart the enantiomorphic dimensional parts, thereby changing them into Directional Parts. Through the labelling it is possible to distinguish between two locations that are not intrinsic differentiated otherwise. See Figure 2.9.E. If there is some agreed-upon convention that one may use with the object, then it is possible to use such labelling in conversation. For instance, if the one (intrinsic) directed dimension is the *top-bottom* dimension then the other (intrinsic) dimension might be assigned directionality when half-axes are (non-intrinsic) labelled with *left* and *right* under the *top-bottom* Perspective. Such labelling thus takes into account the particular directional marking of the other dimension as a kind of within-object Perspective. Note that this thus implies a natural order in assigning directionality to dimensions with respect to a bilateral symmetric 2D object. See Figure 2.9.F

The orienting of dimensions as described above is the only way that this can be done with independent dimensional directionality. That this is so can be shown by trying to divide the object into Directional Parts in another way, such as shown in Figure 2.9.G. By independent dimensional description alone such a dimension setting will fail, because this and any other dimension setting other than along the axis of symmetry, has an ‘enantiomorphic dimension setting’ as illustrated in Figure 2.9.G. An

[22] This (secondary) assignment of directionality is not based on the object parts, because these are the same, but on, e.g., an analogy to the human body (see Corballis and Beale, 1976). The suggested analogy involves a *left-right* definition, as will also be suggested in Section 2.4. It will even be argued that the symmetric Directional Parts of a bilateral symmetric object cannot be anything else but the *left* and *right side*. *Left-right* definitions are always not strictly intrinsic.

intrinsic point of view cannot tell apart these two enantiomorphic dimension settings. Note however that it is possible to use a description with dependent dimensional directionality to distinguish between the two enantiomorphic dimension settings. With the use of dependent dimensions, that is with a pre-defined signed co-ordinate system or directed Frame of Reference attached in some specific way to intrinsic aspects of the Referent (as shown in Figure 2.9.H), one may define locations and directions. I see no need for that, however, as there is a way in which dimensions can be set intrinsic and independently. Thus, there is only a single way to impose dimensions and assign directionality on a bilateral symmetric 2D shape in an (almost) intrinsic manner. Moreover, assigning directionality to dimensions has an order.

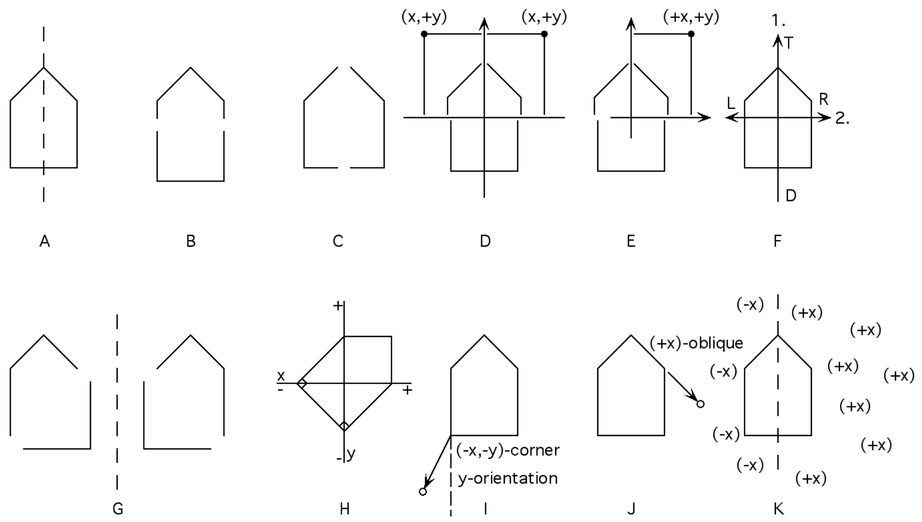

Figure 2.9. How Directional Parts may be defined (oriented) with respect to a 2D symmetric object.

Keep in mind however that this example only shows that it is fundamentally possible to define an Intrinsic Object Centred Frame of Reference on a bilateral symmetric 2D object. Whether an object is suited as a Referent for intrinsic categorisation of Spatial Relations depends upon the object being a member of an object category or not. Depending on the object category, Directional Prepositions are shown (Section 2.4) to refer to Directional Relations that are based on category knowledge. The object category defines if some dimension is, e.g., the *top-bottom* dimension or the *front-back* dimension and it defines also if some part is, e.g., the *front* or the *back*. When an Intrinsic Object Centred Frame of Reference is defined, however, the bilateral symmetric object allows only a single way to orient the dimensions. There is no natural origin within the point group. One dimension may either be localised at the axis of symmetry or characterised through the same orientation as the axis of symmetry. The other dimension can only be characterised through an orientation, but not localised at an axis. Therefore, a description that generalises over dimensions would do without axes. Directionality is assigned first to the dimension that has the same orientation as the axis of symmetry.

Independent of these categorisation questions, the intrinsic structure of a bilateral symmetric 2D object is suited to define Intrinsic Locations for memory. To code a location, however, one needs to define some origin, which can be about anywhere, for instance from the bottom-left corner (see Figure 2.9.I). The co-ordinate system used from an origin can be one of many either, for instance, it may be Cartesian along the directed dimensions as in Figure 2.9.E. Alternatively, one might code the location by a polar co-ordinate system (i.e. with an angle and a distance) using one of the dimensions as a reference orientation (note that this requires specification towards which other signed half-axis the angle is). As still another example, aspects of the object may be used directly, e.g. by extension of one of the oblique object parts ('oblique' is defined here in relation to dimensional orientation). This possibility however requires that the two oblique parts are differentiated within the intrinsic structure of the Referent (by conventional labelling or some pre-defined co-ordinate system). See Figure 2.9.J. It is possible to come up with other possibilities.

In any case, however, the coding of Intrinsic Location relative to a bilateral symmetric 2D object necessarily needs to involve a reference to the side it is on from the axis of symmetry unless the location is on the axis of symmetry. Similarly to a possible intrinsic Frame of Reference for language it thus needs reference to a Perspective laid on the axis of symmetry and some way of labelling the half-spaces at either side of the axis (e.g. as *left* versus *right*, clockwise versus counter clockwise, or **[+X]** versus **[-X]**). This is thus an example that the coding of Intrinsic Location for memory and the Intrinsic Object Centred Frame of Reference for language, if both are defined from the object's structure as much as possible (that is with independent dimensional directionality), have necessarily something in common. See Figure 2.9.K. The half-planes at either side of the axis of symmetry are good candidates for (well-defined) spatial categories in the coding of Intrinsic Location for memory. Whether these regions are also categories for Spatial Relations in Intrinsic Object Centred Reference for language (i.e., Directional Regions) remains to be seen.

Finally, consider the 2D point group without rotation and reflection invariance. In principle all aspects of the Frame of Reference can be set with objects belonging to this group: Each object part and each intrinsic direction and location can be uniquely defined. However, as opposed to the bilateral symmetric case where dimensions can only be oriented in a single manner, in the a-symmetric case spatial structure does not restrict this. On which aspects of an object origin (if any), dimensions, and directions may be based is not defined beforehand. For instance in Figure 2.10 dimensions may be oriented along the sides that meet at the 'right angle' (A) but there is nothing intrinsic to the object not allowing the dimension to be oriented along its 'longest side' and orthogonal to it (B). Given some dimensional orientation, directionality may always be assigned. Other object properties than belongingness to this symmetry point group must play a role in defining dimensions and directions on asymmetric 2D objects. Regarding asymmetric 2D objects, the potential to use such objects for the intrinsic categorisation of Spatial Relations depends upon the object's categorisation, which determines how dimensions are oriented, and how directionality is assigned.

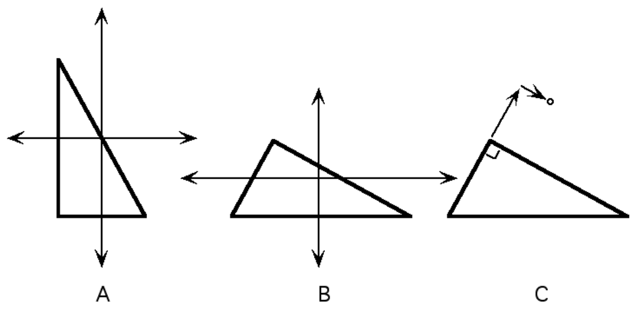

Figure 2.10. Members of the C_1 point group allow every Intrinsic Location on and around themselves to be uniquely defined. The group as such does not restrict axis orientation or any other Frame of Reference parameter as can be seen when comparing A and B.

The use of asymmetric objects to define Intrinsic Locations for memory seems always possible and possible in many different ways. One example of how a location can be coded is shown in Figure 2.10.C: Define the origin at the object's straight angle, define some distance by extending the shortest object side away from the object, define a second distance along the other side with which the shortest side makes the straight angle. Note that one may define an Intrinsic Location like that even if an Intrinsic Object Centred Frame of Reference for language would be defined as in Figure 2.10.B.

2.2.1.2. 3D Rotation Symmetry Groups

Figure 2.11 illustrates the rotation symmetry subgroups of 3D objects. It is also possible to investigate these subgroups regarding the extent to which their structure supports unique intrinsic definitions of direction. Regarding 3D objects one may consider which spatial object structures allow for a full Frame of Reference, that is three directed dimensions, and which only allow for a partial Frame of Reference, that is less than three directed dimensions. Again, it is apparent that the number of rotational invariance transformations is important. Only with the C_1 rotation symmetry subgroup (i.e., no rotational invariance transformations) is it possible to define every part of the object and (thus) every direction relative to it unambiguously by means of an intrinsic description with independent dimensional directionality (with one notable exception: The inverse symmetry point group C_{1i}). An object with rotational invariance transformations cannot support a full intrinsic Reference Frame (6 directions). For a full Frame of Reference to be intrinsic defined on an object, this object may not possess more than one plane of mirror symmetry and no axes of rotational symmetry nor a point of inversion symmetry.

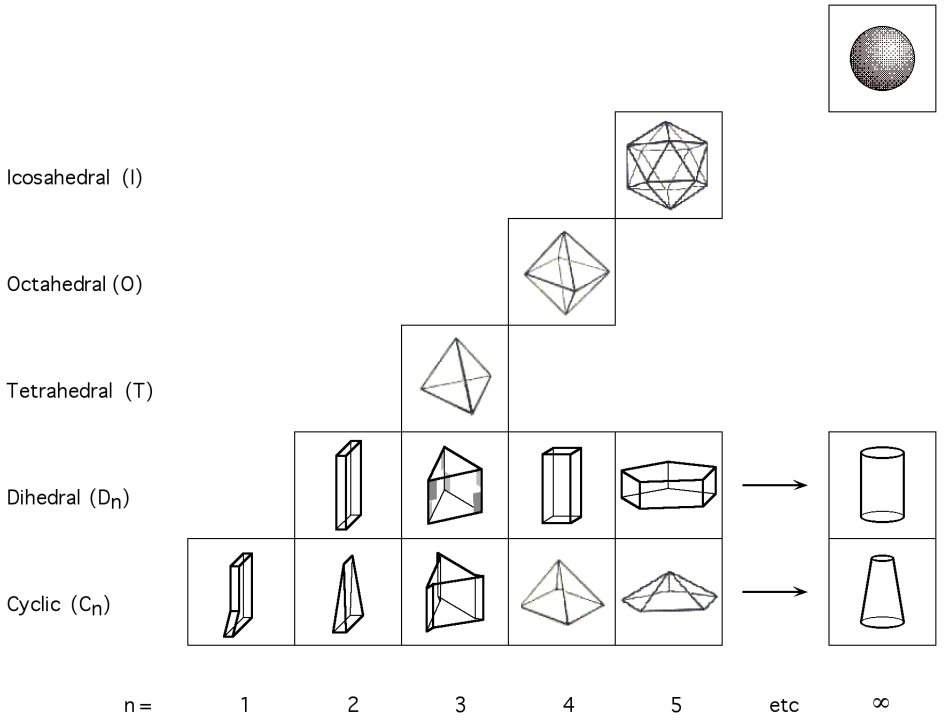

Figure 2.11. Examples of the 3D rotation subgroups of the symmetry groups. Except for $D_{n;\{n\geq6\}}$ and $C_{n;\{n\geq6\}}$ these are all existing groups. Because the Figure considers only rotation invariance transformations, the, e.g., C_2 rotation group includes the symmetry point groups C_{2v} (shown), C_2, C_{2h}, as well as S_4.

An object with rotational invariance transformations may support a partial intrinsic Frame of Reference (less than three directed dimensions). In that case, the only intrinsic signed axis is the *single* axis of rotation around which the object may be rotated and remain invariant. Therefore, objects with the maximum potential of supporting a partial Frame of Reference belong to one of the $C_{n;\{n\geq2\}}$ rotation subgroups. The $C_{n;\{n\geq2\}}$ subgroups allow one intrinsic directed dimension to be defined unambiguously (but again with exceptions within the rotation groups, see below). Uniquely defined intrinsic directions are along the axis of rotation. Similarly, it is possible to define all locations on this axis in an intrinsic manner. For a partial Frame of Reference to be intrinsic defined on an object with independent dimensional directionality, this object may not have more than one axis of rotational symmetry, and have no natural origin.

No rotation subgroups other than C_n support intrinsic Frames of Reference. No unique intrinsic directions can be defined with respect to these groups. Some of them may allow the definition of an origin and orthogonal dimensions while no directionality can be assigned. It is thus possible to consider more generally what combinations of dimensions and directionality assigned to dimensions can be supported by the symmetry subgroups. In specifying how spatial object structure may support intrinsic Frames of Reference parameters, not only the number of dimensions of a frame needs differentiation, but also the number of distinctive dimensions, that is, the differentiation of dimensions among one another. Only when there are distinctive dimensions, may eventually exist a possibility to label one as, e.g., the *front-back* dimension, and another as the *left-right* dimension. Further, one needs to distinguish between how many of the dimensions may have directionality assigned to them.

The following holds when dimensions (axes) are restricted to having an orthogonal orientation with respect to one another. Objects exist with no separable dimensions (R_3, i.e. a sphere). Other objects have only one definable dimension, where either no directionality can be assigned to the dimension (**[X]**; D_∞-member, e.g. a cylinder) or directionality can be assigned to it (**[±X]**; C_∞-member, e.g. a cone). Next, an object may have two orthogonal dimensions, in which case it follows that it has a third dimension as well (orthogonal to both others). It may happen that the three dimensions are not distinctive, that is, that each axis is the same. If this is the case, then the object belongs to the Octahedral subgroup (**[$\mathbf{X_1}$, $\mathbf{X_2}$, $\mathbf{X_3}$]**; O-member, e.g. a cube).[23] However,

[23] Equal dimensions can have no directionality assigned to them, because if there were, then a unique other directed dimension would prevail. An example is a cube with three black sides meeting at one corner and three white sides meeting at the opposite corner: A unique three-fold rotation axis with

if one of the dimensions is different from the other dimensions, then the different axis (**[X]**) may allow no directionality assigned to it (**[X, Y_1, Y_2]**; D_4-member, e.g. a tile) or it does allow directionality to be assigned (**[±X, Y_1, Y_2]**; C_4-member, e.g. a regular square pyramid).[24] Finally, all dimensions may be distinct. If this is the case, then there are three possibilities regarding the assignment of directionality to the dimensions: None of the axes has sign attached to it (**[X, Y, Z]**; D_2-member, e.g. a cuboid), one of the axes allows sign to be attached (**[±X, Y, Z]**; C_2-member, e.g. a rectangular wedge), or all axes may obtain sign (if two axes obtain sign, it follows that the third axis obtains sign as well: **[±X, ±Y, ±Z]**; C_1-member, e.g. a left shoe).

2.2.1.2.1. Various Examples

The above classification is somewhat coarse. Nevertheless, I will first illustrate it with an object with a single unsigned axis, an object with a single signed axis, an object with three unsigned axes, and an object with three axes of which one is signed. These objects and the way in which Intrinsic Location may be defined are illustrated in Figure 2.12. Thereafter I will nuance the classification somewhat for the C_2 and the C_1 rotation subgroups by considering these more closely. The point groups collapsed in these rotation subgroups will be looked at in more detail regarding the partial respectively full intrinsic Frames of Reference that can be supported when using intrinsic description with independent dimensional directionality. Descriptions may be supplemented with a non-intrinsic aspect that can be used independent from the orientation of the object. I leave it to the reader to consider other rotation subgroups in more detail if she/he likes.

directionality assigned to it appears between the corner where the black sides meet and the corner where the white sides meet.

[24] Tiles and regular rectangular pyramids are actually ambiguous about the orientation of the dimensions that are the same (i.e., **[Y_1]** and **[Y_2]**). For instance, regarding tiles, the dimensions may be oriented orthogonal to two opposing sides or oriented between opposing corners.

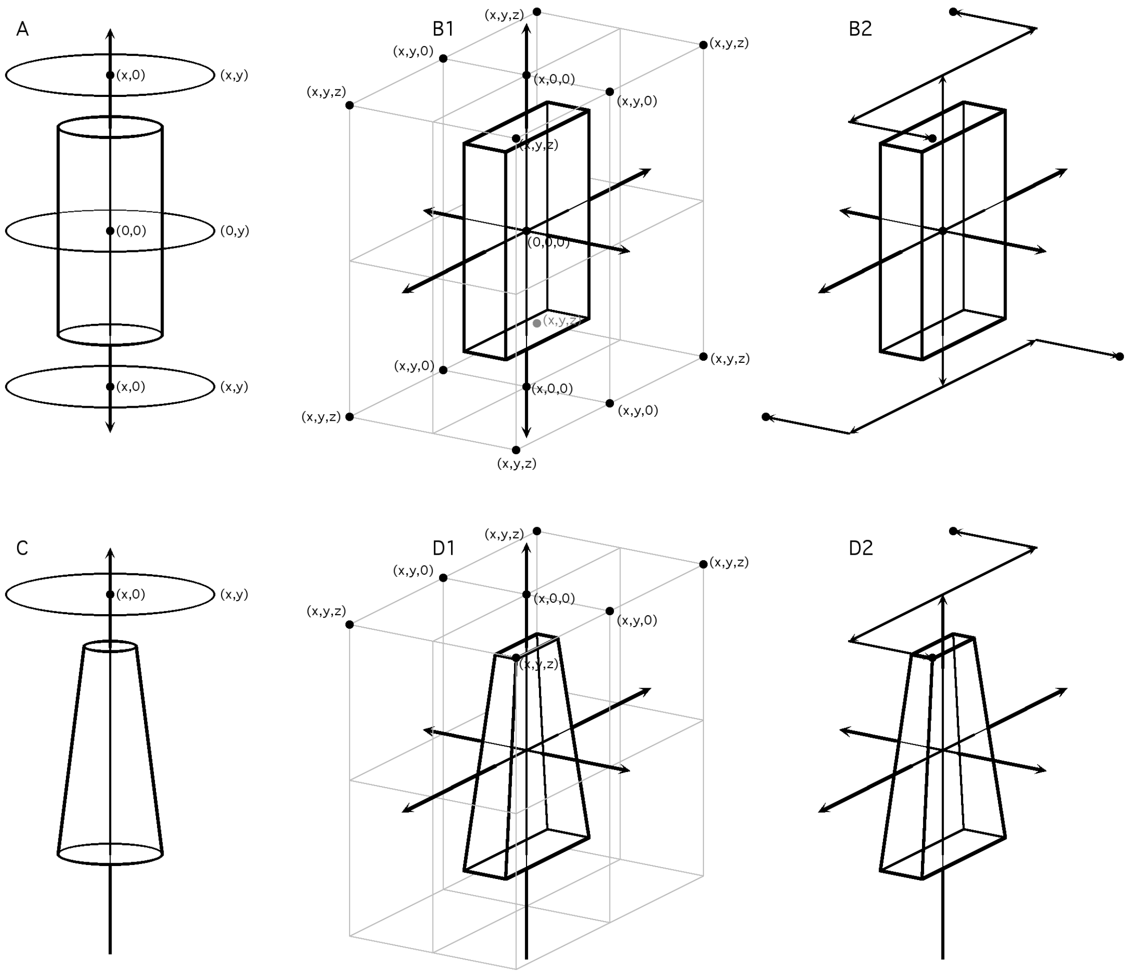

Figure 2.12. The definition of Intrinsic Location relative to four objects. A. An object with one (non-directed) dimension. B. An object with three (non-directed) dimensions. C. An object with one directed dimension. D. An object with two (non-directed) dimensions and one directed dimension.

A cylinder (Figure 2.12.A) is an object whose structure allows the definition of one dimension but no assignment of directionality. The object has an 'infinite-fold' rotation axis with infinitely many parallel planes of symmetry and an additional orthogonal plane of symmetry and infinitely many 2-fold rotation axes lying in this orthogonal plane and intersecting the 'infinite-fold' rotation axis. Therefore, a cylinder is a member of the point group D_{∞}. One location of the object is unique: The origin or **(0, 0)**. The 'infinite-fold' rotation axis and the orthogonal plane of symmetry have unique intrinsic characterisations. A description of a location on the rotation axis **(x, 0)**, applies as well to another location on the axis at the other side of the origin. Describing a location in the plane of symmetry **(x = 0)** is possible through a distance from the origin and therefore such a description **(0, y)** applies equally well to a circular array of locations. All remaining intrinsic descriptions of locations **(x, y)** apply to two circular arrays of locations. Because there are no locations outside the object that have a unique intrinsic definition, unambiguous intrinsic directional definitions are not possible.

A cuboid (Figure 2.12.B1) is an object whose structure allows the definition of three different dimensions but does not allow the assignment of directionality to any of these. The object possesses three two-fold rotation axes and three planes of symmetry (i.e. the axial planes). Therefore, a cuboid is an example of the symmetry point group D_{2h}. The intrinsic dimensions of this object coincide with the rotation axes, because only these axis orientations can be defined without 'enantiomorphic dimension setting' being possible. Again, only one location is unique: The origin or **(0, 0, 0)**. An intrinsic description of a location on a rotation axis applies equally well to a location on the same axis at the other side of the origin as exemplified for one axis in the Figure by **(x, 0, 0)**. An intrinsic description of a location in an axial plane applies equally well to three other locations in the same plane as illustrated for one plane in the Figure by **(x, y, 0)**. An intrinsic description of any other location applies equally well to seven other locations as **(x, y, z)** shows.

Although an intrinsic description cannot distinguish between eight locations, it is possible to add orientation-invariant non-intrinsic information that allows describing four of these eight locations in one way and the other four in another way. If in Figure 2.12.B2, two Perspectives defined from the origin along the longest dimension are labelled 'up', and along the second longest dimension 'forward', it is possible define only four locations by labelling turns as *left* or as *right*. Because no locations exist outside the object with a unique intrinsic definition, unambiguous intrinsic directional definitions are not possible.

A cone (Figure 2.12.C) is an object whose structure allows the definition of one directed dimension. The object has an 'infinite-fold' rotation axis with infinitely many parallel planes of symmetry. Therefore, a cylinder is a member of the point group $C_{\infty v}$. This time, more than one location of the object is unique: For all locations on the rotation axis **(x, 0)** there can be a unique description. There is thus no natural origin with this object. Any other intrinsic description of location **(x, y)** applies equally well to one circular array of locations. Intrinsic directional definition is possible: One unique direction may be defined along the rotation axis starting from one side (e.g., from the base) of the object, and the opposed direction may be defined from the opposed side (the apex) along the rotational axis. Thus: it is possible that an object with such a spatial structure supports an Intrinsic Object Centred Frame of Reference for Language with one directed dimension. Regarding the coding of Intrinsic Location for memory, objects with this spatial structure allow coding of locations on the rotation axis only.

The symmetry properties of and the intrinsic definitions of location and direction relative to the object (a member of point symmetry group C_{2v}) in Figure 2.12.D1 and D2 can be easily inferred given Figure 2.12.A, B and C. However, note that although in Figure 2.12.D1 and D2 two axes are drawn orthogonal to the two-fold rotation axis, the location of the axes is unknown because there is no natural origin with this object. However, the orientation of the axial dimension is known. In Figure 2.12.D2 one may define the 'up'-orientation along the directed axis, then define 'forward' along the second longest dimension, and finally make *left* respectively *right* turns non-intrinsic but orientation-invariant.

Thus, an Intrinsic Object Centred Frame of Reference for language may be supported by this structure. If so, then one directed dimension (on or along the rotation axis) is defined for the categorisation of Spatial Relations and two non-directed dimensions (characterised by orientation only, not localised) can also be defined with which dimensional parts can be established. The rectangular table mentioned at the start of Section 2.2.1 may have this spatial structure. For the table it was established that horizontal directional reference is not possible, but that horizontal dimensional parts can be defined. Regarding the coding of Intrinsic Location for memory, only locations on the rotation axis can be defined unambiguously.

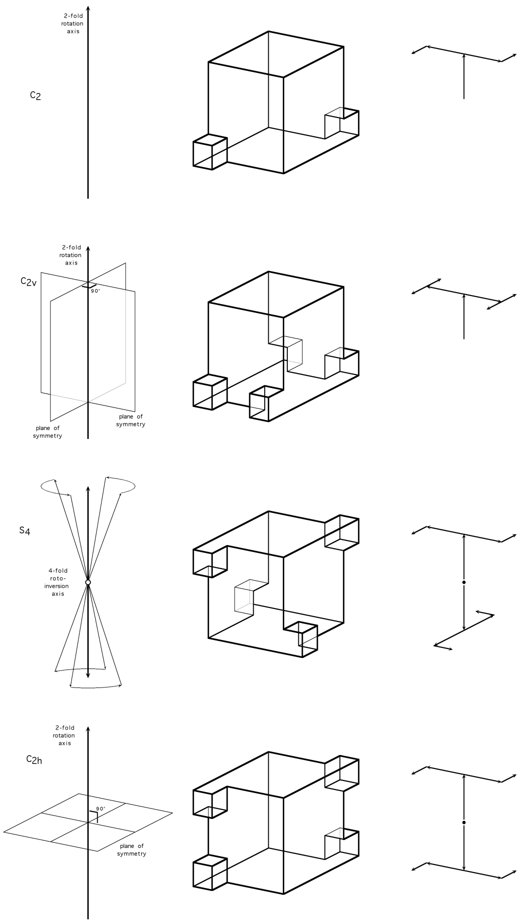

Figure 2.13. The definition of Intrinsic Location relative to the four point groups collapsed in rotation symmetry group C_2.

2.2.1.2.2. Two-fold Rotation Invariance

Another example of the point symmetry group C_{2v} is shown in Figure 2.13 with examples of the other point symmetry groups that were collapsed in the rotation group C_2 in Figure 2.11. Purely intrinsic definitions of location in the case of point group C_{2v} and the example of point group C_2 are similar in that directionality assigned to the rotation axis can be defined intrinsic. The orientation of the other dimensions is known in the case of C_{2v}, but has to depend on other factors in the case of C_2. In the C_{2v} case non-intrinsic information is required to describe a location such that it indistinguishable only from one other location (given the two fold rotation characteristics). In the C_2 case, if the other dimensions are set by factors not inherent to the symmetry point group, then a location description is valid for two locations on an intrinsic basis only (compare with the 2D examples in Figure 2.7 and Figure 2.8).

Regarding the intrinsic definitions of location for the point groups C_{2h} and S_4, the examples are chosen such that it becomes clear that the description of location has to follow a similar pattern. In both cases, the object parts along the two-fold rotation axis at either side of the origin are enantiomorphs whereby the difference between the cases is the degree to which the orientation of the parts deviate from one another.[25] It is only possible to differentiate between these enantiomorphs by means of some non-intrinsic information. This is actually possible in an orientation invariant manner by using a description with dependent dimensional directionality. For instance, in Figure 2.13, the, say, *top* part of the rotation axis can be defined by characterising the corresponding object part having the smaller parts attached in a clockwise or counter clockwise manner. Consequently, the only directed dimension of the object is based on the information that specific object parts are attached such-and-so to a pre-defined co-ordinate system. An intrinsic description with independent dimensional directionality does not work here, but dependent dimensional directionality does. At this point one may speculate that dependent dimensional directionality is the better explanatory mechanism because of its wider applicability. However, as will be shown in Section 2.4, objects that cannot be assigned directionality by independent dimensions but instead require dependent dimensions to define directionality onto surrounding space, are not suited as a Referent for Intrinsic Object Centred Reference in language.

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[25] An example of point group C_2 could also be constructed that has a structure that is intermediate of the examples of point groups C_{2h} and S_4.

In any case, also with these objects, Intrinsic Locations on the rotation axis can be uniquely coded, but need some pre-defined co-ordinate systems, that is, an intrinsic description with dependent dimensional directionality. Coding locations by means of independent dimensional directionality is not possible. Each definition of location that is not on the rotation axis applies to two locations equally well.

The observations regarding the C_2 rotation subgroup can be generalised to the other Cyclic rotation subgroups. An object with n-fold rotational invariance around a single axis may support a partial Frame of Reference. An intrinsic description with independent dimensional directionality can be used only when n planes of symmetry are available in the object parallel to the rotation axis (as is the case with $C_{nv; \{n \geq 2\}}$) or when no additional symmetries are available next to the rotation axis (as is the case with $C_{n; \{n \geq 2\}}$). An intrinsic description with independent dimensional directionality is not successful when object parts at either side along the rotation axis are enantiomorphs, and the object thus possesses a natural origin. Now consider the point groups with no rotation invariance transformations.

2.2.1.2.3. No Rotation Invariance

Bilateral symmetric 3D objects (point group C_s; see Figure 2.14) display restriction with respect to dimension placement. In order to avoid the possibility of an ‘enantiomorphic dimension setting’, two dimensions must be aligned with the plane of symmetry, while the third dimension is fixed orthogonal to this plane. The symmetry group does not restrict how the two dimensions within the plane are oriented. This has to depend on other factors. Also in this case, there is a natural order in assigning directionality to dimension, be it only partial. The directionality of the two dimensions within the plane of symmetry has to be assigned first before the directionality of the dimension orthogonal to the plane of symmetry can be defined. Again, this is so because the two parts separated by the plane of symmetry are enantiomorphs. Analogous locations at either side of the plane of symmetry are not distinguishable in an exclusively intrinsic description with independent dimensional directionality. Some convention is needed to label each part, location, and direction at either side of the plane of symmetry, for which it is required that the directionality of the other dimensions is taken into account (i.e., under the Perspective of the other directed dimensions). If there is an order in assigning directionality with respect to the other two dimensions, and if so, which order, is not defined by the symmetry point group.

A bilateral symmetric object may thus support an Intrinsic Object Centred Frame of Reference for Language with three directed dimensions. Regarding the coding of Intrinsic Location for memory, on the one hand, each location within the plane of symmetry can be uniquely defined. On the other hand, each other location has a unique definition as well, but only if it is marked for the half-space it is in. The half-spaces are good candidates for well-defined spatial categories.

Next to the asymmetric and the bilateral symmetric object, there is one other 3D object point group with no rotational invariance: the inverse symmetric object (point group C_i; see Figure 2.14). This object is extraordinarily in that it does not seem to allow the definition of an intrinsic Frame of Reference on it, at least when using an intrinsic description with independent dimensional directionality, although it possess no rotation invariance. The point group does not restrict dimension setting, but axes should be located such that they intersect at the object's natural origin, its point of inversion, which can be uniquely defined. However, any directionality assigned to a dimension would be associated with enantiomorphic object parts. The reasons for this are that every dimension setting produces enantiomorphs (or equal parts if the parts themselves happen to be bilateral symmetric). It follows that no unique intrinsic definition of direction is possible to begin with.[26] Each location given by **(x, y, z)** describes two locations that are at opposing sides of the inversion point.

[26] No matter how signed axes are oriented in a C_i object, any location with co-ordinates **(+x, +y, +z)** has a corresponding location with co-ordinates **(-x, -y, -z)** from which it is intrinsic indistinguishable.

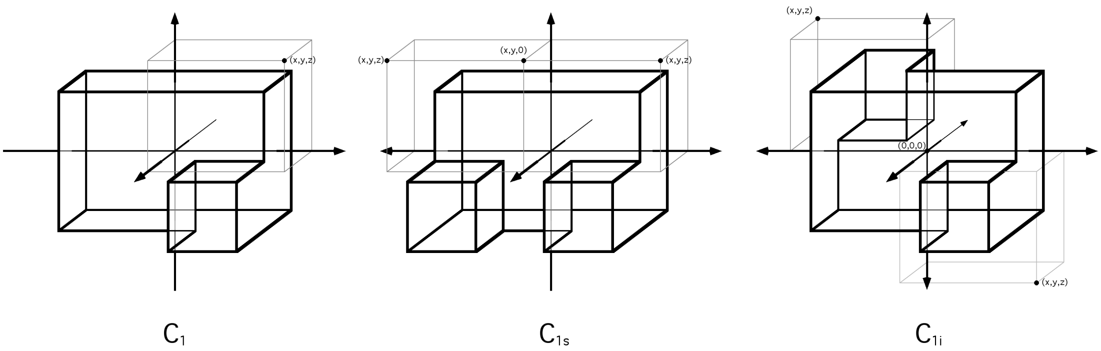

Figure 2.14. Defining Intrinsic Location relative to the rotation symmetry group C_1. The objects are not rotational invariant: Point group C_1 has no symmetries at all, C_i is inversion invariant, and C_s is mirror invariant.

It is however possible to conceive of space surrounding this object with some pre-defined co-ordinate system using an intrinsic description with dependent dimensional directionality. Figure 2.14 can be described to consist of a major cuboid part with relative measures of three by two by one where two minor cubic parts with measure one are attached. It is possible to keep track of sides and directions around the object by denoting those sides, where the minor parts are attached to, as, say, the *front* and the *back* (or to associate them with the **[X]** dimension). Now, one of the minor parts may be denoted as attached at the (say) *left-top* corner (or at **[+Y, +Z]**) of the *front* (**[+X]**). Following, the other minor part can be described as attached to the *back* (**[-X]**), at the *right-bottom* corner (or at **[-Y, -Z]**). Such a strategy functions independent of the object's orientation. In Section 2.4, however, it will be argued that objects with a spatial structure that require intrinsic descriptions with dependent dimensional directionality are unsuited as a Referent for Intrinsic Object Centred Frames of Reference for Language. It is possible to code each Intrinsic Location for memory with such a description though.

Finally, the last object group that is considered concerns asymmetric objects, the symmetry point group C_1 (see Figure 2.14). It is possible to define every location and direction intrinsic with respect to such objects. However, the point group places no restriction regarding dimensional orientation and assigning of directionality. All reference frame parameters have to depend on factors not shared by the symmetry group. The objects have the potential to support an Intrinsic Object Centred Frame of Reference for language with three directed dimensions. Each Intrinsic Location can be coded for memory.

2.2.1.3. Rotation Symmetry Groups Summary

Because the preceding sections were quite lengthy, it may be helpful to summarise the observations here. Only observations taken from intrinsic descriptions with independent dimensional directionality are mentioned. Regarding the spatial structure of 3D objects, a spatial intrinsic Frame of Reference with orthogonal oriented dimensions can have zero, one, or three dimensions. When there are no dimensions, only origin and scale can be defined. If there is one dimension, then this dimension can have directionality assigned to it or not. If there are three dimensions, then zero, one, or three of these can be unique. If there is one unique dimension, then this dimension may have directionality assigned to it or it may not. If there are three unique dimensions, then zero, one, or three of these can have directionality assigned to them. In the 2D object case, there can be zero or two dimensions. When there are two dimensions, zero (e.g. a square[27]) or two of these can be unique. When two are unique, zero or two can have directionality assigned. In all cases, if directionality can be defined, then there is no natural origin.

It was further shown that in case of a 2D bilateral symmetric object there is only one way to define an intrinsic Frame of Reference. The bilateral symmetric dimension restricts the other dimension along the axis of symmetry. Directionality assigned to this latter dimension precedes directionality assigned to the bilateral symmetric dimension.

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[27] A square actually allows setting dimensions in two different ways: Bisecting opposing sides, or bisecting opposing corners. See, e.g., Rock (1973).

Asymmetric 2D objects allow dimensions and assigned directionality, there are no restrictions beforehand on how to orient these however.

Similarly, in case of a 3D bilateral symmetric object, one dimension is oriented orthogonal to the plane of symmetry, whereby the other dimensions are restricted to lie within the plane of symmetry although their orientation there is not restricted any further beforehand. Directionality must be assigned to the dimensions within the plane of symmetry first, before directionality to the bilateral symmetric dimension can be assigned. Asymmetric 3D objects place no a priori restrictions on placement of dimension or on order of directionality assignment. Finally, in the 3D case that potentially supports partial Frames of Reference, only one dimension can be defined to which directionality may be assigned. This dimension is aligned with the single rotation axis of the object.

2.2.2. Structural Complexity and Regularity

An object's regularity and complexity relate to its symmetry characteristics. If the number of object parts and relations between parts is kept constant, then, on the one hand, the more regular an object is, the more likely it is to be symmetric. On the other hand, the more complex an object is, the less likely it is to be symmetric. If an object happens to be completely regular, that is, when all its sides and angles are the same, then the object will necessarily be rotation and reflection invariant. An object that happens to be less regular, that is, when not all sides and angles are the same, is more complex than a more regular object with the same number of sides and angles. This is so because describing or representing the less regular shape requires the coding of more differences in sides and angles and their arrangement. However, because objects may have different numbers of object parts and relations between parts, higher complexity does not necessarily mean less regularity. More parts and more relations between parts increase an object's complexity simply because of the number, but an object with many parts may still be completely regular when all sides and angles are equal.

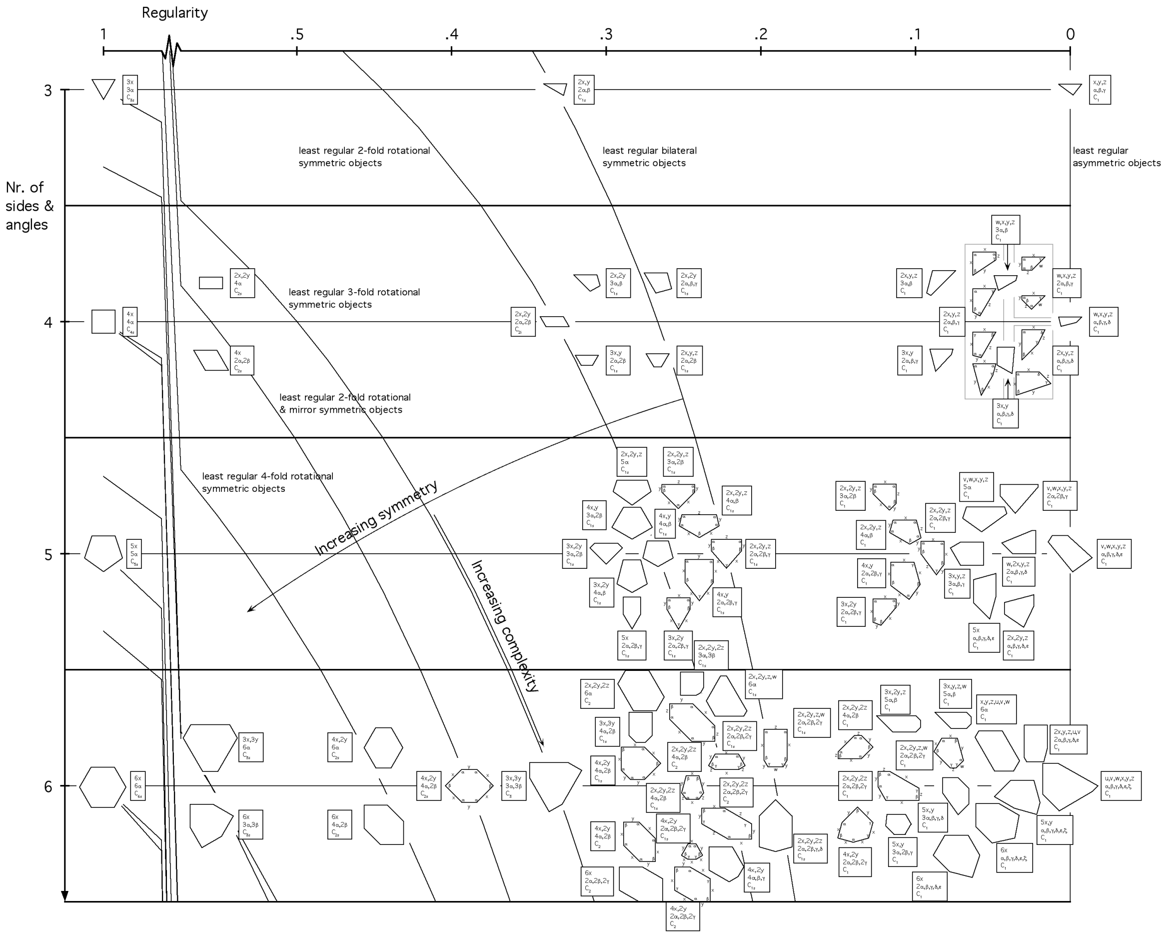

Figure 2.15. The relations between complexity, regularity, symmetry, and the number of sides of an object for simple convex polygons. The annotations of the objects refer to within-object repetitions of angle width and side length. Specific sides and angles are labelled on objects that have the same part identities but different arrangements of identical parts. Only triangular and quadrilateral objects are shown exhaustively, others show a sub-set of the possibilities. Objects are roughly ordered on regularity measure, where one means perfect regularity (all angles and sides are the same) and zero means no regularity at all (all angles and sides are different). Symmetry increases from right to left and from top to bottom. Complexity increases with the number of sides given a certain global structure (symmetry), and increases from left to right and from top to bottom.

Figure 2.15 illustrates how the relations between the number of sides and angles, the regularity, the complexity and the invariance transformations (symmetry characteristics) may be conceptualised. The Figure serves only as an illustration; the relations present do not exemplify a theory on the objective measurement or the subjective experience of goodness or complexity. See Van der Helm and Leeuwenberg (1991) for a full-fledged theory on the perceived goodness of patterns. The relevance of the related aspects of complexity and regularity for Intrinsic Object Centred Reference is two-fold. The amount of structural complexity and regularity of an object determines if intrinsic reference is possible at all (in principle) but may also determine if, or the difficulty with which, this is possible for a human observer with its limited information-processing capacities. An object that is too regular (or has too little complexity given a certain number of sides) possesses rotational invariance and is therefore unsuited as a Referent as explained in the previous section. For instance, it is fundamentally impossible to use intrinsic reference with respect to a sphere and, thus, for a human observer this is impossible as well.

On the other hand, too much complexity and/or irregularity can have another effect. Although it may be essentially possible to use highly complex objects as Referents for Intrinsic Object Centred Reference in language or for the coding of Intrinsic Location, this may be very difficult if not impossible for a human observer, due to limited information-processing capacities. Thus, when the object becomes more complex, the definition of a Frame of Reference or the coding of Intrinsic Location may become more complex as well. For instance, if an object has many parts that are quite similar and an Intrinsic Location is defined by reference to one of these, then it may be necessary to have a very accurate description of the part, or to locate the part within the configuration of parts with greater scrutiny. A related complicating aspect regarding the use of highly complex objects as Referents is the potential multitude of aspects upon which an Intrinsic Object Centred Frame of Reference can be based. Considering that these Frames of Reference are employed in communicative situations, it is apparent that highly complex objects may allow many opportunities for communication errors. Highly complex objects may thus be unsuited as Referents or unlikely to be used as such in languages. Medium structural complexity seems most suited for a human observer (see Phillips, Todd, Koenderink, and Kappers (1997) for a similar argument regarding memory for surface position; see also the left part of Figure 2.16).

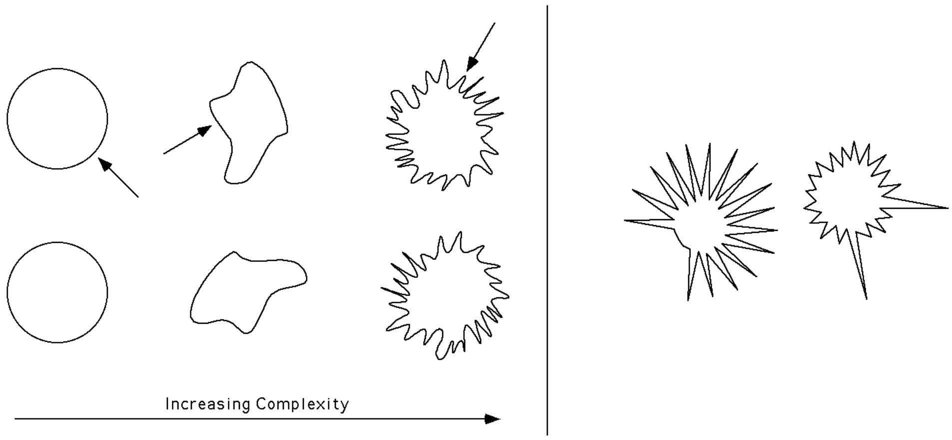

Figure 2.16. The effect of complexity on memory for surface location (left); complexity can be ignored when not 'global' (right). Imagine remembering the surface position denoted by the arrows at the top three objects at the left. Then search for the same surface position of the bottom objects at the left, which are the same objects that have changed their orientation. For the circle, this is impossible. For the middle object, the task is quite easy. For the object on the right, the task is very difficult when concentrating on the global shape. The task can be performed with scrutiny by concentrating on selected parts of the shape. The example is adapted from Phillips *et al.* (1997). The objects at the right illustrate that the hampering effects of high complexity on the identification of parts of the objects diminishes when the complexity is not a 'global aspect' of the object or the complexity can be overcome by some salient aspects of the object.

The hindering effects of high complexity on intrinsic reference need to be qualified though. The right part of Figure 2.16 shows two objects that, although quite complex, seem more suitable for intrinsic reference than the most complex object in the left part of the Figure. The reason is that their global shape allows ignoring much of the complexity that is locally available. Only globally complex objects may thus lead to difficulties for humans trying to use these objects for intrinsic reference. If certain aspects of an object are salient enough for use in the definition of an intrinsic structural description, then the complexity of the remaining aspects of the objects can be ignored and the object may thus be (potentially) suited as a Referent for Intrinsic Object Centred Reference for Language.

2.2.2.1. An Example

The strong influence that structural spatial characteristics of (perceptual) objects such as rotational invariance, complexity, and regularity have on the possibility to use objects as intrinsic Referents is illustrated with two less abstract objects in Figure 2.17. On wineglasses as well as trees, only two intrinsic Directional Relations can be defined for language: The objects only have a directed *top-bottom* dimension. The example of the wineglass illustrates that the infinite rotation invariance around the *top-bottom* axis does not allow the unambiguous definition of any other direction (it is a perfect example of rotational sub-group C_∞). For use in memory, the coding of Intrinsic Locations is unambiguous only on the rotation axis. For use in language, it is possible to define two directionality parameters. Spatial Relations that can be categorised as Directional Relations in terms of these directionality parameters are not confined to the locations on the rotation axis (see also Section 2.5).

The tree shows that –although the object is not rotational invariant around the *top-bottom* axis– it could be the structural complexity in the horizontal plane that makes intrinsic reference for language impossible there. Another possibility is that the tree is idealised (e.g., by schematisation, see Herskovits (1986; 1998) and Talmy (1983)) to a spatial structure with the same symmetric properties as the glass. However, there is another plausible reason why a tree has only one dimension as explained below. Note here that the tree has enough structure to code each Intrinsic Location for memory in the horizontal plane. Due to the tree's complexity, this may not always be an easy task. As an example, there seems to be no problem in defining a direction based on a big branch of the tree in order to remember where something was hidden.

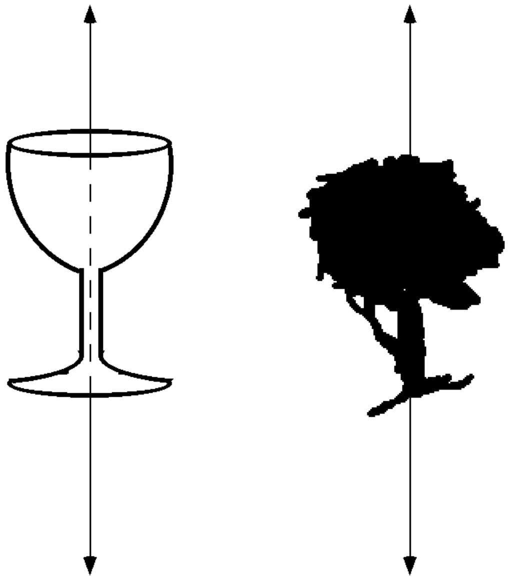

Figure 2.17. Objects such as glasses and trees have a *top* and a *bottom*, but no *front, back, left side,* and *right side*. For the glass, the lack of structural complexity in dimensions other than the *top-bottom* dimension is responsible for this. The tree, on the other hand, may have too much structural complexity, but a part (the big branch) could be used here to build a Directional Relation in the horizontal plane. However, there is no horizontal Intrinsic Directional Preposition available for use with a tree as Referent.

2.3. Category, Spatial Structure, and Intrinsic Reference

In the previous section rotational invariance, complexity, and regularity were identified as important spatial characteristics influencing the suitability of a Referent for Intrinsic Object Centred Reference. These aspects may make intrinsic reference impossible or quite difficult. Therefore, objects in possession of specified degrees of these spatial characteristics may be unsuited as an intrinsic Referent. This applies to Intrinsic Frames of Reference for language as well as to the coding of Intrinsic Location. However, this is only one part of the story. The other part is that the presence of Directional Parts on the Referent and, thus, the possibility to refer to the location of a Figure by means of intrinsic Directional Relations is dependent on category characteristics of the Referent. The reason why it is not possible to use Directional Prepositions to refer to intrinsic directionality in the horizontal plane relative to the tree in Figure 2.17 is, in that case, not the complexity of the particular instance of the tree, but the lack of agreement between instances of the category TREE regarding their overall spatial structure.

Before expanding on the relation between the Referent's object category and the perceptual Referent (i.e. the instance of the category relative to which directionality needs to be defined), note first that the successful communication of information about the location of a Figure by means of an Intrinsic Object Centred Frame of Reference implies the availability of a suitable Referent. To determine its suitability for Intrinsic Object Centred Reference, a Referent needs to be identified (categorised). The next Sentence shows the importance of identification.

(15) *THE BALL IS TO THE LEFT OF THAT THING [From the thing's Perspective].

There are two reasons why Sentence (15), if not incomprehensible, is not particularly suited for an addressee to restrict his/her domain of search for locating the Figure. On the one hand, by not identifying the Referent, for an addressee it may be impossible to find the Referent and thus to define the as-yet-undifferentiated region around the Referent in which 'the ball' is supposed to be. On the other hand, it makes no sense to define an intrinsic Directional Relation with respect to an unidentified Referent, because it is unknown whether an intrinsic Frame of Reference can be defined at all. Moreover, even when assuming that a frame of reference could be defined, it is still unknown which part of surrounding space happens to be the relevant Directional Region. Thus even if the addressee succeeds in finding the Referent, it would still not be possible to restrict search for the Figure any further because it is unknown how to subdivide the global region around the unidentified Referent (see also Miller and Johnson-Laird, 1983). The addressee could however search the whole region around the Referent [28]

[28] There may be ways for a speaker to direct the attention of the addressee to a Referent even when it is not identified by language, e.g., through gesturing. The speaker should not know which Directional

The identification (or categorisation) of an object is thought to make accessible information concerning the object's category. Knowledge about the Referent's object category includes information concerning the intrinsic Frame of Reference of an object. Having a particular big branch is not a defining characteristic of the category TREE. The vertical arrangement of roots, trunk, twigs, and leaves however is. Following, an intrinsic directed *top-bottom* dimension may be defined, but horizontal *front-back* and *left-right* directions may not. The category scheme of TREE does not provide sufficient (spatial) structure to define horizontal dimensions and directionality on any tree in such a way that makes it possible to refer to these with Directional Prepositions.[29]

2.3.1. Category Structure and Perceptual Instances

If an object can or cannot be used as an intrinsic Referent depends upon the general structure of the object category if a Directional Relation is to be expressed in language. For instance, one may imagine some unconventionally shaped table, which essentially has enough structure to define horizontal directions unambiguously. Such a table can actually be used to define parts and directions in the horizontal plane, if, for instance, one wants to remember where exactly one hid a microphone, or which of its legs is loose. However, employing the structure of the table to explain to someone else where the microphone has been hidden is not possible with an intrinsic horizontal Directional Preposition. The addressee would not know how to apply the Directional Preposition to the table because there are other tables that do not allow intrinsic horizontal directions to be defined on them (e.g., round, rectangular, or square tables). Horizontal Directional

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Preposition to use if she/he has no clue to the identity of the Referent. It is possible however, that identification to some degree suffices to allow intrinsic Reference. For instance, the speaker may identify an object as 'some animal', and it can be argued that this usually allows the object to be used a Referent.

[29] In the literature (Herskovits, 1986; Landau and Jackendoff, 1993; Talmy, 1983), it is often assumed that for spatial language use Referents are only represented in schematised form. It would be interesting to consider if, concerning Intrinsic Object Centred Reference, such schematisation can be traced back to the category structure of objects which –in many cases– necessarily needs to be quite coarse to be able to encompass all instances included in the category.

Prepositions do not apply to tables as such, that is, to the overall spatial structure of the category TABLE. Having a *front*, *back*, and *sides* is not a category characteristic of tables. Having a *top* and a *bottom* however is.[30]

It is thus proposed that the spatial properties mentioned in the previous section are pre-conditions for Intrinsic Object Centred Reference to occur. That is, defining intrinsic reference directions with respect to a Referent presupposes certain spatial characteristics of the Referent. However, the Intrinsic Frame of Reference that can be used to categorise Spatial Relations in order to express these by means of Directional Prepositions is considered a category feature of the Referent. These two may not always be in perfect correspondence. It may be the case that there is enough spatial structure defined in the perceptual object, but that this available structure does not constitute a defining characteristic of the object category to which the perceptual object belongs. It may then be possible to use the structure of the object to define an intrinsic direction (one may define a direction on the basis of a big branch of a tree and hide a treasure in that direction), but not to refer to this direction with a Directional Preposition. Similarly, if there are glasses that are rotation invariant about the vertical axis, then horizontal Directional Prepositions are not applicable to glasses in general even if some glasses have a spatial structure with the potential of defining horizontal Directional Relations. An instance of a category with a suited spatial structure does not imply the category having a particular reference direction. An instance of a category with too little spatial structure does imply the category lacking particular reference directions.

Intrinsic Directional Prepositions refer to spatial distinctions linked to category defining structure, that is, structure common to all members of the category. Intrinsic Object Centred Frames of Reference and their dimension and directionality parameters

[30] It might be possible that objects such as tables obtain an accidental *front* and therefore a *back*, *left side* and *right side*, for instance depending upon the way a table is put against a wall (see Miller and Johnson-Laird, 1983). Alternatively, there may be a 'head' of the table depending on the social status of the person sitting there. Such possibilities are ignored.

with which a Spatial Relation can be categorised as a Directional Relation thus depend on the defining structure of the Referent's object category.

2.3.1.1. Perceptual Structure and Intrinsic Frames of Reference

At this point one may write out which combinations exist of different Intrinsic Object Centred Frames of Reference for language and different possibilities regarding the coding of Intrinsic Location for memory. The frame that can be employed for language depends on the Referent's category, while the frame that can be used for memory depends on the actual structure of the Referent. In the 3D case, if a Referent's object category allows the definition of three intrinsic directed dimensions for language, then it is always the case that each Intrinsic Location can be coded for memory. Because the spatial structure of the Referent's category allows three directed dimensions, it is necessarily the case that each instance of the category can provide a co-ordinate system with which to code each location around it since each instance possesses the category defining structure. If a Referent's object category allows only the definition of one intrinsic directed dimension, then it is at least the case that Intrinsic Locations on one axis can be coded for memory. It is also possible that the Referent allows the coding of all Intrinsic Locations for memory. Whether this is the case depends on the spatial structure of the particular instance of the category that happens to be involved. In the 2D case, if a Referent allows two intrinsic directed dimensions for language, then each Intrinsic Location can be coded for memory. In both the 2D and 3D case, if an object does not allow any definition of intrinsic directed dimensions for language, then it solely depends on the spatial structure of the object if and which Intrinsic Locations may be coded for memory.

2.3.2. The Role of Features

The possibility to define an Intrinsic Object Centred Frame of Reference for language is dependent on the Referent's object category. Using an object as an intrinsic Referent thus requires access to the Referent's object category (i.e. the Referent needs to be identified). Category characteristics determine if and which Directional Parts can be defined as well as where they are defined with respect to the perceptual Referent. Category information thus needs to specify which features of category members have to be considered as, e.g., the *front* part as opposed to the *back* part. The category specifies spatial structure along directed dimensions, that is, the distribution of the category defining features. This specification allows defining Directional Parts on the perceptual instance of the category that is to function as an intrinsic Referent. A process is needed that transfers information from the stored category representation to the perceptual object. This transfer of information to the Referent provides it with the intrinsic description required for defining the Directional Parts and, from these, the directional information in perceptual space needed for Intrinsic Object Centred Reference.

Because it is assumed that the intrinsic Frame of Reference is linked to a stored structural description (representation) that *defines* the category, it must be the case that relevant features of an object can be defined on every instance of a Referent's object category. Note however that those same features, or –alternatively– global characteristics (within which the features are implicitly included), of the perceptual object are decisive in identifying a Referent, and to access its category structure. Because information about the spatial structure of the object category defines the Intrinsic Frame of Reference on the perceptual instance, it does not necessarily need to be assumed that the perceptual Referent has an intrinsic structural description before identification. So, it *might* be the case, that global characteristics of the perceptual object, that is without any decomposition in parts or a description in intrinsic structural terms, mediates access to category information (identification). However, regarding the present subject it probably *needs* to be assumed that decomposition into Directional Parts, and how object features relate to these, is specified in the stored representation of object category structure. Moreover, this part decomposition needs to be transferred or applied to the perceptual instance of the category (the Referent) under the particular viewing conditions that it is in. Therefore, the perceptual representation of the Referent *must* be able to support the resulting definition of Directional Parts. One way in which this might happen is by associating Directional Parts with perceptual features of the Referent. It will be assumed here that features of an object are perceptually represented, even before an object is identified (irrespective of the object being identified). A perceptual object thus has a componential structure that allows assignment of a directional dimensional ordering. Access to information on the structure of the object category mediates directional dimensional ordering.

The minimal assumption is thus that –irrespective of the representational aspect(s) of the perceptual object used for identification– category representation allows establishing an intrinsic structural description of the perceptual Referent in terms of *top-bottom*, *front-back*, and/or *left-right* distinctions. The componential structure (features) of the perceptual object representation gets ordered along orthogonal directed dimensions. Category information specifies how to order the perceptual features along directed dimensions while the perceptual features define how the intrinsic Frame of Reference is oriented with respect to Ego or Environment Centred space. The perceptual features thus need to be available in the representation of the perceptual object in order to be able to attach the intrinsic Frame of Reference to the perceptual Referent. Note that it is possible to refer to Directional Parts of objects and that many words exist that refer to (non-Directional) parts of objects. The processes involved in identifying an object and in identifying its Directional Parts are discussed in more detail in Chapter 3.

It cannot only be the presence of perceptual features as such that allows using an object for intrinsic reference. Having a particular part does not mean that an intrinsic frame can be defined if other parts have not been taken into account. The distribution of the features over the space the object occupies is important as well. For instance, *top* features need to be contrasted to *bottom* features, and an eye may be on the *front* of a head (e.g., a human being) or on the *side* of a head (e.g., a hare). Perceptual features as such do not allow identification either as they may be shared by different categories. The distribution of features and the combination present is important as well. This is illustrated by the next Figure.

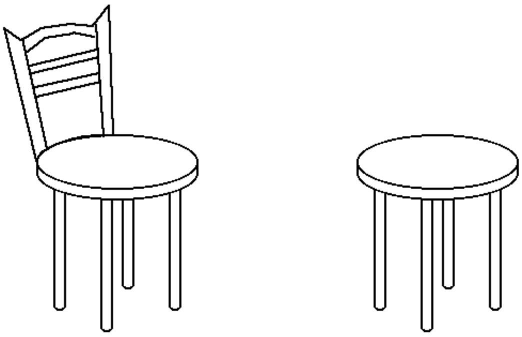

Figure 2.18. A chair and a stool.

The –probably decisive– difference in category structure characteristics between a chair and a stool is the presence or absence of the ‘backrest'. The availability of legs and seat are characteristic of a chair, but when available alone does not allow identification as CHAIR. For CHAIR the backrest is needed as well. It is exactly the presence of this category-defining characteristic that makes it possible to identify six intrinsic directions with respect to chairs, while its absence restricts the Frame of Reference to only two intrinsic directions with respect to stools. If only the joint characteristics of the legs and the seat and their arrangement is available as a perceptual object, then recognition as STOOL is possible, and only the definition of the *top-bottom* directed dimension is allowed, but not any other dimensions. If the backrest is also available within the perceptual object, then recognition as chair is possible as well as the definition of three directed dimensions. Note that it is possible in that case to differentiate between, e.g., the '*front* legs' and the '*hind* legs' of the chair. Legs can thus be ordered along the *front-back* directed dimension (and also along the *left-right* directed dimension), and may obtain a corresponding naming, even when there is no difference between the legs (i.e., features) when considered on their own.

Of course, other instances of the category CHAIR may have other characteristics that strengthen the directional definitions that are available through the backrest, but these seem only optional (e.g., armrests, bowed legs, or the specific shape of the seat). Stools and chairs may have different numbers of legs and quite some different shapes. The category structure of these object categories may thus be quite abstract. However, the category defining characteristics must minimally include the vertical arrangement of the legs and the seat. In addition, regarding chairs, category-defining structure must include the presence of the backrest and the directed *front-back* dimension needs to be associated with it.

2.3.3. Levels of Categorisation

One complicating aspect regarding object category is that objects can be categorised at different levels of identity. It will be assumed here that the object identity level that defines if an object can be used as an intrinsic Referent is the so-called basic level or entry level category (see Rosch, Mervis, Gray, Johnson, and Boyes-Braem, 1976, respectively Jolicoeur, Gluck, and Kosslyn, 1984). This is the category-level at which an object presumably is identified first and at which it is usually named (e.g. DOG). One may define levels of categorisation above or below the basic-level. Subordinate level categorisation involves a more specific category (e.g. GERMAN SHEPHERD), while superordinate categorisation involves a more general category (e.g. MAMMAL). According to Rosch *et al.*, basic level categories share among their instances the most attributes such as shape, motor programmes, and functional characteristics. I will assume that instances of basic level categories share Intrinsic Frames of Reference as well. Thus, STOOL and CHAIR are two different basic level categories, whereas FURNITURE is a superordinate category. The superordinate category does not define which intrinsic Frame of Reference applies to its instances. The basic level category chair does define an intrinsic Frame of Reference that applies to all its subordinate categories, i.e., specific kinds of chairs as ROCKING CHAIR, or ARMCHAIR.

2.4. Category Membership and Directional Labelling

After having posited that category structure determines whether Directional Prepositions can be used with respect to an intrinsic Referent, one may ask what kind of category information is responsible for this, and how intrinsic directions are actually labelled. Apart from geometrical properties, which were already described in detail, force-dynamic and functional properties of the Referent are prominent in the literature (see e.g. Clark, 1973; Jackendoff, 1996; Levinson, 1996; Landau, 1998; Miller and Johnson-Laird, 1976). The present characterisation borrows freely from the mentioned sources and builds upon the characterisations formulated there. Force-dynamic properties usually refer to the characteristic direction of an object's motion. Functional properties can be sub-divided in canonical encounter, canonical orientation, and canonical use.

Canonical orientation, encounter and use respectively refer to the way that objects are normally oriented in the world (i.e., the vertical orientation; therefore the orientation that is normally perceived), how objects are normally encountered by human beings (i.e., in the horizontal plane), and the way human beings normally use objects. It seems sure that these aspects (at least partially) determine the labelling of sides on and directions relative to objects. The normal orientation of a tree determines what we call the tree*top*. The way we normally confronted (encounter) houses (seen from the street) determines what we call the *front* door. How we read (use) a book determines what we call the *back* cover. It thus appears that the labelling of Intrinsic Reference Frame dimensions and directions depends on various aspects of how objects are 'upright in the world' and how we confront and handle objects. However, the labelling that results can be used without this orientation being respected (but see Section 1.4) and without confronting or handling the Referent in any specific manner. The labelling appears to be an acquired aspect of object categories, 'conceptually assigned by some algorithm, or learned on a case-by-case basis, or (...) a combination of these' (Levinson, 1996, p. 140). The orientation and labelling of dimensions and directionality thus involves accessing such knowledge about the Referent.

When considering the labelling of directions around objects, it may first be useful to roughly classify objects in order to mention the obvious and then consider the less obvious. Directional labelling with respect to non-ego human-being objects is similar to the directional labelling with respect to ego. Directional labelling with respect to many other animals is analogous. The typical direction of movement and position of the perceptual apparatus are usually in agreement with human directional labelling. I will refer to such Referents as 'autonomous Referents'. The typical direction of movement (a force-dynamic property) also determines the linguistic labelling with respect to many artefacts human beings use to travel around with. I will call such Referents 'mobile Referents'. Now the pairs of opposite intrinsic directions will be considered in turn.

2.4.1. Intrinsic *above* and *below*

Regarding the *top* and *bottom* parts and the *above* and *below* reference frame directions, canonical orientation and canonical encounter seem to agree. How objects are normally oriented in the world complies with one aspect of the usual encounter with objects, that is, upright. Therefore, what is called the *top* of a tree depends on the canonical orientation of a tree, but ‘tree*top*’ is applicable even when the tree has fallen over. This agreement at least applies to (relatively) unmoveable objects such as trees and mountains. Smaller objects and in particular handheld tools and apparates may however be encountered in many different orientations. Glasses are often put upside-down when put away, and other handheld objects may be encountered in many orientations when put on a table, thrown in a drawer, or folded together. Still many of such objects seem to have a canonical orientation that is instrumental in labelling reference frame directions when they are used. How a glass is canonically used determines what is called the *top* and the *bottom* (foot) of a glass based on its orientation when it is so used. Similarly, even while a camera may be hanging at some tourist's wrist most of the day, this orientation does not determine what is considered the *top* and *bottom* of the camera. However, the typical (canonical) orientation of the camera when a picture is shot (canonical use) is instrumental for what we label to be the *top* and the *bottom*, and intrinsic *above* and *below* reference frame directions (see Landau and Munnich, 1998). Canonical orientation ‘determines’ the *top-bottom* directional labelling of autonomous and mobile Referents and (relatively) unmoveable objects, while the canonical orientation during canonical use determines this for many artefacts. Reference to the intrinsic *top* and *bottom* or intrinsic *above* and *below* requires knowledge on the canonical orientation of the Referent's object category, that is, the category's typical orientation with respect to gravity. In order to determine the *top* and *bottom* of a perceptual instance by means of information on the canonical orientation of the category, the stored category-defining structure needs to specify a differentiation along the *top-bottom* axis (i.e. the *top* needs to be different from the *bottom*) that can be identified on the perceptual Referent. If there were no such difference, *top* and *bottom* could not be defined, upright could not be distinguished from upside-down, and, thus, there would be no canonical orientation.

2.4.2. Intrinsic *in front of* and *behind*

The Directional Nouns *front* and *back* and the Intrinsic Directional Prepositions *in front of* and *behind* seem to depend mostly on how, except the autonomous and mobile cases, Referents are encountered, or how they are encountered when they are canonical used. Interestingly, regarding this directional labelling there seem to be two possibilities. A similar distinction was already observed in Section 1.3 where differences between different languages were mentioned for relative Frames of Reference (those involving a forward projection). As noted there, forward projection might be a simple translation, a mirroring translation, or a rotating translation. In analogy, some Intrinsic Frames of Reference seem to imply that the object has acquired its directional labelling as if there were some kind of simple translation of Ego Centred Reference Frame directions. For instance, cars, bikes, and other vehicles have a *front-back* labelling as if a simple translation of ego directions occurs when ego uses the vehicles. However, with vehicles (mobile Referents) the labelling of the directions can also be argued to depend on typical direction of motion (moreover, the *front* of a modern electrical train depends exactly on direction of motion). Less ambiguous examples include chairs, couches, telescopes, and cameras that have an intrinsic *front-back* labelling as if a simple translation of the relevant ego reference directions on the objects occurs dependent on their horizontal encounter orientation when they are canonically used by the ego.

In contrast to these objects, there are other object categories whose acquired intrinsic Frames of Reference *front-back* directions seem derived from a mirroring translation of Ego Reference Frame distinctions. Thus, an object such as a television has its *front* where it is looked at during canonical use and encounter. I will in analogy to Hill (1983) refer to object categories that have an acquired *front-back* labelling apparently derived from Ego Frame translation with 'aligning Referents' and to object categories that have an acquired *front-back* labelling apparently derived from mirroring Ego Frame translation with 'facing Referents'.

There may be some overlap between autonomous, mobile, facing, and aligning Referents regarding the information responsible for *front-back* labelling. For instance, another person (autonomous Referent) has a *front* and *back* in analogy to ego, and at the same time has a typical direction of motion. A car (mobile Referent) has a typical direction of motion as well, but also has the same *front-back* aligning properties as a chair (aligning Referent). Leaving apart autonomous and mobile Referents, one may ask what category aspect is responsible for the difference between aligning Referents and facing Referents, thus what category characteristics do chairs and cameras share and sets them apart from televisions and cabinets. Whereas Miller and Johnson-Laird (1976) refer to inside versus outside perspective to explain the difference[31], I suppose that it has something to do with the way that an object is used. Some objects are used to do something *with* them while others are used to do something *at* them. Thus, while one looks through (with) the camera, one looks at the television. The focus of attention is not at the camera when being used, whereas it is at the television when being used.

In any case, the Referent's category structure must provide a differentiation in the spatial structure of the Referent for *front-back* discrimination on the perceptual object. Only with such a differentiation, one may tell which is *front* and which is *back*. In this case, however, the kind of Referent needs to be taken into account. Depending on the Referent different sources of information determine *front-back* labelling. On top of that, if the information concerns canonical encounter, it is not only encounter that determines what is *front* and what is *back* (although it determines the *front-back* dimension), but also it requires differentiation between facing and aligning Referents to determine directional labelling.

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[31] Another difference to the present description is that, e.g., a camera's *front-back* labelling is thought to be derived from being used as an extension of the perceptual apparatus.

2.4.3. Intrinsic *to the left of* and *to the right of*

Finally, the linguistic labelling of the Directional Parts *left side* and *right side* and the intrinsic Directional Prepositions *to the left of* and *to the right of* seems merely to depend on the other labelling. Object category characteristics do usually not seem to define any functional or spatial characteristics for differentiating between the *left* and *right side* except through the definitions of the other sides and intrinsic directions. What is called *left* and what is called *right* seems to depend on the *front-back* definition as explained above given that there is a canonical orientation defining *top* and *bottom.* There thus appears to be no acquired canonical category characteristic for the definition of the *left* and the *right side*. Instead, there appears to be a 'categorical symmetry' regarding *left-right* directionality.

Left and *right* always seem to be in accordance with egocentric *left* and *right*. *Left* and *right* are defined in analogy to ego with respect to autonomous Referents. Where *left* and *right* are with respect to mobile Referents is in analogy to ego's canonical direction of motion. Arguably, *left* and *right* are defined in analogy for facing and aligning Referents as well if the canonical orientation and encounter is respected. If the Referent is used according to its function, then *left* and *right* are parallel to ego's *left* and *right.*[32] In case of aligning Referents all labelling is analogous to labelling with respect to ego. However, regarding facing Referents labelling of *left* and *right* is reversed to ego if the *top-bottom* and *front-back* directions of ego and the facing Referent are aligned (it can be argued however that *front-back* directionality of facing Referents is reversed compared to ego).

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[32] There may however be some different intuitions here. From informal discussions with various informants I got the impression that normally in Dutch and German the intrinsic directions of, e.g., a cabinet seem to comply with a mirroring translation (Intrinsic **[±Y,±$Z_{P/m}$,±X]**) of the ego-frame when standing *in front of* it. Intrinsic *left* and *right* of the cabinet thus point in the same direction as *left* and *right* of the ego at that moment when the ego is using the cabinet canonically. However, two informants insisted that the intrinsic directions comply with a rotating translation of the ego-frame (Intrinsic **[±Y,±Z_{P2},±X]**). In this case, cabinet *left* and *right* directions are reversed relative to ego *left* and *right* directions. Some confusion may thus exist between speakers of the same language regarding intrinsic *left* and *right* labelling (see also Miller and Johnson-Laird, 1976).

This observation, that facing and aligning Referents have opposed directionality assigned to the *left-right* dimension (or a reversed *front-back* dimension), is taken here as an indication that intrinsic descriptions of Referents that can be used for the definition of Intrinsic Directional Relations for Language should employ independent dimensional directionality. Intrinsic descriptions with independent dimensional directionality can encompass partial reference frames, as well as full reference frames for both aligning and facing Referents. If one were to use intrinsic descriptions with dependent dimensional directionality, one needed to suppose that different intrinsic Frames of Reference are available and that, dependent on Referent category, the applicable frame is picked.

2.4.4. Taxonomy

It is now possible to classify Intrinsic Object Centred Frames of Reference. It is taken into account that an Intrinsic Object Centred Frame of Reference has one or three dimensions, that *front-back* directionality is assigned in a facing or aligning manner, and that *left-right* directionality is not defined by acquired category characteristics (knowledge). The classification is primarily thought to apply to Western European languages as Dutch, English, and German. There are objects whose intrinsic Frame of Reference consists only out of the vertical dimension and directions (Intrinsic **[±Y]**; e.g. a tree, table, or glass). Other objects possess intrinsic Frames of Reference with only the horizontal *front-back* dimension and the directionality there. In this case, there are two possibilities. The dimension may have its labelling acquired through translation during canonical use and/or encounter (Intrinsic **[±Z_P]**; *front-back* axis directionality is aligned with one's own if the object is being canonically used; e.g. circular telescope for one eye). Alternatively the directionality may have had its labelling acquired through a mirroring translation (Intrinsic **[±$Z_{P/m}$]**; *front-back* axis directionality is reflected relative to one's own if the object is being canonically used; e.g. a circular or rectangular hand-mirror). Objects with intrinsic Frames of Reference with three directed dimensions can likewise be differentiated by simple or mirroring translation relative to normal use and/or encounter. Thus, there are objects with respect to which six Intrinsic Reference Frame directions can be defined that are all aligned with the Ego Centred Reference Frame directions (Intrinsic **[±Y,±Z_P,±X]**; all directionality aligned with that of ego, e.g. a car, chair, camera). There are also objects relative to which six Intrinsic Reference Frame directions can be defined that are mirrored in the frontal plane with respect to the Ego Centred Reference Frame directions (Intrinsic **[±Y,±$Z_{P/m}$,±X_P]**; *top-bottom* and *left-right* directionality aligned with and *front-back* directionality reflected relative to that of ego when such an object is being canonically used, e.g., a cabinet, computer, or television, or being canonically encountered, e.g., a building).

Additionally, there are intrinsic Frames of Reference whose linguistic labelling is only (or also) based on the typical movement of the objects involved. Objects exist with only *front* and *back* labelling (Intrinsic **[±Z_{Move}]**; e.g., an arrow or a bullet). Objects exist with *front* and *back* labelling in addition to *top-bottom* labelling through orientation, whereby both also define *left* and *right* labelling (Intrinsic **[±Y,±Z_{Move},±X]**; e.g., a modern electrical train whose *front* could be one of both ends and depends solely on the direction the train happens to move). Finally, autonomous Referents have an intrinsic Frame of Reference completely in analogy with that of ego (Intrinsic **[±Y_{Ori},±$Z_{Perc/Move}$,±X_{Ana}]**; e.g., 'You' or a dog).

2.4.5. Labelling by Category and Spatial Structure

The terminology of canonical orientation and canonical encounter and canonical use and how reference frame directionality corresponds to these customaries has one important implication, namely that this knowledge never refers to symmetric parts of an object. A symmetric part of a bilateral symmetric object can never be canonical encountered, oriented, or used, while it might otherwise have been the other symmetric part as well. Therefore, the customaries always refer to asymmetric parts (that is, a distinction in category structure that can be identified in each Referent instance). It follows that if an object on which a full intrinsic Frame of Reference can be defined is mirror symmetric (that is, bilateral symmetric) the symmetric halves will be the *left side* and the *right side*. It was argued that directionality could only be assigned to symmetric parts once directionality has been assigned to the other dimensions. It follows that with bilateral symmetric objects *left* and *right* is only assigned after the other directionality is assigned. Moreover, it can be argued that an object not even needs to be actually symmetric for *left* and *right* directionality to be assigned last. If there is no functional differentiation in category structure regarding *left* and *right* Directional Parts (as argued), then, irrespective the actual structure of the Referent, *left* and *right* directionality is only assigned after *top-bottom* and *front-back* directionality has already been defined. The structure of the *left side* and the *right side* of the perceptual Referent may thus differ. Such a difference cannot help in the definition of *left* and *right* though. *Left* and *right* are not defined in a strictly intrinsic sense, but by reference to the convention on how we use these terms given the *top-bottom* and *front-back* directionality. The Referent's category structure does not have any functional (and thus structural) differentiation between *left* and *right*. Therefore, no matter the *left-right* structure of the perceptual Referent (instance of the category), *left-right* directionality cannot be assigned to the perceptual Referent by means of category information before other directionality is defined while there is no category differentiation.

There is one interesting consequence of having different kinds of Referents and the *left-right* directionality being defined only after other directionality. Although the difference between facing and aligning Referents may have its origin in an acquired *front-back* directed dimension that is labelled as if the Ego Centred *front-back* directed dimension is translated or reflected, the difference between such Referents must be considered a *left-right* reversal in information-processing terms.

In the section on spatial structure, a few examples were encountered where intrinsic descriptions with independent dimensional directionality would not work, whereas those with dependent dimensional directionality are able to define Intrinsic Locations or directions. In all these cases however, dependent dimensional directionality would be needed to differentiate between enantiomorphs either along the one possible directed dimension or along all of up to three directed dimensions. Taking into account the category features just mentioned and that symmetric parts are unsuited to define canonical orientation, encounter, and use, it becomes clear objects with such a spatial structure are not suited for Intrinsic Object Centred Reference. Therefore, intrinsic descriptions with independent dimensional directionality can still be used with regard to all objects on which Intrinsic Object Centred Frames of Reference can be defined for language. As mentioned above, the existence of facing and aligning Referents favours independent over dependent dimensional directionality. Note here as well that with the exclusion of those objects with which independent dimensional directionality would fail, that no object that is suited as a Referent for Intrinsic Object Centred Reference for language possesses a natural origin.

2.5. Categorising a Spatial Relation and Directional Regions

The previous sections were primarily concerned with how intrinsic directional definitions might be constructed around a Referent. Concluding this chapter, I will now consider what can be said at this stage about how a Spatial Relation is categorised, that is how a relation between Figure and Referent can be appreciated in terms of directional aspects of the Frame of Reference. In Intrinsic Object Centred Reference, the location of the Figure relative to the Referent (in the perceptual representation) is evaluated against directional distinctions derived from the categorical structural properties of the

Referent. Apart from assigning directionality to perceptual space, the location of the Figure has to be linked to the directional definitions in order to categorise the Spatial Relation as a member of a specific Directional Relation or a combination of Directional Relations. I will thus consider how it can be established that the specific location a Figure occupies belongs to a particular Directional Region or to particular Directional Regions. In order not to complicate matters too much, it is assumed that the Figure has no extendedness, i.e., the Figure is a point, occupying only a single location.

Considering the definition of reference frame parameters, the definition of Spatial Relations, as well as the way in which Spatial Relations are categorised in terms of the Frame of Reference, puts one in the position of facing a multitude of possibilities. In addition, a Referent may posses one directed dimension, two directed dimensions (2D objects) or three directed dimensions. In the first case, a Spatial Relation can only be categorised on one dimension: The Figure is, e.g., *above* or *below* the Referent, or none of these. In the case of three directed dimensions, a Spatial Relation can be categorised as one Directional Relation (i.e., *above*, *below*, *in front of*, *behind*, *to the left of*, or *to the right of*) or arguably as a combination of Directional Relations, whereby a combination is built from different dimensions. It would definitely be helpful if there were a theory that would describe which (combinations of) Directional Relations are applicable under what circumstances. No such clear in-/output theory is available however. Therefore, the present approach is more intuitive.

It is considered which locations will be categorised as a Directional Relation regarding three questions. The first question is when the Intrinsic Location of a Figure can be said to comply with an exclusively 'directional interpretation' of an intrinsic Directional Relation. This interpretation would involve the Figure being directly, e.g., *in front of* the Referent, meaning that if the Referent were to move forward, it would collide with the Figure. An alternative formulation would hold that if a line is projected from the *front* of the Referent to the Figure, that the line has (about) the same orientation as a line projected from the *front* to the *back* of the Referent (note the possible circularity of giving an interpretation to Directional Relations and the regions implied in the interpretation). See Figure 2.19.A. The collection of all locations where the direct interpretation applies will be called the ‘direct region’.

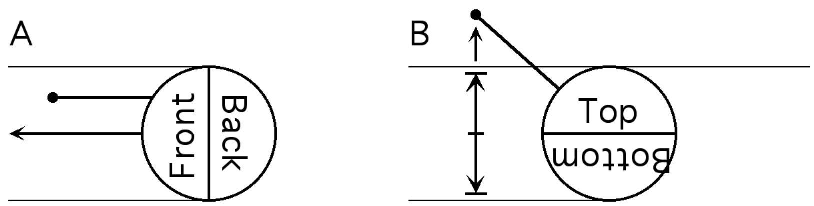

Figure 2.19. Different interpretations of regions where Directional Prepositions apply.

The second question is when the Spatial Relation can be said to comply with an 'ordering interpretation' of intrinsic Directional Relations. This interpretation would involve the Figure being, e.g., *above* the Referent in that sense that, within the intrinsic vertical orientation of the Referent, the Figure would be 'higher than' the Referent, but not necessarily directly *above* it. See Figure 2.19.B. The collection of all locations where the ordering interpretation applies shares many locations with the direct region. The region resulting after subtraction of the direct region will be called the ‘oblique region’. The third question concerns the categorisation that results if a choice between two Directional Prepositions were to be forced regarding Spatial Relations, even when the Spatial Relations would not be categorised as such without a forced choice. Different forced-choice questions are possible if a Referent has more than one directed dimension. One may consider forced-choice within a dimension and forced-choice between dimensions. Regions resulting from forced choices after subtraction of the direct and oblique regions will be called ‘forced-choice region’.

2.5.1. General Considerations

A Spatial Relation is preferably categorised in similar reference frame distinctions whether there is only one dimension with opposing directions or three dimensions with opposing directions. Thus as a generality consideration, I will assume that there are similar mechanisms for objects with one directed dimension and objects with 2 or 3 directed dimensions. Clearly, an independent assignment of directionality to dimensions seems suited for this task. However, the categorisation with 1 directed dimension is restricted to categorisation on this dimension while categorisation with more than one directed dimension may not only involve choices for categorisation within dimensions, but also a choice between the dimensions.

Additionally, if possible, the reference frame definitions, Spatial Relation definitions, and categorisation procedures for Intrinsic Object Centred Reference should ideally be applicable to other Frames of Reference as well. The easiest way to achieve this, it seems to me, is, first, to define the Spatial Relation independent from the Frame of Reference. Second, the reference frame distinctions need to be defined with enough generality over Perspectives, that is, one, two, or three orthogonal directional oppositions have to be defined in the same way irrespective of the particular Perspective (although the Perspective defines number, orientation, and labelling). Third, the Spatial Relation is interpreted through goodness-of-fit procedures that are generally applicable over the number of dimensions and different Perspectives. Based on degree of fit or any other measure such as deviation from directed dimensions, a (general) decision rule defines the choice for a categorisation.

The Spatial Relation defines the location of the Figure relative to the Referent. The relation can be conceptualised through a vector from the Referent to the Figure. There are different ways to define such a vector. For instance, the vector might be described in Cartesian co-ordinates or in polar co-ordinates. However, if a Spatial Relation is similarly defined over different Frames of Reference in an independent way, then a definition of the vector in Cartesian co-ordinates cannot be used simultaneously for two Frames of Reference that, e.g., differ in the orientation of their dimensions by 45°. A description of the vector in polar co-ordinates[33] can however be used. Now, while it is not impossible to use Cartesian co-ordinates within a Frame of Reference and to redefine the vector in other Cartesian co-ordinates suiting another Frame of Reference, defining the vector in polar co-ordinates seems most straightforward and parsimonious at first glance. In addition, that polar co-ordinates involve an angle seems more naturally in line with *directional* definitions. However, it is not clear if a polar vector can be defined in such a way to be suited for different Frames of Reference. This depends on exactly how the vector is defined between a location and a spatially extended Referent. Is the vector defined from some geometrical midpoint of the perceptual Referent, on the basis of the proximal distance between the location and some aspect of the extended Referent, or on some attention mechanism (such as the Attentional Vector-Sum of Regier and Carlson (2001); see also Chapter 3)? Again, maybe a vector is defined (or re-interpreted) in a way that depends on the Frame of Reference used to categorise the Spatial Relation. It could even be the case that no vector is defined between the Figure and the Referent, but that instead regions are projected from the Referent while the Figure is localised with respect to these regions. Anyway, in this section it will be assumed the Spatial Relation can be defined with a polar vector, and only definitions of polar vectors for intrinsic categorisation will be considered (and not if the vectors can also be used within other Frames of Reference).

The definition of distinctions of any reference frame must allow comparison with the definition of the vector as a basis for categorisation. An Intrinsic Frame of Reference must somehow be attached to the (category) structure of the Referent. The Frame of Reference defines directionality in perceptual space surrounding the Referent. Apart from that, there may be a few other uses of the intrinsic spatial category structure

[33] Polar co-ordinates define an angle for vector orientation and a distance for vector length in 2D cases, while in the 3D case two angles need to be defined next to the distance.

of an object. The category structure of or conceptual knowledge about an object must also allow one to define Directional Parts. The intrinsic Frame of Reference thus needs to be able to define, e.g., the *top* and *bottom* of an object.[34] In addition, directional definitions based on the category structure of an object can be projected on a Referent within the object or on the outer surface of the object to locate a Figure relative to that Referent. Thus, an object's category structure may provide a Perspective whose directional definitions are projected 'inward' for Environment Centred reference. Finally –in some cases– an object's category structure may provide a Perspective for 'forward' projection of directional distinctions on a Referent for allocentric relative reference. The chosen characterisation of the Frame of Reference for Intrinsic Object Centred Reference should thus be extendable to these possibilities. Apart from that, the characterisation of an Intrinsic Object Centred Frame of Reference must be applicable to a host of different object shapes and structures.

Regarding the categorisation of a Spatial Relation, it is required that the definition of the specific location of the Figure (defined by the vector) or of the specific direction the Figure (defined by the vector component angle) allows comparison with the directionality parameters of the Frame of Reference. That is, the definitions of directionality and the definition of a perceptual Spatial Relation between Figure and Referent need to be –at least partially– of the same kind. Thus, reference frame distinctions and Spatial Relation definitions may both have an orientation or direction component that can be compared. A perceptual relation can be evaluated within one specific directed dimension independent of the presence of other directed dimensions in the Intrinsic Frame of Reference. Additionally, given that a perceptual relation can be categorised on more than one dimension, there must be a possibility to decide which dimensional categorisation applies best to the perceptual relation. An orientation or direction comparison mechanism is needed on the basis of which it is possible to decide

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[34] Spaces within an object can also be defined through Directional Parts, e.g. 'in the *top* of the Referent'.

which is the suiting direction or which are the suiting directions, and to decide which of the dimensions having a suited direction suits best.

Below it is considered how Spatial Relations may be categorised in Intrinsic Object Centred Frames of Reference with one, two, and three directed dimensions respectively. In each of these cases, the coding of Intrinsic Location for memory will also be considered while keeping into account the spatial structure Referents with one, two, or three directed dimensions may have and how these dimensions are labelled. How an Intrinsic Location may be coded for memory is compared to how the Spatial Relation is defined for categorisation. Of particular interest are the questions when the Intrinsic Object Centred Frame of Reference can be used to code an Intrinsic Location and when it needs to be used for this coding. The coding of the Spatial Relation that is compared to the directionality parameters (i.e. the angle component of the vector) may also be a coding used regarding memory for Intrinsic Location (angle and distance components of vector). However, whereas the categorisation of Spatial Relations for language is defined on the basis of category information shared by the language community, the coding of location for memory does not need to rely on such shared knowledge, as the coding may be for personal use only.

2.5.2. 3D Objects with One Directed Dimension

The case that is considered first is the 3D object with one directed dimension. The example will involve Referents with a *top-bottom* directed dimension. Other objects with one directed dimension have a *front-back* directed dimension instead. It is assumed that there are no differences between these cases except for labelling. Perceptual Referents with one directed dimension may have a spatial structure that ranges from being asymmetric to being infinite-fold rotation invariant about a single axis. Apart from that, there can be great variety in shape. The description should be able to generalise over these possibilities.

Similar to all objects with an intrinsic *top-bottom* directed dimension is that the shape of the Referent needs to change along this *top-bottom* dimension in a way that is part of the overall structure of the Referent's object category. *Top-bottom* directionality was found to depend on the canonical orientation (when being used) of an object. The representation of the object category provides this information. The information must be applied to the perceptual instance of the category that is to function as the Referent. The Referent's object category must provide some way to distinguish *top* from *bottom* on the perceptual object and to base directional information on this distinction. The basis for dimensional directionality must thus be within that spatial structure of the Referent that is shared by the object category. There is not necessarily an axis definition in the spatial structure of the perceptual object along which the dimension can be oriented.

Because there is not necessarily an axis on the perceptual Referent, it seems advantageous to start with finding the *top* and the *bottom* of the Referent. The category structure defines what is *top* and what is *bottom*. The perceptual instance of the category (i.e., the Referent) needs to mirror this category structure. Irrespective of the actual spatial structure of the Referent, a distinction needs to be identified in the Referent's structure that defines which part is the *top* and which part is the *bottom*. When such a distinction is established on the perceptual Referent, one directional object part is in some way *separated* from the opposite directional object part. Therefore, some bounding entity must be defined between these parts. This entity should be some bounding plane (while presently considering 3D objects). See Figure 2.20.A. With this characterisation I do not wish to say that a plane is imposed that, so to say, cuts the Referent sharply in two parts. The within-structure differentiation probably invokes a bounding plane that is defined more or less precisely.[35] What I do want to say, however, is that by separating (identifying) the *top* and *bottom* some kind of bounding plane is (at

[35] Precise could for instance mean exactly half-way along the dimension while imprecise could be up to a definition of a gradual boundary from the *top*most point along the dimension to the *bottom*most point of the dimension.

least implicitly) constructed, and that it is possible to define an orthogonal orientation against this plane. The planar entity is the *result* of separating *top* from *bottom* but provides the basis for the orientation. The orientation can be defined from any point on the plane, that is, there is not necessarily a localisation of the orientation (i.e., there is no localised axis). See Figure 2.20.B. The orientation extending from one side of the Directional Parts separating planar entity intersects the *top* and can accordingly be assigned the *top* directionality, while the orientation extending from the other side of the plane intersects the *bottom* and can be assigned the *bottom* directionality. Thus, e.g., the *top* directionality is defined by orienting it orthogonal to the separation of *top* from *bottom* and marking it with the directionality given to the *top* (see also Clark, 1973).

Also in those cases where there happens to be a rotation axis on the perceptual Referent, there must be a separation of the *top* from the *bottom* in order to assign directionality to half-axes. The rotation axis as such only defines an orientation, but no directionality. Referents with a rotation axis could allow that the Spatial Relations to the Referent, that Figures located on this axis have, might be considered, e.g., 'exactly *above*' the Referent. However, on Referents without a rotation axis, such an 'exactly *above*' region might not exist. Therefore, any definition of a Frame of Reference that wishes to be generally applicable should not make use of such an axis. If the perceptual Referent happens to be rotational invariant, the rotation axis could be helpful in defining the exact *top*-*bottom* orientation as well as the orientation of the bounding plane imposed by separating *top* from *bottom*. If the Referent is not rotation invariant, then the determination of the dimensional orientation and the orientation of the bounding plane may be less precise. The definition of intrinsic *above* and *below* could be more inexact with regard to particular skewed instances of an object category.

It was established that there could be no natural origin on an object when intrinsic directional definitions are possible. Therefore, I assume that the whole object functions as the origin for the Intrinsic Object Centred Frame of Reference. Thus an 'extended' origin is defined where one directionality parameter is defined from the *top*most point of the Referent, and the opposed directionality parameter from the '*bottom*most' point of the Referent. One interesting possibility is that with the extension of the origin to the whole object, that the plane bounding *top* and *bottom* changes its extension to the (intrinsic) highest and lowest parts of the Referent as well. A signed reference orientation is defined at either side of the Referent (origin). See Figure 2.20.C. Thus, the bounding plane separating *top* and *bottom* might be 'widened' in order to give directionality to surrounding space. Such flexibility in the setting of an orientation-defining plane seems convenient for defining Environment Centred reference as well. It could be focused on a Referent within (or on the outer surface of) the object to enable Environment Centred Frame of Reference. Additionally, it could be used relative to a part of the object (e.g., '*above* the glasses foot').

With the bounding plane as well as the directed dimension attached to the Referent in such a way, different regions may be defined. The specification of the Spatial Relation has to be taken into account though. This specification was assumed a vector in polar co-ordinates. However, a vector must be defined from an origin as well. More inclusive, next to the definition of the Spatial Relation, the reference orientation and rules of comparison for making category decisions are required. I will approach this in an integrative fashion by considering to what extent Directional Regions can be defined given the three interpretations of Directional Relations described before and the characterisation of the Frame of Reference described thus far.

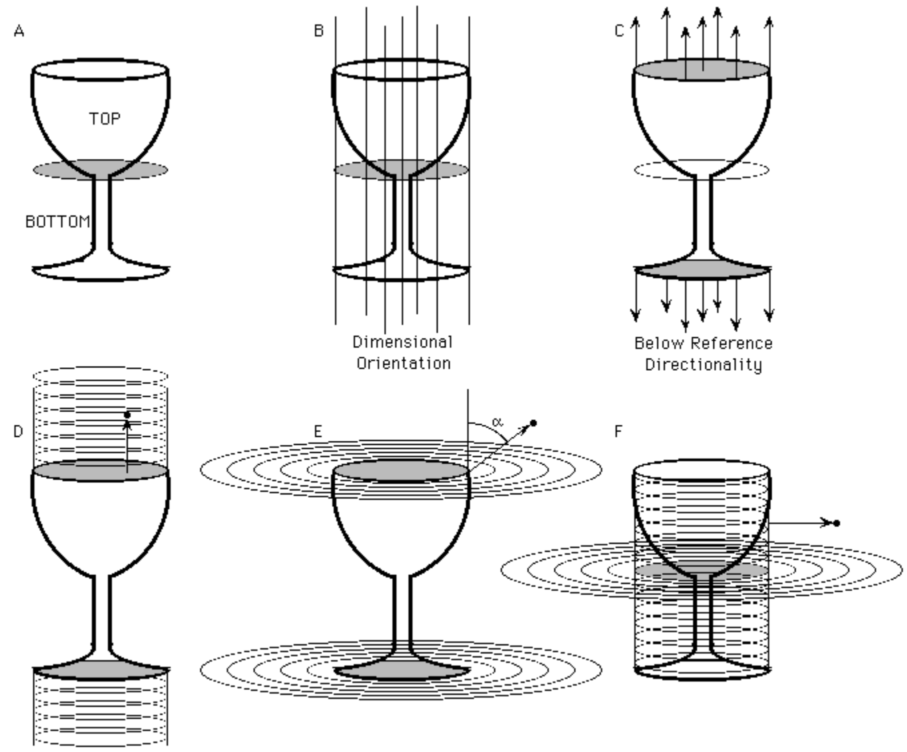

Figure 2.20. How a combination of Directional Parts and vector definitions may be used to define Intrinsic Directional Regions relative to a 3D object with one directed dimension. See text for details.

Regarding the direct interpretation of Directional Relations, it is possible to define a direct region through vectors whose orientation component has the same value as the reference direction for *above*. Having the bounding plane extend to the intrinsic 'highest' and 'lowest' parts of the Referent allows that vectors may be defined from this so-called *grazing* plane. Any Figure located in the region that is so defined can doubtlessly be considered as having a Spatial Relation to the Referent that can be categorised as *above*. The categorisation rule for this region is equality. This is illustrated in Figure 2.20.D. There may be Intrinsic Locations that are not compatible with this characterisation, that is, there may be Figure locations that are *above* some part of a Referent, but *below* the extension of the bounding plane to the highest part of the Referent. While my intuitions give no definite answer as to how such locations are categorised, they will simply be ignored. Do note however, that extension of the bounding plane to the grazing plane does correctly exclude some locations to be categorised as *above,* for instance, locations that are correctly categorised as 'in' with respect to a glass, as in Figure 2.20.

Regarding the 'ordering interpretation' of Directional Relations it is possible to construct the oblique region by vectors whose orientation component deviates less than 90° from the directional orientation for *above*. This categorisation rule applies to all locations that are intrinsic *above* the grazing plane if extended orthogonal to the directed dimension. If the Spatial Relation is defined with a vector from the Referent to the Figure, then the orientation component of the vector has a value that deviates less than 90° from the reference direction for any Figure located above this plane. This actually is so irrespective of the aspect of the Referent that the vector is defined from and functions as the vector's origin. All Figures located in this region can also be said to be *above*, at least in the sense 'intrinsic higher than'. See Figure 2.20.E.

Regarding the 'forced-choice interpretation' of Directional Relations, categorisation is considered for that portion of space that is unaccounted for after the definition of direct and oblique regions for *above* and *below*. Regarding Figures located in this part of space, the question is what categorisation would prevail if the relation of Figure and Referent is forced to be categorised as either *above* or *below*. It is however assumed that Spatial Relations are not usually categorised on this dimension in that portion of space. The reasons for considering this forced-choice categorisation will be made clear below. Because Figure locations are not in the direct and oblique regions, it is proposed here that the Directional Part to which a Figure-Referent vector is attached determines categorisation in this portion of space. Some Intrinsic Locations can be described with a vector from the *top* part of the Referent and other locations with a vector from the *bottom* part of the Referent. The bounding plane that was proposed as the *top-bottom* separating entity now describes the boundary between the forced-choice for *above* and the forced-choice region for *below*. See Figure 2.20.F.

The vectors shown in Figure 2.20 are based on proximal distance to a bounding cylinder projected on the Referent. The cylinder is reminiscent of a bounding box proposed for Referents with three directed dimensions (see Van der Zee, 1996; Van der Zee and Eshuis, 2003). Also here, a box results if the same mechanisms are used for three directed dimensions. At least the cylinder is a convenient construct to illustrate important regions when it is additionally assumed that vectors (Spatial Relations) are defined on the basis of proximal distance to this cylinder. The cylinder also excludes Figure locations within it. One may thus consider whether a cylinder would be a suited schematisation for Referents with one intrinsic directed dimension. This does not appear to be the case in general. The definition of a bounding cylinder may not suit Referents such as a rectangular shaped table. Therefore, it seems better to allow more variation in the shape of the bounding plane. The Spatial Relation definition (vectors) and categorisation rules would not need to change if it were assumed that a schematised Referent has a constant cross-section from the *top* grazing plane to the *bottom* grazing plane. This cross-section might be defined by the Referent's greatest extension orthogonal to the *top-bottom* dimension. If the cross-section is constant, then a proximal distance vector that deviates 90° from the *top-bottom* dimension always defines Intrinsic Locations between *top* and *bottom* grazing planes.

Notwithstanding the hypothetical nature of such a schematised Referent description, it remains to be seen if vector definitions based on proximal distance to the schematised object are compatible with directional definitions for other Frames of Reference. It could be questioned if vector definition from the sketched *top-bottom* schematised Referent would be used if the Figure-Referent relation were to be defined Ego Centred. In the present case however, the definition of Directional Parts by a bounding plane and the accompanying orientation orthogonal to this plane partially determines the schematised Referent. The definition of Directional Parts is based on object category structure, which generalises over instances of the object category and can therefore exist only in a schematised fashion. In addition, vector definitions in combination with categorisation rules suit personal intuitions about what Figure locations can be called *above* and *below* even in case of a forced choice.

Categorisation rules for a Referent with one intrinsic directed dimension are thus as follows. If a Figure occupies a location whose Spatial Relation to the Referent can be described by a vector with the same orientation as one of the Reference directions, then the Spatial Relation is categorised as the accompanying Directional Relation and the Figure is in the direct region. If a Figure occupies a location whose Spatial Relation to the Referent can be described by a vector with an orientation that deviates less then 90° from one of the reference directions, then the Spatial Relation is also categorised as the Directional Relation. The Figure is in the oblique region. If a Figure occupies a location whose Spatial Relation to the Referent can be described by a vector with an orientation that deviates 90° from both reference directions, then the Spatial Relation is not suited to be categorised as a Directional Relation at least when one is not forced to.

2.5.2.1. Intrinsic Location and One Directed Dimension

When comparing the categorisation of Spatial Relations with the coding of Intrinsic Location, objects with rotation invariance and objects without rotation invariance need to be distinguished. Regarding the coding of Intrinsic Locations and rotation invariant perceptual Referents, it was already shown that only Intrinsic Locations on the rotation axis can be defined unambiguously. In contrast to this limited possibility to code an Intrinsic Location, more Spatial Relations than Figure locations at the rotation axis can be categorised. The Directional Prepositions *above* and *below* can thus be applied more widely than to locations on the rotation axis (although it is possible to argue that only on the axis 'exactly *above*' and 'exactly *below*' applies). Categorisation of Spatial Relations is possible with Figures at Intrinsic Locations that cannot be unambiguously defined.

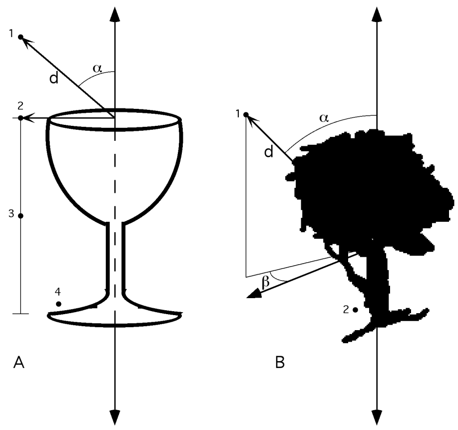

Figure 2.21. Defining Intrinsic Locations with respect to 3D objects with one directed dimension. The object in A is rotation invariant; the object in B is not.

It is possible to code partially for Intrinsic Location, that is, one may code the intrinsic verticality of a location (and a distance). When doing so, the same structure of the Referent that is used to define the intrinsic directed dimension, needs to be invoked in the coding of intrinsic verticality as well. Location 1 in Figure 2.21.A can be defined with a distance and a deviation from the reference direction for *above* from an origin at the intersection of the rotation axis and the grazing plane. The structure used to define intrinsic verticality is also applicable to those portions of space that would not otherwise be categorised as *above* or *below* unless forced so. In Figure 2.21.A, the vertical position of location 2 is that of the *top* grazing plane, while that for location 3 is halfway between the two grazing planes. It is also possible to code vertical orientation by applying intrinsic verticality information to specific parts of the Referent (e.g., 'slightly higher than the glass's foot'). See Figure 2.21.A's location 4.

Regarding the coding of Intrinsic Location with respect to an asymmetric object (or bilateral symmetric object), it was shown that all locations can be defined unambiguously. At least a part of the description of the location however necessarily involves aspects of the Perceptual Referent that are not used in the construction of the Intrinsic Object Centred Frame of Reference for language. Some aspects of the coding of an Intrinsic Location need to involve aspects of the perceptual Referent that are not necessarily shared by the Referent's object category.[36] Intrinsic coding of location may however use a component in the code that refers to the intrinsic structure of the Referent along the directed dimension. In that sense it is similar to rotation invariant perceptual Referents. See the locations in Figure 2.21.B.

In any case, one cannot use the Intrinsic Object Centred Frame of Reference to code an Intrinsic Location with respect to a 3D Referent with one directed dimension. If the Referent is not rotation invariant, then it is possible to use the structure used for the Intrinsic Object Centred Frame of Reference to code the vertical component of the coding of an Intrinsic Location for memory. However, one does not necessarily need to.

2.5.3. 2D Objects with Two Directed Dimensions

A Referent’s category may provide more than one directed dimension. 2D objects may have two directed dimensions. The 2D Referents may be bilateral symmetric or they may be asymmetric. A bilateral symmetric object has a *left-right* directed dimension and a *front-back* or *top-bottom* directed dimension. It is assumed that these two cases differ only in the labelling of the *top-bottom* respectively *front-back* dimension but are similar otherwise. An asymmetric 2D object may have dimensions as the bilateral symmetric object or it may have a *front-back* directed dimension and a *top-bottom* directed dimension. *Left-right* directionality is assigned only after the *front-back* or *top-bottom* directionality has already been established. Regarding *front-back* and *top-bottom* directionality, no ordering has been established thus far (but see Chapter 3).

Regarding the definition of the Frame of Reference, it is assumed that similar distinctions are needed for each dimension as the distinctions made for cases with one directed dimension. It is assumed that the directed dimensions are represented

[36] A location definition may involve features that are common or category-defining, but these features do not have a spatial category defining distribution that is used to define the Frame of Reference

independently. Because the situation is 2D here, the bounding plane defined with regard to 3D objects reduces to a bounding axis and the grazing plane reduces to a grazing line. The assignment of *top* and *bottom* depends on the object category structure and knowledge of the object's canonical orientation, while the separation of *front* and *back* depends on category structure as well and on knowledge on the canonical encounter. The establishment of the *left* and *right side* depends neither on the object category structure nor on knowledge about customaries.[37]

The direct, oblique, and forced-choice Directional Regions are shown for the *above* and *to the right of* directionality in respectively Figure 2.22.A and B whereby forced-choice refers to the forced-choice within a dimension, that is, between opposing directions. The Referent in Figure 2.22 is bilateral symmetric. The axis of symmetry could be of help in defining reference directions more exactly (for the *top-bottom* direction in this case) but the assigning of directionality should be based on the distinction between the Directional Parts *top* and *bottom*, that is, orthogonal to the bounding axis between these. Similarly, the axis of symmetry could aid orienting the exact bounding axis between the Directional Parts *left side* and *right side*. In this case, one may argue that when the perceptual Referent is bilateral symmetric that the axis of symmetry actually is the bounding axis (and defined precisely). Also, Figures located at this axis can be argued to have a Spatial Relation to the Referent that can be categorised as 'exactly *above* or *below*' because they are located on the precisely defined bounding axis between the *left side* and the *right side.* Therefore these locations are completely neutral with respect to the *left-right* opposition. Regarding other perceptual Referents, however, the Directional Parts *left side* and *right side* do not need to be separated by an axis of symmetry.

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[37] To avoid confusion, it is possible that a certain category structure is associated with the object's sides. The category object structure is however assumed to be symmetric and not coded for directionality. Thus although a structure may be defined for side, it is not coded which side is the *left side* and which side is the *right side*.

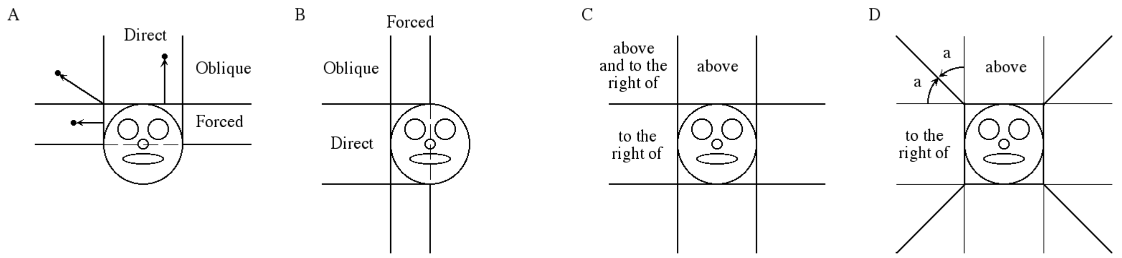

Figure 2.22. Defining Directional Regions with respect to 2D objects with two directed dimensions.

Comparing Figure 2.22.A and B shows that the Directional Regions for *above* and *to the right of* overlap. One may consider what the description of the Spatial Relation of a Figure in the region may be like if description were free, that is, excluding the forced-choice regions. Figure 2.22.C shows this for *above* and *to the right of* and their shared region. It is thus assumed that one may refer to a Spatial Relation by using a combination of Directional Prepositions. One may also consider what would happen if a forced-choice is made between directionality of different dimensions. This is shown in Figure 2.22.D. The boundary between Directional Regions that are defined in this way probably lies half-way between the reference directions, that is when the Spatial Relation can be defined with a vector with an angle component of 45° from both reference directions. If the angle component of a vector would be less than 45° from one of the reference directions (and therefore over 45° from the other), the Spatial Relation can be categorised as a Directional Relation for that reference direction and the Figure is thus within its Directional Region.

2.5.3.1. Intrinsic Location and Two Directed Dimensions

Regarding the coding of an Intrinsic Location relative to a bilateral symmetric object it has already been established before that the side of the axis of symmetry at which the Figure is located must always be defined (for instance, by marking it with *left* or *right* under the Perspective of the other directed dimension whose directionality is defined first).[38] Apart from that there may be much variation in the coding of a location. A few examples are given in Figure 2.23.A. A definition of a location may involve two features of the Referent and a direction through these (location 1), or a single aspect with enough structure (location 2). In both cases, however, the intrinsic *to the right of* spatial category has to be coded as well in order to define the locations unambiguously. It is also possible to use the reference directions of the Intrinsic Object Centred Frame of Reference to code a location. One may code an Intrinsic Location by referring to, say, 'somewhat *above*, and slightly *to the left of* the axis of symmetry' (location 3). As another possibility, a location might be coded by 'somewhat *to the left* and at 1/4 on the way from *bottom* to *top*' (location 4). Note that locations 3 and 4 are in the direct Directional Regions for *above* respectively *to the left of* and that a Spatial Relation is usually not categorised on the *left-right* respectively *above-below* dimension there.

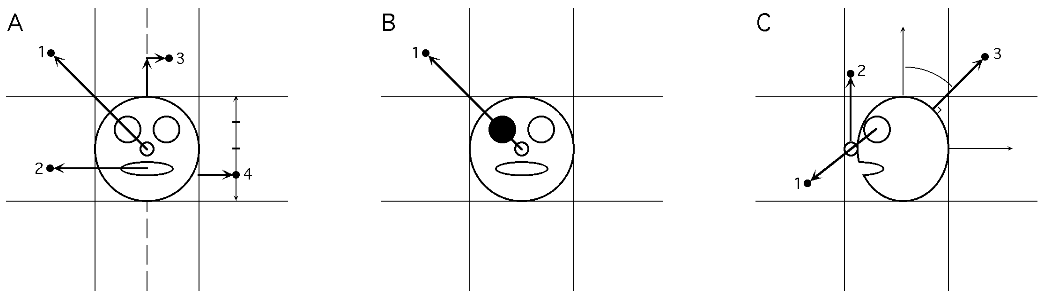

Figure 2.23. Coding an Intrinsic Location relative to 2D objects with two directed dimensions.

In Figure 2.23.B, an asymmetric object is shown with a *left-right* directed dimension. For the intrinsic Frame of Reference for language this does not matter while the spatial structure of the Referent's object category does not code at which side the black eye is. However, that the black eye happens to be at the *right side* of the perceptual Referent may directly influence the coding of Intrinsic Location. One example shows a direction

[38] At least, conventional *left* and *right* labelling is expected in language. For memory this does not need to be so, as any other marking might be used instead. In the text *left* and *right* will be used, because any other labelling would refer to exactly the same distinction; the labelling is as good as any other.

based on two features of the Referent. Because one of the features is the black eye, the coding of location is unambiguous. Referring to 'black-eye side' respectively 'white-eye side' is possible for most other locations as well. Regarding the coding of Intrinsic Location, it is therefore not necessary anymore that directionality be assigned to the *above-below* dimension first. Of course, it is still possible to code locations by using the intrinsic Frame of Reference as in Figure 2.23.A.

An asymmetric object with an *above-below* directed dimension and a *front-back* directed dimension is shown in Figure 2.23.C. One may use two features and define a direction (location 1). It is possible to use a reference direction and apply it to a feature of the Referent (location 2). The intrinsic Frame of Reference may also be used to code a location (location 3). In that example, the deviation of a proximal distance vector from the *above* reference direction defines the location. It then also needs to be coded that the deviation is towards the *behind* reference direction.

2.5.3.2. Memory versus Language or Contrast versus Similarity

In the bilateral symmetric case, the only way to code an Intrinsic Location is to refer (also) to the symmetric structure of a Referent (which is used by the intrinsic Frame of Reference for language as well). In the asymmetric case, it is possible to code an Intrinsic Location by referring to features of the Referent's structure that are not used for language. Therefore, in order to make sure that the coding of an Intrinsic Location for memory is necessarily comparable to the categorisation of Spatial Relations as intrinsic Directional Relations for language, the use of a bilateral symmetric 2D Referent is recommended. However, with asymmetric Referents it is also possible to code an Intrinsic Location for memory by using the intrinsic Frame of Reference. Establishing that the two tasks must or may be (partially) comparable is one thing. Another question is how to compare the two tasks.

For the precise coding of Intrinsic Location for memory by means of an Intrinsic Frame of Reference (also used for language), it does not suffice to code location by a Directional Relation. Remembering that the Figure is *in front of* the Referent does not specify *where in front of* the Referent the Figure was located. *In front of* does not differentiate between locations within the Directional Region, that is, all locations where the Figure has a relation to the Referent that can be categorised as the Directional Relation *in front of*.

Whereas categorisation of Spatial Relations as Directional Relations appears to be based on the *similarity* of a vector orientation and a reference direction, the coding of an Intrinsic Location cannot rely on similarity. Instead, the precise coding of Intrinsic Location needs to be based on the *contrast* to reference directions and, in particular, on the way that the location deviates from a reference direction in terms of the orthogonal dimension. The example that allows the clearest illustration hereof involves the bilateral symmetric object as a Referent. There is a portion of space that is exclusively categorised as *above*, and would not be categorised on the *left-right* dimension unless forced to (i.e., the direct region). For the coding of an Intrinsic Location in that portion of space, it does not suffice to use the description *above*. It needs to be explicitly coded at which side of the axis of symmetry the location is. The location thus needs to be coded on the orthogonal dimension as well, that is whether it is *at the left* or *at the right* of the axis of symmetry that functions as the bounding axis between the *left side* and the *right side* of the Referent. See location 3 in Figure 2.23.A.

Similarly, but somewhat less easily illustrated, if a location is to be coded that about complies with the reference direction for *to the left of*, it does not suffice to code it simply like that. Also here, a coding is required on the orthogonal dimension whose Directional Parts may not be that sharply delineated as parts are within the *left-right* dimension. It needs to be coded however, one way or another, if the location is closer to the *top* or closer to the *bottom* of the Referent. See location 4 in Figure 2.23.A.

An Intrinsic Location may be coded by similarity to a reference direction (say, it is *above*) and in this respect location coding is like the categorisation of Spatial Relations. Additionally, however, the location needs to be contrasted on the orthogonal dimension, that is, the position relative to the *left-right* bounding plane needs to be coded as well (say, slightly *to the left of* the axis of symmetry). In this respect, the coding of an Intrinsic Location is different from the categorisation of Spatial Relations. Some questions regarding the categorisation of Spatial Relations, e.g., the question whether a particular location can still be categorised as *in front of* or should be categorised as *to the left of* instead, may not be very interesting when it comes to the exact coding of an Intrinsic Location.

Thus although the coding of Intrinsic Location and the categorisation of Spatial Relation as intrinsic Directional Relations may use the same (category) structure of the Referent, the structure seems to be used differently. Whereas categorisation seems primarily based on the similarity of a Spatial Relation to a reference direction, the coding of an Intrinsic Location (also) involves contrasting on the orthogonal dimension. In experiments on memory for Intrinsic Location, this difference has to be kept in mind. This is particularly so, if the reasons for conducting such experiments is to obtain insight in how Spatial Relations are defined in non-linguistic spatial tasks and that such insight aids understanding how Spatial Relations are defined and categorised in order to refer to them with Directional Prepositions.

2.5.4. 3D Objects with Three Directed Dimensions

Almost everything necessary for 3D objects with three directed dimensions can be taken from the discussion of objects with one and two directed dimensions before. Both the *front-back* dimension and the *above-below* dimension are assigned directionality before the *left-right* dimension. The perceptual Referent may be bilateral symmetric or it may be asymmetric. If a 3D object happens to be bilateral symmetric, the bounding plane separating the *left side* from the *right side* coincides with the plane of symmetry. This bounding plane may also help in orienting the other dimensions, but only to certain degree. It does not restrict their orientation within this plane. Regarding categorisation the forced-choice question may in this case allow more possibilities: A choice between three directed dimension can be forced, but also a choice could be forced between two directed dimensions, while the third is forced to be ignored.

2.5.4.1. Intrinsic Location and Three Directed Dimensions

Regarding the coding of Intrinsic Location, if the Referent happens to be bilateral symmetric, the coding must refer to being on the *left side* or the *right side* of the plane of symmetry. Of course, the intrinsic Frame of Reference can be used for the coding of all aspects of an Intrinsic Location with respect to a bilateral symmetric or asymmetric Referent. Again, in contrast with categorisation of Spatial Relations based on similarity, coding of Intrinsic Location needs to include a contrast on the orthogonal dimensions.

Chapter 3.Processing Space to Obtain Language

In this chapter, the representations and processes involved in the perception and communication of intrinsic Spatial Relations between objects are considered. As a starting point, I will exemplify the necessary processing by a communicative situation:

A: Hey, do you see that strange duck walking in our garden?
B: Duck? What duck? I ain't seeing no duck.
A: It is *to the left of* the wheelbarrow.
B: Oh, that duck. A very strange duck indeed.

In this small example, speaker A tries to draw addressee B's attention to a specific object 'walking in the garden'. In the first sentence, communicating the location of the Figure 'the duck' by defining it relative to the Referent 'the garden' by using the topological relation denoted by the topological preposition 'in' is not successful. From the second sentence, it becomes clear that B fails to find the Figure. With the third sentence speaker A therefore defines the location of the Figure with the Directional Preposition *to the left of* defined with respect to the Referent 'the wheelbarrow'. This spatial information suffices for addressee B to locate the Figure as sentence 4 shows. With this example, two routes of information-processing can be illustrated. One route concerns A who uses the information in his/her perceptual representation to compose a sentence containing a Directional Prepositional phrase. The other route concerns B, who on the basis of A's linguistic expression identifies the meant Spatial Relation in his/her perceptual representation and succeeds in visual search for the Figure.

The first route concerns the information-processing of A eager to tell B about something interesting that she/he noted. Comparing the first sentence with the third sentence exemplifies that different Spatial Relations can be defined and that different possible Referents can be used. Additionally, as explained in Chapter 1, the Directional Preposition used in sentence 3 can be defined by different Frames of Reference. Here, it will of course be assumed that the Directional Preposition refers to a Spatial Relation that was categorised in an Intrinsic Object Centred Frame of Reference. In Chapter 2, it was shown that different objects might not be equally well suited for use as an Intrinsic Referent. Thus, when speaker A analyses the perceptual scene to find a suitable way to communicate the location of the Figure to addressee B, the speaker may be confronted with a multitude of possibilities as well as restrictions on how this can be done. How Speaker A decides among all available possibilities is not considered. In the present context, only those cases are considered in which a speaker finds a Referent from which an Intrinsic Object Centred Frame of Reference can be defined, uses it accordingly to categorise the Spatial Relation, and utters a sentence containing the corresponding Directional Preposition that more or less accurately describes the Spatial Relation between Figure and Referent.

The goal of this route is thus to communicate information concerning the location of the Figure by means of a Directional Preposition applied within an Intrinsic Object Centred Frame of Reference. The information-processing required for this can be crudely divided in several stages. First, perceptual processing establishes a perceptual representation. This processing is ignored here. Second, the array of objects in the perceptual scene has to be analysed to find a suitable Referent. Following Logan (1995) it will be assumed here that a visual search is conducted whereby attention mechanisms are used to establish correspondence between the perceptual representation and the conceptual representation. Long-term object memory needs to be invoked to allow the identification (categorisation) of attentionally focused potential Referents. This second stage thus comes down to establishing the arguments of the yet-to-be-defined conceptual relation. The argument Referent is identified against which the location of the argument Figure will be defined. This establishes correspondence between perceptual objects and conceptual arguments.

In the third stage, the Intrinsic Frame of Reference of the identified Referent is extracted and this establishes the dimensions and assigned directionality in perceptual space. Referent identification and Reference Frame extraction may not be completely independent however (see Section 3.1.1). Dimensionality and directionality of perceptual space around the Referent thus depends on the intrinsic frame of the Referent and therefore the Referent's orientation has to be taken into account. The directional definitions of the Frame of Reference can be used to define locations and/or directions in perceptual space (see Logan, 1995).

In the fourth stage, the Spatial Relation between Figure and Referent is compared to the established Intrinsic Object Centred Frame of Reference, and a decision is made on which (combination of) Reference Frame relation (-s) applies best. The conceptual Directional Relation is established between the arguments by comparing the Spatial Relation between the perceptual objects with the established directional definition of perceptual space around the Referent. The result of this comparison procedure is the categorisation of the specific Spatial Relation. The perceptual Spatial Relation corresponds to the conceptual Directional Relation.

Finally, the decided-upon relation is expressed through language. This final stage comes down to establishing the correspondence between the conceptual representation (i.e. the arguments and the conceptual relation between them) and syntactic and phonologic linguistic representations needed to formulate the conceptual content. This stage is not considered any further.

The second route of information-processing concerns the processing of addressee B in the small dialogue above. It involves the successful search for the Figure by means of the information derived from A's linguistic descriptions. In this case, the linguistic expression provides the arguments and the relation between them. It is not necessarily clear to B, which Frame of Reference applies. Also here, it will be assumed that the Directional Preposition is interpreted in an Intrinsic Object Centred Frame of Reference. Again, it is possible to define different stages in information-processing.

First, from the linguistic expression a conceptual representation is built which specifies the arguments (Figure and Referent) and the Directional Relation (i.e., phonological and syntactical processing of the auditory input results in a conceptual representation that indicates the Directional Relation between the Figure and Referent). This stage is basically the inverse of stage 5 from route 1.

When B does not already know the position of the Referent, the second stage involves finding the Referent by searching the perceptual representation.[39] It is possible that attention focuses some different perceptual objects before finding the correct one. The argument Referent can however be used to access stored information on the Referent from object memory. Stored perceptual and/or structural information about the Referent (i.e. how such a Referent looks likes, what features it has and how these interrelate) might thus facilitate the visual search.[40] Search is successful when the Referent is focussed upon and identified. When the Referent is found, correspondence between the perceptual representation and the conceptual representation is established regarding the Referent.

The third stage is the extraction of the Frame of Reference. This stage is basically the same as step 2 from route 1. It defines dimensions and assigns directionality around the Referent in perceptual space.

The fourth and final stage involves directing attention from the Referent into the direction given by the Directional Preposition in line with the Intrinsic Object Centred Frame of Reference (Logan, 1995). In the dialogue above, this is successful and the Figure was found in that direction. This stage can also be considered as a verification

[39] Also addressee B is required to build a perceptual representation.
[40] B may not only search the perceptual representation as it is, but also change his/her perceptual representation. B may move his/her eyes and head when scanning the environment and focus on different parts of the garden.

procedure, whereby the truth of the sentence (i.e., A's description of the Figure's whereabouts) is verified when the Figure is found and falsified when the Figure is not found in the specified direction. The goal of the fourth step (and the whole route) is to establish correspondence between a perceptual object and the conceptual argument Figure. To attain this goal attention moves from the perceptual object corresponding to the conceptual argument Referent in the perceptual direction corresponding to the conceptual intrinsic Directional Relation.

As the main topics of this thesis concern the intrinsic definition of directions and the categorisation of a specific relation on the one hand, and the Coding of Intrinsic Location for memory on the other, it suffices to mainly consider only one route in more detail. This will be the first route of a speaker defining an Intrinsic Directional Relation. In this route, the specific Spatial Relation between Figure and Referent needs to be defined in order compare it to the intrinsic Frame of Reference for categorisation. This route thus allows comparison to the coding of Intrinsic Location for memory, which also involves the definition of the specific Spatial Relation between Figure and Referent. The other information-processing route for the addressee trying to find the Figure does not guarantee that the Spatial Relation between Figure and Referent is defined. Ignoring visual perception and linguistic processing, the second, third, and fourth stages of the first route is discussed. The focus is thus on the correspondence between the perceptual representation and the conceptual representation.

3.1. Identifying a Referent and Extraction of the Frame

The three stages of the first information-processing route that establish correspondence between a perceptual Spatial Relation and a conceptual Directional Relation comprise only a crude subdivision. Other intermediate steps may be necessary and not all of the stages can be neatly divided. Stages 2 and 3 are considered together in this section and involve finding the Referent, identifying it, and extracting its Frame of Reference. Stage 4 is considered in Section 3.2 and involves the categorisation of the specific relation.

3.1.1. Finding and Identifying a Referent

It is assumed that attention is needed in the apprehension of a Spatial Relation (Logan, 1994; 1995; see also Carlson-Radvansky and Logan, 1997; Logan and Sadler, 1996). Establishing correspondence between a perceptual object and a conceptual argument occurs through a visual-spatial attention mechanism that selects one part of perceptual space for further (or more enhanced) processing. The mechanism I will adhere to here is the spatial indexing process (Pylyshyn, 1989; Scholl, 1999), which selects a perceptual object (i.e., indexes it, thereby giving it a symbolic address) and the index establishes correspondence to a conceptual argument (i.e., binding of the representations). There are other proposed mechanisms of attention than spatial indices, such as spotlights, zoomlenses, and gradients (Eriksen and St. James, 1986; LaBerge and Brown, 1989; Treisman and Gormican, 1988). The spatial indexing process is chosen because indices capture single objects while spotlights, zoomlenses, and gradients capture regions of space. Spatial indices are an object based attention mechanism while the others are space based attention mechanisms. Indices are naturally more in line with the present subject, Intrinsic Object Centred Frames of Reference. The present choice therefore does not imply a preference on theoretical or empirical grounds other than this. Actually, when scanning perceptual space in order to find a suitable Referent or when directing attention from the Referent to the Figure, a spotlight-like mechanism may be more suited. Object-based and space-based attention mechanisms are not necessarily mutual exclusive though, as is noted by Logan (1995) as well as by Scholl (1999).

Two extensions of object-based attention mechanisms have the potential of being relevant to the present subject. First, the same mechanisms proposed for attending to single objects may allow attending to parts of objects (see, e.g., Vecera, Behrmann, and McGoldrick, 2000; Vecera, Behrmann, and Filapek, 2001). The experimental evidence on part-based attention, as far as I know, involves attention effects regarding simple parts (i.e., same-part advantages) in controlled experimental circumstances with abstract objects only. It is therefore unclear if attention can be focussed on Directional Parts as well. Second, the Multiple Object Tracking paradigm (Pylyshyn and Storm, 1988; Scholl and Pylyshyn, 1999) shows that it is possible to attend to different objects simultaneously (to up to five identical moving targets among identical moving distracters). These findings show that it is possible to divide attention between Figure and Referent when the Spatial Relation between them is assessed and/or categorised. Furthermore, one might speculate whether a combination of these two extensions could be employed to establish a differentiation between Directional Parts, that is, to assign directionality by dividing attention between, e.g., the *top* part and the *bottom* part of an object. These interesting possibilities have to await future research though.

If a speaker wants to communicate the location of a Figure to an addressee, the speaker may scan the environment around the Figure to find a suitable Referent. The focus of attention may thus consider several candidates before finding a suited object. This is a visual search. How this search is accomplished in detail is not important here. Several objects may be indexed in the search however. An interesting possibility regarding spatial indexing is that establishing the index on the Referent may be the same as establishing the origin of a Frame of Reference (Logan, 1995). For reasons of parsimony I will assume it is. That the object based attention mechanism captures a whole object and that this may equal the setting of an origin suits nicely with the suggestion in Section 2.5 that the whole Referent could function as the origin of an intrinsic Frame of Reference.

Spatial indexing not only establishes correspondence between the perceptual object and a conceptual argument, but also allows the identification of the potential

Referent. Spatial indexing a perceptual object (focusing on an object) selects the object (among other objects) in perceptual space, and assures a more enhanced processing of the object, which allows identification. The Referent has to be categorised as one thing or another because, as explained in Chapter 2, the obtained intrinsic Reference Frame against which the location of the Figure will be defined depends on knowledge associated with the category (such as its canonical orientation). The identity of the Referent (i.e., the object category) determines the number of intrinsic dimensions, the orientation of the intrinsic dimensions with respect to the Referent (i.e., the perceptual instance of the Referent's category), and the directionality of intrinsic horizontal dimensions (i.e., intrinsic **[±Z]**, **[±Z_{Move}]**, **[±Z_P]**, or **[±$Z_{P/m}$]**, depending on an autonomous, mobile, aligning, or facing Referent being involved; see Chapter 2). Accessing knowledge associated with the Referent requires categorising it.

The information structures and processes that attain object identification are highly controversial. In general, theories on object identification assume a representation of the perceptual object, stored representations of objects in memory, and a procedure for matching these. One possibility is thus that 3D structural (intrinsic) descriptions are derived from the perceptual objects that are then matched against similar stored descriptions (Marr, 1982; Marr and Nishihara, 1978). Such a theoretical stance explains orientation and viewpoint invariance in object recognition. Another possibility is that the perceptual appearance of the object is compared with stored views of the object (multiple representations) whereby these stored views in memory have a specific orientation. An interpolation process solves orientation mismatches between the perceptual object and stored views (Edelman and Bülthoff, 1992; Hayward and Tarr, 1994; 1997; Tarr and Pinker, 1989). A natural consequence of this approach is viewpoint and orientation dependency of object identification. Still other approaches assume that discerning object features or some global characteristics of the perceptual object can be used to access stored object descriptions in memory (Biederman, 1987;

Hinton, 1981; Hoffman and Richards, 1984; Jolicoeur, 1990; Ullman, 1989). In this case, the stored object description may take different forms. For instance, object descriptions may be stored in their canonical orientation (Jolicoeur, 1990), or be built from componential descriptions of object parts and 'TOP-OF' relations between these (Biederman, 1987; Hummel and Biederman, 1992). It has also been suggested that identification requires finding the *top* (or *top-bottom* axis) of an object (Rock, 1973).

All approaches to object recognition try to explain object constancy. Object constancy refers to the ability to identify objects independent of things as size, position, orientation, and parity/handedness (under most circumstances). Object recognition is thus usually invariant under dilation, translation, rotation, and reflection. This does not mean however that recognition is equally fast and accurate under all circumstances. Geometric manipulation of objects may make recognition slower or lead to more recognition errors. Regarding Intrinsic Object Centred Frame of Reference, it will be assumed here that object constancy over dilations and translations is unimportant. The reference frame parameters scale and origin depend on the extendedness and the location of the Referent. Attending to the Referent sets both. These geometric transformations are ignored regarding object recognition as well. The orientation of a Referent is however important as it's clear effects on object recognition show. At the same time, the Referent's orientation determines how intrinsic dimensions are oriented in perceptual space. The intrinsic Frame of Reference needs to be aligned with the Referent's orientation. Therefore, when considering object recognition I will focus on effects of object (i.e. Referent) orientation. Reflection issues are treated when they may appear important.

There is abundant evidence for the quite interesting aspect of object identification that it often appears dependent on the orientation of an object (see Jolicoeur and Murray, 1998, for a review). For one thing, specific orientations may keep diagnostic information on object identity out of sight (see Palmer, Rosch and Chase, 1981). More importantly for present purposes, object identification appears slower the more the object's orientation deviates from its normal upright (see, e.g., Jolicoeur, 1985; Corballis, 1988; McMullen and Jolicoeur, 1990; Murray, 1995; Hamm and McMullen, 1998; De Caro and Reeves, 2000). The definition of intrinsic directions onto perceptual space naturally changes along with the orientation of the perceptual object (as do the perceptual positions of Directional Parts). It is here where a link between object identification and intrinsic Frames of Reference may be suspected.

The time required to recognise and name objects depends upon the normal upright of the object, that is, identification (as it is, e.g., measured by time needed for object naming) is slower the more an object’s orientation deviates from its canonical orientation. There may be a relative advantage for the upside-down orientation (180° deviation from upright) when compared to almost upside-down orientations (up to 120° deviation from upright, or so). Another relevant aspect of the orientation effect is that it diminishes with practice. Given repeated presentation of the same stimuli, it is not only the case that reaction times get somewhat faster overall, but also that the slope of the curve relating reaction time to deviation from upright becomes less steep. This diminuated orientation effect cannot be ascribed to practice in recognising disoriented objects in general as it does not transfer to new stimuli (Jolicoeur, 1985). In addition, the attenuation does not depend on the previous orientations of repeated stimuli (Murray, Jolicoeur, McMullen, and Ingleton, 1993), as long as the previous orientations deviate from the upright as well (Jolicoeur and Milliken, 1989).

These findings are often taken as an indication that object recognition is based on matching a perceptual object with viewpoint-dependent stored representations and that a normalisation of the perceptual object to the orientation of the stored object occurs *before* recognition (see Jolicoeur, 1985, who also mentions possibilities how other object recognition approaches might explain the orientation effect). The reaction time increase up to 120° would then be due to ‘spinning’ the perceptual object while the relative advantage of (almost) upside down would be due to 'flipping' it (Murray, 1997). Not surprisingly, the question was posed how one knows in which way to normalise the perceptual object unless its identity is already known (e.g. Corballis, 1988). Another relevant question is what is actually being normalised, and what processes are involved herein: Is the perceptual object rotated to the upright by mental rotation (e.g., Cooper and Shepard, 1973; Jolicoeur, 1985; Kosslyn, 1987), or is the stored object (or a Frame of Reference) rotated to the orientation of the perceptual object by a similar or other mechanism (see, e.g., Hinton and Parsons, 1981; Robertson, Palmer, and Gomez, 1987; Ullman, 1989)? I will shortly consider these questions in turn.

3.1.1.1. Identification and Normalisation

One seemingly straightforward explanation for the orientation effect (i.e., that identification is slower the more an object deviates from upright) is that a normalisation (by mental rotation or some other mechanism) is performed in order to be able to identify the object. In this kind of explanation, normalisation is considered a process in which the orientation of the perceptual object and the (presumed) upright orientation of the stored objects in memory are brought into agreement (whichever representation is being changed to accomplish this). Only after reaching the agreement (i.e., the correction for the orientation difference), can the perceptual object be matched with its object category. However, Corballis (1988) asked how it is known before recognition in which direction the perceptual object should be normalised. This question addresses theories that state that the perceptual object is rotated to upright, but similar questions are possible for other 'rotate-to-recognise' normalisation theories. Thus: How is it established in which direction normalisation needs to occur if one does not know already what the perceptual object is, and if one already knows what the object is why does normalisation need to occur at all? This suggests that some kind of identification might precede normalisation. However, given that it is consistently found, normalisation probably still has to be assumed to play some role and thus to have an influence in object identification. I will assume here –following Corballis (1988)– that there must already be some (level of) early identification of the Referent before normalisation can proceed (see also Biederman, 1987; Hamm and McMullen, 1998). The normalisation procedure could then serve as an extra check on the identity of the object. Normalisation corrects for the difference between the orientation of the perceptual object and the upright stored object representation and allows verifying early identification. Thus, based on some orientation invariant perceptual object features (or, perhaps, some global object characteristics), at least 'some notion' regarding the object's category must have been attained before normalisation occurs. However, normalisation not only requires 'some notion' of identity, but also 'some notion' of orientation of the perceptual object. If (orientation invariant) perceptual object features accomplish early identification, the same features might signal a perceptual orientation as well. Normalisation could then be guided by stored *top-bottom* features and corresponding perceptual features.

Evidence for such a 'double-checking' explanation of orientation effects in object recognition can be found in De Caro and Reeves (2000). By using a backward masking experimental procedure they found that the stimulus onset asynchrony (SOA) between stimulus and mask needs to be larger to achieve a given level of performance if the orientation of an object (i.e. the stimulus) is to be verified than if its (basic-level) identity is to be verified. In addition they found that whereas the SOA required to reach the same level of performance increases with the object's orientation from upright if orientation is to be verified, it only increases to up to 60° from upright but remains the same for greater deviations from upright if object identity is to be verified (see also Lawson and Jolicoeur, 1998). If a mask that is presented shortly after a stimulus (which itself is shown only during a very short interval), is presented slightly earlier, it disrupts the verification of orientation more than it disrupts the verification of identity and more so if the to-be-verified orientation deviates from upright more strongly. These results strongly suggest that identification proceeds before normalisation. Their findings thus support the 'rotate-to-orient' hypothesis as opposed to the 'rotate-to-recognise' hypothesis. De Caro and Reeves suggest that orientation effects in object naming are a result of double-checking after initial recognition. The initial recognition is thought to be based on (almost) viewpoint-invariant processing (see e.g. Biederman, 1987; Hinton, 1981; Hoffman and Richards, 1984). Normalisation occurs as verification on the identity of a rotated object (Corballis, 1988).

Approaches to object recognition that assume a match between similarly oriented objects in perceptual views and canonical views in memory (Edelman and Bülthoff, 1992; Tarr and Pinker, 1989) and therefore require normalisation (or interpolation) before recognition cannot explain why object identification is not deteriorating for objects disoriented over 60° from upright in the backward masking procedure. Instead, these results suggest that stored object representations are indeed stored in a canonical orientation (i.e. upright), but that (almost) orientation invariant object features mediate access to the stored representation. If the perceptual object is upright as well, a direct match is the result. If the orientation of the perceptual object is over 60° from upright, matching is apparently somewhat more time-consuming but not dependent on orientation any further.

Theories that also assume that objects are normalised to the upright before a match with stored representations is made and additionally assume that normalisation is guided by the *top* or *top-bottom* axis (Rock, 1973) cannot explain these findings either for similar reasons. Such theories are further undermined by experimental evidence which shows that cueing participants to the *top* or *top-bottom* axis does not have an influence on the orientation effect found with object naming (McMullen, Hamm and Jolicoeur, 1995). Similar problems exist for theories that hold that perceptual objects are first given a structural description –by organising features along axes of symmetry or elongation– before being matched to similarly organised stored representations (Marr, 1982; Marr and Nishihara, 1978). Varying objects to-be-named in terms of axis of elongation and axis of symmetry does not produce a difference in the orientation effects for object naming (Large, McMullen and Hamm, 2003).[41]

Findings reported by Hamm and McMullen (1998) show that normalisation may not necessarily be required for verifying basic level categorisation (Rosch, Mervis, Gray, Johnson, and Boyes-Braem, 1976; see also Jolicoeur, Gluck, and Kosslyn, 1984) of line drawings, but does appear when verifying subordinate level categorisation. This could suggest that normalisation comes about because basic level category information needs to be applied to perceptual objects if lower level categorisation is needed, that is, basic level identity enables normalisation that is used in and allows for subordinate level categorisation. However, Murray (1998) shows that basic level categorisation is not always orientation invariant and that normalisation may occur for verifying basic level categories as well. The results of Hamm and McMullen are shown to depend more on the task requirements (i.e., the verification of a given identity versus the (unrestrained) naming of an object) and on the visual similarity of the objects in the experimental set. These determine if normalisation is used or not. Thus, only if the task and the stimulus set allow it, orientation effects may disappear regarding (basic level) categorisation. Verification tasks where category response alternatives refer to dissimilar objects (e.g., is the stimulus a horse or a television?) or where the to-be-verified object name (e.g., is or isn't the stimulus a horse?) is paired with a highly incongruent stimulus (e.g., a picture of a television) may produce orientation-invariant results. However, if category response alternatives refer to similar objects (e.g., is the stimulus a horse or a donkey?), if the to-be-verified object name (e.g., is or isn't the stimulus a horse?) is paired with a quite congruent stimulus (e.g., a picture of a donkey), if the task involves subordinate level categorisation, or if the task is object naming, then orientation-variant results may

[41] A minor effect on orientation at first naming was however observed for objects with both a vertical axis of symmetry and a horizontal axis of elongation presented at extreme orientations (120°). Symmetric objects are named faster overall, and symmetric objects show stronger attenuation of the orientation effect after practice.

emerge because of normalisation. Object naming tasks involve an open-ended unrestrained response format, which may lead to scrutiny before producing a response. The choice between a horse and a television may be made without normalisation, but in object naming, participants may need to verify that an object is not a donkey before responding that it is a horse.

Notwithstanding these task demands and stimulus considerations influencing if normalisation is used or not, the basic level category could provide the information that guides normalisation. The basic level category is the level of identity at which an object is usually categorised first and whose members are thought to share most aspects. Participants typically produce basic level names in object naming experiments (actually that is why those categorisations have been called basic level; in object naming experiments, normalisation is usually apparent when participants respond with basic level names). Subordinate classification normally involves discriminating between object categories that are quite similar while regarding superordinate classification they are quite dissimilar. It thus seems justified to suppose that categorisation at about basic level provides the information that is necessary to decide upon the direction of normalisation (see also Section 2.3), and that normalisation involves the application of category information to the perceptual instance to see if the category fits. Normalisation allows further (perceptual) processing in case subordinate categorisation is required (see Large, McMullen and Hamm, 2003). Given that different instances of basic level categories are quite similar, it makes sense to suppose that (almost) orientation-invariant features access basic level categories first.

As mentioned in Section 2.3, basic level members share *top* and *bottom* features (at least the category defines a distinction between *top* and *bottom* that can be identified on each instance of the category). These features may then guide normalisation. More specifically, the features that access basic level category before normalisation may guide normalisation by their location in the perceptual field. *Top* and *bottom* features thus initially signal some, not necessarily very accurate, implicit orientation of the object. It probably suffices that upright (direct match), upside-down (flipping), left-rotated (spinning one way), and right-rotated (spinning the other way) perceptual objects can be discerned (see also Braine, Plastow, and Greene, 1987). Normalisation allows the explicit processing of the Spatial Relations between features of the perceptual object along the *top-bottom* axis. As an additional advantage of this approach, normalisation makes explicit the orientation of the perceptual object relative to upright.[42] Normalisation and recognition together thus explain that an object is perceived as an instance of a specific category in a specific orientation (De Caro and Reeves, 2000).

Regarding the present subject, basic level categorisation is more important than any other classification, because it was assumed that intrinsic Frames of Reference are similar for members of a basic level category (see Section 2.3). For the extraction of an intrinsic Frame of Reference it is thus suggested that there must be some orientation invariant recognition of the basic level category by means of features while normalisation occurs to 'align' the perceptual instance with the category or vice versa. Normalisation determines the orientation of the perceptual object relative to upright and makes possible the processing of the Spatial Relations between the features along the *top-bottom* axis of the perceptual object in order to check on its identity (De Caro and Reeves, 2000; Large, McMullen, and Hamm, 2003). An intriguing possibility is that determining the *top-bottom* axis on the perceptual object equals giving the perceptual object a structural intrinsic description in the sense of Marr (1982), that is that the object's components get organised along the *top-bottom* axis. In the present approach, such a structural description is however established only after the object is recognised

[42] The upright orientation relative to which normalization (mental rotation or otherwise) occurs may be dependent on the task at hand. The upright reference direction seems to be influenced by retinotopic and environmental upright to different degrees if the task involves naming, *top-bottom* discrimination, *left-right* discrimination, or mirror image judgment (see McMullen and Jolicoeur, 1990; 1992). Different senses of upright for different tasks will be ignored here, in order not to complicate things too much.

(at least to some extent; see Corballis, 1988). Defining the *top-bottom* axis on a perceptual object by reference to stored object representation in a canonical orientation seems a good first step before other dimensions and directions are extracted (Section 3.1.2). Defining the *top-bottom* axis on a perceptual object orients the object in perceptual space (relative to upright) and allows other dimension to be oriented orthogonal.

3.1.1.2. What is Normalised?

The second issue mentioned before concerns the interpretation of the orientation effect, that is, *what* is being normalised. The orientation effect in object recognition is reminiscent of mental rotation, which supposedly involves rotation of perceptual objects (Shepard and Metzler, 1971; Cooper and Shepard, 1973). According to some, orientation effects on object identification are similar to mental rotation effects (Rock, 1973; Jolicoeur, 1985). Others however find that orientation effects appear to be different from mental rotation tasks while the normalisation appears to be too fast (e.g., Corballis and Cullen, 1986). According to this stance, orientation effects where mental rotation plays a role are restricted to mirror symmetry judgements (Cooper and Shepard, 1973) and *left-right* discriminations (Corballis and Beale, 1976). Mental rotation or not, the normalisation observed in object recognition appears similar to mental rotation in that it suggests an analogue adjustment procedure as well.

I see no sense in making a clear assumption if normalisation in object recognition involves mental rotation. It seems more worthwhile to concentrate on what task requirements are involved in different orientation effects as there are more tasks showing orientation effects. (Linear) orientation effects are observed if it needs to be determined if two objects are the same or mirror images (Shepard and Metzler, 1971), if a single letter is 'normal' or mirror reversed ('backward'; Cooper and Shepard, 1973), if an object is facing *left* or *right* if upright (Jolicoeur, 1985; McMullen and Jolicoeur, 1990), if an object is facing *left* or *right* as it is (Greene, Plastow, and Braine, 1985), what an object's name is (Jolicoeur, 1985; Maki, 1986) and, indeed, where an object's intrinsic Reference Frame directions are. Regarding the latter task, I will consider what task requirements may explain different normalisation rates for different dimensions. Otherwise, the peculiarities of the rotating mechanism are not discussed in much detail any further, but instead the most straightforward interpretation for the present subject will be taken.

Irrespective of the mechanism that is used, some researchers suppose that the perceptual object is being normalised to the upright (Edelman and Bülthoff, 1992; Jolicoeur, 1985; Tarr and Pinker, 1991). In this explanation, a normalisation procedure rotates the perceptual object to its canonical orientation, that is, to the object orientation stored in memory. The perceptual object is thus somehow turned in its upright position in order to match it to the upright representation of the object in long-term memory. This explanation is rejected here, because the normalisation of the perceptual object to the upright seems counterproductive to one of the computational goals pursued. Defining intrinsic directions into perceptual space appears not to be made easier by assuming that the perceptual object is normalised to an orientation that differs from the orientation it has in perceptual space. Regarding intrinsic directional definitions, the straightforward alternative explanation might seem more parsimonious, namely that the orientation of the remembered normal upright position (i.e. the object representation in memory) is normalised with respect to the perceptual object (e.g. Ullman, 1989). If this would be the case, then this would allow –in a single step– the normalisation to perform its verification function in object recognition as well as the definition of *top-bottom* directions in perceptual space.

There is –at least– a third possibility. Pashler (1990) suggested, regarding symmetry detection and its relation to object recognition[43] that a computational

[43] Symmetry detection and Reference Frame alignment for object recognition are in Pashler's view intertwined because detecting the axis of symmetry is supposed to be a good cue for finding the *top-*

algorithm between the perceptual object and the object representation in memory could be set to establish correspondence between them. Following this suggestion, it will not be assumed that the perceptual object is normalised to the upright or that the stored object representation is normalised to the perceptual instance. Instead, it will be assumed that the *top-bottom* directions of an Intrinsic Object Centred Frame of Reference are normalised with respect to perceptual space, that is, relative to the orientation of the perceptual object in the perceptual scene (see also Hinton, 1979; Hinton and Parsons, 1981; Koriat and Norman, 1984; Robertson, Palmer and Gomez, 1987). The continuous change of spatial relationships between an intrinsic Frame of Reference and an Ego Centred Frame of Reference has been proposed as an alternative view on mental rotation effects (see Hinton and Parsons, 1981). In the present case, normalisation would be the continuous change of an intrinsic Frame of Reference from the default upright to the orientation of the perceptual object.

This assumption suits the suggestion of Logan (1995) that a Frame of Reference is rotated in perceptual space and aligned with the Referent. According to Logan, the Reference Frame establishes correspondence between the perceptual representation and the conceptual representation whereby setting orientation is one of the parameters of the frame. If one assumes normalisation (rotation) of the Frame of Reference from the default canonical orientation (i.e. upright) to the orientation of the perceptual object, then a single process can explain the orientation effect on object identification and the establishment of an intrinsic directed dimension in perceptual space. The orientation of the perceptual object corresponds through the Frame of Reference with the canonical orientation of the object in memory. The perceptual object corresponds through object memory to the conceptual argument representation whereby the Frame of Reference may play a role in double-checking on the object's identity. The perceptual object and the conceptual argument are bound and the *top-bottom* dimension is set. Additionally,

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bottom dimension of the object. Actually Chapter 2 supports this position, although one could also find the *front-back* dimension.

by means of the normalisation, the orientation (i.e. deviation) of the perceptual object relative to the (default) upright reference orientation is determined as well (see also Hinton, 1979).

Summarising, the present stance is the following: (Almost) orientation invariant perceptual object features or parts produce a direct match with object representation stored in memory if the perceptual object happens to be upright. The same features also produce an (initial) match with object representation stored in memory and define an implicit orientation if the orientation of the perceptual instance deviates from the (basic-level) object category. On the basis of this match it is possible rotate an intrinsic directed *top-bottom* dimension to the (presumed) *top-bottom* orientation of the perceptual object, whereby the rotation is probably guided by some *top* and/or *bottom* perceptual features that are also a defining part of the category structure. The rotation of the directed axis makes the orientation of the Referent explicit (relative to upright) and allows a 'double-check' on identity by processing the spatial relations between the perceptual object’s features that should comply with the spatial structure of the stored object category. It can be argued that with this normalisation process an intrinsic structural (*top*-to-*bottom*) description (interpretation) is given (assigned) to the perceptual object. The structural intrinsic description of the perceptual object matches the description of the stored object by the orientation difference assessed in the normalisation process.

The role for a Frame of Reference in object identification is thus thought to be an intermediate representation between the perceptual representation and the representation in memory. The Frame of Reference is adjusted from the default upright orientation to the orientation of the perceptual object, which then is time-dependent (see Hinton, 1979; Hinton and Parsons, 1981; Koriat and Norman, 1984; Robertson, Palmer and Gomez, 1987). This frame setting establishes correspondence between the normal orientation of the object in memory and the orientation of the perceptual object. This correspondence then seems a good first step to establish intrinsic directions in perceptual space.

Normalisation was introduced in Section 2.1 as a way to correct for the difference in orientation between an object and an extrinsic description. Normalisation between *top* and *bottom* features of the perceptual object and the stored object category may indeed partly involve an orientation-variant extrinsic description on behalf of the stored object category. Correction for orientation is then required to give the perceptual object an intrinsic description. This not that surprising if one realises that in Section 2.4 it was established that *top-bottom* directional information is only dependent on the canonical orientation of the object category. The canonical orientation is the orientation relative to gravity, which, indeed, is extrinsic. However, only the *top-bottom* directed dimension is thus far implied in normalisation relative to the perceptual object in order to provide it with an intrinsic directed *top-bottom* dimension. That is, while only the *top-bottom* dimension is involved, normalisation does not imply a description of the object with dependent dimensional directionality. Thus, object features allow an initial identification of a perceptual object and normalisation of a *top-bottom* directed dimension in accord with the perceptual instance for 'double-checked' object identification. The deviation from upright sets the orientation of the *top-bottom* directed dimension (and of the perceptual object; De Caro and Reeves, 2000). Moreover, the perceptual object has been given an intrinsic structural definition (Marr, 1982) that resembles (or mirrors) the definition of the object category.

3.1.1.3. Normalisation and the Intrinsic Frame of Reference

Notwithstanding the evidence of normalisation in object recognition, proof that orientation effects have anything to do with Reference Frame alignment and the definition of intrinsic directed dimensions has remained circumstantial until now. The same orientation effects have however been found when *top-bottom* discriminations have to be made regarding objects (McMullen and Jolicoeur, 1992; see also Corballis and Cullen, 1986, and Jolicoeur, Ingleton, Bartram and Booth, 1993, whose research will be considered in Section 3.1.2 while they not only investigated *top-bottom* but also *left-right* and *front-back* discriminations). McMullen and Jolicoeur presented participants with line drawings of different (novel) objects in different orientations accompanied with a dot that was (intrinsic) *above* or *below* the objects. The task of the participant was to indicate as quickly as possible whether the dot was near the *top* or the *bottom* of the object. Also in this *top-bottom* discrimination task, reaction time increases with the Referent's deviation from upright. Moreover, McMullen and Jolicoeur found no difference in the slope of the orientation effect between *top-bottom* discriminations and the naming of the same novel objects in various orientations in another condition in the experiment. These results strongly suggest that the same processes are used in the two tasks. One additional piece of evidence makes the suggestion even stronger.

The orientation effect found in object naming tasks attenuates with practice (Jolicoeur, 1985). The practice effect is restricted to the specific trained objects and does not generalise to novel disoriented objects. Regarding *top-bottom* discriminations, however, the orientation effect does not attenuate with practice (McMullen and Jolicoeur, 1992). McMullen and Jolicoeur did find that the orientation effect is diminished when the same objects are used in an object-naming task that were used in *top-bottom* discriminations before. Apparently, the same mechanisms that produce a reduction of the orientation effect in repeated naming are at work when making *top-bottom* discriminations. The mechanisms do not produce a smaller orientation effect in *top-bottom* discrimination however. This different pattern of results for object naming and *top-bottom* discrimination does not cast doubt on the conjectured link between object identification and Reference Frame setting. The results rather strengthen the hypothesis that orientation effects in object identification and *top-bottom* discrimination have the same cause and are exactly what might have been expected in the first place.

The pattern of results can be interpreted as showing that it is possible in identification tasks to rely more on (almost orientation invariant) features of disoriented perceptual objects for comparison with object representations in memory given that the perceptual objects and the representation in memory have been paired before in the experiment. Thus over repeated exposure to the same objects, a participant may learn to rely more (or more often) on orientation invariant features than on time-consuming double-checking through normalisation (De Caro and Reeves, 2000; Jolicoeur, 1990; McMullen and Jolicoeur, 1992; Murray, Jolicoeur, McMullen and Ingleton, 1993). If spatial relations are processed in double-checking normalisation, then this produces an increased familiarity with those features, and possibly an active pairing of the features with the object category. In subsequent naming of the same objects normalisation is used to a lesser degree (less often and/or by less participants). Similarly, in *top-bottom* discriminations, spatial relations between *top* and *bottom* features need to be processed. Additionally object category needs to be accessed to determine what the object's *top* and *bottom* is. Thus, also with this task, familiarity with features is increased, and features are paired with categories. This explains that smaller orientation effects are found when objects are named that had been previously used for *top-bottom* discriminations.

Intrinsic Frame of Reference alignment for *top-bottom* discriminations must always depend on the canonical upright orientation of an object in order to be able to apply category information correctly to the perceptual instance. Knowledge regarding the canonical orientation of an object category must be applied to an instance of the category. There must thus be spatial processing of the object features of the perceptual instance involved. It is not possible to rely more on orientation-invariants features of an object if the task is to determine where a dot is (intrinsic) located with respect to a repeatedly presented perceptual Referent. The presence of such features in the perceptual object as such does not signal where the dot is. The intrinsic directed *top-bottom* dimension needs to become aligned with the perceptual Referent in every case.

Therefore, no attenuation of the orientation effect after repeated exposure to the same objects is expected regarding *top-bottom* discriminations.[44] It is thus assumed that identification of a novel Referent is (usually) accompanied by the orienting of the intrinsic *top-bottom* directed dimension. It is also hypothesised regarding the extraction of Intrinsic Object Centred Frames of Reference that the intrinsic *top-bottom* directed dimension is made available by means of stored object representations. This is illustrated in Diagram 3.1.

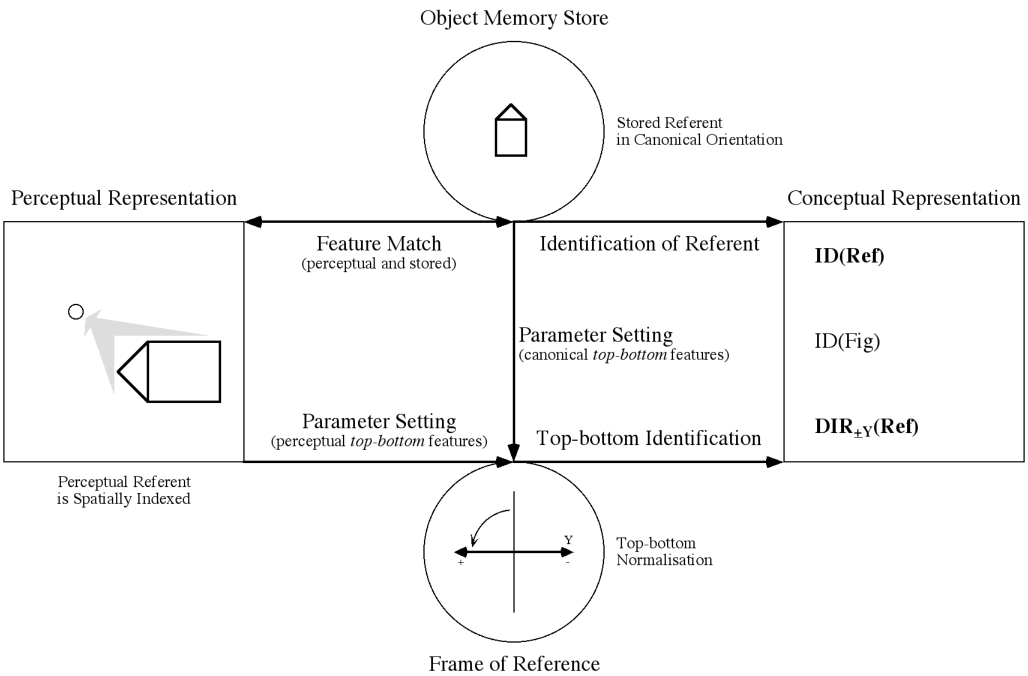

Diagram 3.1. Extraction of the intrinsic *top-bottom* directed dimension.

In Diagram 3.1 a perceptual representation is shown. A perceptual object is spatially indexed (object based attention). The enhanced processing of the object allows (almost) orientation invariant features to access object memory. Based on the canonical orientation in memory, the intrinsic *top-bottom* directed dimension is rotated in

[44] McMullen and Jolicoeur (1992) did not find attenuated orientation effect in *top-bottom* discrimination after 5 blocks of trials in which objects were repeated. The possibility cannot be excluded that more practice with the same objects would allow participants to pair *top* and *bottom* features directly to dot location by proximity.

congruence with the perceptual object (guided by the same features). The object is identified and established as the conceptual argument Referent in the conceptual representation. By means of the normalisation the *top-bottom* directed dimension is identified as well on the perceptual object and the *top* and *bottom* can be accessed conceptually.

The above characterisation concerns itself only with the effect of disorientation from the upright, and most experimental results are based on rotation of stimuli in the image plane. However, not only the deviation from upright of the orientation of an object may be important in identification at all times (see Jolicoeur and Humphrey, 1998). Moreover, for Referents possessing only a *front-back* directed dimension it cannot even be important. One other important factor may be diagnosticity of the information currently in view (Palmer, Rosch, and Chase, 1981). For instance, once the clock face is in view, identification of the object as a clock is easy, arguably easier then when the clock face is not visible. In this case, and there may be others, it could also be the case that the *front-back* direction parameters of the intrinsic Frame of Reference is set first. However, it will be assumed that this possibility is the exception rather than the rule, and, thus, that the *top-bottom* dimension is the first intrinsic directionality parameter that is set.

3.1.2. Extracting the Intrinsic Frame of Reference

Logan (1995) hypothesises regarding Frames of Reference in general, that they need to be aligned with the Referent, that is, Frames of Reference are translated and rotated around perceptual space, whereby the frame parameters origin, scale, orientation, and direction are set (see also Carlson-Radvansky and Logan, 1997; Logan and Sadler, 1996). The perceptual objects between which a Directional Relation is built need to be chosen through an act of attention. Spatial indexing accomplishes this and keeps track of the arguments of the relation (it establishes correspondence between perceptual objects and conceptual arguments). Spatial indexing the Referent translates the origin of the Frame of Reference on the Referent. In the Intrinsic Object Centred case, the other Frame of Reference parameters need extraction from the Referent. The orientation of the Frame of Reference must thus be rotated such that it coincides with the (intrinsic) orientation of the Referent. Frames of Reference also establish correspondence between perceptual and conceptual representations in that they allow perceptual Spatial Relations to be categorised as a Directional Relation. Similarly, an addressee can interpret Directional Relations in perceptual space by means of both the Referent (i.e., the origin) and the Frame of Reference (i.e., the directionality).

The present approach can be considered a more detailed version of Logan's characterisation, one that is particularly designed for Intrinsic Object Centred Frames of Reference. As described above, I stick to spatial indexing the Referent as setting the origin of the Frame of Reference and establishing correspondence between perceptual object and conceptual argument. However, instead of rotating the Frame of Reference as such (i.e. three directed dimensions at once) to the orientation of the Referent an ordered definition of directed dimensions is assumed. The assigning of directionality is thus hypothesised to have an order and an intrinsic description of the perceptual Referent with independent dimensional directionality should be the result. First, *top-bottom* directions are normalised on the basis of perceptual object features that correspond to characteristics of stored object category representations that define canonical orientation. The *top-bottom* directed dimension is thus rotated into accordance with the orientation of the perceptual object. As explained, this normalisation by reference to canonical orientation may already happen at identification but definitely needs to occur when making *top-bottom* discriminations. It is thus assumed that once a suitable Referent has been found and identified, that the origin and the *top-bottom* directed dimension are set. Thereafter, the remainder of the Frame of Reference can be extracted whereby the other dimensions and directions are established in perceptual space according to the intrinsic (category) structure of the Referent.

Because it was established (in Chapter 2) that *left-right* directionality is assigned last, it simply follows that *front-back* directionality should be assigned between the *top-bottom* directionality and the *left-right* directionality (see also Bryant and Tversky, 1999; Bryant, Tversky and Lanca, 2001). Thus, after identification and the definition of the *top-bottom* directed dimension, second, the *front-back* directionality is assigned. This directionality needs to take the identity of the Referent into account (what kind of Referent it is), and directionality is set by reference to category information on the perceptual apparatus, on the typical direction of motion, and/or on the typical encounter. Additionally one may need to determine if the Referent possesses a facing or aligning Frame of Reference (see Section 2.4). Finally, *left-right* directionality is set. As argued in Chapter 2, there are no category characteristics distinguishing *left* from *right* (categorical symmetry). Therefore, the assignment of *left-right* directionality should be conventional (what we call *left* and *right*). In addition, for *left-right* directionality it also needs to be taken into account if there is a facing Referent or an autonomous, mobile, or aligning Referent. Once the *top-bottom* and *front-back* directionality has been set, facing Referents and autonomous, mobile, and aligning Referents have opposed *left-right* directionality relative to these.

3.1.2.1. Front-back Directionality

That *front-back* directionality is set after *top-bottom* directionality at least makes sense if it is assumed that recognition involves stored object representations possessing a (canonical) upright orientation and also that for *front-back* directionality there is no such provision in memory. If *top-bottom* orientation is stored in memory, but *front-back* orientation is not, then, on the one hand, regarding *top-bottom* directionality, the Referent's category (identity) must be established as well as the category's canonical orientation as it is stored in object memory used to establish the category. *Front-back* directionality, on the other hand, also needs to involve the identity of the perceptual Referent, but –because the *front-back* directionality is not stored in object memory and not used to establish identity with– requires additional information, and thus additional processing as well. *Front-back* directionality needs to depend on one or more of various sources of information. Identity (object category) is required for determining whether the Referent is autonomous, mobile, facing, or aligning. *Front-back* directionality refers to one or more of perceptual apparatus, canonical direction of motion, and canonical encounter and/or use. If canonical encounter is involved, it additionally depends on whether a facing or aligning Referent is involved to determine how *front-back* directionality has to be set on the (canonical encounter based) *front-back* dimension. The additional conceptual information needs to specify which category-defining structure is the *front* and which is the *back*. The features associated with these parts need to be identified on the perceptual object. *Front* perceptual features need to be contrasted with *back* perceptual features, that is, the perceptual object gets ordered along the *front-back* directed dimension. The second independent intrinsic dimension is established. With this possibility, no normalisation is expected as normalisation supposedly involves a default *front-back* orientation in memory.

Alternatively, one could suppose that both *top-bottom* and *front-back* orientation are stored in memory. It might then be that *front-back* directionality is normalised as well. In that case, the arguments for the assignment of *top-bottom* directionality first are somewhat less conclusive. If *top-bottom* as well as *front-back* orientations were stored in memory, then regarding *top-bottom* directionality, as before, normalisation with respect to upright can be assumed. Regarding *front-back* directionality one needs to ask if there could be an analogous stored (horizontal) reference orientation as well, and, if so, which orientation is stored. The experimental evidence on object identification mentioned before strongly implies that objects are stored in a canonical upright orientation. However, this orientation does not imply anything about if there is a horizontal stored orientation as well. The upright orientation could be a front view, back view, left view, right view, or anywhere in between. Regarding the *top-bottom* upright stored orientation, objects are supposedly stored as such because upright is the normal orientation of objects with respect to the environment (i.e., gravity). While human beings usually move around in an upright position as well, it is also the orientation in which they normally encounter and experience objects. A horizontal *front-back* orientation that may be stored because it is the normal encounter is more difficult to specify. A specification of the canonical horizontal orientation of objects with respect to the observer or the environment would be needed. With respect to the environment, there is no such orientation in the horizontal plane at least in open spaces.[45] A canonical horizontal orientation with respect to the viewer cannot be easily defined either, as the viewer is often able to navigate freely around objects, and thus to experience views on the object from different horizontal angles. Some theories on object recognition posit that multiple representations could be stored (e.g., Tarr and Pinker, 1989). If this were the case, normalisation could principally occur relative to different orientations. Following, no clear normalisation pattern with respect to a single specific orientation would be expected.

It is also possible to assume that the stored *front-back* orientation of objects involves a frontal view of the object or that it involves the canonical encounter view of the object. Of these, the canonical encounter does not suffice as a reference for normalisation as upright orientation does because there are facing and aligning Referents. Canonical encounter goes with two opposed directional definitions, one for facing, and one for aligning Referents. If a canonical encounter orientation were to be stored in object memory, knowledge on the kind of Referent (and thus additional

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[45] Within closed spaces, such as rooms, there may be canonical horizontal orientations, in particular the facing off the wall of many objects (clocks, cabinets). Such an orientation could thus determine a typical orientation of objects in the horizontal plane as well, and so determine a reference orientation in object memory.

information-processing) would still be needed in order to know how to label the poles of the orientation relative to which one were to normalise. A stored object representation involving a frontal view of objects could serve as a basis for normalisation though without the need to access additional information.

A horizontal orientation may actually be involved in object memory. Palmer, Rosch, and Chase (1981; see also Jolicoeur and Humphrey, 1998) show that object recognition is faster and more accurate when a three-quarter front view of objects is presented. Such views show an about upright object almost from the *front* but somewhat turned away from it such that a *side* of the object is visible. These views however go together with the visibility of more parts than a full frontal view, and may thus allow easier inferences on the 3D structure of the object. It is thus not clear if the advantage of such views is brought about because such views are stored in memory, or because more parts are perceptually available. Note also that a three-quarter view could show the *left side* or the *right side*. If a three-quarter view were stored for the definition of *front-back* directionality on a perceptual Referent, which of these views would be used (if not both)? An alternative explanation of the three-quarter-view advantage might assume that it is caused by the combination of front view (as stored in memory), the visibility of parts, and easier access to the object's 3D structure (which, of course, are stored as well). Thus, whereas regarding *top-bottom* directionality there appears to be a clear upright reference orientation with respect to which intrinsic directionality may be normalised and, moreover, this reference orientation appears to be the orientation in which objects are stored in memory, regarding *front-back* directionality there is not necessarily such an unambiguous reference orientation. It is unclear whether any stored horizontal orientation can be defined for any object (Referent) relative to which perceptual *front-back* directionality can be normalised. The best candidate for such a stored orientation is a frontal view however.

Another concern regarding possible normalisation effects of the *front-back* directed dimension is the experimental procedure with which to estimate such effects. The strength of the recognition experiments discussed previously is that the orientation of the *top-bottom* axis can be changed without changing any of the visible parts of the objects. Typically, front or side views of objects are used, and those same views with all their aspects can be used over different orientations (i.e., deviations from upright). It is unclear if experimental stimulus material possessing similar qualities could be constructed that varies in the orientation of the *front-back* directed dimension exactly because the stored *front-back* view in memory would be frontal. Any change of the *front-back* directed axis away from the line of sight of the participant would lead to differences in the parts of the object that are visible. It is probably no coincidence that the effects of deviation from upright seem to have been investigated in much more detail, and are –in my opinion– less susceptible to alternative explanations (especially confounds with visibility of parts) than the effects of deviation from 'frontal-ness'.

Thus even if there were normalisation for *front-back* directionality, and this normalisation would be relative to a stored front view of an object, it would be still be difficult to show *front-back* normalisation effects. As a matter of fact, the sparse experimental evidence regarding *front-back* discriminations, do not show any normalisation (see below), and could not even show normalisation given the views and the orientation manipulations that are used in the experiments; at least they are not able to show normalisation relative to a canonical *front-back* orientation. Thus in consideration of these conceptual problems, as well as the methodological problem, and (therefore) lack of enough conclusive data, it is simply assumed here that there is no stored orientation relative to which *front-back* directionality is normalised. Instead, it is assumed that identification allows access to conceptual category information with which it is established what kind of a Referent is involved. Conceptual knowledge regarding the Referent (autonomous, mobile, facing, or aligning) needs to be taken into account. Once an intrinsic description of the perceptual Referent has been established for the *top-bottom* dimension, knowledge about the object category determines which features in the stored object representation define the *front* and *back*. These features need to be identified on the perceptual object.

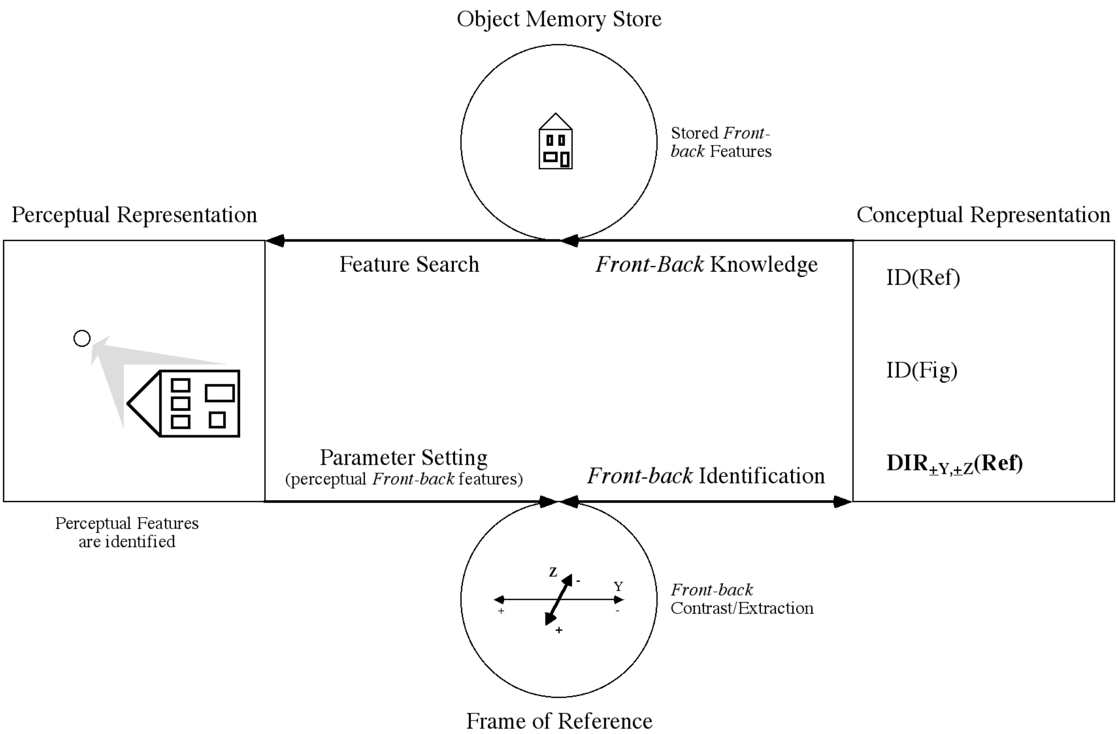

Diagram 3.2. Extraction of the intrinsic *front-back* directed dimension.

Identification thus makes available knowledge about the Referent and, in particular, how to assign directionality to the *front-back* dimension. The conceptual category information specifies which stored category-defining features of the Referent are the *front* and the *back*. Perceptual object features need to be identified as the perceptual equivalents of the stored features description. Thus not only conceptual knowledge about the Referent's object category is involved, but also category defining structure (object memory) needs to be used to identify the *front-back* features on the perceptual object. The *front* respectively *back* features are identified on the perceptual Referent and contrasted with the *back* and *front* features. The *front-back* directed dimension is thus defined in perceptual space based on stored object category features. Instead of normalisation, *front-back* features are assumed to be contrasted directly on the perceptual object, and thereby the *front-back* directed dimension is defined orthogonal to the *top-bottom* directed dimension. By means of this contrast, the Referent gets organised along a second directed dimension. The perceptual Referent acquires an intrinsic description along the *front-back* directed dimension as well.

In Diagram 3.2, the conceptual representation determines the *front-back* directionality. Of course, the stored object representation is required as well to define the dimension with respect to the perceptual Referent, that is, the perceptual equivalents of the stored *front* and *back* features have to be defined on the perceptual Referent. This allows extracting the *front-back* directed dimension of the Frame of Reference. The *front-back* directed dimension is identified on the perceptual object and the *front* and *back* can be accessed conceptually.

3.1.2.2. Left-right Directionality

Finally, directionality has to be assigned to the *left-right* dimension. *Left-right* directionality was argued to be set last, while there is no differentiation regarding *left* and *right* in stored representations nor (usually) in conceptual knowledge about the object. In Chapter 2 *left* and *right* were defined as categorical symmetric, that is, there is no functional difference between them, and thus there is no spatial structure that can be reliable used over perceptual instances of a category to define the *left* and *right sides*. Definition of the *left* and *right side* by normalisation relative to stored *left-right* guided by *left-right* perceptual features is therefore not possible. It is possible that the stored category provides defining structure that can be used to identify sides on the perceptual object, that is, the *left-right* dimension can be set. The identification of a side does not enable to define *left* or *right side* unless it is known where *top*, *bottom*, *front*, and *back* are. *Left-right* directionality therefore cannot be set unless directionality has been assigned to the other dimensions. Moreover, *left-right* directionality needs to be assigned by conventional labelling. *Left* and *right* assignment may refer to Ego Centred or Environment Centred differentiation (Corballis and Beale, 1976; Hinton, 1979). It is thus a directionality assignment by reference to what 'we' call *left* and *right* given the other directed dimensions and, possibly, if a facing or aligning Referent is involved. If an object has an acquired Frame of Reference labelling that is derived from being used in a facing or aligning way, then the way that *left* and *right* are defined given the definitions of *front-back* and *top-bottom* directed dimensions varies over facing and aligning Referents. Given that *top-bottom* directionally is defined (first) and that *front-back* directionality is defined as well (second), there thus remain two ways to define *left-right* directionality (last). Therefore *left-right* directionality needs to be defined with respect to the other directed dimensions while keeping conceptual information associated with the category into account.

Object recognition is indifferent to reflection, that is, recognition of left views and right views is equally easy. There cannot even be a difference. Even if there is information that aids recognition and happens to be on one particular side, it is possible to imagine another case where this information happens to be on the opposite side. Experimental evidence supports this view: *Left-right* reversals do not affect recognition, and recognition priming transfers to reflected views (see Biederman and Cooper, 1991).

Left-right directionality is defined conventionally. Directionality of other dimensions has to be taken into account as well as the kind of Referent involved. This could imply that *left* and *right* are assigned *given that the other directed dimensions are oriented such-and-so*. It thus is probable that there is normalisation regarding *left* and *right*. Normalisation to assign *left-right* directionality would involve reference to an orientation in which *we* know what to call *left* and *right.* That is, if intrinsic dimensional directionality is thus far assigned independently, then it may be impossible to say what is *left* and *right* unless by reference to some specific orientation of the Referent (no *left-right* defining features can be defined because categorical symmetric). One possible orientation is one in which the Referent's *left* and *right* coincide with ego's left and right. However, this is so in various orientations. In fact, it is possible, given an encounter with such an orientation, to rotate the Referent any number of degrees about its *left-right* axis to obtain any of the other orientations. The relation between the assignment of *left-right* directionality and the normalisation required to do so with respect to 3D Referents may be quite complicated as it involves normalisation with respect to two dimensions simultaneously in order to assign directionality to the third dimension (fortunately, with 2D Referents, things are easier).

This characterisation of *left-right* directionality could indicate that its assignment refers to upright aligning or facing orientations of the Referent, that is, by a normalisation procedure. However, this normalisation is not normalisation guided by *left-right* distinguishing features. Instead, it involves a normalisation by the distinguishing aspects of the other directed dimensions until the *left-right* dimension is oriented such that we know what to label *left* and *right*. The assignment of *left-right* directionality could use information on what is conventionally labelled as *left* and *right* given an upright facing or aligning (reference) orientation of the Referent.

In Diagram 3.3, it is conceptual information about the Referent (facing versus the others) that defines which is *left* and which is *right* given the other directed dimensions. This information determines how to assign directionality to the remaining dimension in the frame of reference and how to impose the *left side* and the *right side* on the perceptual object. *Left-right* directionality may be assigned by some kind of spatial inference (depending on the Referent involved) or by normalisation relative to an orientation of the Referent in which it is known how to label the sides. *Left side* and *right side* are (conventionally) imposed on the perceptual object, that is, they are not extracted from the perceptual object by features. By the imposition, the *left-right* directed dimension is identified on the perceptual object and the *left side* and *right side* can be accessed conceptually.

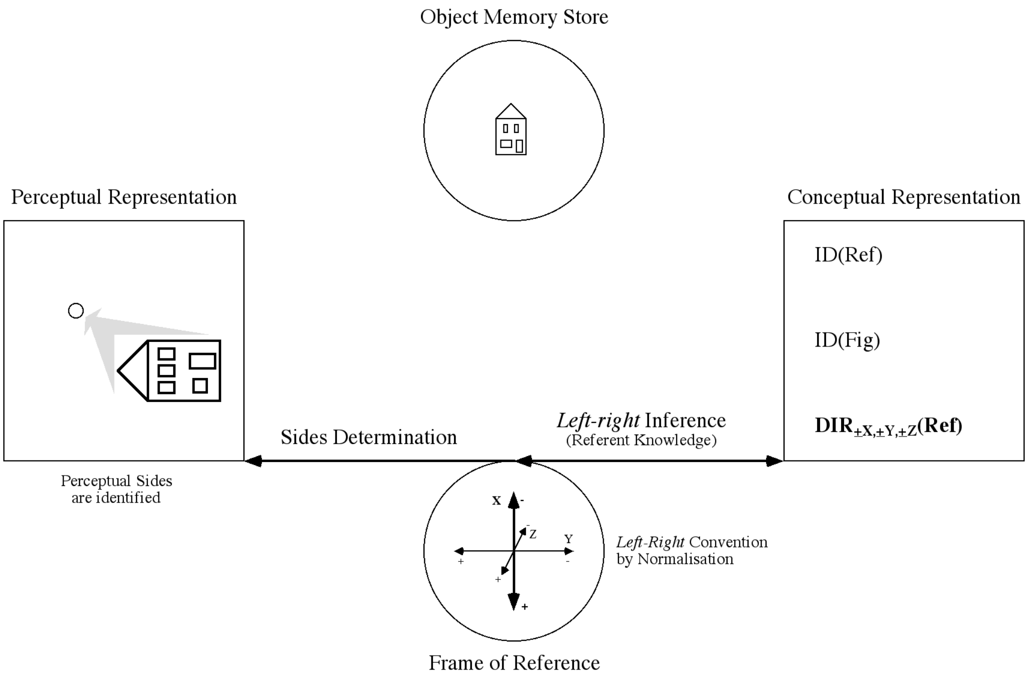

Diagram 3.3. Imposition of the intrinsic *left-right* directed dimension.

Now I will look at some of the sparse experimental evidence regarding the establishment of an intrinsic object-centred Frame of Reference.

3.1.2.3. Intrinsic left-right and top-bottom Decisions relative to Letters

Corballis and Cullen (1986), who conducted their research with the orientation effects on object identification in mind, used an experimental set-up that employs letters as intrinsic Referents. First of all, note the (extraordinary) spatial peculiarities of the used letters. One set of letters (A, T, U, and V) has a vertical axis of symmetry and symmetric *left* and *right sides.* These letters follow the characterisation given previously that *top* and *bottom* have a feature distinction, but *left* and *right side* have not. Another set of letters (F, G, L, and R) has feature distinction between *top* and *bottom* as well, but also displays feature differentiation of the *left* and *right side*. One may argue that this feature differentiation is not only an accidental aspect of the perceptual object, but that it is part of the stored object representation. A third set of letters (B, C, D, and E) possesses a horizontal axis of symmetry and thus a symmetric *top* and *bottom.* In this set, the *left* and *right side* are thus featurally differentiated, while the *top* and *bottom* are not. This variation of feature differentiation over *top-bottom* and *left-right* dimension is probably reflected in stored representations of the objects, but is hard to find outside the alphanumerical domain and similar symbol systems. In any case, using letters as Referents provides an interesting test for the theory developed thus far, although it has to be kept in mind that the letters are an exceptional case and that letter recognition usually proceeds *as they are oriented* among other letters, i.e., in reading.[46]

In one experiment, participants were confronted with the letters in varying degrees of disorientation from upright (0° to 300° in 60° steps) and an accompanying asterisk at the intrinsic *top*, *bottom*, *left*, or *right* of the letter. Participants had to call out the Intrinsic Location of the asterisk. All Directional Relations were tested simultaneously, that is, discrimination between four directions was required. Results showed an orientation effect for *top* and *bottom* Directional Relations similar to that found in object naming tasks. Responses to *left* and *right* Directional Relations were slower, and additionally showed a much stronger orientation effect (i.e., the slope relating reaction time to deviation from upright was steeper than the slope found for *top* and *bottom* Directional Relations).

In another experiment, Corballis and Cullen had participants only determine whether the asterisk was on the *top-bottom* or on the *left-right* axis. Participants thus had to discriminate between the dimensions, meaning that these needed to be established, but could ignore their directionality. If participants can dissociate setting

[46] Some letter are only identifiable in a certain orientation and handedness (e.g., b, d, p, and q). Other letters are rotation invariant (e.g., S, X, I, and O). These letters cannot be used in the experiments of Corballis and Cullen (1986).

dimensions and assigning directionality, results should be different from tasks that need discrimination between directed half-axes as well. In this case, the curve relating reaction time to letter orientation was even flatter than that found for *top* and *bottom* Directional Relations before. Not only was the curve flatter, additionally there was no difference between the *left-right* and *top-bottom* axis responses.

Corballis and Cullen's explanation of the findings is (roughly) as follows. They suppose that identification is required before axes (intrinsic dimensions) can be determined. The results regarding dimensional discrimination show that first dimensions are set before directionality is assigned. Regarding directional decisions, *top-bottom* discriminations do not show mental rotation (mental rotation is defined by the slope of the peaked orientation function found by Shepard and Cooper (1973)). *Top-bottom* discriminations, they suggest, are (usually) based on features. *Left-right* discriminations, on the other hand, do show mental rotation. *Left* and *right* are defined Ego Centred (see Corballis and Beale, 1976). The feature distinction between *left* and *right side*s occasionally displayed by the letters is not explicitly labelled as *left* and *right* in stored descriptions. Therefore, *left-right* discrimination requires mental rotation to the upright also for letters with different *left* and *right sides*.

3.1.2.3.1. Present Interpretation

The present explanation of the results bears on the previous discussion regarding object recognition, and the presumed order in directionality assignment (as well as preserving some aspects of Corballis and Cullen's explanation). Of course, in agreement with Corballis and Cullen (1986), it is acknowledged here that intrinsic *front-back* and *left-right* dimensions can logically only be accessed after identification of the Referent (letter) or together with identification. Discrimination between dimensions was almost orientation-invariant in the experiment. This suggests that the identification of the letters was almost orientation-invariant as well. This orientation-invariance is probably due to the limited set of objects, which are already highly familiar to begin with and were repeated quite often in the experiment (e.g., in the first experiment each letter was presented 48 times to each participant). Only a very small increase of reaction time over orientation was found for both axes. This suggests that normalisation for double-checking on the identity of the letter was not used or used only seldom. The task as such (respond "O" if *left* or *right* and respond "X" if *top* or *bottom* or *vice versa*) does not exclude that participants occasionally do assign directionality. Probably, (almost) orientation invariant features of the perceptual objects access stored representations in object memory by which participants identify letters and apparently define their dimensions as well.

The assignment of directionality requires the processing of the Spatial Relations within the perceptual object, that is, spatial relations between object (directional) parts. Normalising the *top-bottom* directionality with respect to the perceptual object by reference to the canonical orientation stored in memory allows discriminating between *top* and *bottom*. Apparently, normalisation relative to upright occurs also for *left-right* directionality. This comes as no surprise while in the upright orientation the *left side* of a letter points in the same direction as the *left side* of ego and labelling can be conventional there. However, *left-right* discrimination is slower and much more dependent on orientation than *top-bottom* discrimination. This suggests that there is either another mechanism for the assignment of *left-right* directionality (as suggested by Corballis and Cullen: Mental rotation for *left-right* discrimination, but not for *top-bottom* discrimination), or the same mechanism is operating slower, or it needs to operate more than once. Alternatively, it could be the case that normalisation is consistently used both within and between participants regarding the assignment of *left-right* directionality, but that normalisation is less often used regarding the assignment of *top-bottom* directionality.

3.1.2.3.2. Features and Normalisation

It is possible to take the last option because, as argued, *top-bottom* distinctions need a corresponding distinction between features, while *left-right* distinctions need not (but need conventional distinction instead). Maybe *top-bottom* discriminations might use features instead of normalisation. This explanation appears however unfavourably in the light of the findings of McMullen and Jolicoeur (1990) that *top-bottom* discriminations show no attenuation of orientation effects after practice. Do note however that the letters used by Corballis and Cullen are highly familiar objects, that a limited number of letters were used, and that each letter was used quite often. It is possible therefore that practice effects regarding directional discriminations that are correlated with feature differences led to learning to use those features without normalisation and thus to an attenuation of orientation effects regarding *top-bottom* discriminations. The lack of practice effects found by McMullen and Jolicoeur (1990) would then be the result of too little practice. However, the set of letters that is used by Corballis and Cullen speak against this explanation.

Although there appears no more difficulty in identifying an axis as the *left-right* axis or the *top-bottom* axis, the discrimination between *left* and *right* is slower than the discrimination between *top* and *bottom* and much more dependent on orientation. This is not only the case when letters have differences between *top* and *bottom* but symmetric sides (A, T, U, and V) but also when the letter has clearly different *left* and *right side*s (F, G, L, and R) and even so when *top* and *bottom* happen to be symmetric (B, C, D, and E). The orientation effect on *top-bottom* discriminations appears somewhat stronger in the latter case, but was never close to the orientation effects on *left-right* discriminations. Practice with features of letters can therefore not explain the smaller orientation effect of *top-bottom* discriminations.

The only slight difference in results between letters with different symmetry aspects is quite interesting. Irrespective whether *top* and *bottom* or *left* and *right* are symmetric or not, *top-bottom* discriminations are faster than *left-right* discriminations.[47] In any case, this is evidence that *left-right* directionality is assigned after *top-bottom* directionality and that this order is not just the result of feature particulars that usually accompany objects. One could suppose that the *top-bottom* orientation is always the first aspect of the letter (or any other object) that is determined. This is accompanied by a normalisation procedure. If the asterisk happens to be at the *top* or the *bottom* of the letter, then this first normalisation procedure suffices to determine its location. Because the slope (orientation effect) of *left-right* discriminations is so much steeper than that of *top-bottom* discriminations, one might assume that a second normalisation might be required to determine what is *left* and what is *right*, given that the location of the asterisk relative to the (already normalised) *top-bottom* directed dimension requires that this needs to be determined.

In this possible explanation, *top-bottom* normalisation is assumed to function in the same way as in the identification of novel objects (rotate-to-orient) and to be relative to upright. Note that it cannot only be *top* and *bottom* features of the letters that guide *top-bottom* normalisation while this would not function for letters whose *top* and *bottom* are symmetric. Thus, more features than this might actually be involved (this is quite an interesting issue that I will ignore for the moment but come back to later). At least, letters with symmetric *top* and *bottom* show a somewhat stronger orientation effect, which can be ascribed to the absence of defining features between *top* and *bottom.* Normalisation for *left* and *right* is also supposed to be relative to the upright reference orientation. In that orientation, the sides of letters overlap with sides of ego and

[47] These findings speak against mental rotation of the Referent to the upright for each direction discrimination. If the disoriented letter is rotated to the upright to be able to make direction discriminations, there is absolutely no reason to expect that mental rotation to the upright for making *left-right* discriminations occurs at a slower pace than mental rotation to the upright for making *above-below* discriminations. Also, supposing that mental rotation is only involved in making mirror-symmetry judgments cannot explain the differences between *top-bottom* discriminations on letters with a horizontal axis of symmetry (B, C, D, and E) and *left-right* discrimination on letters with a vertical axis of symmetry (A, T, U, and V), nor can it explain the difference between *left-right* and *top-bottom* discriminations on asymmetric letters (F, G, L, and R).

therefore the conventional labelling is possible. If it is true that *left-right* discriminations require a second normalisation, then this would explain the steeper slopes in that task.[48]

Against this explanation however speaks that there were no differences between the axes in dimensional discrimination. The *top-bottom* axis and the *left-right* axis were equally easy accessible. In an almost orientation-invariant manner, participants could thus determine identity *and the axis that the asterisk is on*. This suggests that there would be no need to first determine *top-bottom* orientation, and only then use a second normalisation if the location of the asterisk relative to the *top-bottom* directionality would require this. The location of the asterisk relative to the *top-bottom* axis would be known in advance. However, there may be another reason why *top-bottom* normalisation is performed first regardless of the knowledge one has about the axis where the asterisk is on.

3.1.2.3.3. Comparison to Another Task: Normal/Backward Judgements

To explain this argument it is worthwhile to consider another task, normal/backward decisions on rotated letters (see Cooper and Shepard, 1973). In such tasks, participants are presented with normal or mirror-reversed (or backward) letters in differing orientations and need to determine as fast and accurate as possible if the letter is normal or a mirror-image version. Note that only asymmetric letters can be used for this task. A typical pattern of results is shown in Figure 3.1. Such results are explained by mental rotation of the perceptual object to upright (which also is normalisation). The orientation effect in normal/backward discrimination is comparable to that obtained

[48] If one supposes that exactly the same normalization procedure functions regarding *top-bottom* and *left-right* discriminations, then it might even be possible to explain differences in slope regarding *top-bottom* discriminations for different letters, but no such effect regarding *left-right* discrimination. If features would guide normalization, then *top-bottom* normalization might be least dependent on orientation with A, T, U, and V, somewhat more dependent on orientation with F, G, L, and R, and most dependent on orientation with B, C, D, and E (this order is based on defining features and a symmetry effect, see also Large, McMullen, and Hamm, 2003). The orientation dependency of the second normalization required for *left-right* discriminations would follow the opposite order. Overall the faster and slower normalizations cancel each other out, and therefore the slopes for *left-right* discriminations are similar.

with *left-right* discrimination while the slope is flatter (less steep) with *top-bottom* discrimination (see Corballis and Cullen, 1986).

In Figure 3.1, the straight lines show the typical pattern of results. Normal letters are processed somewhat faster than backward letters (the difference in the Figure does not intend to correctly illustrate the magnitude of the advantage of normal letters as compared to the strength of the orientation effect), and both kinds of stimuli show the same dependence on orientation. There is thus normalisation, and the normalisation is relative to the upright.

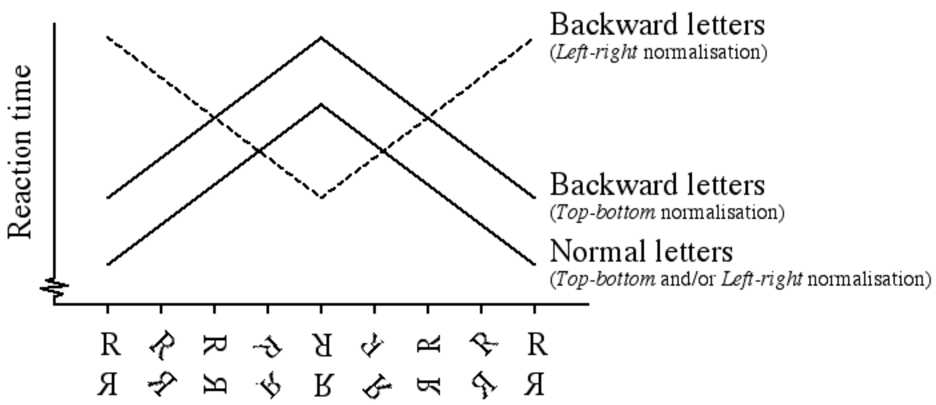

Figure 3.1. Typical results on a normal/backward judgement task with letters.

There is a difference between normal and backward letters. In the case of normal letters, normalisation relative to the upright reference orientation implies normalisation of the *top-bottom* as well as the *left-right* axis (these can not be differentiated). In the case of backward letters however, normalisation relative to the upright reference orientation implies that only the *top-bottom* axis is normalised, because the *left-right* axis is reversed relative to the normal letter case when upright.[49] Thus, backward letters are

[49] That is, the *left-right* axis can be said to be reversed if one takes to *top-bottom* structure as a non-reversed reference. Similarly, the *top-bottom* axis can be said to be reversed, if the *left-right* structure is interpreted as a non-reversed reference, and in fact any other axis, such as the 'topleft-bottomright' axis, could be constructed as reversed, if the orthogonal structure is take as a non-reversed reference. Note however that the use of the word 'upright' in this context already seems to imply *top-bottom* alignment,

normalised relative to the *top-bottom* axis, and then the *left-right* structure of the perceptual letter is compared to the *left-right* structure in the stored description of the letter to define a response. It follows that for normal letters the procedure is the same. The task is to differentiate between normal and backward letters, and the process that leads to differentiating between them must be the same for both.

Another strategy could essentially have been used instead. Disoriented normal and backward letters could be normalised relative to the *left-right* axis. Then the *top-bottom* structure of the perceptual letter could be compared to the *top-bottom* structure in the stored description of the letter to define a response. This strategy would produce exactly the same orientation effect for normal letters. However, regarding backward letters, the orientation effect would have been as given by the dashed line in Figure 3.1. (Note that the pairings of normal and backward letters on the orientation axis is according to orientation of *top-bottom* structure; one could re-pair according to *left-right* structure.) See also Corballis (1988).

The lesson to be learned from these results is that normalisation relative to the *top-bottom* dimension is performed in order to compare perceptual *left-right* structure with stored *left-right* structure, although this is not always the most efficient strategy (e.g., the upside-down backward letter has its *left* and *right* features at the correct location, and the *top-bottom* structure could be directly compared to the stored *top-bottom* structure in memory without any normalisation). The normalisation employed in this task thus involves alignment of the perceptual *top-bottom* structure and the stored (upright) *top-bottom* structure independent of the *left-right* structure being normal or reversed. This suggests, on the one hand, that structural descriptions of objects are independently represented for each dimension (see also Hinton and Parsons, 1981). On the other hand, it also suggests that participants do not normalise with respect to the *left-right* dimension. Before, it was stated that normalisation of perceptual *left-right* relative

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and not, or only secondary, *left-right* alignment. This already shows the paramount importance of *top-bottom* orientation.

to stored *left-right* is not possible because there is no category defining *left* versus *right* structure. The asymmetric letters in this task do however have the extraordinary property of having a different *left* and *right* that can be argued to be stored in object representation (that is, it *needs* to be stored somehow, because normal/backward decisions are possible). The question is why participants do not use *left-right* normalisation, at least under those circumstances where it would be more efficient than *top-bottom* normalisation.

One possible answer would be to say that they cannot. This is the position that Corballis (1988) seems to take. In this view, *left* and *right side*s are not *explicitly* stored in object representations and (therefore) not identifiable on the perceptual object either. Using feature distinction to define *left* and *right side*s as one may do with *top* and *bottom* is therefore not possible. Only once the object is mentally rotated to the upright can *left* and *right* be defined. Normal/backward discrimination is possible –in the upright orientation– by some stored alignment code specifying object structure in Ego Centred *left-right* terms, but apparently this code is stored separate from the stored object representation. This sounds complicated, and so it may be, but it is possible that there is some truth to it. However, this explanation needs not be invoked regarding normal/backward discrimination (but see below).

Another possible answer would be that it is simply not the preferred strategy by participants, possibly while they have no experience with this procedure (*because left* and *right* usually do not have a feature distinction), or while they always have a strong tendency to define *top-bottom* orientation first. Given that deviation from upright as guided by *top-bottom* features is defined first, it might be easier to stick with this strategy, while it would be more difficult to change to the alternative *left-right* strategy. If there are independent represented dimensions, then it is not possible to directly compare a perceptual object with its stored representation regarding normal/reflection issues (intrinsic descriptions, see Section 2.2). In mental rotation tasks in which it has to be decided if two presented objects are the same or mirror images, the reaction time data suggest that one dimension (2D objects) or two dimensions (3D objects) are mentally aligned (normalised) and that the objects are compared on the remaining dimension to define a response. Normal/backward decisions with letters involve the same task, but only one of the objects is presented while the other is stored in memory (Hinton and Parsons, 1981). Also in this case, a normalisation with respect to one dimension is required in order to make a comparison on the orthogonal dimension.

Whatever the reasons for defining the *top-bottom* orientation first, it may make sense –once it has been defined– to compare *left-right* structure on this basis instead of letting go of this orientation and then define *left-right* orientation to compare *top-bottom* structure. The preference for *top-bottom* orientation may come about because it is always the primary dimension for dealing with disoriented objects (see Rock, 1973), or because *left-right* directionality is defined after other directionality. In any case, this explanation can do without assuming that the *left* and *right* structure of a letter is not explicitly stored in memory. The explanation can do without reference to the labels 'left' and 'right', and 'top' and 'bottom' as well, given that normalisation can be performed relative to the (Ego Centred defined) vertical dimension of the stored representation to allow comparison on the horizontal dimension.

This explanation of normal/backward decision effects can take into account the discussion on recognition, orientation, and directionality. It is proposed, first, that the identity of the letter/character is determined and the *top-bottom* orientation is normalised. This establishes an intrinsic description of the perceptual letter's *top-bottom* structure. If, thereafter, *left-right* normalisation were possible, similar to *top-bottom* directionality, the normal/backward question would still not be solved, while the directionality would then be assigned independently. To solve the question, the normalisation thus requires comparison of the relevant *left-right* structures while the *top-bottom* directionality has to be taken into account. The *left-right* structure as it is stored relative to the *top-bottom* direction and the *left-right* perceptual structure as it is relative to the perceptual *top-bottom* direction need to be compared. The normalisation that accomplishes the *left-right* comparison is thus performed under guidance of the *top-bottom* direction, i.e., relative to the stored upright. There is thus normalisation of one dimension, while the directed structure of the orthogonal dimension has to be taken into account because it needs to be compared. In effect, this establishes that the structure of the orthogonal dimension is made *dependent* on the normalised dimension.

3.1.2.3.4. *Left-right* Discriminations require a Second Normalisation

Concerning the results of Corballis and Cullen (1986) regarding *left-right* discrimination one may now consider, because they are similar to results on normal/backward decisions, if an explanation along similar lines can be stated. If so, with *left-right* decisions normalisation relative to *top-bottom* would also occur to compare on the orthogonal dimension. In this case, however, the perceptual *left-right* structure is not compared to the stored *left-right* structure, but instead it is compared to Ego Centred *left* and *right*, in order to define intrinsic *left* and *right side*s on the perceptual Referent. This actually comes down to normalisation on one dimension in order to determine what we call *left* and *right* on the other dimension (conventionally defined, see Section 3.1.2.2). However, in this case, with regard to letters that happen to be featurally *left-right* distinctive, there may really be no good reason in terms of computational efficiency to do it like this. In fact, regarding the letters B, C, D, and E as well as F, G, L, and R, a normalisation of perceptual *left-right* with stored *left-right*, along the same lines as the usual *top-bottom* normalisation, would do the job. Still, compared to *top* and *bottom* decisions, reaction times on *left* and *right* decisions with these letters are slower and much more dependent on orientation. The orientation effect is comparable to that found with normal/backward decisions.

Either there is sense in Corballis' suggestion that stored *left-right* structure is not labelled as such, or *left-right* is always defined Ego Centred regardless of actual structure and if this could be used for *left-right* normalisation. It is assumed here that the usual way to define intrinsic *left* and *right* on objects is applied also in those special cases in which it could be done differently. The 'usual way' to define intrinsic *left* and *right*, that is not with normalisation by features because there are no defining *left-right* features, but instead by normalisation of the other dimension relative to an orientation where we know how to define *left* and *right* Ego Centred, is the general strategy to define intrinsic *left* and *right.*

First, as always, the *top-bottom* axis is normalised with respect to the perceptual Referent. This establishes the orientation of the perceptual object relative to upright and gives it a structural *top-bottom* description. However, this structural description of the Referent along this single dimension is, by itself, ignorant regarding what is *left* and what is *right* even if the letters happen to have different *left* and *right side*s (while at this point, only *top-bottom* structure has its directionally assigned, and dimensions are represented independently). A second normalisation relative to Ego Centred *left-right* (as it is upright) is necessary to give directionality to the perceptual Referent's *left-right* dimension. It appears that a *left-right* axis is never normalised directly, but is always defined Ego Centred. If letters happen to be *left-right* symmetric, there could not even be direct normalisation. *Left-right* directionality is only assigned relative to Ego Centred *left* and *right* (compulsive for letters with symmetric *left* and *right side*s, but also assumed for letters that have the extraordinary property of identity defining different *left* and *right* structure) and has to be aligned correctly relative to the Referent's *top-bottom* structure. It is assumed that the (Ego Centred) directional information is rotated to the perceptual object to define directions in perceptual space under the guidance of the *top-bottom* upright dimension (i.e., dependent thereupon). Ego Centred *left* and *right* as it is in upright needs to be applied to the *left-right* dimension of the perceptual object given its perceptual *top-bottom* direction. As argued before, rotation of the perceptual object to upright appears counterproductive to the present goals.

3.1.2.3.5. *Left-right* Discriminations require Slower Normalisation

The previous explanation assumed a second normalisation for *left-right* discrimination. This is not necessarily the case. One might also assume similar reasoning, but instead suppose there is only a single, but slower normalisation for *left-right* discrimination. This alternative explanation is the following. Because dimensionality was found to be equally available, it could be supposed that knowledge is available whether a *top-bottom* or *left-right* discrimination has to be performed on the asterisk. If *top-bottom* discrimination is required, then only the *top-bottom* directed axis needs to be rotated. If *left-right* discrimination is required, the *top-bottom* directed dimension and Ego Centred *left* and *right* are rotated simultaneously. Ego *left* and *right* in upright has to be assigned correctly to the *left-right* dimension of the Referent under consideration of its *top-bottom* structure orientation. Thus, the *top-bottom* structure of the letter needs to be determined along with it. *Left-right* directionality is thus normalised along the *top-bottom* directed axis, which is guided by *top-bottom* features (and the reference frame is rotated towards the perceptual object). While this is arguably a more complex process (information load), normalisation is accordingly slower. An equivalent alternative can be formulated regarding normal/backward decisions.

Next to these alternative explanations ('more than once' respectively 'slower'), it can also be assumed that different normalisation mechanisms are responsible for different orientation effects on *left-right* and *top-bottom* discriminations (as Corballis and Cullen propose). For instance, *top-bottom* discrimination might involve a rotation of the *top-bottom* axis to the perceptual object while *left-right* discrimination involves mental rotation of the whole object to the upright. Rotation of the *top-bottom* axis defines the orientation of the perceptual object relative to upright. The same information that allows normalising the *top-bottom* dimension could be instrumental in defining the direction for mental rotation in *left-right* discrimination. To produce a response with this possible strategy, it is necessary that the asterisk is rotated along with the object, that the side the asterisk is closest to is marked before and during mental rotation, or that after mental rotation the acquired *left-right* assignment is somehow transferred to the perceptual object in its orientation in perceptual space (by normalisation?).

3.1.2.3.6. Normalisation and Symmetric *top* and *bottom*

One interesting issue has been kept out of the discussion until now. This issue concerns the assignment of *top-bottom* directionality on letters with symmetric *tops* and *bottoms* (B, C, D, and E). While *top* and *bottom* are symmetric, *top-bottom* normalisation cannot be performed under guidance of *top* and *bottom* features only. It thus has to be assumed that features on the horizontal dimension need to be instrumental somehow in the normalisation of the *top-bottom* axis (e.g., that the *top* half and the *bottom* half of 'C' are connected '*left*'). Although horizontal features must somehow be helpful in determining the perceptual letter's *top-bottom* directed axis, apparently they are not or cannot be used in defining *left* and *right* directly. Supposedly, stored representations are ignorant in the explicit representation of *left-right* structure, that is, there is no labelling of structure regarding *left* and *right* (i.e., Corballis' (1988) explanation). Therefore, it could tentatively be argued that the implicitly stored *left-right* structure (i.e., although not explicit labelled as *left* and *right*, the horizontal structure is stored as evidenced by normal/backward decisions with asymmetric letters) is helpful in normalisation of the *top-bottom* directed axis. For instance, implicit *left-right* structure might be helpful in determining if normalisation needs to be performed clockwise or counter clockwise, but assigns no explicit *left-right* directionality. However it is done, also in those cases that the only feature distinction in object structure refers to a *left-right* distinction, the *top-bottom* directionality is defined first, before the *left-right* directionality. Even when such objects are the exception rather than the rule, such results still clearly point to the primary importance of *top-bottom* orientation in object perception. In any case, regarding this issue and the previous issues, many questions remain and quite some scientific work might still be needed.

3.1.2.3.7. Tasks and Normalisation Rates

Regardless of all remaining questions, it may now be possible to dichotomise tasks showing normalisation effects as slower (steeper slope) or faster. On the one hand, one may define tasks in which dimensions are aligned in order to make a comparison and/or decision on the orthogonal dimension. Among these are mental rotation with two presented objects (Shepard and Metzler, 1971), normal/backward decisions (Cooper and Shepard, 1973), determining if a profile view of an object would face left or right if it were upright (Jolicoeur, 1985), and defining intrinsic *left* and *right* (Corballis and Cullen, 1986; and see Logan, 1995, discussed below). On the other hand, there are tasks in which it suffices to normalise only one dimension to define a response. These are the orientation effects in object naming (Jolicoeur, 1985), and, at least, defining intrinsic *top* and *bottom* (Corballis and Cullen, 1986; and see Jolicoeur, Ingleton, Bartram and Booth, 1993, and Logan, 1995, discussed below). The latter effects may however appear as well when the normalisation assumed to be responsible for the effects does not seem to be instrumental for the task. For instance, in defining intrinsic *front* and *back* on profile views (see Jolicoeur, Ingleton, Bartram and Booth, 1993, and Logan, 1995, discussed below) and determining if a profile view of an object faces left or right in the orientation in which it is presented (Braine, Plastow and Greene, 1987).

3.1.2.4. Intrinsic front-back and top-bottom Decisions relative to Line Drawings

Also working against the background of recognition of disoriented objects, Jolicoeur, Ingleton, Bartram and Booth (1993) contrasted the *top-bottom* and *front-back* directed dimensions. Instead of using a limited set of letters as Referents that were presented many times, a larger number (60) of different line drawings of objects were used that were presented repeatedly, though not that often as in Corballis and Cullen (1986). All objects had definable *top*, *bottoms*, *fronts*, and *backs* (i.e. they were all Profile views). *Top-bottom* and *front-back* tasks were given separately to each participant and within each task block there were sub-blocks of head tilt conditions. Over all blocks, an object was presented 12 times to a participant, three times for each direction. Each object was presented with a dot at a suited Intrinsic Location and participants responded by pushing one of two buttons that were assigned to the directions used in the respective task. The orientation of the objects was varied between 0° and 300° in 60° steps.

Head tilt conditions are ignored here (see Note 42), as will effects regarding differences between directions of the same dimension.[50] Task order did not produce any effect. Familiarity with the objects obtained in the first block (one of the discrimination tasks) apparently had no effect on the following block (the other discrimination task). Familiarity with object features appears not to influence processing the spatial relations between object features with respect to *front-back* discriminations and *top-bottom* discriminations, which for the latter discrimination had already been shown by McMullen and Jolicoeur (1990).

Top-bottom discriminations are faster than *front-behind* discriminations, while both depend on the orientation of the Referent from upright. Orientation effects did not differ over both tasks. Jolicoeur *et al.* explicitly relate their findings to the findings of Corballis and Cullen (1986). In particular they wondered whether the higher magnitude of the orientation effect in *left-right* decisions were dependent on the use of the labels '*left*' and '*right*' or if it is enough that the Ego Centred *left-right* axis needs to be labelled

[50] Although *top-bottom* and *front-back* directionality is treated here as if directionality within the dimension is always the same, it is not necessarily under all circumstances found that e.g. *top* responses are as fast as *bottom* responses. Differences have been found here, but *top-bottom* was faster than *front-back* in each condition. Similar differences have been reported by McMullen and Jolicoeur (1992). See also Chambers, McBeath, Schiano, and Metz (1999). Differences between directionality within a dimension will be ignored here.

(with any label). They assume that the *front-back* task requires that the poles of the Ego Centred *left-right* axis have to be labelled (note that they *thus* assume beforehand that *front-back* labelling requires normalisation to the upright). In this case, however, the labelling would involve *front-back* and not *left-right* and this manipulation allows deciding among the alternatives. Given that they found no difference in orientation effect over the two tasks, they conclude that assigning directionality along the Ego Centred *left-right* dimension as such does not produce the larger orientation effects, but that instead explicit reference to '*left*' and '*right*' may be required. The finding that *top-bottom* decisions were faster than *front-back* decisions they relate to “Braine, Plastow, and Greene's (1987) hierarchy of contrasts along the three Cartesian dimensions of visual space (top-bottom, front-back, left-right)” (pp. 673), which is a relation I completely fail to see, and to other findings such as Rock's (1973) that the *top-bottom* dimension is perceptually more important than other dimensions.

3.1.2.4.1. Present Interpretation

Within the present framework, the results suggest that an object is first normalised relative to upright to determine its orientation and the *top-bottom* directed axis. Only thereafter, the *front-back* directionality is assigned by means of features. No additional orientation effect is observed regarding *front-behind* decisions. The identity of the object makes it possible to determine by means of stored object representations, which features define *front* and *back* and to identify these on the perceptual object. Importantly, it is not at all instrumental for *front-back* discrimination that the object is normalised to the upright, because profile views of objects can have *fronts* facing left or *fronts* facing right when upright. Normalisation with canonical upright does not determine which of these possibilities happens to be the case. Still, *front-behind* discriminations show orientation effects relative to the upright. Together with the results of Corballis and Cullen (1986), this suggests that *top-bottom* normalisation occurs always if Spatial Relations are to be processed.

The results actually do not exclude that additional normalisation did take place for *front-back* discriminations after normalisation relative to upright. If objects are stored in an upright and frontal orientation, then it may be the case that the objects are first normalised with respect to upright and thereafter with respect to the frontal view.[51] However, while profile views are used in the experiments, normalisation relative to the frontal view would be constant over all the orientations that are used in the experiment (i.e., in all cases the difference in orientation between the perceptual object and the stored object would be 90°). Following, it would be expected, as found, that the orientation effect for *front-back* decisions equals that for *top-bottom* decisions, but that an additional time-consuming step would be required for *front-back* decisions that is constant over the experimental orientations. In any case, the results clearly favour the assumption that *top-bottom* directionality is assigned before *front-back* directionality. If *front-back* discriminations could be performed by means of features or by normalisation relative to a stored front view irrespective of the stimulus' ‘uprightness’, that is, defined before *top-bottom* normalisation, no normalisation pattern should have been found.

It could also be the case, however, that the normalisation relative to upright observed for *front-behind* discriminations is nothing but the normalisation that occurs in the process of double-checking on the identity of the Referent. It is possible to suppose that the features that define the *front* and the *back* can be accessed in the stored representation and identified on the perceptual object only after identification. If identity double-checking occurs in this experiment, then this would explain the normalisation relative to upright in case of *front-behind* decisions. Although this cannot be excluded as an explanation of a part of the orientation effect, the need for double-checking normalisation should diminish after repetition of the objects. No effect of

[51] This would require on the part of the participant that the presented 2D stimulus be given a 3D interpretation.

block was found however. The lack of such an effect suggests, although *top-bottom* normalisation used for double-checking is not necessary to the same degree upon repeated presentation as with the first presentation of an object, that normalisation relative to upright is nonetheless used to the same degree if *front-behind* decisions are made in the first or in the second block. Therefore, it appears that *front-behind* decisions are always made after *top-bottom* normalisation with these Profile-View-Referents.

The influence of *top-bottom* orientation on *front-back* discrimination (although not instrumental in determining the correct answer) can also be seen in Greene, Plastow, and Braine (1985) who show that determining if an object faces left or right (as it is oriented, not as it would in its upright orientation, which is a task that, e.g., Jolicoeur (1985) and Maki (1986) used and where normalisation is instrumental in defining a response) is slower if the object is upside-down than when it is upright.

Thus, *front-back* discrimination shows a normalisation effect relative to upright as well. It is hypothesised here that the *top-bottom* directionality is normalised first with respect to the perceptual object (possibly also partially because of double-checking for recognition). Given the orientation of the object relative to upright and the structural description along the *top-bottom* axis, features that are also part of the stored object description (and that define *front* and *back*) are identified on the perceptual object as a basis for *front-back* discrimination. For *front-back* discrimination, no additional normalisation is required (but note again that any normalisation with the Profile views relative to a stored front view would be the same over all orientations). *Front-back* discrimination shows a similar slope as *top-bottom* discrimination, but is a bit slower. This indeed suggests that determination of the *top-bottom* directed dimension is of primary importance in the processing of Spatial Relations relative to a disoriented object, and that *top-bottom* normalisation is always performed first.

3.1.2.5. Intrinsic Decisions relative to 2D Head Drawings

Logan (1995) reports experiments explicitly conducted to investigate Intrinsic Object Centred Frames of Reference for language (and others) and their relation to the directing of attention. Regarding intrinsic direction discrimination Logan distinguishes between dimensions in terms of their 'accessibility'. Some regions of space are easier accessible from the Frame of Reference than other regions. His analysis builds upon work by Franklin and Tversky (1990) and Bryant, Tversky, and Franklin (1992; see also next section), in which differential accessibility is explained through the support that Spatial Relations within dimensions get from the environment. Bryant and Tversky (1999) note that there is an inconsistency between the intrinsic experimental situation and the explanatory framework used by Logan (1995). Therefore, mainly Logan's experimental results and the present interpretation will be discussed here while the adjusted explanatory framework (the so-called ‘intrinsic computation analysis’) used in Bryant and Tversky (1999) and Bryant, Tversky, and Lanca (2001) will be considered in the next section with their experimental results.

Logan reports two experiments on intrinsic Spatial Relations. The Referents that he uses are a Front, Profile and Top view of a human head. The Figure and distracters were red and green dots. After being shown an instruction word (Above, Below, Front, Back, Left or Right; the possible directions depend on the view of the Referent involved) participants had to determine the colour of the dot in the specified intrinsic direction in the display that followed. In the display the Referent, the dot Figure, and three distracter dots (located at the other intrinsic directions) were shown. The Referent could be in one of four orientations (0°, 90°, 180°, or 270°). Within trial blocks only a single view of the head Referent was shown.

In Logan's experiment 10, the same view (or a mirror image) was presented 256 times. Over three blocks participants saw all views of the head. The distracter that was on the same axis as the Figure could have the same colour as the Figure or have the other colour. Thus, if the instruction said Left, the distracter dot at the Right could have the same colour as the Referent dot at the Left, and in such a case it would not necessarily be required to assign directionality to the *left-right* axis to make the correct response. If the Referent dot and the same-axis distracter do not have the same colour, directionality must be assigned to give the correct response. Logan gives graphs of reaction times that generalise over these two conditions. In Figure 3.2 they have been torn apart by means of the table he gives.[52]

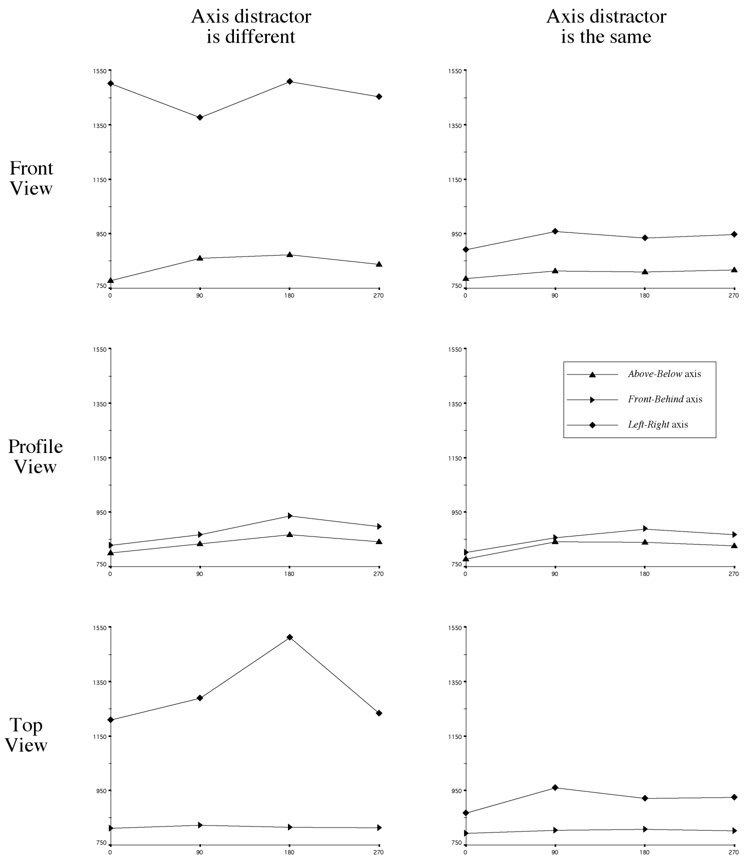

Figure 3.2. Reaction times in ms by orientation of the Referent. Findings by Logan (1995) from his experiment 10 and separated for each distracter condition. In the different condition, the distracter that is on the same axis as the target is different while in the same condition it is the same. For front and top views of the Referent (human head), the orientation is in clockwise degrees from upright, while for the top view it is in clockwise degree from the orientation in which 'the nose faces up'.

[52] Logan does not mention whether the reaction times he gives include both false and correct responses or only correct responses. Figure 3.2 assumes the first option. If the second option were true, some minor differences in exact values would result. The general pattern in the graphs would not change, however.

3.1.2.5.1. Front View Directional Decisions

The conditions where the distracter on the same axis has a different colour than the target (left column of Figure 3.2) are discussed first. The Front view conditions involve *above-below* and *left-right* discriminations also performed in the Corballis and Cullen (1986) experiments. One difference to some of the stimuli of Corballis and Cullen is that the Referents used by Logan do not allow that object features are used for the definition of *left* and *right*. In the Front view (as well as in the Top view), it is actually not the case that *left* and *right* are perfectly symmetric, but the perceptual difference between the sides does not allow any consequence regarding *left* and *right* (as one may argue to be the case with the letters F, G, L, R, B, C, D, and E). For instance, having its hair parting at a particular side does not determine if this side is the *left side* or the *right side*. Moreover, while mirror images of the views were used, both could be the case, and this made it impossible for participants to associate particulars of the head drawings with *left* and *right side*s. Therefore, present results should be compared with results of Corballis and Cullen with respect to the letters A, T, U, and V.

If the relevant results are compared one finds a partially similar pattern. Similar to Corballis and Cullen, an orientation effect for *top-bottom* discriminations is observed, and the magnitude of this effect appears of about equal magnitude (although the tasks are different).[53] It can (again) be concluded that normalisation of the *top-bottom* axis occurs for *top-bottom* discrimination even if the used Referent is the same for many consecutive trials. Regarding *left-right* discrimination there is far less similarity to the results of Corballis and Cullen. This difference seems particularly due to *left-right* discriminations in the upright orientation (i.e. the 0° condition). The explanation for this discrepancy may be straightforward: Whereas in the Corballis and Cullen experiments *left* and *right* of the Referent (letter) coincide with respectively *left* and *right* of the

[53] The effect of orientation on *top-bottom* discrimination in the condition where the same axis distracter has a different colour probably reached significance. Logan (1995) reports significant interaction effects of orientation, same-axis distracter and relation as well as of orientation and same-axis distracter, but does not consider the effects in more detail. The difference in reaction time between upright and upside-down orientations is however comparable to the reaction time difference found by Corballis and Cullen (1986).

participant when the Referent is upright, in the Logan experiments they are opposed. If the Front view of the human head is upright, then Ego Centred *left* coincides with the head's intrinsic *right*. This conflict in potential labelling may have lead to the stronger increase of reaction times for *left-right* discriminations when compared to *top-bottom* discriminations. Moreover, the present results do not even show a clear normalisation pattern (but note that fewer orientations were used in the present case, which makes it harder to detect normalisation patterns). If it is assumed that *left* and *right* are conventionally labelled, and that *top-bottom* normalisation occurs first, then it is an interesting question how participants have performed this task (i.e., intrinsic *left-right* discrimination relative to a Front view of a facing Referent). If the Referent’s orientation has been normalised relative to upright, then Ego Centred *left-right* suggests the opposite directions than the actual intrinsic directions.

It is also possible to compare the experimental orientations to an upright orientation of the stimulus in which Ego Centred *left* and *right* do agree with intrinsic *left* and *right*. This reference orientation of the stimulus would involve an upright, back view of the head. The shortest path between stimulus orientation and this reference would be 180° in all cases. In the upright condition, this would be 180° about the vertical axis, in the upside-down condition about the horizontal axis, and in the other conditions about the oblique axes. Normalisation relative to this reference orientation over the shortest path would indeed predict no normalisation pattern. However, it would require knowledge on *top-bottom* (and *front-back*) orientation first in order to perform such normalisation. This potential procedure is also incredible given the documented difficulties of participants regarding orientation reasoning by means of rotations over oblique (i.e., non-canonical) axes (see Parsons, 1995). If normalisation relative to upright (i.e. Front view) needs to be performed first, however, before normalisation to the back view, then differences between conditions do not change, because the additional normalisation relative to the back view were the same over all conditions.

If one assumes that *top-bottom* normalisation always occurs, then in the Corballis and Cullen experiment this normalisation would facilitate *left-right* discrimination (because relative to an orientation where intrinsic and Ego Centred *left-right* coincide). In the Jolicoeur *et al.* (1993) experiment, it would not make a difference for *front-back* discrimination (see also below). In the present Front view of the human head however, the normalisation relative to upright could be counterproductive to the assignment of intrinsic *left* and *right*. It is assumed here that the lack of normalisation effects regarding *left-right* discrimination has to do with this difficulty.

3.1.2.5.2. Profile View Directional Decisions

In the Profile view condition with a same-axis distracter of different colour, the results are similar to the results of Jolicoeur, Ingleton, Bartram, and Booth (1993). *Top-bottom* discrimination is faster than *front-back* discrimination and similar orientation effects are found for both decisions. Notwithstanding the differences between the experiments of Jolicoeur *et al.* and Logan the same effects are found. Finding a particular dot by means of a defined relation or describing the relation given by a single dot, administering the decision tasks separately or together, and using 60 Referents or only one, appear not to make a difference. Importantly, the use of normalisation in double-checking on the identity of the Referent can be excluded here because the same Referent was used repeatedly. It can be concluded that, regarding Profile views, *top-bottom* normalisation is always performed first, before the Referent's features on the other dimension are categorised as *front* and *back*. The *top-bottom* directed dimension (i.e., the orientation relative to upright) is of primary importance in the processing of Spatial Relations.

3.1.2.5.3. Top View Directional Decisions

The Top view condition has not been encountered before and involves *left-right* and *front-back* decisions but no *top-bottom* decisions. Normalisation relative to upright is not possible with this view of the Referent except when the 2D stimulus is given a 3D interpretation and is normalised out of the 2D stimulus plane. *Front-back* decisions were hypothesised to be based on features, while *left-right* decisions have to be conventionally defined which has to await the *front-back* directed axis, because *left* and *right* need to be applied correctly to the Referent's orientation. The findings of Logan when the same-axis distracter is of different colour confirm this hypothesis. No effect of orientation is apparent for *front-back* decisions, and therefore no evidence of any specific stored orientation relative to which the Referent's orientation is compared. Again, normalisation relative to a front view (in any *top-bottom* orientation) would predict no difference between the experimental orientations. Normalisation relative to an upright front view of the Referent however would predict differences. Differences would result if there were first normalisation relative to upright, and then normalisation relative to the front view. Normalisation relative to upright involves a 90° difference in all experimental orientations. The additional normalisation to the front view would involve an orientation difference of 180°, 90°, 0°, and 90° for the 0°, 90°, 180°, and 270° experimental orientations respectively. Differences between the experimental orientations would also be expected if normalisation were performed directly over the shortest path between the experimental view and a stored upright front view. The normalisations involved would correct for orientation differences of respectively 180° (obtainable by rotation about an axis that is oriented obliquely with respect to the stimulus plane), 90° (about an axis lying obliquely within the stimulus plane), 90° (about the *left-right* axis), and 90° (about an axis lying obliquely within the stimulus plane) for the 0°, 90°, 180°, and 270° experimental stimulus orientations. No corresponding differences between experimental orientations are apparent in the reaction time data. Therefore, these hypothetical possibilities are rejected.

Left-right decisions, on the other hand, do show clear effects of orientation. Note first that the Referent's intrinsic *left* and *right side* coincide with Ego Centred *left* and *right* in the 'nose facing up' orientation (0°). Reaction times in the 0° condition are shortest and increase to 180°. This suggests that the assignment of *left-right* directionality in the Top view condition involves normalisation with respect to the 'nose facing up' orientation where *left* and *right* coincides with the participants' *left* and *right.*

Although no normalisation regarding *front-back* is required nor found, the orientation effect for *left-right* decisions has about a similar slope to the orientation effect in Corballis and Cullen (1986), that is, a slope which is steeper than that found with *top-bottom* normalisation. This may suggest that the hypothesis of a double normalisation should be abandoned in favour of the hypothesis of slower normalisation. If there is no normalisation required for *front-back* decisions, and if, on the other hand, there is normalisation for *left-right* decisions, the slope of this normalisation may be attributed exclusively to the slower normalisation that occurs under the guidance of the *front-back* aspects in order to make a decision on the orthogonal dimension. Ego Centred *left* and *right* thus needs to be normalised along (i.e. dependent on) the *front-back* directed axis to align it correctly with the Referent's orientation. However, in this case the *front-back* directed axis is normalised relative to the vertical however, that is, the nose-facing-up orientation. The nose-facing-up orientation could function as an ad hoc adopted reference orientation for *left-right* discrimination. This might have as a consequence that for *left-right* discriminations (but not for *front-back* discriminations) that first the *front-back* orientation has to be determined relative to this reference orientation (i.e. normalised) before a second normalisation for *left-right* may occur. The first normalisation is required to define the stimulus' deviation from a reference orientation in which it is possible to define *left* and *right* Ego Centred. Thus, also this experiment does not determine with certainty the reasons for slower normalisation for *left-right* discriminations. At least it can be argued that under the given experimental circumstances, that is, one view of the head within a block, the participants can easily discover the ‘normalise relative to the nose-facing-up orientation’ strategy. That is, the reference orientation is not thought to be stored in memory, but to become quickly adopted in the experiment as a suited reference orientation for defining a response.

Because it may be argued that the normalisation for *left-right* decisions is only a single normalisation in this case, however, it will be assumed that the *left-right* decisions in Corballis and Cullen (1986) are a result of a single (slower) normalisation as well. Do note however that the tasks are different. In the experiments of Corballis and Cullen the task was to determine where the single dot was, while here the task is to determine the colour of a dot denoted by a Directional Relation among three distracter dots. In both cases, the normalisation could be a rotation of a default directed reference direction plus the (dependent) orthogonal dimension along with it. Alternatively, however, whereas in the Corballis and Cullen case there is essentially the possibility to mentally rotate letter plus dot to the upright to determine *left* or *right*, in the present case this should at least involve two of the dots (if not four) together with their colour to apply the Directional Relation in the upright position and define the colour response. Still other possibilities might be thought of. From the sparse experimental evidence regarding intrinsic direction discrimination, it is difficult to tell what is appropriate.

3.1.2.5.4. Dimensional Decisions

Now consider the conditions where the distracter on the same axis has the same colour as the Figure (right column of Figure 3.2). From the graphs, it is clear that mainly (but not exclusively) *left-right* decisions are influenced if the same-axis distracter has the same colour as the target. Differences between the different discriminations are still apparent. Participants that have looked for the correct target anyway may have caused this. These conditions were mixed with the conditions in which the same-axis distracter had a different colour than the target. The Corballis and Cullen experiment on dimensional discrimination was separate. It would therefore be no surprise if in the present case the assignment of directionality has occurred more frequently. This might explain that responses on the *left-right* dimension are slower in the present case but were not in the Corballis and Cullen case. It seems justified to conclude that dimensionality is available before directionality, and that the slower responses on *left-right* decisions where the same-axis distracter is different can be attributed (almost) completely to the assignment of directionality.

3.1.2.6. Intrinsic Decisions relative to a 3D Human Model

Bryant (1998), Bryant and Tversky (1999), and Bryant, Tversky, and Lanca (2001) present evidence in favour of their Intrinsic Computation Analysis. This analysis of the Intrinsic Object Centred Frame of Reference used in memory and perception predicts the same pattern of reaction times as the present approach. First, consider an experiment briefly discussed in Bryant (1998). Schematic diagrams of a person surrounded by six differently coloured circles were the stimuli in this experiment. The coloured circles were in pairs connected by an axis running through the person whereby the diagonal axis indicated the axis in depth. The person could be upright, reclining to the left, reclining to the right, or upside-down. Within each of these postures, the orientation of the person about its *top-bottom* axis varied in 90° steps. Posture and orientation of the person varied from trial to trial and so did the colour of the circles. Participants were probed with a direction term (*head*, *feet*, *front*, *back*, *left*, or *right*) and named the colour of the circle at that direction from the person's Perspective, that is, intrinsic.

In all postures it was found that responses to *head* and *feet* directions were faster than responses to *front* and *back* directions which were faster than responses to *left* and *right* directions. From the table of results that Bryant gives, it can further be seen that the upright posture produces faster reaction times than the other postures, although this is clear for *front*, *back*, *left*, and *right* directions only. In addition, *left* and *right* directions in the upside-down posture are clearly slower than in the reclining postures. The results of this experiment thus appear to generalise the findings discussed before to the schematic depictions of a 3D situation. Similar explanatory mechanisms can be invoked. Unfortunately, the presented results do not differentiate between the four orientations the person could have within a posture. The results generalise over orientations within a posture, and thus over different views on the Referent. It would be interesting to know if the same pattern of results is found over all orientations or if there are differences between orientations. Similarly, it would be of interest to have data on the two postures that have not been probed, that is, the postures in which the Referent's *top-bottom* axis is aligned with the schematic axis in depth.

In the experiments of Bryant and Tversky (1999) and Bryant, Tversky, and Lanca (2001) participants are presented with a model of a person (a 'Homer Simpson' doll) with six objects around it positioned in relation to the doll's axial directions. In memory experiments (see Bryant and Tversky, 1999) the configuration of six objects (called a scene) and the Referent first has to be learned. The scene is then removed before testing begins. In a perception experiment (see Bryant, Tversky, and Lanca, 2001) testing starts immediately. In the test phase, the participant is told each time that the doll changes its orientation in the scene to face another object (memory), or the doll is actually being re-oriented (perception). The participant is then probed with the six axial direction terms (*head*, *feet*, *front*, *back*, *left* or *right* in random order) and has to decide for each term as fast as possible which of the objects is in that *intrinsic* direction with respect to the Referent in the scene. Thereafter the doll changes its orientation again by a rotation of 90° about the *top-bottom* axis to face a new object or, after a rotation cycle about the *top-bottom* axis is completed, changes its posture among upright, reclining and upside-down (Bryant *et al.*, 2001, did not use the upside-down posture). The six axial terms are probed, the doll's orientation is changed again, and so on. When all probed postures and orientations in a scene are through, the scene is changed and the procedure repeated. In the perception experiment of Bryant, Tversky, and Lanca, there was one additional condition. In this condition, the scene was changed after each block of six direction probes and the posture and orientation of the doll was determined 'randomly' (i.e., over all blocks the same postures and orientations were presented equally often as in the other condition). Importantly, this manipulation appears not to influence the results.

In the memory experiments, if the participant imagines to be looking at the remembered configuration from outside, then the Intrinsic Object Centred Frame of Reference has to be extracted from the imagined Referent (the doll). In this case, the intrinsic computation analysis applies. Alternatively, a participant may imagine that he/she takes the Perspective of 'Homer Simpson' (the doll), and an intrinsic Ego Centred Frame of Reference is used. In such cases, the spatial framework analysis applies which predicts partially different results (see Bryant, Tversky, and Franklin, 1992; Franklin and Tversky, 1990; see also Von Wolff, 2001). In perception experiments, participants are assumed to use the intrinsic frame of the Referent because if participants were to imagine taking the Perspective of the Referent, then this Perspective would conflict with their Ego Centred Frame of Reference during perception. In general, both memory and perception conditions responses are found to be fastest on the *above-below* dimension, followed by the *front-back* dimension and, finally, the *left-right* dimension, independent of the posture of the imagined person. Reaction times are slower when not upright (memory and perception), and slower for upside-down postures than reclining postures (memory; upside-down was not tested in the perception condition).

The intrinsic computation analysis explains the pattern of reaction times. Objects need to be identified at specified directions from the doll (or any other possible Referent). By using cognitive and perceptual mechanisms, intrinsic sides are determined and the objects located at these sides are named. According to this analysis of Spatial Relations in the Intrinsic Object Centred Frame of Reference, the *above-below* axis of an object is always defined first. The *front-back* axis should be determined second, and finally the *left-right* axis, while *left* and *right* can only be defined with respect to the other axes, which implies that the other two axes are determined before. Identifying objects at the *top* and *bottom* should thus be fastest, followed by objects at the *front* and *back*, and objects located at *left* and *right* should be identified slowest. This pattern of so-called *accessibility* of axes is not influenced by the orientation of the Referent although disoriented objects may produce some overall slower reaction times. Accessibility instead depends only on the cognitive and perceptual mechanisms used to identify the intrinsic sides on the Referent.

3.1.2.6.1. Comparison to the Present Approach

During the development of the present approach, the present author has been aware of the publications regarding the Intrinsic Computation Analysis, and has profited from these to some degree. It is no coincidence therefore, that partially the same sources are used for experimental and theoretical support for both approaches. Here, however, the focus is more directly on structural, intrinsic descriptions of objects that can be used for the definition of Intrinsic Directional Relations and the mechanisms by which such structural descriptions might be given to perceptual objects. So while I have been concentrating on how a perceptual object can obtain a structural description that can be used for Intrinsic Directional Relations, the research of Bryant and colleagues focuses more on how objects and their locations are organised within an Intrinsic Object Centred Frame of Reference. The organisation of object locations is accompanied by differences in accessibility of the Referent's axes that are used in memory to identify the surrounding objects. And indeed, because the focus is different to some degree, there are aspects in their experimental procedure that makes it difficult to explain their results solely with the establishment of intrinsic directed dimensions.

One interesting aspect of these experiments is that the same pattern of results hypothesised to be a consequence of the *assignment* of directed dimensions, is found in the present experimental conditions although, in the perception condition, the participant sees the Referent being moved to face a new object[54], or, in the memory condition, is told how the Referent moves to face a new object. It can thus be doubted that the reaction time pattern found, should be ascribed to the assignment of an intrinsic description to the Referent, because it can be argued that the participant should already be aware of this description (i.e., already have established the description). That is, previous sections were concerned with how a perceptual object obtains an intrinsic description in terms of directed dimensions under the assumption that it did not have one yet. In the present case, things are somewhat different because an intrinsic description must have been established before the Referent is re-oriented, and because the surrounding scene of objects (usually) remains stable. Thus, the same pattern of reaction times is found when a Referent, which has been probed with direction terms before and therefore has already been given an intrinsic description, is re-oriented within a stable scene to face a new object. The question is if the same mechanisms as described before can account for this or if a different explanation is needed.

Reaction time differences in the experiments discussed previously were ascribed to the assignment of an intrinsic description to an object that is repeated quite often but presented without regularity among other objects in different orientations (Corballis and Cullen, 1986), to some new object (or seen a few times before) presented among other objects in various orientations (Jolicoeur *et al.*, 1993; McMullen and Jolicoeur, 1990), or to an object that, although the same over trials, unpredictably changes its orientation from trial to trial (Bryant, 1998; Logan, 1995). The first two experimental procedures thus arguably involve identification, orienting, and the extraction of intrinsic directions while the third involves orienting and the extraction of intrinsic direction to define a response. Moreover, in these experiments there was no set of fixed objects around the Referent relative to which a change in orientation of the Referent can be defined. In the experiments of Bryant and Tversky and Bryant, Tversky, and Lanca, not only does the

[54] During re-orientations in the perception experiment, participants were instructed to look at the Referent only and not to the surrounding objects in order to prevent any *precomputing* of Spatial Relations.

Referent change its orientation in some specific way before probing directions, but also does it do so against a background of fixed objects. Such a background of objects can potentially be used to define the orientation of the Referent relative to it as well as to describe the orientation change during re-orientations. The orientation of the Referent can be specified by defining the intrinsic Frame of Reference *with respect to* the fixed objects and so can changes in orientation of the Referent.

It could be argued that in the experiments of Bryant and Tversky and Bryant, Tversky, and Lanca orienting and the extraction of intrinsic direction are not necessary to define a response, at least not all the time. When all direction terms have been probed once, it could be argued that an intrinsic description of the Referent with directed dimensions has been attained and that the Referent's description should remain stable. If re-orientation of the Referent occurs, then the Referent first changes its orientation, and the participant sees this or imagines this happening. Therefore, orienting the Referent could already be accomplished before the participant is being probed. Additionally, regarding the memory experiment, the locations of the surrounding objects relative to the Referent are known beforehand, probably defined in a Relative Ego Centred Frame of Reference. Regarding the perception experiment, the locations of the surrounding objects might be known after all direction terms are probed once. Given that both the locations of surrounding objects and the intrinsic description of the Referent are known, it could be possible for participants to precompute which objects are located at the intrinsic directions directly upon reorientation and before being probed. The difference in reaction times for different directed dimensions however seems to imply that this is not the case. Regarding the perception experiment, the lack of a difference in results between scene-change conditions speaks strongly against it.

However, with respect to the memory experiment, the *top* and *bottom* are always fixed to the same objects over four successive blocks of direction probes.[55] In addition,

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[55] Although in the memory experiment of Bryant and Tversky (1999) the set of surrounding objects (the scene) was changed a few times, a scene was fixed for 96 direction probes. Within a single scene the

the participant is told each time that the Referent changes its orientation to *face* another object. Following, an object identity may be associated with the Referent's *front* at the re-orientation. The same object is to be identified when in the subsequent testing of direction probes the object at the Referent's *front* needs to be identified. Regarding the perception experiment, *top* and *bottom* are fixed to the same objects over four successive blocks of direction probes only in one condition of the experiment.[56] Because the Referent actually changes its orientation, a surrounding object's identity does not become explicitly associated with the Referent's *front*.

What is missing in the intrinsic computation analysis regarding the memory experiment and part of the perception experiment is why cognitive and perceptual mechanisms used to define intrinsic sides would have to be applied to the Referent repeatedly on each trial. There may be different ways in which the intrinsic computation analysis could be interpreted in a manner directly related to the previous sections. I will start with the memory experiments. First, it is possible to simply assume that an intrinsic description is not or cannot be kept up over reorientations, or that at least the labelling of the sides is or cannot. Maybe participants are not capable to keep up six 'Directional Part'-‘surrounding object identity’ associations simultaneously. During the imagination of the Referent surrounded by six objects, it may indeed be difficult to associate the six object identities with six Directional Part labels. Following, each direction probe would lead participants to extract the intrinsic Frame of Reference. Alternatively, but not necessary excluding the previous possibility, one could try to explain the results by the experimental procedure. The procedure used in the memory experiment implies participants not having to update the *top* and *bottom* object identities

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Referent was presented upright, reclining to the left, upside-down, and reclining to the right. For each of these postures there were 4 successive blocks of 6 directions probes and the Referent faced another object in each block (with 90° rotation about the Referent’s *top-bottom* axis between blocks).

[56] Although in the perception experiment of Bryant, Tversky and Lanca (2001) the set of surrounding objects (the scene) was changed a few times, in one condition a scene was fixed for 48 direction probes. Within a single scene the Referent was presented upright and reclining. For each posture there were 4 successive blocks of 6 directions probes and the Referent faced another object each block.

over a few blocks of trials. This gives these directions an advantage. Additionally, the re-orientation instruction in which the Referent *faces* a new object (between direction probe blocks) could give the *front* direction and –possibly– by implication the *back* direction (surrounding objects may be organised in pairs, see below), an advantage over *left* and *right* directions. As a third possibility, again not completely incompatible with the previous, it could be the case that the image of the Referent in its orientation among the surrounding objects is actually organised in the manner that is apparent from the reaction time data. The primary orientation organisation would then involve *top-bottom* orientation, the secondary organisation the *front-back* orientation, and the final organisation the *left-right* orientation. The first and last possibilities are in line with the previous sections. A combination of the alternatives is possible as well.

A beginning of a more principled account of the intrinsic computation analysis memory experiment imaginative situation may take advantage of Hinton and Parsons (1981). A fully defined Intrinsic Object Centred Frame of Reference includes the relation of this frame to the Ego or Environment Centred Frame of Reference. In the present situation, there is the organisation of the fixed objects, the definition of the Referent and its intrinsic Frame of Reference, and the definition of Ego Centred imaginative space. The fixed objects (scene) can be defined in a Relative Ego Centred frame around the Referent. The objects are organised along the poles of the Relative Ego Centred Frames of Reference (and thus organised in **[±Y_{ego}]**, **[±Z_{ego}]**, and **[±X_{ego}]**). Changing a scene simply means exchanging the object identities at the poles. The intrinsic Frame of Reference, on the other hand, can be defined as has been done before and as such does not change over different postures and orientations of the Referent. The orientation of the Referent can be defined by specifying the relation of the Intrinsic Object Centred Frame of Reference to the Relative Ego Centred Frame of Reference. According to Hinton and Parsons (1981), the relation between two Frames of Reference can be captured by seven values (degrees of freedom): three for orientation, three for translation, and one for dilation. Translation and dilation can be ignored while there is neither change in location nor change in scale in the present setting.

To define posture and orientation while keeping the primacy of *top-bottom* orientation and the conventional labelling of *left-right* into account, it could be assumed that two values define the *top-bottom* orientation while the third defines the *front-back* orientation. Given the limited set of postures (upright, left/right reclining, and upside-down) in the experiment, two values can define all postures and orientations of the Referent in Ego Centred imaginative space. If one assumes that an imagined upright front view of the object is the default case, and both orientation values are zero, then **$[\pm Y_{intr}] = [\pm Y_{ego}]$** and **$[\pm Z_{intr}] = [\pm Z_{ego}]$**. If it is imagined that the Referent rotates 90° about the *top-bottom* axis, then the orientation value may change continuously to **$[\pm Y_{intr}] = 0 + [\pm Y_{ego}]$** and **$[\pm Z_{intr}] = 90 + [\pm Z_{ego}]$** (or **$[\pm Z_{intr}] = [\pm X_{ego}]$**). If it is imagined that the Referent changes posture from the default upright orientation to reclining, then the orientation value may change continuously to **$[\pm Y_{intr}] = 90 + [\pm Y_{ego}]$** (or **$[\pm Y_{intr}] = [\pm X_{ego}]$**) and **$[\pm Z_{intr}] = 0 + [\pm Z_{ego}]$**. If from this posture and orientation a rotation of 90° about the *top-bottom* axis is imagined, then **$[\pm Y_{intr}] = 90 + [\pm Y_{ego}]$** (or **$[\pm Y_{intr}] = [\pm X_{ego}]$**) and **$[\pm Z_{intr}] = 90 + [\pm Z_{ego}]$** (*but* **$[\pm Z_{intr}] = 180 + [\pm Y_{ego}]$**). The primary value thus defines *top-bottom* orientation and therefore posture. The secondary value defines *front-back* orientation but needs an interpretation relative to the primary value. It thus defines orientation within posture. *Left-right* orientation is not defined explicitly but needs to be inferred from the other values.

3.1.2.6.2. Methodological Worries

Due to the experimental procedure, the object identities at *head* and *feet* remain unchanged over three out of four direction probes blocks. In contrast, object identities at *front* and *back* and at *left* and *right* remain unchanged over (at most) one out of four direction probe blocks. Additionally the Referent is re-oriented by telling participants the object that it is now facing. Clearly, this might have an influence on the results. Another aspect to be worried about is the availability of two Frames of Reference. One of these is the intrinsic frame of the Referent; the other is the Relative Ego Centred frame used to define the locations of the objects surrounding the Referent irrespective of the Referent's orientation and posture. If the labels for the Intrinsic Frame agree with the labels for the Relative Ego Centred frame, then responding could be speeded relative to when they disagree. For facilitation and/or interference between Frames of Reference regarding *above*, see Carlson-Radvansky and Irwin (1993; 1994). *Head* and *feet* intrinsic directions are positively correlated with Relative Ego Centred *above* and *below* in 25% of the cases, correlated with Relative Ego Centred *left* and *right* in 50% of the cases, and negatively correlated with Relative Ego Centred *above* and *below* in 25% of the cases. *Front* and *back* intrinsic directions are positively correlated with Relative Ego Centred *in front of* and *behind* in 25% of the cases, correlated with Relative Ego Centred *left* and *right* in 25% of the cases, correlated with Relative Ego Centred *above* and *below* in 25% of the cases, and negatively correlated with Relative Ego Centred *front* and *behind* in 25% of the cases. *Left* and *right* intrinsic directions are positively correlated with Relative Ego Centred *left* and *right* in 12.5% of the cases, correlated with Relative Ego Centred *in front of* and *behind* in 50% of the cases, correlated with Relative Ego Centred *above* and *below* in 25% of the cases, and negatively correlated with Relative Ego Centred *left* and *right* in 12.5% of the cases. Depending on the exact degree of facilitation and/or interference in case of positive correlation, neutral correlation, and negative correlation, in particular the *left* and *right* directions may affected differently than the other directions.

In the perception experiment (both scene-change conditions) the alignment worries apply as well. The proportions are different here while the upside-down posture was not used. *Head* and *feet* intrinsic directions are positively correlated with Relative Ego Centred *above* and *below* in 50% of the cases, and correlated with Relative Ego

Centred *left* and *right* in 50% of the cases. *Front* and *back* intrinsic directions are positively correlated with Relative Ego Centred *in front of* and *behind* in 25% of the cases, correlated with Relative Ego Centred *left* and *right* in 25% of the cases, correlated with Relative Ego Centred *above* and *below* in 25% of the cases, and negatively correlated with Relative Ego Centred *front* and *behind* in 25% of the cases. *Left* and *right* intrinsic directions are positively correlated with Relative Ego Centred *left* and *right* in 12.5% of the cases, correlated with Relative Ego Centred *in front of* and *behind* in 50% of the cases, correlated with Relative Ego Centred *above* and *below* in 25% of the cases, and negatively correlated with Relative Ego Centred *left* and *right* in 12.5% of the cases. In this case, there are differences between all pairs of directions. In particular, the *top* and *bottom* directions could benefit from being aligned with Ego Centred *top* and *bottom* half of the time. The number of times object identity changes at an intrinsic direction could be invoked as an explanatory factor in only one condition of the perception experiment. Because there was no difference between the two conditions, this factor can be ruled out for the perception experiment.

Thus, notwithstanding the similarity in results of these experiments with the ones discussed previously, care has to be taken in interpreting the results. Especially, regarding the memory experiment, alternative explanations can be identified because of the experimental procedure and the introduction of a second Frame of Reference. In particular, what is needed –as a supplement of the intrinsic computation analysis– is a specification of how the perceptual and cognitive factors involved in the establishment of intrinsic Frames of Reference can be generalised to the memory situation.

3.1.2.6.3. Accessibility and the Present Approach

Independent of the previous considerations, comparison is possible of the present approach and the assumptions that apply to the intrinsic computation analysis as well as to the spatial framework analysis. The approach of Bryant and colleagues does argue with the ordering of establishing intrinsic sides but this order is thought to determine the *accessibility* of object centred axes. Differences in the accessibility of reference axes are caused primarily by the axes' relative salience that depends upon their respective symmetries. Tversky (1996) refers to the *front-back* and the *top-bottom* axes of a body as asymmetric axes, and the *left-right* axis as a symmetric axis. Similarly, Landau and Jackendoff (1993) refer to directed and symmetric axes respectively. In Landau and Jackendoff's terminology, an axis is a directed (asymmetric) axis if it "indicates inherent regularities that distinguish one end from the other" (pp. 221), while another axis is a symmetric axis because it "indicates equivalent elaborations of the object at both ends of the axis" (pp. 221). Geometrically, in 2D, an axis orthogonal to a so-defined symmetric axis is an axis of symmetry and, in 3D, a plane orthogonal to a symmetric axis is a plane of symmetry. Thus, in Tversky's and Landau and Jackendoff's use of the terms, an axis is a symmetric axis by virtue of the whole object being bilateral symmetric over an orthogonal plane or axis. This manner of using the terms symmetric is potentially confusing with present use and therefore I will try to avoid it. Anyway, according to Tversky (1996), asymmetric axes are relatively easy accessible. In other words, a dimension with Directional Parts that are not symmetric is relatively easy accessible.

Regarding the intrinsic computation analysis, intrinsic sides need to be defined on a Referent. By reference to mechanisms used in object recognition (see Bryant, 1998), it is proposed that *top-bottom* is defined first. While *left-right* can only be derived from knowing the other sides, it is defined last, and thus the hypothesised order comes about. In this sense the analysis is not that much different from the present approach, but whereas I stress the definition of sides they stress the accessibility of axes. Now note that in the present approach on Intrinsic Object Centred Frames of Reference, the directed dimensions of *top-bottom* and *front-back* were associated with information such as canonical orientation and canonical encounter. If an object category has a canonical orientation, it is necessarily the case that *top* and *bottom* are different, that is, not symmetric, and thus distinctive (ignoring Corballis and Cullen's letters). If they were not different, there could be no canonical orientation. The same goes for *front-back* and canonical encounter. Therefore, the *top-bottom* and *front-back* axes are always directed (asymmetric) axes. However, it is perfectly well possible that the actual *left-right* structure of an object is asymmetric as well. This does not make the *left-right* axis directed though. The *left-right* structure of the object's *category* is symmetric; there is no information such as canonical encounter that defines *left* versus *right*. Therefore *left* and *right* Directional Parts that are not symmetric are still not easy accessible. Instead the relative slow accessibility of *left-right* is the consequence of a lack of features defining *left* versus *right* and the conventional labelling of the parts that is the consequence (taking the other directionality into account and thus only thereafter).

3.1.3. Summarising

The extraction of the Intrinsic Object Centred Frame of Reference is hypothesised to be as follows. First, attention is focussed on the Referent. The Referent is spatially indexed and corresponds to a conceptual argument. The origin of the reference frame is set. The object based attention ensures enhanced processing of the Referent, which allows it to be identified. Object features of the perceptual Referent are matched with object representations in long-term memory. As a double-check on the identity of the Referent, the canonical orientation of the basic level category representation is used to normalise the *top-bottom* directed dimension of the intrinsic Frame of Reference with respect to the perceptual Referent. The categorisation of the Referent allows access to information about its object category. Based on conceptual information if the basic level category comprises autonomous, mobile, facing or aligning Referents, the *front-back* dimensionality of the Frame of Reference can be set. This may involve identifying the *front-back* features of the Referent and assigning directionality accordingly. Finally, some kind of spatial inference is necessary to assign directionality to the *left-right* dimensionality because this directionality is not defined by category information, but needs conventional labelling while considering the other dimensions. It is possible that normalisation is required to be able assign *left-right* directionality, that is, that a reference has to be made to some known orientation of the Referent in order to correctly label the sides.

All experiments that have been discussed show that intrinsic directional decisions are performed fastest for *top-bottom* distinctions, somewhat slower for *front-back* decisions, and slowest regarding *left-right* discriminations. *Top-bottom* discriminations show normalisation effects and so do *left-right* decisions. *Front-back* decisions show normalisation only if a *top-bottom* directed dimension is available, but this normalisation appears to be *top-bottom* normalisation and not *front-back* normalisation. It is possible that the ordered assignment of directionality can be applied to memory tasks as well. Many peculiarities of the experiments offer fodder for further research however.

3.2. Categorising Spatial Relations as Directional Relations

A (perceptual) Spatial Relation can be categorised within an Intrinsic Object Centred Frame of Reference once this Frame of Reference has been established. One may ask, however, whether it is at all times necessary that all directed dimensions are extracted before categorisation takes place. It could be the case –once the *top-bottom* directed dimension is set– that it is clear that the Spatial Relation applies well enough to one of its directions and that there is no reason to extract the other directed dimensions. In addition, given that an addressee is provided with a single Directional Preposition, it may suffice for her/him to consider only the corresponding Direction Relation and search in that Directional Region while ignoring the other Directional Relations. The experimental evidence discussed in the previous section, that is, the differences in reaction time regarding decisions on different dimensions, actually confirm that it is not necessary to extract the full Frame of Reference before a Spatial Relation can be categorised or before a categorisation of a Spatial Relation can be verified. This does however depend on the dimension involved because *left-right* directionality cannot be assigned unless the other directed dimensions are defined. In addition, *front-back* categorisations appeared to occur only after *top-bottom* normalisation (if a *top-bottom* dimension is available, that is). No locations in overlapping Directional Regions were used in those experiments, however. That is, no Spatial Relations were probed that can be categorised as more than one intrinsic direction. All experiments described in the previous section involved decisions between exclusive directions. Care was taken that all used Spatial Relations were unambiguous regarding their categorisation as a Directional Relation.

Any theory that considers more Spatial Relations than those that can be categorised on one dimension only, has to consider how the specific (perceptual) Spatial Relation is encoded. The encoded Spatial Relation between Figure and Referent needs to be compared to the established Frame of Reference. Next to the comparison process, decision rules need to be posited that determine which Directional Relation or which combination of Directional Relations applies best within the Frame of Reference. The Directional Relation between the conceptual arguments is established by comparing the perceptual Spatial Relation between the perceptual objects with the established directional definition of perceptual space around the Referent (i.e., the extracted Intrinsic Frame of Reference). The result of this comparison is the categorisation of the specific relation that establishes the conceptual relation that can be used for linguistic expression. The distinctions made by the extraction of the Frame of Reference, that is, the established directional interpretation of perceptual space, and the distinctions made when the perceptual Spatial Relation is defined, that is, a vector, have to be –at least partially– of the same kind. A comparison process between a specific relation and a Reference Frame requires that there is some aspect in both that can be compared.

Not all approaches to the categorisation of Spatial Relations necessarily follow this reasoning. The computational analysis of Logan and Sadler (1996) makes them suggest that, next to the Frame of Reference parameters, *spatial templates* are needed. A spatial template is a representation of the regions of acceptability for a given Directional Relation. A template, coarsely spoken, divides space surrounding the Referent in good, acceptable, and bad regions for a given Directional Preposition. Spatial templates need to be aligned with the Frame of Reference. The perceptual Spatial Relation is compared with the spatial templates to determine if the location the Figure occupies is in a good, acceptable, or bad region. Logan and Sadler assume that this goodness-of-fit assessment involves parallel spatial processing over the whole visual field simultaneously. If one defines Directional Regions in this way, then one may do without the encoding of the specific perceptual Spatial Relation that defines the location of the Figure by means of a vector from the Referent. Instead, the location of the Figure is assigned to (or defined within) regions projected around the Referent.

The regions proposed in Section 2.5, that is, the direct, oblique, and forced-choice regions, actually do show some similarity to the spatial templates. The regions defined there, however, are the *result* of rules that compare vectors with assigned directionality. This appears the more parsimonious approach to me. Logan and Sadler's theory introduces an additional representational entity next to the Frame of Reference for which I see no good reason. In fact, the spatial templates do nothing but describe which Spatial Relations are considered by participants to be acceptable or not for a given Directional Preposition; they do not offer an account for why Spatial Relations produce patterns of acceptability, that is, they are not a principled account for why Directional Prepositions are differentially applicable to Spatial Relations. Another (pragmatic and/or opportunistic) reason why the spatial template approach will not be followed here is exactly that there is no explicit encoding of the perceptual Spatial Relation. Given the goal of the present thesis as laid out in the introduction, a definition of the perceptual relation is needed which could also be used for the coding of an Intrinsic Location. Regarding the comparison of Intrinsic Object Centred Frames of Reference for language with the coding of Intrinsic Location for memory, it would be convenient if both tasks involve the encoding of the Spatial Relation between Figure and Referent. If it is possible to define regions by comparison of an encoded perceptual relation and an established Frame of Reference, then this is clearly preferred (but see Sections 3.2.3 and 5.2.2).

Experimental data is lacking on the use of Directional Prepositions defined in an Intrinsic Object Centred Frame of Reference relative to Spatial Relations that vary widely in the Intrinsic Location of the Figure with respect to a Referent. Because of this lacuna, research is considered that involves situations with several superimposed Frames of Reference. It will be assumed that the results reported from such settings are similar to the results that would be found if an exclusively Intrinsic Object Centred Frame of Reference had been considered. Thus, e.g., Hayward and Tarr (1995) observe axial effects in their experiments on linguistic descriptions of location relative to a Referent (see below). However, one could attribute the effects found to different reference systems. The observed axial system can be defined in relation to several superimposed Frames of Reference: An Intrinsic Object Centred Frame of Reference (based on the Referent), a Relative Ego Centred Frame of Reference (based on the participant), and a Relative Environment Centred Frame of Reference (based on the gravitational vertical and/or the computer or the sheet of paper on which the stimuli were presented). All research described below shows this ambiguousness.

3.2.1. Descriptions of Spatial Relations

To shed some light on the underlying principles of linguistic and non-linguistic Spatial Relations Hayward and Tarr (1995) report four experiments. Similar constellations of Referents and Figures were used in linguistic as well as non-linguistic spatial tasks. One constellation of a Figure (a circle) and a Referent (a computer monitor) that was used in all experiments is shown in Figure 3.3. The grid defines the places where the Figure could be located and was not visible to the participants at any time during the experiments. The Referent was always in the centre (row 4, column 4). In this section, only their experiment 1 is considered in which participants described Spatial Relations, that is, they described the position of the Figure relative to the Referent. In Chapter 4, their experiment 3 is considered in which Spatial Relations were reproduced from memory. The relation that Hayward and Tarr assume between linguistic data and spatial memory data is discussed in Chapter 5.

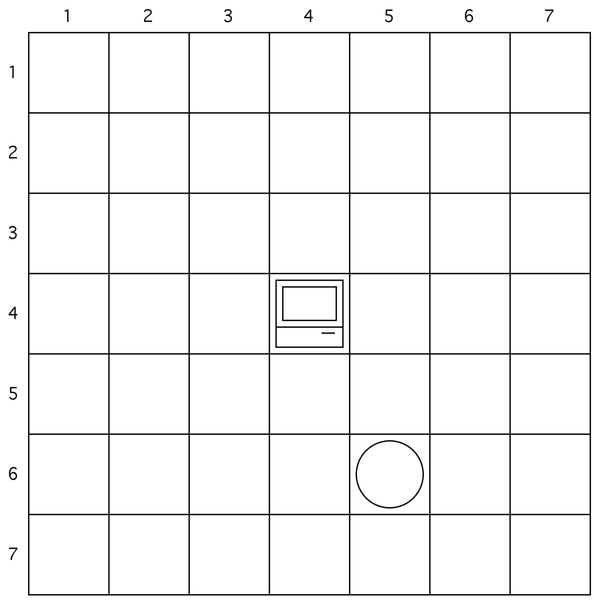

Figure 3.3. One of the stimulus configurations used by Hayward and Tarr (1995).

In their experiment 1, Hayward and Tarr found that participants used a single Directional Preposition when the Figure was positioned directly vertical (*above* or *below* in column 4) or horizontal (*to the left of* or *to right of* in row 4) relative to the Referent. When the Figure was in another position, mostly a combination of two Directional Prepositions was used. To avoid ceiling effects only the preposition mentioned first by a participant was used to analyse the relative amounts of use of the different prepositions over the locations around the Referent (see their section 2.4, p. 51). In this way they found the highest percentage use of vertical terms (*above / below*) and horizontal terms (*left / right*) in column 4 respectively row 4, with gradually decreasing usage with distance from the –conjectured– axes.

Thus although Hayward and Tarr prefer to analyse results as described, they actually find that mostly two prepositions are used to describe Figure locations that are not on an axis. At these locations an object is, according to the participants, apparently not only, e.g., *above* but *to the left* as well. At a location on an axis, on the other hand, an object is, e.g., *above* but neither *to the left of* nor *to the right of* the object. Thus what Hayward and Tarr consider to be the (prototypical) *above* and *below* half-axes may also be interpreted to function as the boundary between *left* and *right* regions.

3.2.1.1. Using One or Two Directional Prepositions in a Description

Zimmer, Speiser, and Baus (2001) and Zimmer, Speiser, Baus, Blocher, and Stopp (1998) have reported similar results. Zimmer *et al.* (1998) used a blue dot as a Figure and a red dot as a Referent (the choice for this Referent actually makes an Intrinsic Object Centred Frame of Reference impossible). The position of the Figure was varied circularly in 15° steps. In their experiments, one participant had to describe the relation while another had to find the Figure by means of the description. This manipulation served to make the task more similar to normal use of spatial language, that is, describing the location of the Figure to an addressee such that he/she can find it. In the first experiment, the Spatial Relation had to be described with a single Directional Preposition or a combination of two Directional Prepositions.[57]

Single Directional Prepositions to describe the location of the Figure were used consistently over participants only at the direct regions (i.e., the axial directions). Referents at locations close to these direct regions (i.e., 15° away from the axial directions) were described with a single preposition only by about one fourth of the participants. The other participants used two Directional Prepositions to describe the relation. Regarding all other Figure locations, virtually all participants used two Directional Prepositions. There is thus only a very small region where it is actually found that a single Directional Preposition is used. Participants were also timed as to how long it took them to formulate a description of the location of the Figure. Responses in the direct region (single Directional Preposition) were fastest; responses in the oblique region were somewhat slower (two Directional Prepositions). The slowest responses were however obtained at those Figure locations where some participants used a single Directional Preposition while others used two Directional Prepositions.

These results suggest that Figure locations on axial directions, that is, where only a single categorisation is possible, produce fast formulations of a single Directional Preposition. Figure locations in oblique regions, that is, where categorisation on two dimensions is possible, produce slower formulations of two Directional Prepositions. Categorisation on one dimension apparently is faster than categorisation on two orthogonal dimensions. Slowest responses are however obtained close to the axial directions, that is, with Figure locations where participants arguably doubt whether to use a formulation with one Directional Preposition or to use a formulation with two Directional Prepositions. Given the substantial portion of space where about all participants prefer to use two Directional Prepositions, participants apparently do not

[57] The second experiment did not constrain language use and only about half of the participants used Directional Prepositions while others used different reference systems as geographical directions or clock face descriptions.

consider whether to use, e.g., *above* or to use, e.g., *to the left of*. Instead, they simply use both. This produces a delay compared to cases where only one Directional Preposition is possible. In contrast, participants do need to consider whether to use, e.g., *above* or to use, e.g., *to the left of and above* leading to a further delay in formulating a response. These results can be interpreted as mainly reflecting regional effects. The use of two Directional Prepositions simply reflects two overlapping (oblique) Directional Regions. Doubt regarding the use of one or two Directional Preposition occurs only when the Figure location is close to, e.g., the *top* axial direction, which is the boundary between the *left* and *right* Directional Regions.

3.2.1.2. Varying Figure Locations within the Direct Regions

The experiments described so far did not vary Figure locations within the direct region. Munnich, Landau, and Dosher (2001) did conduct some experiments in which direct regions for Directional Prepositions were considered more closely. Constellations of Figure and Referent were used in description tasks as well as in identity judgement tasks (the latter task is considered in Chapter 4 and comparison between tasks in Chapter 5).[58] The position of the Figure within the direct regions was varied more widely, such that, if Figure 3.3 had been used in their experiments, column (row) 4 would be sub-divided in three or five columns (rows). With native speakers of English, Korean, and Japanese, they investigated use of Directional Prepositions and of contact and support terms in the description task.

As was the case in the Hayward and Tarr experiment, in the description task often more than a single Directional Preposition was used. Munnich *et al.*, however, did not use the first term in a description to analyse the relative amounts of use of the different prepositions over the locations relative to the Referent, but only those descriptions were used in which a single directional spatial term was given.

[58] The Referent used by Munnich, Landau, and Dosher (2001) in their first experiment is unsuited to define an Intrinsic Object Centred Frame of Reference because of rotation invariance.

Descriptions of the Directional Relations thereby appeared to follow an axial pattern, with the highest use of *above* and *below* (or their Japanese and Korean equivalents) on the vertical axis (central column of sub-divided column 4) and *to the left of* and *to the right of* (or equivalents) on the horizontal axis (central row of sub-divided row 4). Analogous to Hayward and Tarr, these effects were considered to be axial. However, for locations still in the direct region but not on the axis, the percentage of responses using only a single preposition dropped below 50%. The percentage dropped to 10% or less for locations that were not in the direct region anymore.

These effects can again be re-interpreted as being regional with an axis as the boundary between two opposed regions. In this case, Figure locations were varied more widely in direct regions. Thus, in the direct region of, e.g., *above*, Figure locations were used that are in the forced-choice regions of the orthogonal dimension (i.e., *left* or *right*) as well. The results show that an orthogonal dimension even produces effects in direct regions, that is, even forced-choice regions exert an influence in the free description of relations between Figure and Referent.[59] Figure locations at either side of the axis of symmetry, which the used Referents happen to have, apparently possess some degree of, e.g., 'leftness' or 'rightness' even when in the direct region for *above*. This is an important finding: Figure locations within the direct region for *above* can also be categorised with respect to *left* and *right.* Data on descriptions of Figure locations with respect to a Referent thus seem to support the provisions assumed in Section 2.5. Only locations at the central value in the direct region for *above* (and for *below* as well) are not categorisable as either *left* or *right.* This central value can thus be considered as the bounding axis between *left* and *right* regions. The assumed prototypical *top-bottom* axis (see Hayward and Tarr, 1995; actually, prototypical *top* and *bottom half*-axes would

[59] The variation in Figure locations in the second experiment of Munnich *et al.* was quite limited. All locations were in the direct region for *above*. It is possible that this has lead participants to produce some variability in their responses that would not have been produced (or not to same extent) had the set of tested Figure locations been extended to locations outside the direct region. Responding *above* all the time might have been boring, or may have appeared contrary to the experimenter's wishes given the great variety within the direct *above* region.

have been a more accurate description) can thus be considered as the bounding axis for the orthogonal directional opposition *left* versus *right*. On the bounding axis itself neither *left* nor *right* applies, and therefore only *above* or *below* can be used on this axis.

3.2.2. Rating the Applicability of Directional Prepositions

Another method to investigate Directional Regions is by collecting *applicability ratings* for different locations around a Referent. A participant is confronted with Referent and Figure and has to rate the applicability of a *given* Directional Preposition for the constellation by giving it a number on a scale that (usually) ranges from 'not at all applicable' to 'perfectly applicable' or equivalent end-points. For instance, Crawford, Regier, and Huttenlocher (2000) present experiments in which participants first rated the applicability of *above* with respect to Figure-Referent configurations and thereafter reproduced Figure locations relative to the Referent (the spatial reproduction is discussed in Chapter 4, the assumed relation between tasks in Chapter 5). Depending on the shape of the Referent involved (square or rectangular) they used a circular or elliptical array of Figure test locations.[60] Only the applicability of *above* was tested. Crawford *et al*. found that the applicability of *above* was rated less the more the Figure location deviated from the Referent's *top* half-axis. See experiment 2 of Hayward and Tarr (1995) for similar results.

Crawford *et al*. interpret these results as reflecting an axial pattern. The graded nature of the ratings is then the result of a comparison of the tested Spatial Relations (Figure locations) with the prototypical value (i.e., the *top* half-axis). At first glance, this seems to oppose any regional interpretation of Directional Prepositions. Hayward and Tarr (1995) found the same graded pattern in their rating experiment with the same

[60] Crawford, Regier, and Huttenlocher (2000) use in their first experiment a symmetric version of the Referent used by Hayward and Tarr (1995) that is shown in Figure 3.3. In the second experiment they use a rectangle, which is rotation invariant, and therefore not suited to define an Intrinsic Object Centred Frame of Reference.

kind of stimuli as used in their description experiment. The results of the rating and the description experiment clearly differ. A similar discrepancy between description data and rating data is observed by Zimmer *et al*. (1998), when their description data (see above) are compared with the rating data reported by Gapp (1995; 1997; see also Franklin, Henkel, and Zangas, 1995, for a similar discrepancy). There may thus be methodological problems with rating findings that make it difficult to use ratings as a predictor of how Spatial Relations are actually described (as discussed below). Specifically it is unknown what participants are rating: Are they rating the applicability of the description *above* to a given Spatial Relation as such, that is, without taking other possible descriptions into account, or as compared to the description *below*, the descriptions *left* or *right*, or even the description *above and to the left/right of*? In addition, different participants may accordingly rate differently. Notwithstanding these interpretation difficulties, the results reported by Crawford *et al*. show that almost all test locations in the direct and oblique region for *above* were rated less than three on average. With the 5-point scale (Very good (1), Good (2), Fair (3), Poor (4), Very poor (5)) they used, this means that the test locations there were considered to be a better than fair example for *above* on average.

3.2.2.1. The Attentional Vector-Sum Model

The Attentional Vector-Sum (AVS) model of Regier and Carlson (2001; see also Carlson, Regier, and Covey, 2003) tries to explain applicability ratings by means of an attention mechanism. This is interesting because at the beginning of this Chapter attention mechanisms were mentioned as well. If attention is involved in finding and identifying a Referent, and also in the extraction of its Frame of Reference, it could be involved in the categorisation of a perceptual relation as well. However, the AVS model cannot be used for the present subject without some modification.

The AVS model assumes a gradient rather than the spatial index assumed in Section 3.1. This is not necessarily a big problem because the AVS model was not designed for explaining how intrinsic reference directions are defined. It does not at all consider how reference directions (whatever Frame of Reference) are defined but simply assumes that *above*, *below*, *left*, and *right* reference directions are given. The AVS model instead considers how the perceptual Spatial Relation between the Figure and Referent is defined (i.e. by means of a vector specified through the attentional vector-sum) that is then compared with a certain reference direction and produces an applicability rating. Even when the object based attention mechanism (i.e., the spatial indexing) is assumed to be used for identification and reference frame extraction, it is still possible to assume that a space-based mechanism (such as a gradient) is used for the categorisation of perceptual Spatial Relations. The vector defined by the gradient then needs to be compared to the intrinsic reference directions that are extracted while the Referent was spatially indexed.

The AVS model predicts acceptability ratings of Directional Relations with respect to spatial configurations. For instance, regarding ratings of *above*, the model assumes that the attention mechanism (the gradient) is centred at the point of the Referent that is vertically closest to the Figure. This is qualitatively different from having to categorise a Spatial Relation as some Directional Relation (i.e. as in description). If a Spatial Relation is to be categorised as a not-yet-specified Directional Relation, then it cannot be assumed that the focus of the attention mechanism is set beforehand, unless one assumes that attention is focussed several times for all directional distinctions that are available. The latter option would however mean that in some cases different vectors can be defined for a single location (depending on the shape of the Referent). A more general qualitative difference may exist between rating the applicability of a *given* Directional Preposition to a Spatial Relation and the description of a Spatial Relation by means of *any* Directional Preposition that is reflected in this aspect of the AVS-model. As Zimmer *et al.* (1998) put it, rating the applicability of given Directional Relation is the "listener's perspective", and the evaluation process from this perspective could be different from the situation in which a relation has to be described, that is, "real language output" has to be generated. Rating involves determining the degree to which a given Directional Preposition fits while describing involves choosing out of a set of available Directional Prepositions. Thus: "that 'what is acceptable' might differ from those things 'which are suitable or which are optimal to reach the communicative goal', i.e., a quick search for LO [i.e. the Figure]" (Zimmer *et al.* (1998), p. 237). The description chosen by the speaker should restrict the domain of search for the addressee (see Miller and Johnson-Laird, 1976). Thus, what is rated acceptable would not necessarily correspond to the (unrestrained) description used for the constellation or to the expression that is most efficient for the addressee to quickly find the Figure.

An additionally worry, when a participant has to evaluate given Directional Prepositions against given perceptual Spatial Relations, is that a participant starts to reason about his/her rating strategy, that is, the participant contemplates on why one Spatial Relation gets another rating than another Spatial Relation. The reasons for variation in ratings may be different from the reasons to describe a Spatial Relation by one Directional Preposition, by an alternative Directional Preposition, or by a combination. This is quite a basic question regarding applicability ratings: What is exactly being rated in acceptability ratings? Considering that in free description of Spatial Relations, closely besides the direct region or besides the axis of symmetry already two Directional Prepositions are often used, one may ask what is being measured if participants are to rate, say, *above*. Do participants rate *above* as opposed to *below*, that is, is *above* rated acceptable as long as it does not conflict with *below*? Do participants rate *above* as opposed to, e.g., *to the left of*, that is, is *above* rated acceptable as long as *to the left of* is not more acceptable? Or do participants even rate *above* as opposed to *above and to the left of*? It is important to know how participants understand the task and what strategies they use when rating Spatial Relations.

That participants might use strategies could also explain some of the individual difference that Regier and Carlson find. They report that some participants give highest ratings for *above* all over the direct region, while others use more variation within the direct region. It would be interesting to know if participants giving highest ratings would also be participants that use a single preposition in the direct region in free description of relations (see findings by Munnich *et al.*, 2001). These participants seem not to be influenced whether the Figure is more to the *left side* or if it is more to the *right side* of the Referent if it is in the direct region. In contrast, other participants give highest ratings for *above* to some central axis in the direct region and somewhat lower ratings for Figure locations still within the direct region but at either side of the central axis. It can be assumed that these participants take into account the *left-right* distinction in their ratings. It is quite unclear if the strategy that a participant uses should be explained with an attention mechanism. The AVS model can in fact model such patterns of acceptability ratings by assuming a different width of the attentional gradient. However, assuming that the width of an attention mechanism is different over participants and so causes differences in the applicability rating patterns of participants is not my favourite guess.

Another way of explaining different patterns in applicability ratings is to first acknowledge that the rating paradigm gives participants enough possibilities of *switching* attention between Figure and Referent when they have to evaluate a description with respect to a spatial configuration. It is quite possible that participants consciously consider where along the horizontal dimensions a Figure location can still be said to '*above* some point of the Referent' (i.e., within the direct region). If this is the case, the participant may give the highest possible applicability rating for *above*. Other participants may consider what would be the central value on the horizontal dimension.

If the Referent happens to have a vertical axis of symmetry, then the central value is there. If not, other considerations, such as centre-of-mass, might be taken into account. These participants would give highest applicability ratings to Figure locations at these central values, but would take into account the slight 'leftness' or 'rightness' of other Figure locations in the direct regions. Both considerations of participants could be mediated by serial visual routines, such as visual curve tracing (Jolicoeur, Ullman and Mackay, 1986; Ullman, 1984, 1989). Such an explanation of individual differences transfers it to higher cognitive processes (strategies) and can do without relatively low-level ones such as the Attentional Vector-Sum.

This brings me directly to another, somewhat problematic, aspect of the AVS model: The *grazing line*. As acknowledged by Carlson and Regier, there is no principled reason to include it into the model, that is, there is no explanatory account on why it should be represented in an attention-driven model. What the grazing line does in the model is to give an advantage to Figure locations at the relevant side of it, which results in higher ratings. It can be argued that effectively the grazing line defines a second localisation of the Figure. Next to the attentional vector-sum, the Figure's position is also defined relative to regions defined around the Referent. The Referent’s extremities with respect to the Frame of Reference define these regions. Based on particularities of the Referent regions are defined and the Figure is localised within or outside these regions. Note that using grazing lines for each Directional Relation would produce a bounding box (see Van der Zee, 1996; see also Section 2.5). Again, participants could consciously (i.e., strategically) consider what is the highest point on the object, and make a difference between locations '*above* all parts of the Referent' and locations '*above* some parts of the Referent'. Also here serial visual routines, such as visual curve tracing, may be used to define the horizontal position of a Figure with respect to the outermost left and right points of the Referent, as well as to define vertical position of the Figure with respect to the highest and lowest point of the Referent.

The AVS model was developed to incorporate effects of the Figure location in terms of both centre-of-mass and proximal distance definitions on ratings. The proposed gradient is interesting in that the attention mechanism elegantly does this. If it turns out however that participants are aware of the location of the Figure relative to the Referent's centre-of-mass and with respect to proximal distance to the Referent, and consider the highest, lowest, 'leftest', and 'rightest' points of the Referent, and deliberately take these into account in rating experiments, then one may doubt the need for an attention mechanism to explain ratings.

3.2.3. Intrinsic Categorisation of a Spatial Relation

The Spatial Relation needs to be categorised in terms of Reference Frame distinctions, and in the present case, these are directional distinctions within the object's intrinsic structure. The perceptual Spatial Relation needs a definition itself in order to be categorised and described. The mechanism with which the perceptual Spatial Relation is defined happens to be quite unclear however. Different possibilities can be proposed regarding the assessment of the Spatial Relation. For instance, it can be hypothesised that Spatial Relations are assessed by a shift of attention from the Referent to the Figure, by the gradient focussed on the point of the Referent closest to the Figure, by a division of attention over (some Directional Parts of) the Referent and the Figure, and probably by quite a few other (attention) mechanisms as well. Which of these, if any, is used, is an open question. An attention mechanism is however needed. Once the Intrinsic Object Centred Frame of Reference has been defined in perceptual space, the specific Spatial Relation defined by the attention mechanism needs to be evaluated against it. This is illustrated in Diagram 3.4.

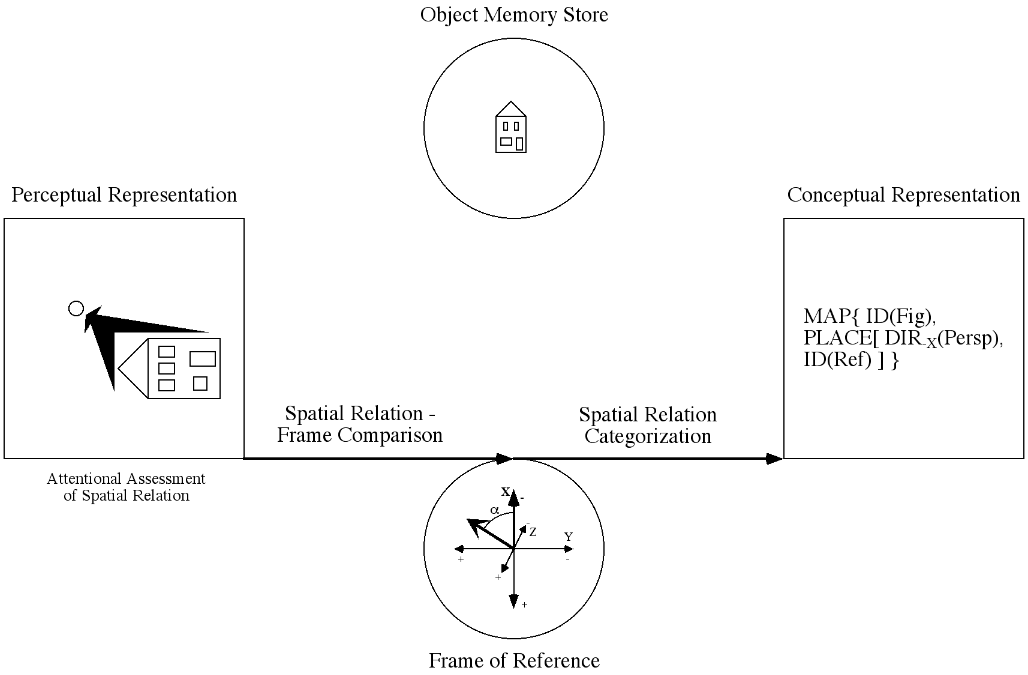

Diagram 3.4. The categorisation of a Spatial Relation as a Directional Relation.

In Diagram 3.4, the perceptual Spatial Relation is compared with the directional distinctions of the intrinsic Frame of Reference. The result is a categorisation of the Spatial Relation and the establishment of the Directional Relation in the conceptual representation, which can then be expressed (for instance with Sentence (1)). The Spatial Relation is defined and rules of categorisation define the Directional Relation to which it is assigned. The rules of categorisation may differ depending on the specifics of the Spatial Relation, the available reference frame distinctions, and the precision with which the relation needs to be expressed. A perceptual Spatial Relation can always be categorised on a dimension that the intrinsic Frame of Reference possesses unless the Figure happens to be located exactly in the extension of the bounding plane between the Directional Parts of that dimension. A Spatial Relation may be described with one or more Directional Prepositions.

3.2.3.1. Directing Attention to Find a Figure

Given that a suited description of a Spatial Relation is a description that allows an addressee to quickly locate the Figure, it may be worthwhile to consider how an addressee would shift its attention away from the Referent to search a part of surrounding space. If a Figure location is described by, e.g., '*above* the Referent', then it seems natural to assume that attention is directed in line with the Directional Part opposition *top* versus *bottom*, and thus orthogonal to the bounding plane between *top* and *bottom.* A simple illustration of this idea is given in Figure 3.4. In the example, the Referent is a 2D picture of an 'egg'. It shows a *top-bottom* dimension and a *left-right* dimension whereby, however, the *left-right* dimension is obtained through the 2D context. This poses no problems to an example of intrinsic Reference, because *left* and *right* are always defined conventionally.[61] Figure 3.4.A is the unattended Referent in the addressee's perceptual representation. Upon hearing the description, the addressee finds the Referent and attends to it (Figure 3.4.B; thick lines denote being attended to). In Figure 3.4.C the *top* and *bottom* are contrasted; the contrast is defined sharply by a bounding axis. Figure 3.4.D shows that the *top* part is selected (attended), and in addition that the whole half-plane at that side of the bounding axis can be associated with the *top* part by extension of the bounding axis. It is assumed that the typical search for the Figure will involve directing attention in line with the differentiation of *top* and *bottom*, and thus orthogonal to the bounding axis (or orthogonal to some less sharply defined contrast). The (object-based) attentional capture of the *top* part is dissolved and the (space-based) gradient or spotlight is moving away from the Referent, thus searching the Direct Region (Figure 3.4.E).

[61] The intrinsic interpretation of the Referent as it is assumed here is corroborated by experimental evidence of Harris and Strommen (1974). They used a similar object and asked participants to draw a line in the object separating the *front* from the *back*. The typical result (over 80 percent of the responses) is that the line separates the 'tapered' end from the 'broader' end (as the horizontal boundary in Figure 3.4.C does).

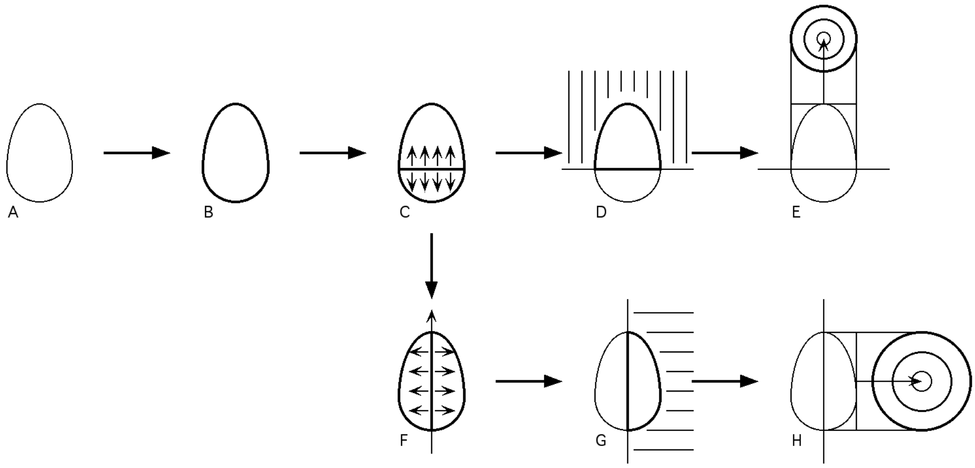

Figure 3.4. How an addressee may search for the Figure.

If the Figure location is described by, e.g., '*to the right of* the Referent', the search performed by the addressee is expected to be analogous. In this case, the *left-right* directionality can only be assigned when taking *top-bottom* directionality into account (Figure 3.4.F). Otherwise, the procedure is the same (Figure 3.4.F-H). Note that the direct regions have different width. If a Figure location is described by, e.g., '*above and to the right of* the Referent', then an addressee would probably search in between the direct regions for *above* and for *to the right of*.

This specification would be in line with the findings of Zimmer *et al*. (1998) where, in the context of one participant describing Spatial Relations so that another participant can quickly find the Figure, only in the Direct Region the speaker used a single Directional Preposition, while two Directional Prepositions were used in the oblique regions. Thus, possibly, the speaker chooses its description according to expectancies regarding the addressee's search strategy. If so, then regardless of the mechanism with which the speaker assesses the Spatial Relation, his/her preferred categorisation as evidenced by description complies with dividing space surrounding the Referent in Direct Regions and overlapping (oblique) regions. The speaker would thus divide space surrounding the Referent in regions, localise the Figure with respect to these regions, and determine his/her choice regarding one or two Directional Prepositions to describe the relation upon the region in which the Figure is located. In fact, this possibility might be an alternative formulation of the spatial templates proposed by Logan and Sadler (1996; see above). In this case, no definition of the Spatial Relation from the Referent directly determines categorisation. Instead, the location of the Figure relative to regions imposed around the Referent is instrumental in categorisation.

Chapter 4. Space and Memory

The experimental task described in Chapter 6 involves memory for Intrinsic Locations around a Referent. Therefore, this Chapter will consider spatial memory, both regarding some general aspects and specifically regarding locations relative to objects. In particular, it is considered how reports from memory can reveal something about underlying processes and representations. The question how memory for Intrinsic Location relates to linguistic intrinsic spatial reference described in the previous chapter is considered in Chapter 5.

4.1. Memory Accuracy

Koriat, Goldsmith, and Pansky (2000; see also Koriat and Goldsmith, 1996) contrast two metaphors in memory research. This contrast appears a good starting point for the present subject although the contrast may be somewhat exaggerated (as acknowledged by Koriat *et al*.). They find that, next to considering the capacity of memory processes (i.e., how many items can be remembered), an increasing amount of research is done which focuses on memory accuracy (i.e., how and why memory can go wrong). As opposed to what they call the *storehouse metaphor*, that is, a quantity-oriented approach which leads researchers to consider storage capacity, the internal architecture of a store, the transfer of units (items) from one store department to another, competition between units, and information loss, the so-called *correspondence metaphor* is used in research investigating how precisely information is retained and how it may become distorted.

The storehouse metaphor can of course be applied to the subject of spatial memory. For instance, spatial short-term memory has been characterised through the visual-spatial sketchpath (Baddeley, 1986), in which some amount of spatial information can be retained for some short time. Other research however shows that spatial memory probably can not be considered as a unitary storing mechanism. For instance, Woodin and Allport (1998) show that Environment Centred (based on the room) and Ego Centred spatial memory is differentially disrupted by interference tasks and may thus need to be dissociated. As another example, Postma and De Haan (1996; see also Postma, 1996; Postma, Izendoorn, and De Haan, 1998) suggest that memory for locations, memory for object identities, and a process linking these may have to be differentiated. These and other studies may provide important evidence on the functional build-up of the spatial information storage capacity.

For the present research, such store related memory studies are of limited importance. The present study focuses on the spatial information structures involved in remembering the location of one object with respect to one other object in terms of intrinsic characteristics of the latter object. Questions pertaining to dissociable stores and dissociable processes at present put no constraint on the information structures involved herein.[62] Because the experiment described later in the thesis actually does involve a memory task, the following assumptions pertaining to the memory store are made. First, there is a memory store in which an intrinsic Spatial Relation may be retained for a short time (Short Term Memory (STM) Store). Whether this is a unitary store and if so, if this store is used solely for this kind of spatial information or if it is used for other kinds of (spatial) information as well, and if not, if relevant store parts are used solely for this kind of spatial information or if they are used for other kinds of (spatial) information as well, will not be subject of investigation. Second, the storage capacity of the STM store as a whole and of any possible substructure or subprocess of the store will pose no specific constraints on remembering solely the location of one object with respect to one other object.

[62] Although information-processing mechanisms may constrain the information structures that may be handled, no study –to my knowledge– presents any such limitation for the present research.

Because the goal is to find (category) information structure influences on reports from memory, and not to find store or capacity related influences, the correspondence metaphor seems more suitable at present. It is the structure of the information by which the location of a Figure is linked to a Referent that is investigated, and not the amount of information. The degree of correspondence between actual Intrinsic Location and reported Intrinsic Location will thus be used to investigate if, how, and why reports become distorted. Thus, given that differences between reports are found and/or that a distortion of reports is observed, an explanation will be sought for in terms of underlying information structures that influence memory. The way that spatial information is structured in memory arguably determines the way in which it may become distorted as well as the way that reports may differ.

Another important issue mentioned by Koriat, Goldsmith, and Pansky (2000) concerns the stage of an information-processing route where distortions of memory reports are caused. If distortion is evident from memory reports, then this does not necessarily mean that the distortion was produced during the act of remembering. One relevant question in this respect is whether memory reports should be compared with reality or with the perception of reality. Does one conclude from an apparent distortion in memory reports that the distortion is caused by memory processes or that memory processes are adequate and that the distortion is caused by misperception?

The present research considers Intrinsic Object Centred Directional Relations, that is, Intrinsic Locations (or relations) and their categorisation that can be used for spatial language. Investigating memory for Intrinsic Location may reveal category influences on memory reports. Categories used to memorise Intrinsic Locations are possibly the categories used to express Spatial Relations as Directional Relation. If this is so (and if category influences on reports from memory are actually found), then memory reports for Intrinsic Location may show something about the structures and processes involved in the categorisation of Spatial Relations for language. In particular, I will consider the content of memory representations of Intrinsic Location and –possibly– the higher-level structuring (categorising) of this content. Differences in accuracy of memory reports as well as systematic errors (bias) in reports may show the underlying components of the information structure giving rise to the memory reports as well as possible higher-order structures (categories) superimposed on these components.

Many findings regarding spatial memory, spatial judgement, and spatial perception point to a hierarchical structure of the representations involved (see, e.g., Hirtle and Jonides, 1985; Hommel, Gehrke, and Knuf, 2000; Maki, 1981; McNamara, 1986; 1991; McNamara and Diwadkar, 1997; McNamara, Hardy, and Hirtle, 1989; Palmer, 1977; Stevens and Coupe, 1978; Taylor and Tversky, 1992; Tversky, 1981). Common to all is that different (nested) levels of detail are considered, whereby spatial information is grouped in, e.g., clusters, graph-theoretic trees, perceptual groups, geographic or political entities, and, indeed, regions. If Directional Regions have an influence on reports from memory, then it may be possible to use reports from memory for Intrinsic Location to infer the structure of Intrinsic Directional Regions. Before reviewing data from relevant memory research, however, it is important to consider memory tasks as such (and in particular spatial memory information acquired through visual input) and to delineate the different phases involved herein.

4.1.1. Memory Tasks

Two kinds of memory tasks exist: Recognition tasks and recollection tasks. Both tasks are similar in their first two phases, which are the encoding phase and the retention phase, but differ in the third phase, which is the reporting phase. During the encoding phase the stimuli are presented that have to be remembered or from which certain aspects have to be remembered. During this phase, information is coded in memory. In the retention phase, the stimuli (more precisely: the represented information about the stimuli) are remembered (or retained). In the reporting phase of a recognition task, stimuli are also presented and the task is to report whether or which stimuli were presented before. This task is not considered in detail as the experiment presented in Chapter 6 involves a recollection task. In the reporting phase of recollection tasks, the (aspects of) previously presented stimuli have to be recalled, which in the present case means that they have to be reproduced spatially.

The first necessary remark at this stage is that spatial information does not necessarily have to be reproduced ‘out of the blue’. It is possible to think of memory tasks in which this is the case such as the reproduction of constellations or forms that *also* contain spatial information. However, when the spatial memory task involves solely the reproduction of an orientation, a direction, a spatial location, or any other spatial attribute, some reference is needed for the reproduction (see Chapter 1 on Frames of Reference). Usually, therefore, such a reference is given.[63] In a memory task where some spatial aspect of the stimulus is to be reported, the stimulus is presented again in the reporting phase without that spatial aspect. In a recollection task on Intrinsic Location, the Referent and the Intrinsic Location are presented in the encoding phase while only the Referent is presented in the reporting phase.

In the encoding phase, two classes of factors may influence the memory trace that is construed during this phase. One class concerns the perception of the spatial situation, while the other concerns the actual encoding or extraction of the spatial information. Possible perceptual factors influencing the encoding of spatial information are illusions and differences in perceptual accuracy. Actual encoding factors concern the kind of extracted information. In some cases, spatial information can be encoded in different manners (e.g., a location can be encoded in Cartesian or in polar co-ordinates), and relative to different references. While perceptual factors may be difficult to

[63] This does not mean that it is impossible to construct a spatial memory experiment where a location or orientation has to be reproduced without presenting a reference. This is the case, e.g., in the reproduction of a location in a circular visual field (Attneave, 1955), in the reproduction of a line orientation without any visible reference orientations (Jastrow, 1893), or in the reproduction of a horizontal direction in a circular room (Franklin, Henkel, and Zangas, 1995). In such cases, however, the ego and/or gravity are still available and therefore the spatial information is still reproduced relative to some reference.

influence and should instead be controlled for, the second class of factors allows manipulation by the experimenter. For instance, explicit instructions may bias participants towards encoding information in a certain way and the context in which spatial stimuli are embedded may implicitly bias participants towards a certain kind of encoding. In addition, the time for encoding given to participants in combination with the amount of information that needs to be retained may influence the quality and/or precision of the memory trace.

During the retention phase the extracted information is retained. It is assumed that the memory trace decays over time. The quality of the memory trace may thus be influenced by the retention time. An experimenter may decide to give an interference task to a participant as a more direct way to influence the retained memory trace (whereby different interference tasks may influence the memory trace to different degrees or regarding different parts of the trace). Tasks may also be given to a participant that do not interfere with the remembered information, but which should keep a participant from active rehearsal of the remembered information.

In the reporting phase, three classes of factors may influence memory reports. The first class concerns the perceptual factors during reporting. The same perceptual factors that may influence encoding could also influence the responses made in the reporting phase. Another class concerns the estimation procedures used to apply the remembered spatial information to the recollection reference situation. In general, an estimation process refers to the way that memory traces are applied to the reproduction situation in order to define the actual response. A third possible class may be factors concerning the actual motor response needed for a reproduction. Instructions may influence the reporting phase by stressing accuracy and/or speed. Additionally, the time to respond may be limited. It is also possible that the kind of response, whether it is an actual reproduction or an adjustment reproduction, will have an influence on reports.

If an experimental effect is obtained in a memory task, then the crucial question is in which phase(s) of the memory task have the effects been caused. If accuracy differences or systematic biases are found, are these due to insufficient time for encoding or insufficient precision at encoding, to quality reduction or the loss of information during retention, or to access problems to the stored information in the reporting phase or insufficient precision when reporting? Many possible influences exist, and therefore many possible explanations can at times be invoked. In the next sections, some explanatory patterns are illustrated by reviewing some exemplary research. First, the reproduction of (actual or virtual) line orientation in an available frame is considered in order to show that perception and category explanations may predict quite similar effects (Section 4.2). Then, memory for locations in circular space is considered in order to demonstrate that memory effects on location reproduction may be interpreted as resulting from different spatial structuring (Section 4.3). Specifically, systematic spatial bias can be interpreted as bias *towards* some theoretical spatial construct or as bias *away from* some other theoretical spatial construct. With these aspects in mind, I will then turn to some of the most relevant research for the present subject, memory for locations relative to objects (Section 4.4). Analogous to the situation regarding linguistic data, memory for locations relative to objects has been investigated only in situations with superimposed Frames of Reference.

There are two reasons for not considering memory for locations relative to objects directly and considering other situations first. One of these is that they highlight some interesting factors that have to be taken into account when considering memory for locations to objects and when considering the experiment in Chapter 6. The other is the existence of a particular model on the effects of spatial categories on reports from memory that has been used as an explanation in all three situations as well as in a hypothesis on the relation between spatial memory and spatial language (see Crawford, Regier, and Huttenlocher, 2000; Engebretson and Huttenlocher, 1996; Huttenlocher, Hedges, and Duncan, 1991). Because one of the goals of the present thesis is to consider spatial categories in memory for Intrinsic Location (and spatial language as well), it is of interest to see how well the category model does in different situations.

4.2. Memory for Orientation: Perception or Category Effects?

Tversky and Schiano (1989) present six experiments investigating systematic errors in memory because of perceptual as well as conceptual factors. Here, only their experiment 5 is shortly considered to sketch the experimental situation. In this experiment, they present a frame (the L-frame) that consists of two lines that originate in the same location (the origin) whereby one line extends up (the vertical axis) while the other extends to the right (the horizontal axis). The L-frame is shown with a third line (the test line) that originates from the same origin, but has a varying orientation between the axes (see Figure 4.1.A). The lines in the L-frame are presented embedded in the context of either graphs or maps. Next to answering questions about the graphs respectively maps (to make sure the pictures were interpreted as the context suggested), participants reproduce the line in an empty L-frame (see Figure 4.1.B). The reproduction of the lines is done by drawing the line from memory in the empty L-frame whereby no corrections were allowed. In the graph context condition reproduced lines show a (systematic) bias towards the diagonal (i.e., towards the 45° orientation between the vertical and horizontal axes of the L-frame; see Figure 4.1.C) but no such nor any other systematic bias is observed for reproduced lines in the map context condition. These results show that a conceptual factor (i.e., the map or graph context) influences the bias pattern of reproduced line orientation in an L-frame.

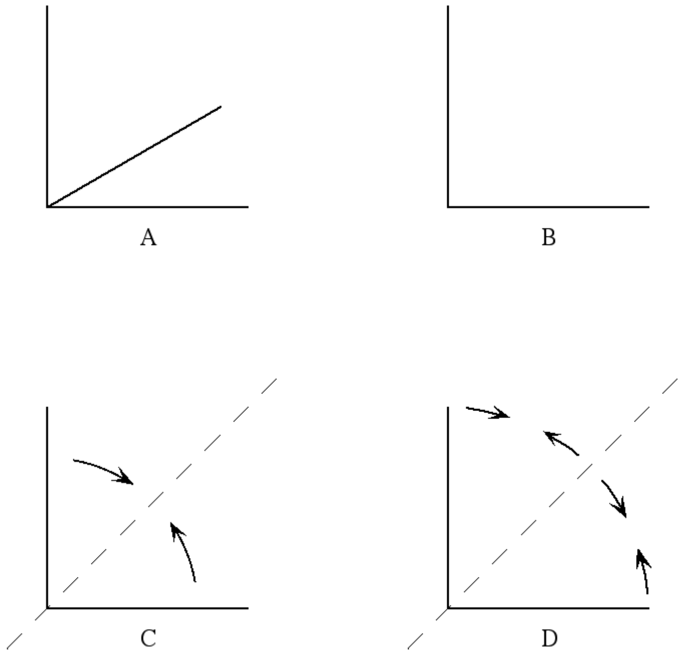

Figure 4.1. The stimuli used and results found by Tversky and Schiano (1989). A. In the encoding phase, a test line is presented in the L-frame. B. In the reporting phase, an empty L-frame is presented in which the test line needs to be reproduced. C. A bias pattern found by Tversky and Schiano (1989). D. A bias pattern found by Schiano and Tversky (1992). Bias effects are exaggerated for visibility.

4.2.1. Bias Effects in Perception and Memory

In another article, the same authors (Schiano and Tversky, 1992) present four follow-up experiments. In experiments 1 and 2 the reproduction of line orientation in an L-frame void of any conceptual context is investigated in a perception condition (experiment 1) and a memory condition (experiment 2). In the perception experiment, reproduction is performed by drawing the test line in an empty L-frame while the to-be-reproduced stimulus in its frame is still perceptually available. In the memory experiment, the line orientations are reproduced without the to-be-reproduced stimulus and after a 10 seconds delay. In both experiments, the reports of line orientations produced by the participants show systematic bias away from the horizontal and the vertical axes as well as away from the diagonal. The diagonal is not perceptually available but is the axis of symmetry of the L-frame (see Figure 4.1.D). There was thus no difference between the memory and perception condition regarding bias pattern. Schiano and Tversky's explanation of this bias pattern is presented below. Comparing these results with those of Tversky and Schiano (1989) makes clear that providing or not providing a conceptual context for spatial characteristic may change the way the spatial characteristic is encoded and therefore change the bias pattern observed in memory reports.

4.2.1.1. A Perceptual Hypothesis

The results of their experiments 1 and 2 are –according to Schiano and Tversky– due to perceptual factors because there is no conceptual context and they find the same effects in a perception as well as a memory condition. They hypothesise that the tilt illusion causes the bias effects. The tilt illusion is the perception of a test orientation at a greater angle with an inducing orientation than it actually is (see Beh, Wenderoth, and Purcell, 1971; Bouma and Andriessen, 1970; Wenderoth, 1997; see Blakemore, Carpenter, and Georgeson, 1970, for a possible neural mechanism). Figure 4.2 shows an example of the tilt illusion.

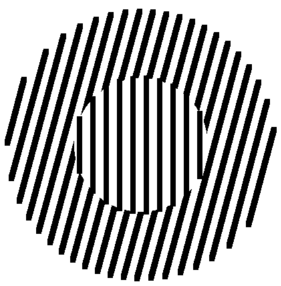

Figure 4.2. The tilt illusion. The line pattern of the inner circle appears to be oriented slightly off vertical, although its line pattern is vertical. The strength of the illusion depends on the orientation of the line pattern of the outer ring.

This explanation of bias effects with perceptual illusory mechanisms still fails to explain how the bias actually comes about in a reproduction task (be it in a perception or a memory condition). If illusionary effects have an influence on the encoding of line orientation, then why does the same illusion not apply at the reproduction of line orientation? If the same illusion applies when reproducing a line orientation, then actually no bias would be expected while the illusionary effects would cancel themselves out. One possible reason why bias effects still occur may have to do with the response method applied in the experiments. Figure 4.3 sketches a possible mechanism.

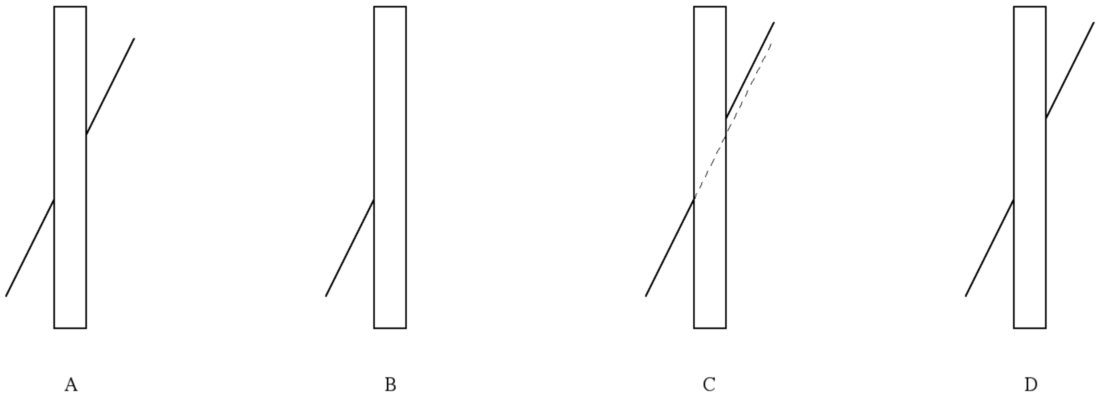

Figure 4.3. How an illusion may produce bias in a perception or memory condition of a reproduction task. A. The illusion is an example of the Poggendorff illusion: Although the two lines attached to the rectangular shape are actually aligned, the lines appear offset. B. Assume that the task is to reproduce one of the lines so that it is exactly positioned as in A. C. A strategy that may be invoked is to imagine a straight extension of the line on the left and draw the reproduction line slightly above the imagined line. D. The resulting line is actually too far up compared to the to-be-reproduced example. Bias has occurred; A and D even look different.

The illusion illustrated in Figure 4.3 is an example of the Poggendorff illusion. The example allows a simple sketch of the hypothetical illusion-produces-bias-mechanism. It is assumed that the lines in A are perceived as parallel but not aligned, which is according to expectations if it is assumed that the illusion is a variant of the tilt illusion: If both lines appear somewhat tilted from the vertical, and both to a similar amount, then the result is that they appear parallel but not aligned. If a participant has to reproduce one of the lines of the so-called transversal, then it seems logical that she/he tries to reproduce what he/she perceived. The participant thus estimates that state of affairs. The estimation process is assumed here to occur similar to aligning a ruler with the one available line and offsetting the response line slightly. The result from this procedure however is a biased reproduced test line. The same example can explain bias in reproduction reports when the initial stimulus is still available (perception condition) and when the initial stimulus is not available anymore (memory condition).

The above example is only valid in the one-try-only drawing response method where no corrections are allowed. If a participant does not draw a line to give a response, but instead adjusts a line (e.g., on a computer screen) until it resembles the originally presented stimulus, then the participant will probably notice –if she/he first tries to adjust the line according to strategy illustrated in Figure 4.3– that the line in D does mirror the line in A. The participant may then adjust the line somewhat more until it looks like the line in A. With such a response method, there is no reason to expect bias. In fact, if a participant is asked to adjust the right line until it *looks* aligned to the left line (i.e., no reproduction task), then the results show that the estimated alignment of the line is lower than the actually aligned line shown in A (see Wenderoth, 1980b).

Similarly, if in a line-within-an-L-frame situation the tilt illusion is at work, then the line stimulus which is actually oriented at **x** degrees from one of the frame axes would appear to have an **x + y** orientation, whereby **y** defines the effect of the illusion. The participant will therefore try to estimate an **x + y** orientated line and therefore try to draw the line at the **x + y** orientation. Once drawn, however, the line orientation may appear even further from the axis orientation than intended. Even if the discrepancy is noted, then, once the line is drawn, no correction is allowed and bias has occurred.

4.2.2. Bias and Virtual Line Orientation

Bryant and Subbiah (1993) present three experiments, which clearly show the relevance of the present overview to the subject of the thesis. Instead of reproduction of line orientation, they investigated reproduction of dot location within an L-frame in memory and perception conditions. Their experiment 1 investigated memory for dot location as reported by drawing. They find the same pattern of results as in the ‘no context’ condition of Schiano and Tversky (1992): Deviation of reported location away from the vertical, the horizontal, and the diagonal. If it is assumed that dot locations are encoded by means of the orientation and distance of the virtual line connecting origin and dot location and that the same perceptual effects (tilt illusion) apply both to actual available line orientations and to encoded (imposed, that is, ‘virtual line’) orientations from origin to dot location, these results are according to expectation. Indeed, Bryant and Subbiah suppose that participants use this ‘virtual line’ strategy for the encoding dot location.

It is thus assumed that a dot location may be encoded through the orientation and the length of an imposed subjective virtual line from the origin to the dot. It is additionally assumed that this imposed line is subject to illusory orientation effects. These assumptions are reasonable because they are supported by findings of Hartley (1982; see also Hartley, 1978; 1979; and compare with Wenderoth, 1978; 1980a; 1983). Hartley's findings are illustrated in Figure 4.4.

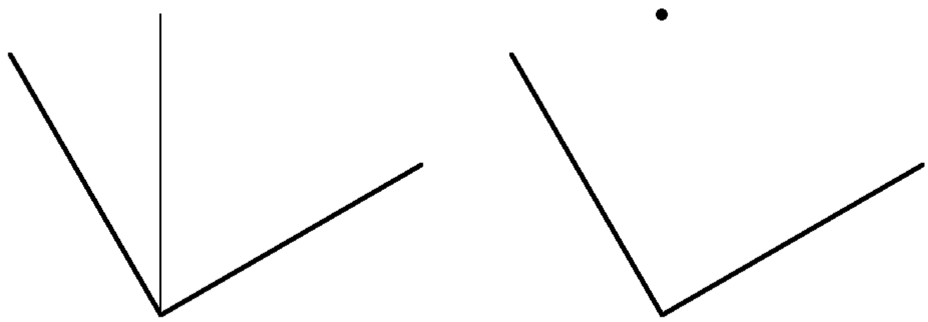

Figure 4.4. Tilt illusion with a virtual line. Hartley (1982) demonstrated that similar tilt illusion effects are found when participants are asked to adjust the orientation of a line exactly vertical (left), and when participants are asked to adjust the position of a dot exactly vertical above the axial origin (right). In both cases the illusion produces an apparent repulsion away from the axis of symmetry of the axial frame (not drawn), which makes the line or dot to appear slightly off vertical (in the CCW direction). When asked to adjust line or dot to be vertical, participants place them slightly off vertical in the CW direction. Regarding dots, this probably occurs because a virtual line from dot to axial origin is imposed.

In their second and third experiments, Bryant and Subbiah investigated only dot location reproduction in a perception condition. Still, the findings are worth mentioning.

In experiment 2, reproduction of dot location by drawing while viewing the original to-be-reproduced stimulus produces deviation away from the 45°, but not away from the cardinals. The bias pattern does therefore not constitute a complete tilt contrast pattern. Thus, whereas Schiano and Tversky (1992) found similar effects in perception and memory conditions regarding line orientation reproductions, Bryant and Subbiah find a difference between such conditions regarding dot location reproductions. They argue that this difference in findings occurs because encoding of dot location requires an encoding strategy, from which the virtual line strategy is only one. Whereas the virtual line strategy seems to be triggered in the memory condition, this is not the case (or less so) in the perception condition. This interesting suggestion thus holds that when dot location is encoded by means of the virtual line (i.e., the participant chooses to use polar co-ordinates) that tilt effects occur. When, however, the participant employs another encoding strategy that does not involve an orientation co-ordinate, tilt effects do not occur. The chosen encoding strategy thus determines if perceptual effects show up.

In their experiment 3 Bryant and Subbiah try to show this dependence of bias pattern on dot location encoding strategy by explicitly instructing participants to use either the 'virtual line' strategy (polar co-ordinates) or the 'axes' strategy (Cartesian co-ordinates) in a perception condition. They find that instructions to encode dot location as orientation and distance produces the tilt effects with bias away from the vertical, horizontal, and diagonal whereas instructions to encode dot location as an X-axis value and an Y-axis value produces no tilt effect (no pattern at all). Although these results are obtained in a perception condition and although the explanation is based on perceptual mechanisms (whose occurrence however depends on the cognitive encoding strategy), the results nicely exemplify that the way in which spatial information is structured may determine the way in which it becomes distorted.

These findings have direct consequences for the present thesis. If an Intrinsic Location is encoded by means of polar co-ordinates (i.e., with an orientation and a distance), then bias observed in memory reports may be the result of the perceptual processing of orientation information. This underlines the need to carefully consider the co-ordinates that participants use to code an Intrinsic Location. Additionally, the possible occurrence of perceptual effects should be taken into account, or there should be control for the occurrence of such effects.

4.2.3. A Category Explanation

Engebretson and Huttenlocher (1996) contrast the perceptual explanation (tilt illusion) of bias in memory for lines in frames with their category explanation of bias (see Huttenlocher, Hedges, and Duncan, 1991). To achieve this end, they report two experiments. Experiment 1 compares memory for line orientation in an L-frame to similar memory in a frame constructed from oblique lines (i.e., the L-frame rotated 45° CCW to become the V-frame). Experiment 2 compares performance with respect to V-frames over a control condition and an interference condition. They presented the encoding stimuli on screen; participants made responses on paper by drawing. Before discussing their findings, I will first consider the model of Huttenlocher, Hedges, and Duncan (1991) in more detail than necessary at present. Because in the remainder of this chapter their model will be dealt with a few more times, it seems more efficient to describe its aspects once in full.

4.2.3.1. The Model of Huttenlocher, Hedges, and Duncan

The model described in Huttenlocher, Hedges, and Duncan (1991) is designed to give a precise characterisation of category effects on reports from memory. That category information (or schemata, frames, prototypes, and the like) may have an effect on memory is a well-known phenomenon in which inexact memory is adjusted in line with the remembered category (see Alba and Hasher, 1983; Brewer and Treyens, 1981).

Huttenlocher *et al*. assume that memory is hierarchically organised and that higher-level category information may be used to adjust lower-level fine-grain information. Reports from memory are thus considered to be a blend between fine-grain and category information. The degree to which category information influences reports depends on the inexactness of the fine-grain information. Only when fine-grain memory is inexact, that is, so to say, when being unsure, does schema or category information influence memory reports. The model could encompass more levels of detail in its hierarchical organisation, but the discussion will be confined to two levels of detail only. It is thus assumed that both a fine-grain value and a category value are coded.

A fine-grain value is assumed unbiased but inexact. It is therefore conceptualised as a probability distribution of values around the true value whereby the dispersion of the distribution characterises the inexactness of the fine-grain value. The inexactness of the fine-grain value depends on the precision of encoding and on information loss during retention. When a fine-grain value is recollected, a value is sampled from the distribution together with the dispersion value signalling the (in-) exactness associated with the fine-grain value.

Next to the fine-grain value, a category value is encoded. The model assumes that categories may be characterised by a specific range of values, by a pattern of values (distribution) around a prototypical value, or both. To conceptualise a range, boundary values constituting the endpoints of category membership are defined. Boundary values may be exact (i.e., when objectively available) or more or less inexact (i.e., when subjectively imposed). Boundary inexactness is conceptualised through a distribution of possible boundary values. On the one hand, boundaries are used to encode the category of the stimulus. On the other hand, they are used to adjust recollected inexact fine-grain values in estimating reports.

To conceptualise a pattern of values constituting the category, a distribution with a central value is assumed. The pattern might take different forms, e.g., a uniform distribution of values across a range in which case each value is as good an example of the category as any other, or a more centred distribution in which case some values are more typical of the category than others. In each case, the central value (or the prototype value) can be regarded as the mean or median of the category pattern and prototype inexactness is associated with it that reflects the dispersion of instances over the category (i.e., the dispersion of the pattern of values that constitutes the category). Prototype values are also used to adjust recollected inexact fine-grain values in estimating reports.

The model assumes that although recollected fine-grain values are unbiased (i.e., centred on the true mean), memory reports may be biased because the uncertainty associated with the fine-grain values interacts with estimation procedures. In cases of uncertain memory, the recollected fine-grain value is combined with the recollected category information in order to estimate the response. First, consider the case in which boundaries are certain, that is, actually available.

4.2.3.1.1. Exact Boundaries

One estimation procedure from which bias may result is truncation at category boundaries. This most notably happens when a previously presented stimulus close to a category boundary is reported from memory. The fine-grain recollection is still centred at the true value but –because of uncertainty– samples from the memory distribution may fall outside the remembered category (outside the category range defined by the boundary values). If such a value were sampled, then it is not eligible for reporting because it does not comply with the remembered category value and another value has to be sampled. This means that the reported fine-grain value is confined to lie within the range defined by the remembered category. As a result, the fine-grain probability distribution is truncated at the boundary value and memory reports for stimuli close to category boundaries will be biased. The top row of Figure 4.5 illustrates this for three true values (and thus three different fine-grain distributions) at different distances from the boundary. In the Figure, the unbiased fine-grain distribution is the standard normal (Gaussian) distribution. Truncated memory reports have reduced variance compared to recollected fine-grain values.

The second estimation procedure that combines fine-grain and category information, and from which bias may result, is weighting of fine-grain samples with the prototype value of the remembered category. The model assumes that no weighting would take place in the extreme case where the fine-grain memory recollection is exact (no variability, i.e., perfect memory) and that all weight is given to the prototype value in the other extreme case where the fine-grain value is simply forgotten completely. In all other cases, weighting depends upon the relative inexactness associated with both the fine-grain value and the prototype value. Weighting produces a pattern of bias towards the prototype value while at the same time it reduces variability of responses. See the second row of Figure 4.5. The prototype value is 3.6 and the weight given to the fine-grain distribution is 0.8 (therefore the weight of the prototype is 0.2). Weighting is thought to adjust uncertain memory in order to improve overall accuracy of reporting. According to Huttenlocher *et al*., if the variance of the unweighted fine-grain memory recollections is greater than the variance of the distribution of instances over the category, then the weighted distribution will produce more accurate reports than non-weighted memory recollections. In the actual situation of dealing with reports from memory, this assumption of the model is evaluated as follows. First, the variance of the unweighted fine-grain distribution is estimated by means of the variance of the reports and the regression slope of bias over the (presumed) category. This estimate is then compared to the variance of the (presumed) pattern of values over the category.

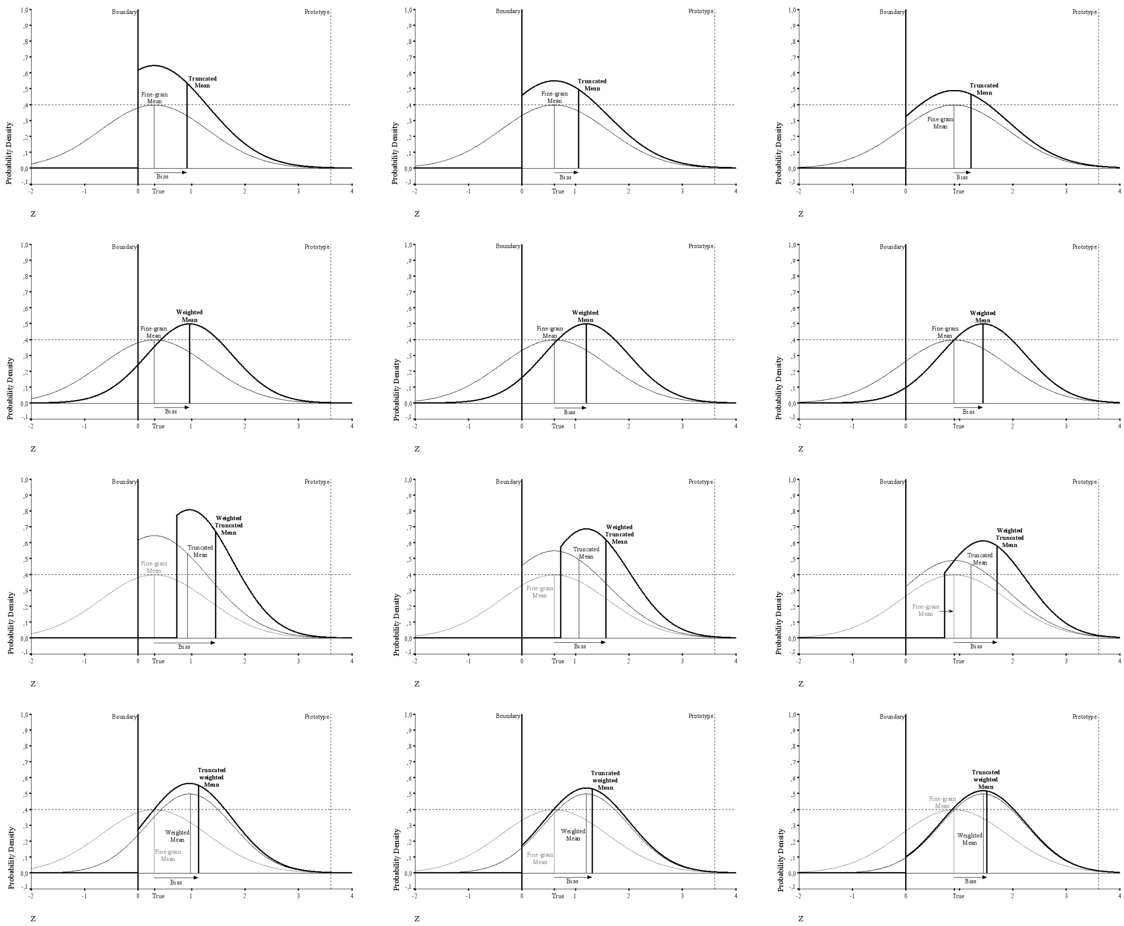

Figure 4.5. Estimation procedures proposed in the model of Huttenlocher, Hedges, and Duncan (1991). The columns show three true values at different distances from an exact boundary. Because memory is thought to be unbiased but inexact, remembered fine-grain values are conceptualised by a sample distribution around the true value. Top Row: Category boundaries bias memory reports by truncating the distribution. Sampled values left of the boundary cannot be reported because they fall outside the range of the remembered category. Because only values to the right of the boundary are eligible, the probability density of these values increases. The mean of the resulting sample distribution is not at the true value anymore. Bias decreases with distance of the true value from the boundary. The variability of the truncated distribution is smaller than the variability of the original fine-grain recollection distribution. Second Row: Reports also get biased through the weighting of fine-grain samples with the prototype value of the category. The result is a distribution with smaller variability and a mean between the true value and the central category value. Bias increases with distance of the true value from the prototype. Third and Fourth Row: Combining truncation and weighting remains somewhat unclear from the model description (see text). In the Third Row, the truncated distribution is weighted whereas in the Fourth Row the weighted distribution is truncated. These two ways of combining truncation and weighting produce bias, that is less then the summed bias of truncation and weighting.

Depending on the expected pattern of fine-grain inexactness over the category, the shape of the bias pattern over the category range can be predicted qualitatively. For example, if it is expected that the inexactness of the fine-grain recollection is the same for all values in the category (i.e., there are neither differences in encoding accuracy nor differences in memory loss for different true values), then the predicted bias pattern is linear. If all true values in the category would be weighted as the examples in Figure 4.5, then the line describing the relation between bias in reports and true value has a slope of -0.20 (with zero bias at the category prototype) and all weighted memory distributions have a standard deviation that is 0.80 times the standard deviation of the non-weighted memory distribution. For true values close to or coincident with the prototype this would surely mean an increase in reporting accuracy compared to the fine-grain recollection. For values farther away from the prototype, the decreased variance of reports (which is the same for all values in the category) is counteracted by an increase in bias (which increases with distance from the central value).

Although these two mechanisms producing bias in reports are unproblematic on their own, there may be a technical problem in combining these mechanisms as described in the model of Huttenlocher, Hedges, and Duncan (1991). The mathematical description of combined bias consists of a simple summation of the truncation bias and the weighting bias. The present author fails to see how a fine-grain sample distribution can be transformed in order to accomplish this. The description ignores the fact that weighting changes the variability of the sample distribution whereas the magnitude of the bias resulting from truncation actually depends on this variability. It seems impossible to simultaneously hold that combined bias is the addition sum of weighting and truncation bias and that weighting reduces the variability of reports.

Two alternative possibilities to combine truncation and weighting appear straightforward. Either it is the case that a truncated distribution is weighted or it is the case that a weighted distribution becomes truncated. The third row of Figure 4.5 illustrates the first possibility. Consequently, the mean of the resulting weighted truncated distribution equals weighting the truncated mean with the prototype value while the bias equals the addition of weighting bias and *weighted* truncated bias. The last row of Figure 4.5 illustrates the second possibility. The mean of the resulting truncated weighted distribution equals the truncated mean of the weighted distribution whereby the point of truncation is the boundary position defined in terms of the weighted distribution parameters. The bias of the resulting distribution equals the addition of weighting bias and truncation bias resulting from truncation of the weighted distribution. The latter possibility seems more in line with the textual description that "the recollection *M* combined with the prototype ρ_c for category *c* lie between the category boundaries a_c and b_c" (p. 374) if this is meant to express that the combination of fine-grain distribution and prototype (i.e., the weighted distribution) is confined within the category boundaries. The former possibility resembles the mathematical description closer, however.[64] In both cases, the resulting mean and bias is less than the mean and bias described in the mathematical formula in Huttenlocher *et al*. Predictions from these alternatives produce merely quantitative differences regarding the magnitude of bias, although the resulting distributions also differ in shape to some degree.

4.2.3.1.2. Inexact Boundaries

Next, consider the case of inexact boundaries, that is, subjectively imposed boundaries. Inexact boundaries have an effect on the categorisation of the true value. A presented stimulus (true value) is categorised according to its relation to (the side that it is on) the imposed boundary value sampled from the boundary distribution. The top row of Figure 4.6 shows this. Lines represent three true values and a boundary distribution with standard deviation 0.32 is given. A boundary value sampled from the boundary distribution results in a categorisation of the stimulus as belonging to 'Category A' if the true value of the stimulus is to the right of the sampled boundary value and as belonging

[64] The only adjustment of the mathematical description given by Huttenlocher, Hedges, and Duncan (1991) that is needed to obtain this specification of combined bias is to multiply the truncation part of the formula by the weight given to the fine-grain distribution.

to 'Category B' if the true value of the stimulus is to the left of the sampled boundary value. The range of possible boundary values is thus compatible with classification of the same true stimulus value at either side of the boundary. The proportion of stimuli categorised as 'A' respectively 'B' is given by the surface below the curve of the boundary distribution at both sides of the line representing the true value of the stimulus. According to the model, stimulus values that are exactly at imposed boundaries (i.e., at the central value of possible boundary values) will be categorised in 50% of the cases on one side of the boundary and in 50% of the cases at the other side of the boundary (as in the left column of Figure 4.6).

The proportions of stimuli that get categorised in one way or the other has a direct effect on the expected reports from memory because estimation procedures depend on the category classification of the stimulus. Weighting and truncation produce bias in opposite directions if the encoded category is ‘A’ or ‘B’. Overall, this means that there is less bias while 'correctly' classified and 'incorrectly' classified fine-grain values cancel each other out to a certain extent (depending on proportions). If the true stimulus value is at the central value of the boundary distribution, if the central values of both categories are at equal distance from the central boundary, and if the weights given to the prototypes and the fine-grain values are the same, then resulting bias is zero.

Uncertain boundaries influence the estimation process of truncation as well. Here, the resulting truncated distribution is an average of truncation effects over the range of potential boundary values. Different values sampled from the boundary distribution produce truncation effects of different strength. Depending on the probability density of the boundary distribution, these different strengths need to be appreciated to a different degree in calculating an average effect (that is, an integral has to be solved). Calculations are thus quite complex, but accurate approximations are possible. The second row of Figure 4.6 shows the fine-grain distribution (grey), the (proportional) truncated distributions for each categorisation (thin black), and the resulting distribution (thick black) with their means.

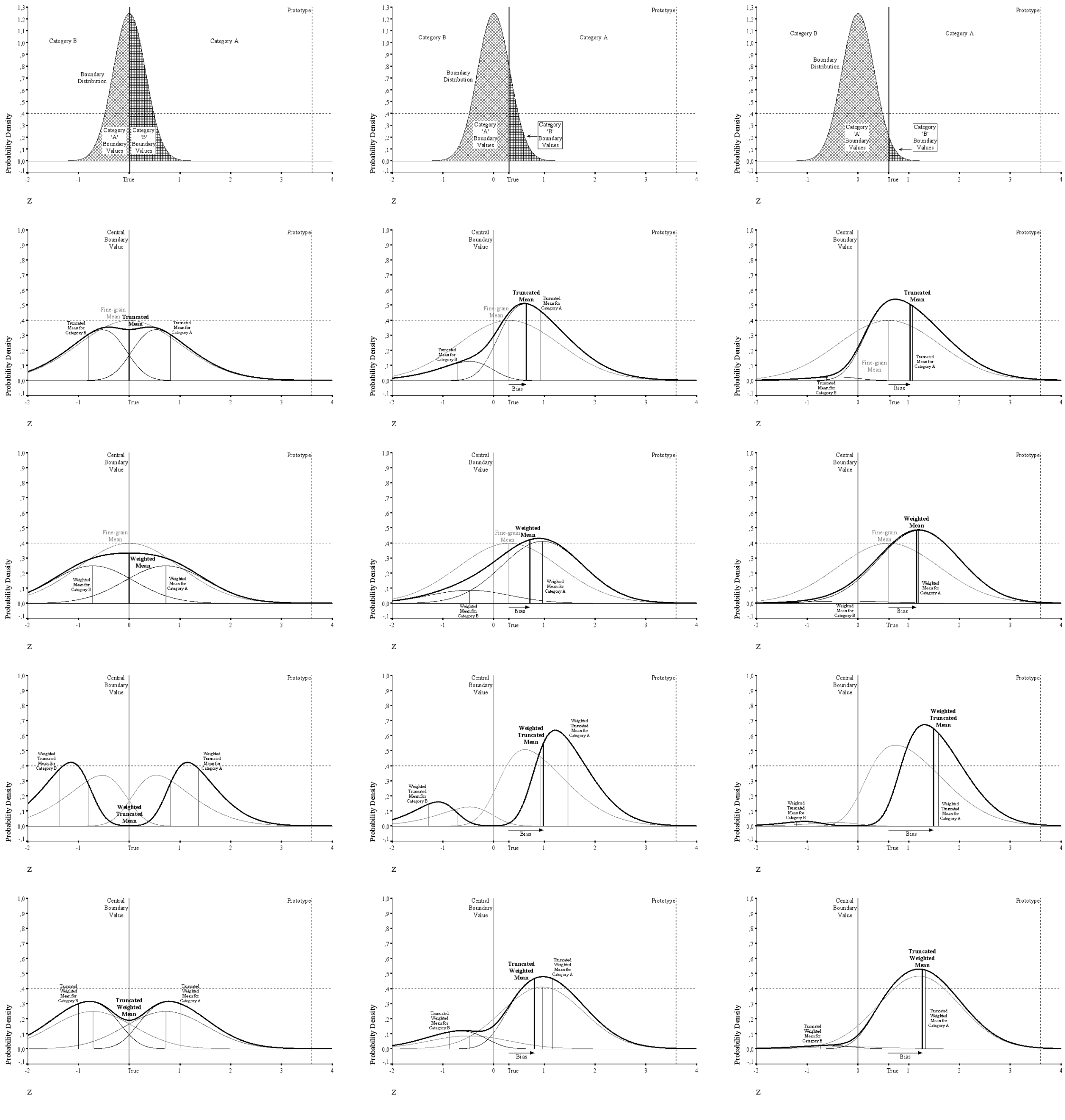

Figure 4.6. Estimation mechanisms with inexact boundaries. The Top Row shows the distribution of imposed boundaries and the proportions category encoding that follow for three different true values. The Second to Fifth Row respectively show truncation, weighting, weighting of truncated, and truncation of weighted similar to the rows in Figure 4.5. In the present case, however, the direction of weighting and truncation bias depends on the encoded category and truncation involves the average effect of the boundary distribution. See text for details.

Inexact boundaries do not directly influence the estimation mechanism of weighting. It functions essentially as described before. However, the prototype with which the weighting occurs depends on the category. The proportion 'Category A' is thus weighted and biased as in Figure 4.5, while the proportion 'Category B' is weighted with the prototype value of 'Category B' (not shown) and biased in the opposite direction. The third row of Figure 4.6 shows the theoretical distribution for each category and the resulting joint distribution.

Combining truncation and weighting may again occur in one of two ways. Either the proportions of truncated distributions are weighted according to their respective categorisation or the proportions of weighted distributions are truncated according to their respective categorisation. These possibilities are illustrated in the fourth respectively bottom row of Figure 4.6. In any case, the variance of the resulting distribution (the expected reports) increases when the true value is closer to the central value of the boundary distribution because the same stimulus value can be classified as belonging to either one or the other category (depending on the boundary value a participant happens to impose). Similarly, bias reduces to zero for true values at the central boundary value, but increases fast for true values somewhat away from the central boundary value.

4.2.3.2. Applying the Category Model to the Line-in-a-Frame Situation

Engebretson and Huttenlocher (1996) think that the results of Schiano and Tversky (1992) regarding the bias pattern in the no-context condition (i.e., bias away from the axes and from the diagonal) can also be explained with the category adjustment model described above. To this end, they assume that memory for line orientations in a frame is organised hierarchically. Fine-grain values consist of particular line orientations and categories are formed by using the actual axes and an imposed axis at 45° as category boundaries. Two orientation categories are thus assumed, each comprising the range between an actual axis and the imposed 45° axis. Note that the actual axes are exact boundaries while the imposed 45° axis is an inexact boundary. Each fine-grain value in one of these category ranges is as good a member of the category as any other. Therefore, the pattern of values in the category is uniformly distributed and the central (prototype) values are located at 22.5° and 67.5°. The bias effects that Schiano and Tversky reported are thus explained by weighting with the prototype values and truncation at actual axes and at the imposed axis.

The rationale of changing the orientation of the frame (the V-frame) is as follows. According to Engebretson and Huttenlocher, the perceptual explanation of bias (i.e., the tilt effect) predicts equal amounts of bias independent of the orientation of the frame. The bias has however to be sub-divided in direct and indirect effects. Direct effects are the results of actual axes whereas indirect effects are the consequence of (imposed) axes of symmetry. Research has shown direct bias effects to be stronger than indirect bias effects (see, e.g., Wenderoth, Johnstone, and Van der Zwan, 1989; Wenderoth, 1997; Wenderoth and Beh, 1977).

Huttenlocher *et al.*’s category adjustment model explains bias in another way. In their model, perceptual mechanisms do not explain bias because they assume that perception is veridical but that memory is inexact. The exactness of a boundary may however have an influence on bias strength, because higher boundary inexactness leads to a higher proportion of misclassification of orientations close to the boundary and thus to a higher proportion of reports that will be constrained to lie into the neighbouring category range. Consequently, the resulting bias (over all reports) will decrease. Therefore, bias due to truncation at actual boundaries should be stronger than bias due to truncation at imposed boundaries. When the orientation of the frame changes from an L-frame to a V-frame, the axis of symmetry of the former, oriented at 45° from vertical, aligns with the vertical in the latter. There exists an anisotropy in acuity for different orientations. In particular, vertical and horizontal orientations allow finer discriminations than oblique orientations: The so-called oblique effect (see Appelle, 1971; Bouma and Andriessen, 1970; Jenkins, 1985). Due to these precision differences in encoding different orientations, the axis of symmetry (imposed boundary) in the V-frame should be a more exactly represented boundary than the axis of symmetry in the L-frame. Note that the perceptual effect of accuracy differences in encoding orientation is assumed to affect the precision with which a boundary of spatial categories can be imposed. Bias strength at the imposed boundary (axis of symmetry) in the V-frame should therefore be greater than bias strength at the imposed boundary in the L-frame.

4.2.3.2.1. The V-Frame and the L-Frame

Experiment 1 compares reproduction of line orientation from memory in the L-frame to similar reproduction in the V-frame. Engebretson and Huttenlocher find that direct effects (i.e., bias at actual axes, or certain boundaries) in the L-frame are about twice as strong as indirect effects (i.e., bias at the axis of symmetry, or the imposed boundary), while in the V-frame this pattern is reversed. They further show that reports are skewed near actual axes, which they think is caused by truncation. In addition, the strength of bias near the axis-of-symmetry-boundary varies between the two frames in the predicted direction, that is, bias is stronger at the imposed boundary in the V-frame than at the imposed boundary in the L-frame. Engebretson and Huttenlocher interpret the results as giving support to their view.

A few comments need to be made here. First, it is not only the case that the strength of bias is different between the frames at the imposed axis of symmetry boundary. This is also the case at the actual axis boundaries. Because the frame axes are available during both encoding and reproduction, there is no inexactness associated with these axes. Therefore, following from the model, bias in reports of values close to these axes should be similar in the L and the V-frame. However, the bias in the V-frame is smaller than the bias in the L-frame for these axes. Engebretson and Huttenlocher fail to explicitly report this. Fortunately, from the histograms they report, the frequencies of reported orientations can be recovered for these stimuli, and –because the V-frame and

L-frame conditions were varied between participants– t-tests can be performed on the data. From these tests, it becomes clear that the bias for stimuli close to actual axes is greater in the L-frame than in the V-frame.[65] The model of Huttenlocher, Hedges, and Duncan (1991) does not predict this effect. There is no reason why the category explanation of bias should predict different precision in the encoding of differently oriented but actual available axes. In fact, the model presented in Huttenlocher *et al*. explicitly states that bias close to more certain boundaries (whereby perceptual available axes are as certain as it can get) should be stronger than bias close to less certain boundaries. One might argue (because boundary exactness cannot be invoked to explain these results) that one has to consider differences in fine-grain encoding. This probably will not give a satisfactory explanation either. Given the above-mentioned oblique effect one would have to assume that encoding accuracy close to the actual axes in the L-frame (horizontal and vertical) is higher than close to actual axes in the V-frame (oblique). It then follows, that memory inexactness of fine-grain values is lower near actual axes in the L-frame. From this it would follow that smaller bias should be obtained. However, the opposite is found.

Second, assuming that the perceptual bias explanation holds that indirect effects of the imposed boundaries (axes of symmetry) are not influenced by the orientation of this axis while the conceptual bias explanation resorts to perceptual encoding effects in order to explain the differing precision with which boundaries are imposed is a somewhat artificial contrast. The perceptual tilt effect account of bias effects is not contradictory to nor prohibits making use of the perceptual encoding oblique effect. Wenderoth (1997) even explicitly links the tilt effect to the oblique effect. In addition,

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[65] Bias at the 5° (3.83°) and 85° (3.17°) orientations in the L-frame is stronger than bias at 5° (1.84°) and 85° (1.77°) orientations in the V-frame. Thus: $t(126) = 5.48$, $p < .001$(5° L-frame and 5° V-frame); $t(127) = 5.61$, $p < .001$ (5° L-frame and 85° V-frame); $t(125) = 3.31$, $p < .005$ (85° L-frame and 5° V-frame); $t(126) = 3.47$, $p < .005$ (85° L-frame and 85° V-frame). Engebretson and Huttenlocher (1996) report that the reports at 5° and 85° deviate significantly from a normal (Gaussian) distribution. Therefore testing for differences among means was repeated with the non-parametric Mann-Whitney-U-test. Significance levels with this test show results with similar magnitudes as the reported p-levels.

Bouma and Andriessen (1970) show that the strength of tilt contrast effects depends heavily on orientation factors.

A third comment concerns an inconsistency between the model of Huttenlocher, Hedges, and Duncan (1991) and the finding that line orientations at imposed boundaries are reported with high precision. According to the model, line orientation at the central value of an imposed boundary distribution is classified in 50% of the cases as belonging to one category and in 50% of the cases to the other category. If this were the case, the categorisations would result in truncation and weighting in opposite directions for half of the cases each. This is not compatible with the high precision of the reports (low standard deviation) found at the vertical in the V-frame. Discussion of this aspect (high accuracy of reports at presumed boundaries) will however be postponed until later.

4.2.3.2.2. Interference Tasks and the V-Frame

Experiment 2 compares performance with respect to V-frames over a control condition and an interference condition. Notwithstanding the mentioned objections to the interpretation of their first experiment, the rationale behind the second experiment of Engebretson and Huttenlocher (1996) certainly presents a more difficult problem for perceptual accounts of bias. The category account holds that memory certainty influences bias strength. The more uncertain memory is the stronger the bias that is expected. Stronger bias is primarily (but not exclusively) due to the weighting of fine-grain orientation information with category information, that is, the weighting of a fine-grain value with the prototype value of the category. Increased uncertainty of the fine-grain memory trace leads to more weight on the prototype in the estimation process. Engebretson and Huttenlocher indeed find that when they administer an interference task between the encoding of the orientation of a line and the reproduction of the line, that the slope of the bias effect is steeper than the slope in a control condition. The manipulation of giving the interference task increases a participant's uncertainty and more uncertainty apparently leads to stronger bias. Radvansky, Carlson-Radvansky, and Irwin (1995) also show that increased uncertainty produces an increase in bias. They show that the bias strength in distance estimation correlates with the confidence that a participant expresses regarding her/his response. It is unclear how a perceptual account of bias could explain the results of Engebretson and Huttenlocher. It thus seems that, at least additionally, an effect different from perceptual effects is involved.

4.2.3. Bias by Perception and Categories

As also argued above, Tversky and Schiano (1997) do not consider the results of the first experiment of Engebretson and Huttenlocher to be convincing. They argue that the tilt illusion explanation would predict nothing but the V-frame findings. The results of the second experiment they do not see as being opposed to their own bias explanation. Rather they think it is complementary. Tversky and Schiano think that memory may be influenced by both perceptual and category factors. On the one hand, different contexts produce different bias patterns as shown in Tversky and Schiano (1989) and Schiano and Tversky (1992). On the other hand, in the ‘no context’ setting, the same bias pattern is found in both perception and memory conditions and this speaks for a perceptual basis. Bias however gets stronger when an interference task is given between encoding and reproduction from memory, and this speaks for an additional category effect in the ‘no context’ setting. Moreover, perceptual distinctions may be at the basis of categorical divisions and therefore perceptual effects may be similar to category effects.

Although to my knowledge no direct reaction on this reply from Tversky and Schiano has followed from Huttenlocher and colleagues, it appears that they might actually agree. This impression is evident from Crawford, Huttenlocher, and Engebretson (2000) in which an experiment is presented which explicitly aims at disentangling encoding and reconstruction (i.e., estimation) factors in the explanation of central-tendency effects (i.e., bias towards a central value of presented stimuli; see also

Huttenlocher, Hedges, and Vevea, 2001; Spencer and Hundt, 2002). The reproduction task involves line length. Both perceptual encoding factors and category factors are manipulated. The Müller-Lyer-illusion influences the apparent length of a line (a perceptual effect), while the stimuli used in the experimental set influence the estimation procedures (a category effect). The particular experimental set of stimuli is assumed to build expectancies on behalf of the participant regarding the distribution of instances over categories. This influences the central value that is used in weighting with fine-grain values. Crawford, Huttenlocher, and Engebretson thus assume and find that perceptual as well as category factors have an effect on the bias found in memory data. Opposed to the assumptions underlying the model of Huttenlocher, Hedges, and Duncan (1991), it appears that perceptual effects may bias fine-grain memory traces.

4.2.4. Summarising

It was shown that reports from memory for location show differences that depend on the co-ordinate system used by participants. Therefore, in the experiment described in Chapter 6, it needs to be discussed if participants use polar or Cartesian co-ordinates when they remember an Intrinsic Location. It was further shown that perceptual as well as category factors may influence memory reports. Notably, the tilt effect and the oblique effect are perceptual effects that may influence orientation estimates and memory for orientation. In addition, the encoding of location may include an orientation component (virtual line) that is subject to the same effects. Finally, category and perception factors may produce similar effects and may be hard to tell apart. Given the primary goal of establishing category effects in intrinsic spatial reference, effects found in memory reports have to be carefully considered in order not to prematurely describe them as category effects while in fact they are perceptual effects.

4.3. Memory for Location within Bounded Spaces

Quite some research has been reported regarding the reproduction of location in simple bounded spaces. An early one is Attneave (1955) for locations in a circle. Similar or somewhat different displays are used by Huttenlocher, Hedges, and Duncan (1991), Laeng and Peters (1995), Laeng, Peters, and McCabe (1998), Nelson and Chaiklin (1980), and Vorwerg (2003). Also early is research by Taylor (1961) and Lederman and Taylor (1969) for reproduction of location in rectangular field with and without landmarks. Werner and colleagues also study memory relative to up to two landmarks with or without the (rectangular) screen sides being visible (see Diedrichsen, Werner, Schmidt, and Trommershäuser, 2004; Schmidt, Werner, and Diedrichsen, 2003; Werner and Diedrichsen, 2002; Werner and Schmidt, 1999; 2000). An interesting note here is that Attneave (1955) already quite accurately predicted some of the basic findings of Werner and colleagues.[66] Similar or somewhat different quadratic or rectangular spaces are also used by Hartley (1978), Hubbard and Ruppel (2000), Huttenlocher, Newcombe, and Sandberg (1994), Igel and Harvey (1991), and Spencer and Hundt (2002).

The approaches to explaining experimental results are quite variable among the researchers. Basic to most of their finding is an increased accuracy on reference lines and/or landmarks and that a systematic deviation is found away from these references for locations that are close to them and towards some neutral value and/or prototype. It is far beyond the scope of this thesis to consider all this research. Only a small subset is discussed below. Some of the mentioned research is compatible with the view described below, while others are not.

[66] Attneave (1955) in particular hypothesized that "Given, for example, a pattern consisting only of two fixed dots on a vertical surface, one might expect the straight line passing through the dots, the perpendiculars to this line passing through either dot and bisecting the distance between them, the vertical and horizontal through either dot, and perhaps several other lines and curves bearing simple geometric relationships to the dots, to serve as implicit landmarks" (p. 80).

4.3.1. Circular Space I: Bias towards Prototypes

Huttenlocher, Hedges, and Duncan (1991) report four experiments to test their model regarding category effects on memory for location. All experiments concern memory for dot location within a circle. Presentation response apparates vary over experiments, but all reporting involved drawing (with a pencil on paper or with a stylus on a digitising pad). The general aspects of the model were discussed in Section 4.2.4.1. Regarding memory for locations in a circle, Huttenlocher *et al*. make the following additional assumptions. Fine-grain encoding can be conceptualised in terms of independent polar co-ordinates. An angular position and a radial position are thus defined within the circle. Location is defined by imputing the shortest (virtual) line from the test location to the circumference (which is objectively available) whereby the line's length defines radial position and the line's orientation defines angular position. Category encoding classifies a location as being in one of four quadrants. The quadrants are formed by subjectively imposing a vertical and a horizontal boundary through the centre of the circle. Body axes may be instrumental in defining these imposed boundaries (i.e., a circle has no intrinsic axes; see Chapter 2). The circumference functions as an objectively available boundary. The expected bias pattern is away from actual and imposed boundaries and towards some central location (prototype) in each of the quadrants. See Figure 4.7.

In four experiments, Huttenlocher *et al*. show that the expected bias pattern actually emerges. They conducted the first two experiments to demonstrate the use of independent polar co-ordinates (fine-grain values) and the organisation of the circle into quadrants with prototype values (categories). The other two experiments were conducted to explicitly test the formal model (see Section 4.2.4.1). Experiment 3 investigated the decrease of bias at uncertain boundaries by using test locations close to these boundaries. Experiment 4 investigated if stronger weighting with the prototype values results when the variability of memory recollections (i.e., uncertainty) is increased through the administration of an interference task.

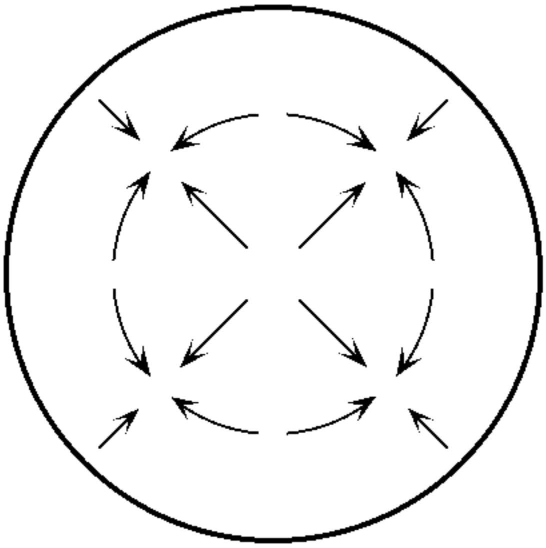

Figure 4.7. The bias pattern found in memory reports for locations within a circle. Bias effects (arrows) are magnified to enhance visibility.

The basic findings are the following. Radial error and angular error seem to be independent because memory reports reveal no significant correlation between radial and angular co-ordinates. Angular bias and radial bias are towards the quadrant centres. Test locations close to the assumed imposed boundaries (the horizontal and vertical axes) lead to more quadrant misclassification and therefore lower angular bias. Bias towards quadrants centres (i.e., the assumed prototype values) increases in strength after an interference task. Huttenlocher, Hedges, and Duncan conclude that their model is suited to explain the findings and that weighting of fine-grain values with category prototypes results in accuracy of reproduction that is higher than reproduction accuracy resulting from fine-grain values only.

4.3.1.1. Circling in for a closer Look

The uncertainty associated with the fine-grain memory recollections –as estimated by fitting the model– is surprisingly high. For example, the uncertainty of angular fine-grain values is estimated with a standard deviation of about 50 degrees. Because the variance of the fine-grain memory recollection is thus by far higher than the variance of the uniform distributed quadrant category (which has a standard deviation of about 26°) Huttenlocher *et al*. conclude that weighting has helped participants produce more accurate reports. Intuitively, however, a standard deviation of 50 degrees for memory recollections of angular values seems far too high.[67] Indeed, a closer look at the way the variance was estimated reveals a serious mistake. The found regression coefficient describing the bias slope over the category (quadrant) was used in an incorrect manner. The typical found slope of -0.2 was used to estimate fine-grain memory variance by dividing the variance of reports through the regression slope's square. However, the slope is not a measure for the weight given to fine-grain memory recollections and therefore it is not a measure for the variance reduction of reports compared to fine-grain recollections.[68] Instead, the slope is a measure for the weight given to the central value of the category. The correct typical weight given to fine-grain memory recollection is therefore 0.8. Using this value to estimate the variance of fine-grain memory recollection reveals that the standard deviation of fine-grain recollections is only about 12.5 degrees according to Huttenlocher *et al.*’s model. The variance of fine-grain recollections is thus smaller than the variance of the distribution of instances over the

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[67] This value would imply that about 63% respectively 93% of the recollections fall into the range mean ± 45° respectively mean ± 90°, which represents $^1/_4$th respectively $^1/_2$ of the response space. Note that angular value is a circular variable. Instead of arithmetic mean and the variance of angles (linear statistics), the direction and length of the mean vector (or derived values; circular statistics) should be used. Using linear statistics as an approximation is usually no problem as long as variance of the circular variable is small. The 50° linear estimate of variable error seems too high, however, and should be taken with care (see Batschelet, 1982; Fisher, 1993).

[68] This can easily be apprehended when it is realized that more weight should be given to prototype values when fine-grain memory recollection variance is greater. More weight on the prototype produces steeper slopes (as is found in Huttenlocher, Hedges, and Duncan's (1991) experiment 4). Applying Huttenlocher *et al.*’s formula $\sigma_m^2 = \sigma_r^2 / \lambda^2$ by using different slope values as weights (λ), say -0.2 and -0.4, to the same variance of reports (σ_r^2) shows that fine-grain memory variance (σ_m^2) decreases with increasing slopes, which cannot have been intended.

quadrant categories. The conclusion drawn by Huttenlocher *et al*. that fitting the data onto their model shows that weighting fine-grain memory recollections with the central value of the category produces more accurate responses cannot be accepted because of fine-grain variance being higher than category variance.

This does not necessarily mean that weighting does not produce more accurate responses (it only means that the reason to assume that weighting produces more accuracy is not confirmed). To see if weighting has a positive effect on accuracy of reports, it is possible to take the model's predictions and consider the resulting absolute angular error as a measure for accuracy. It is assumed that the fine-grain memory distribution has a standard deviation of 12.5 degrees for all angular true values.[69] If reports were not influenced by category information, and only fine-grain values are used to define a response, then the mean absolute error will be almost 10 degrees. Figure 4.8.A shows the expected bias, standard deviation, and absolute error of reports from the fine-grain memory distribution only, that is, without the estimation mechanisms based on category information.

If only weighting is considered in which the weight given to fine-grain values is 0.8, but truncation is ignored, and all values are categorised correctly (as if boundaries were certain, that is, objectively available), then the expected bias, standard deviation and absolute error are as shown in Figure 4.8.B. Bias now shows a slope of -0.2, standard deviation changes by the weight to 10 degrees, and absolute angular error has a minimum of almost 8 degrees at the prototype and increases somewhat towards the boundaries of the category. This decrease in accuracy when closer to the boundaries is caused by the increase in bias there. If Figure 4.8.B is compared to Figure 4.8.A, it

[69] This assumption need not be valid. If it is accepted that participants encode an angular value and that the chosen kind of values determines which perceptual effects occur (Bryant and Subbiah, 1993; see Section 4.2.2), then it may be inferred that the oblique effect may influence accuracy of encoding and, following, the fine-grain memory uncertainty for different angular values. However, given that Huttenlocher, Hedges, and Duncan (1991) themselves ”consider the conditions under which a prototype would improve estimates of angular or radial location under the assumption of a uniform distribution of locations, and of equal (or roughly equal) inexactness for fine-grain values at different locations” (p. 357), the assumption seems justified.

becomes clear that the pure effect of weighting overall indeed produces reports that are more accurate. Overall, that is, averaging over the whole category from boundary to boundary, the increase in accuracy is about .96 degree.

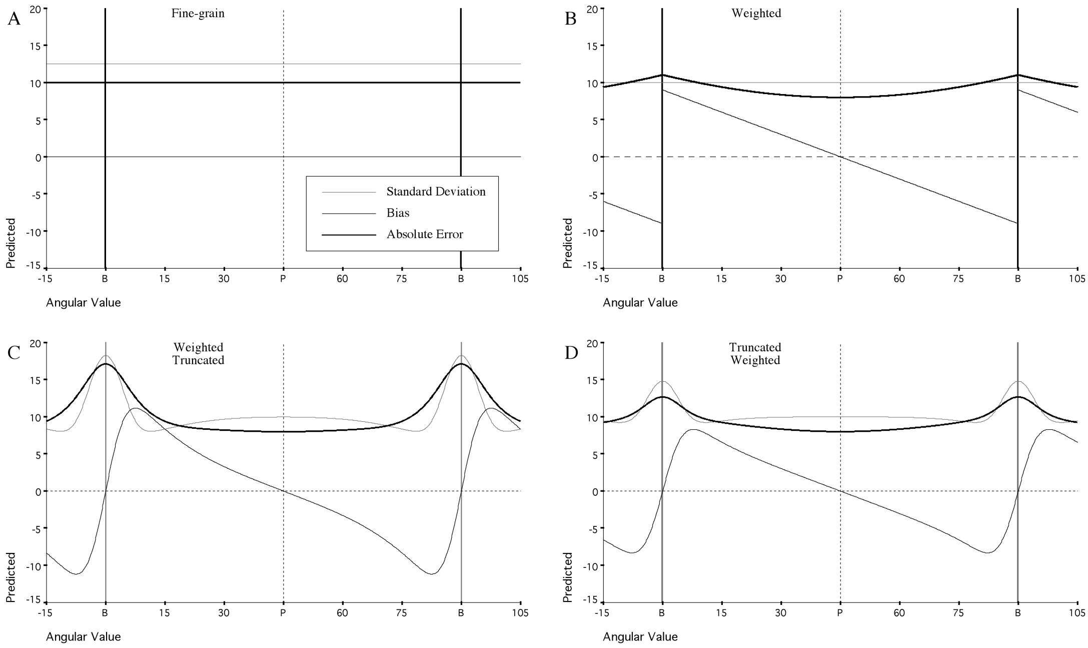

Figure 4.8. Bias, standard deviation, and absolute accuracy of memory reports for angular location according to the *corrected* specifications of Huttenlocher, Hedges, and Duncan (1991). A. Fine-grain recollections. B. Fine-grain weighted with the prototype value. C. Weighted Truncated reports. D. Truncated Weighted reports. Weighting improves accuracy only slightly. See text for details and see Section 4.2.3.1. Note that the probability density examples from Section 4.2.3.1 (see Figure 4.5 and Figure 4.6) provide accurate examples for specific points on the curves if the z-value there is multiplied by 12.5 and the probability density is divided by the same amount.

The model however not only involves prototype effects, but also boundary effects. Regarding angular values, effects of imposed uncertain boundaries have to be taken into account. Inexact boundaries cause that some angular values are compatible with classification in different categories, and cause truncation. Considering this, the expectations of the model change somewhat. It is assumed here that the inexactness of the imposed boundaries can be captured with a normal distribution centred at the vertical or horizontal that has a standard deviation of 4 degrees. This is compatible with

Huttenlocher *et al*.'s assertion that “angular distance must be 8 degrees from a horizontal or vertical axis for subjects to reliably determine in which quadrant a dot was positioned” (p. 361). The expected proportion of misclassification following from this assumed boundary distribution stays slightly below the reported 2.7% misclassification for angular values that are 8 degrees from an axis and the 10.6% misclassification for angular values that are 6 degrees from an axis (p. 364). The expected bias, standard deviation and absolute error for each of the two possible ways of combining truncation and weighting (as defined in Section 4.2.3.1) are shown in Figure 4.8.C and Figure 4.8.D. The curves show that when the full model is considered, that the overall increase in accuracy would be diminished somewhat compared to weighting alone. The average increase in accuracy over the whole category (compared to the accuracy of fine-grain values) is now about .81 degree when weighted distributions are truncated and only about .11 degree when truncated distributions are weighted. Misclassification and –following– weighting and truncation in opposite directions result in relatively high standard deviation and low accuracy close to or at boundaries.

Thus, whereas weighting considered on its own seems to produce reports that are somewhat more accurate overall (but not really that much), the application of the whole model to present circumstances diminishes the slight accuracy improvement or makes it almost vanish. The answer to the question if the use of category information, as defined in the Huttenlocher *et al*. model, produces more accurate reports probably depends on how weighting and truncation is combined and on how strong improvement in accuracy needs to be in order to be relevant. In addition, the question remains whether the small increase in accuracy can be shown empirically and statistically.

The relative inaccuracy of reports at horizontal and vertical orientations predicted by the model seems not backed by the data. Huttenlocher, Hedges, and Duncan (1991) only report with respect to angular locations at the horizontal and vertical axes that the standard deviation of reports is “in the same range as at other locations" (p. 358). The model would predict a somewhat greater standard deviation. This prediction is based on, among others, the assumption that fine-grain sample distributions have the same standard deviation over angular locations. It is possible to think that this assumption is false. According to the oblique effect (Appelle, 1971), perceptual angular accuracy is higher at horizontal and vertical orientations than at oblique orientations. In Section 4.2.2, it was made credible that if a location is coded (in part) by an orientation co-ordinate (as it is also assumed here), then the encoding is subject to perceptual encoding effects.[70] In the model of Huttenlocher *et al*., this would mean the following: The fine-grain recollection distribution would have less variance at or close to the horizontal and vertical, and therefore truncation effects would be less. Additionally, lower fine-grain uncertainty leads to more weight on the fine-grain distribution and less weight on the prototype value, and therefore bias effects of weighting would be smaller as well. However, this possibility cannot be evaluated, as it is not know how exactly weighting depends on the fine-grain inexactness, except for that it depends *somehow* on the ratio prototype inexactness to fine-grain inexactness. Additionally, a clear specification would be needed that defines encoding accuracy over angular orientations in the present situation. Note also that perceptual accuracy may produce differences in the accuracy of reports due to the precision with which a remembered location can be reproduced.

4.3.1.2. Interference and Bias

Notwithstanding this critical ado about various aspects of their model, Huttenlocher, Hedges, and Duncan (1991) do show that bias away from the vertical and horizontal axes and towards oblique orientations occurs reliably. Moreover, bias gets stronger when an interference task is administered between encoding and reproduction of a location. Interference produces steeper bias slopes. This as such is clearly in favour of

[70] In this experimental situation it is thus also possible that (part of) the bias effects are actually tilt effects. See also Vorwerg (2003).

the general characteristic of their model that more uncertainty leads to more bias. Unfortunately, they do not report measures of dispersion for memory reports in the interference task. It is therefore unclear how much the fine-grain distribution is affected by interference.

Summarising, it can be stated that the model of Huttenlocher *et al*. shows some insufficiencies, but that it is not possible to verify or reject (all aspects of) the model at this point. That the predicted increased variance at horizontal and vertical angular orientations is not found is however an interesting point. The description of angular variance at the horizontal and vertical was somewhat unspecific. Fortunately, there is an older –but quite similar– experiment on memory for location in a circle that allows comparison with Huttenlocher *et al*. The interpretation of the older findings differs markedly as well.

4.3.2. Circular Space 2: Bias away from Imposed Landmarks

Huttenlocher, Hedges, and Duncan (1991) happen not to be the first to consider memory for locations in a circle. In fact, the research of Huttenlocher *et al*. can be considered as a replication and extension of somewhat less recent results reported by Attneave (1955). Huttenlocher *et al*. seem unaware of this research as they do not mention it, but instead see their research as an extension of research by Nelson and Chaiklin (1980) who investigated memory for location on diameter lines in a circle. Attneave's research is more alike to Huttenlocher *et al*.'s in that he investigated memory for the location of a point in a big circular field. Responses were made by adjusting a spot of light to the remembered point location. Although Attneave tested each participant in his experiment only for locations in either the left or the right half of the circular field, the results are very similar to those of Huttenlocher *et al*. His data also show a systematic bias of reports towards some central point of a quadrant.

Attneave acknowledges that the bias results can be conceptualised as either a migration towards the interior of a quadrant or a migration away from the imposed horizontal and vertical diameters (which he calls ‘cross-hairs’, i.e., subjective landmarks) and the circumference (an objective landmark). The first option he calls ‘levelling’ (making a point more typical of the quadrant in which it appeared), the other he calls ‘sharpening’ (exaggerating the deviation of a point from the nearest landmark).[71] However, in contrast to Huttenlocher *et al.*, Attneave prefers the second option. His reason for doing so is that he observed that the variable error (i.e., the variability in reports) at the horizontal and vertical diameter of the circular field is smaller than variable error at other diameters. The decrease of variable error at subjective landmarks is similar to the decrease of variable error close to objective landmarks (the circumference). In both cases, constant error (i.e., bias) seems directed away from the landmarks. Both variable and constant error are thus related to the distance from landmarks. Bias effects are the result of repulsion only, from objective landmarks as well as from subjective landmarks.

Attneave further hypothesised that, when a point is clearly deviant from a landmark, participants tend to emphasise the deviation and exaggerate it. 'Clearly deviant' is meant to indicate that the location needs to be far enough from the landmark for the participant to notice the difference (although Attneave did not include any locations that were so close to a landmark, but not on it, that a deviation might go unnoticed). This kind of explanation of the findings has quite some similarity with the explanation given in an older article by Radner and Gibson (1935), which however does not treat memory for location but memory for object orientation. As a side step, I will consider their findings in the next section in order to clarify an alternative position to Huttenlocher *et al.*’s explanatory scheme.

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[71] Levelling and sharpening were dubbed in Gestalt theorists experimental work on distortions in the reproductions of figures to describes loss of detail (distortion towards good form) and addition of detail (exaggeration of deviations from good form) respectively. See, e.g., Wulf (1921) and see Crumbaugh (1954) for a review.

At present, the differences in explanation for similar effects are striking. Huttenlocher, Hedges, and Duncan (1991) hold that memory reports are biased *towards* prototypes and that the vertical and horizontal orientations serve as *boundaries* determining categorisation and truncation to comply with the category.[72] Attneave, on the other hand, thinks that the vertical and horizontal orientations are *landmarks* where memory is defined relative to and reports are biased *away from*. Additionally, Attneave thinks that locations may be encoded *at* the vertical and horizontal orientations, while Huttenlocher *et al*. think that locations at these orientations are always classified in a quadrant category. This contrast in explaining similar results illustrates nicely that assumptions regarding the set of available underlying spatial entities biases the choice of causal factors used to explain bias effects. Are bias effects an attraction towards some spatial entity or are bias effects repulsion away from some other (complementary) spatial entity? Note, however, that in both cases the horizontal and the vertical seem to have a special status. Clearly against the model of Huttenlocher *et al*. speak the findings of Attneave that variability is lower at the horizontal and vertical, and higher at the other diameters. For more recent results at odds with the Huttenlocher *et al*. model for similar reasons, see Schmidt, Werner, and Diedrichsen (2003).

4.3.2.1. Memory for Object Orientation

The explanation Attneave (1955) gives for the observed deviation away from the conjectured subjective landmarks resembles an explanation given by Radner and Gibson (1935) regarding the reproduction of the orientation of forms. In the first experiment they report, participants had to reproduce from memory the order of presentation and the orientation of 6 abstract objects, which had characteristics such as a straight base, parallel lines, and perpendicular lines to make orienting of the objects

[72] Bias resulting from truncation at boundaries cannot be equalled to the repulsion that Attneave has in mind. Truncation does not repel reports as such, that is, reports are not exaggerated. Instead, truncation only makes some part of the fine-grain recollection ineligible for reporting.

possible. Although the objects were tilted a few degrees (2 to 14 degrees) from the 'upright' orientation, participants failed to reproduce this tilt and usually only reproduced the 'upright' orientation. Participants' reports upon questioning suggested that they had not noticed the tilt. Still, the reproduced orientations were 'upright' and so one might conclude that the objects were simply perceived or encoded as 'upright'. In the second experiment, participants were made aware of the tilted character of the shapes, and their task was to reproduce this orientation. In this case, the tilt tended to be exaggerated. The overestimation of tilt was bigger for smaller tilts. Thus, if a participant *sees* an object as tilted (and thus encodes the tilt), then she/he exaggerates tilt whereas when a participant does not see the object as tilted, then he/she reproduces it upright.

In a third experiment, participants reproduced the orientation of a square in different orientations (0 to 45 degrees). In this case, the results were mixed, but there appeared to be a correlation of the results with how participants perceived the square as evidenced by participants' verbal reports upon questioning. If the orientation was slightly deviating from 'normal' (close to 0°, i.e. close to its sides being oriented vertical and horizontal), then participant exaggerated deviation. Exaggeration reduces to almost zero at the orientation that is halfway between the square and diamond orientation. In these cases (2° to 23°), the participants usually reported to perceive the object as a tilted square. If the orientation was closer to the other possible dimensionality of a square (28° to almost 45°, that is, close to the orientation of a diamond), then some participants reported they still perceived the object as a tilted square. For these participants no clear bias was observed. Other participants said they perceived the object as a tilted diamond in these orientations. These participants overestimated the tilt of the diamond, that is, they produced bias in the opposite direction than when the tilt of the square was exaggerated. Still other participants said they had perceived the object in these orientations as being 'nearly a diamond'. These participants reproduced the object orientation more to the diamond orientation than its actual orientation.

Radner and Gibson (1935) explain these results, and try to generalise to other perceptual domains, by assuming that the orientation of an object is coded with respect to 'a centre for the perception of orientation' as a specific example of a 'perceptual centre'. The 'upright' orientation is one such a centre and functions as a landmark. If participants do not consider the exact orientation relative to 'upright', then they do not code deviation from upright, and the reproduced orientation tends to be upright. If, however, participants do note the deviation of an object from upright, then they thus code this deviation, and the reproduced orientation tends to be exaggerated. Following, an object slightly deviant from the upright orientation can be encoded as '(about) upright' or as 'upright plus deviation', and the respective reproduced orientations will be biased in opposite directions.

According to Radner and Gibson, such perceptual centres may exist for many different perceptual aspects, and therefore the contrast between 'central and eccentric perception' can be applied widely. Thus, if a peculiarity of a stimulus is not noted, then the stimulus is reproduced at its landmark or reference value. If the peculiarity is noted, then the reproduced stimulus is exaggerated in this respect. The exact reasons for the exaggeration are not clear from Radner and Gibson, but they speculate that bias to a centre is the general principle in reproducing stimuli, and if a deviation is encoded, then the bias is towards another kind of centre, that is, a centre for eccentricity (from a reference value).

4.3.2.2. The Alternative Viewpoint regarding Memory for Location

The interpretation of Radner and Gibson (1935) can also be applied to the present domain, memory for location in a circle. Thus, it might be assumed that the horizontal and vertical orientations are landmarks, prototypes, and/or reference orientations for the encoding of the location's orientation (or direction) co-ordinate. Locations are encoded relative to the imposed vertical and horizontal reference axes. If the deviation from the vertical and/or horizontal orientation is encoded, then the deviation tends to increase in reproduction. Considering the task involved, that is, the encoding of one location in order to reproduce the location as accurately as possible, it can be argued that participants should encode deviations from landmarks and/or reference directions in order to enable accurate reporting. Encoding and reproduction at the horizontal and vertical axes is possible, when the location is actually there or when a deviation is too small to be perceived. This approach to spatial memory thus stresses the encoded deviation from prototypical reference values (lines, orientations, or directions) or landmarks. See also Franklin, Henkel, and Zangas (1995), Rosch (1975), Sadalla, Burroughs, and Staplin (1980), Schmidt, Werner, and Diedrichsen (2003), and Vorwerg (2003). The reasons for the observed sharpening of deviations from reference orientations are not quite clear. A possible attention mechanism can be found in Suzuki and Cavanagh (1997), while Spencer and Schöner (2000) propose an analogous mechanism for memory.

Not quite accidentally, this approach is congruent as well with the contrast made for memory for Intrinsic Location as opposed to linguistic reference to intrinsic directions (see Section 2.5). It was argued there that, while for language it may be enough that there is a similarity to one direction, for the accurate encoding of location always an encoding on both dimensions is needed. In particular, it is assumed here, regarding the coding of a location in a circle, that a location is defined relative to both the horizontal and vertical axes. If the location happens to be on one of these axes however, it only needs to be defined where it is on the axis, say, e.g., two thirds out (fine-grain) on the *top* part of the vertical axis (directed dimension). On the other hand, if a location is close to the vertical axis, but not on it, the location will be encoded by, e.g., specifying –next to some fine-grain specification– if it is *to the left of* or *to the right of* the vertical (half-) axis. With this, I do not mean to say that necessarily participants use these Directional Prepositions, but that at least a differentiation (not necessarily verbal) is made between the half-circles at either side of the vertical axis that can be referred to by these or similar terms. The same goes for the half-circles at either side of the horizontal axis.

Notwithstanding this interpretation of memory reports of locations within a circle, bias and accuracy effects found in reports are not necessarily caused by it. The accuracy of reports is expected to be highest at the vertical and horizontal axes and lower at other directions. This may be the case because of the imposed reference axes, because of the oblique effect, or because of both. Bias in reports is expected to be away from the horizontal and vertical (reference) axes (and, thus, towards the oblique orientations). This may be the case because of exaggeration of deviations from the cardinal axes, because of tilt effects, or because of both. One other option regarding the bias effects is that these are indeed towards some prototypical oblique orientation, whereby, however, this prototypical (reference) orientation is a secondary prototype, characterised by eccentricity relative to the primary prototypes, that is, the cardinal axes. It is thus possible to consider the bias effects as weighting with a prototype. The location is encoded with respect to horizontal and vertical, which have to be seen as the primary spatial entities. The secondary eccentric prototypes emerge because location has been coded as 'away from' the primary reference orientations. In addition, this possibility can also verbally be referred to, such as with, e.g., the *left and above* prototype.

4.3.2. Reconsidering Memory Capacity

The view presented in the last section may seem at first glance opposed to other research in which it has been found that deviations in memory reports seem to occur not away from reference directions but towards landmarks and prototypical directions instead. Tversky (1981) found, among other effects, that memory for geographical entities in maps tends to become aligned among one another along the cardinal axes, that is, along the *north-south* and the *east-west* axis. Also working with geographical knowledge, Stevens and Coupe (1978) find that memory for locations of cities are biased towards the general location of the state they are in. The organisation of cities within states is one example of grouping. Objects within groups are usually judged and remembered to be closer together than objects between groups. Grouping can be based on spatial proximity to a landmark (e.g., McNamara and Diwadkar, 1997), but can also be based on perceptual grouping principles as colour (Hommel, Gehrke, and Knuf, 2000), and can even be based on subjective principles as being a university building or a commercial building (Hirtle and Jonides, 1985). In any case, the organisation and/or grouping of these various situations seems to involve judgements that are biased to being closer to prototypes (i.e., cardinal directions or group means), and not biased to being farther away.

How can these findings and the above view be reconciled? This may be easier than it seems. First, it is important to note one important difference between the studies described in the last two sections and the literature just mentioned. In the former case, only a single spatial element had to be remembered in a simple controlled condition. In the latter case, the to-be-remembered situations were quite complex, typically involving many elements, which could also be in complex relation among one another. At this point, I like to refer back to the difference between store (capacity) and content-based research mentioned at the beginning of this chapter. Capacity limitations of the memory store for spatial information may force a difference in the encoding of spatial information in the two contexts. When participants are required to remember a single spatial characteristic, which they then have to reproduce as exactly as possible, there may no specific limitation for the memory store and the encoding thus involves both the prototypical spatial information and the deviation of the item from the prototype. On the other hand, when remembering multiple spatial entities in complex displays, capacity limitations may force participants to pay less attention to deviation from prototypes and to encode items as belonging to the prototypes.

Depending on the task at hand, participants may thus code a location either as deviating from an axis, or as being close to an axis, and opposite patterns of bias could be the result. It may be possible to design tasks in which participants do not explicitly code deviations. This may be the case because the deviation does not appear important to participants, because the deviation is ignored when the task load forces participants to such a strategy, or because the deviation is forgotten amidst other relevant information for the task. Unfortunately, there is no research known to me that explicitly tries to investigate if memory load has an influence on repulsion away from respectively attraction towards cardinal directions and/or other prototypes. One investigation comes close to doing this, but has to be interpreted carefully while bias patterns were investigated over the different conditions with only three full data sets. This is an investigation by Igel and Harvey (1991) and in their experiments participants had to remember the location of 1 to 10 dots on a screen with or without the presence of a rectangular frame. Considering only the cases where the frame was present, repulsion away from the vertical and horizontal axes of symmetry of the rectangular frame was observed when one or two dot locations (presented simultaneously) had to be remembered and reported. The effects were strongest in case of only one location. When even more location were presented simultaneously no systematic repulsion pattern was observed anymore, but no attraction to the cardinal axes either. In contrast, if dot locations were presented sequentially, an attraction to the centre of the frame was observed that got stronger the more dots were presented. Note that there was no control for the configuration of dots. Therefore, this research is considered only an indication that bias patterns may differ depending on the memory load involved.

4.4. Memory for Locations relative to Objects

In this section, memory for location relative to objects is considered. Analogous to the situation regarding intrinsic linguistic data with respect to objects, no research on memory for exclusively Intrinsic Location seems to exist. Again, research that uses experimental contexts with superimposed Frames of Reference needs to be considered. For the experiments described in this section, it is not clear which kind of spatial information is responsible for the effects found (if any). An axial system can be defined in relation to several superimposed Frames of Reference: An Intrinsic Object Centred frame (based on the Referent), a Relative Ego Centred frame (based on the participant), and an Environment Centred Frame of Reference (based on the gravitational vertical and/or the computer or the sheet of paper on which the stimuli were presented). The experiment described in Chapter 6 is designed to investigate memory for Spatial Relations in a purely Intrinsic Object Centred Frame of Reference. By manipulating the orientation of the Referent and by explicit instruction, it is assured there that only the Intrinsic Reference Frame is used.

4.4.1. Axes as Prototypes

The experimental situation used by Hayward and Tarr (1995) was explained in Chapter 3. One of their stimulus configurations was shown (see Figure 3.3). In their experiment 3 the task of the participants was to remember the location of the Figure with respect to the Referent and reproduce the Spatial Relation: A constellation of the Referent and Figure was presented briefly, would then disappear, and only the Referent would reappear. Participants had to put the Figure back in the location where it was before by using a computer mouse. The results show that the accuracy of the Figure position estimates follows a similar pattern as the linguistic data (as they interpret these). For locations in the horizontal direct regions (row 4), the error in the vertical direction is smaller than for locations in the other rows; for locations in the vertical direct regions (column 4), the error in the horizontal direction is smaller than for locations in the other columns. Hayward and Tarr conclude that Spatial Relations encode spatial forms as prototypes. The horizontal and vertical axes are thus thought to be axial prototypes that cause the pattern of results on the non-linguistic spatial tasks.

Munnich, Landau, and Dosher (2001) did not use reproduction of the Spatial Relation, but identity judgements as the spatial memory task in their experiments.[73] In this task participants were presented with a Spatial Relation in the encoding phase, and were presented with a Spatial Relation again in the reporting phase that was the same or slightly different. Participants had to determine if the Spatial Relation was the same or not. As mentioned in Chapter 3 when considering their linguistic data, Munnich *et al*. varied Figure location in the direct region as well. The performance of the participants showed a regional pattern. All Figure locations in the direct regions (all sub-divisions of this region) showed an enhanced performance compared to the other locations. Within these vertical and horizontal areas, no differentiation in performance (e.g., ‘on-axis’ locations, that is the central row/column of the direct region, as compared to ‘off-axis’ locations) was observed. Thus, although they did not use a Spatial Relation reproduction task (a recollection task), the results in the identity judgement task (a recognition task) do indicate enhanced discriminability for Spatial Relations over a region. The results on the non-linguistic memory task differ from those on the linguistic task, which showed an axial pattern. Munnich *et al*. conclude that “although axial structure seems to play an important role in spatial memory (...), the underlying spatial organisations that can be used in memory tasks are clearly quite flexible (...)” (p. 200).

The results of Hayward and Tarr as well as Munnich, Landau, and Dosher leave room for different explanations even when ignoring the different Frames of Reference

[73] Hayward and Tarr's (1995) experiment 4 was also an identity (same/different) judgment task. A pattern of results similar to the reproduction task was found even though screen position of the Figure-Referent constellation changed between encoding and same/different judgment (this excludes some of the possible Frames of Reference of being potentially responsible for the results).

that could be responsible for the –presumed– axial prototypes. A perceptual account of the findings may invoke the oblique effect if it is assumed that the orientation and the distance of the proximal distance vector encode the Spatial Relation between Figure and Referent. In the direct regions, the orientation component of the encoded Figure location would then be horizontal or vertical and be associated with enhanced accuracy. See Figure 4.9, locations A and C. All other Figure locations would involve an orientation component, which is (more or less) oblique. See Figure 4.9, location B. There is also another difference between Figure locations in the direct regions and those in the other (oblique) regions. If a proximal distance vector is encoded, then, in direct regions, the vector is defined perpendicular to a side of the Referent as well as parallel to other sides of the Referent. In contrast, in the other regions, the vector is defined from a corner of the Referent, and not parallel to any of its sides. See Figure 4.9, locations A, B, and C.

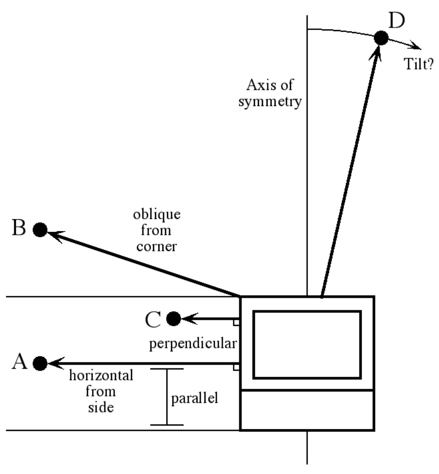

Figure 4.9. The Referent used by Crawford, Regier, and Huttenlocher (2000) and four Figure locations. Locations A and B are similar to locations used by Hayward and Tarr (1995). Location C is similar to a location used by Munnich, Landau, and Dosher (2001). Location D is similar to a location used by Crawford *et al.* (2000). Locations A, B, and C are based on proximal distance. Location D is defined from the centre-of-mass. Encoding of the locations is confounded with different factors. See text for details.

4.4.2. Axes as Boundaries

In Crawford, Regier, and Huttenlocher's (2000) experiments 1 and 2, participants first rated the applicability of *above* with respect to Figure-Referent configurations (see Chapter 3), and then reproduced the Spatial Relations by putting the Figure back in its former position by using a computer mouse. In contrast to the experiments of Hayward and Tarr (1995) and Munnich, Landau, and Dosher (2001), the linguistic and non-linguistic data were not obtained in independent experiments. It is therefore possible that the rating of Spatial Relations influenced the subsequent reproduction of the Spatial Relations. Crawford *et al*. however conclude –because they interpret the results as showing an opposite pattern– that this possibility is improbable. Next to accuracy of the reproduction, Crawford *et al*. also consider the bias of the distributions of Figure positions, i.e., the direction and distance of the mean of the reproduced Figure positions from the true location of the Figure. What they found is that reproduction is relatively accurate on the Referent's axes and that the less accurate reproduction estimates on the remaining test locations show a bias away from the axes and towards a position in between the axes. These results are interpreted according to the model of Huttenlocher, Hedges, and Duncan (1991; see previous sections). Interpreting the results with this model lead Crawford, Regier, and Huttenlocher (2000) to conclude that prototypes of spatial categories exist in between the vertical and horizontal axes, that is at the oblique orientations. They also conclude that the horizontal and vertical axes are boundaries between the quadrant spatial categories.

Crawford, Regier, and Huttenlocher do not consider the two kinds of bias specified in the model of Huttenlocher, Hedges, and Duncan (1991) separately. Bias away from category boundaries and bias resulting from the weighting of the two memory traces point in the same direction and are considered as a whole. Whether the observed bias is a bias towards prototypes, a bias away from boundaries, or both remains unclear. The bias away from the horizontal and vertical axes that Crawford *et* *al*. found may have been caused by boundaries and not by prototypes, or only by prototypes and not by boundaries. They thus assume that the bias pattern reflects four mutually exclusive regions.

In the experiments of Crawford, Regier, and Huttenlocher (2000), the reproduction of the Figure in positions on the horizontal and vertical axes is more accurate than in other locations. Contrary to Hayward and Tarr (1995) enhanced accuracy is associated with category boundaries and not with prototypes. Crawford *et al*. point out that there should be better discrimination of locations at category boundaries. The model of Huttenlocher, Hedges, and Duncan (1991) does not account for this particularity. In particular, Crawford *et al*. hold that spatial categories can be expected to "be characterised by enhanced discrimination at category boundaries, and by estimation bias away from boundaries and towards prototypes, and by an increased category effect under conditions of higher uncertainty" (p. 213). This characterisation of the effects of spatial categories on reports from memory appears partially contradictory to the model of Huttenlocher, Hedges, and Duncan (1991). Primarily, in case of uncertain imposed boundaries, a location at a spatial boundary would be categorised as one of the neighbouring spatial categories in 50% of the cases, and become biased by boundary truncation and prototype weighting according to that category. In the other 50% of the cases classification in the other category results and bias in the opposite direction follows. Crawford *et al*.'s mention of better discrimination at category boundaries seems at odds with this aspect of the model. This is not to say that the model cannot account for encoding accuracy differences over a spatial category, only that it is questionable if an enhanced accuracy at boundaries can overcome the variability increasing effects of opposite bias at imposed boundaries to produce smaller variability in reports for locations at boundaries than for locations that are not at boundaries.[74]

[74] Higher discriminability at boundaries may have the following effects in the model of Huttenlocher, Hedges, and Duncan (1991). First, the variability of the fine-grain recollections is reduced. As a result, more weight is given to the fine-grain value and less to the category prototype. Less bias towards the prototype will occur. Additionally, less fine-grain variability will diminish the biasing effect of boundary

A perceptual account of the bias findings may invoke the tilt effect in particular if an axis of symmetry is available in the Referent (see Section 4.2). In the first experiment, the Referent has a vertical axis of symmetry (see Figure 4.9), while in the second experiment both the horizontal and vertical axis of the Referent are axes of symmetry. If, again, the location of the Figure is encoded with an orientation component, then the perceptual tilt effect may produce bias away from the axes of symmetry. See Figure 4.9, locations D, whose orientation component is not based on proximal distance but on the centre-of-mass of the Referent.

4.4.3. Axes as Boundaries, Half-Axes as Best Examples

The attentive reader probably has some idea already about the present view regarding memory for locations relative to objects. Similar to memory for location within a circle (Section 4.3), it is hypothesised that instead of four mutual exclusive regions (i.e., spatial categories) two pairs of orthogonal oriented, non-exclusive opposite regions (half-planes) are responsible for the results. Locations are encoded on two dimensions. If a location is to be remembered (encoded) that is close to the vertical axis extending upwards from the Referent, then it can be encoded by means of this axis (**y** on **[+Y]**), but is encoded as well on the orthogonal dimension (**x** on **[+X]** or on **[–X]**). Bias effects are an exaggeration of the deviation from the vertical axis (**x + c**). Locations on the vertical axis extending upward from the Referent need only be encoded by this half-axis (**y**, while **x = 0**). Possibly, the use of this axis is responsible for the enhanced accuracy on this axis. It is though explicitly assumed here that a location can be encoded *at* an axis although that axis is the boundary of the orthogonal oriented half-planes.

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truncation. Also, the boundary itself may be imposed with less variability (see Engebretson and Huttenlocher, 1996, or see Section 4.2.3). As a result, reports influenced by the effect of the boundary on categorization and reports influenced by boundary truncation will be restricted to values that are closer to the central boundary value than if there were more boundary variability. However, truncation bias from less variable boundaries is stronger than truncation bias from more variable boundaries.

Next to this explanation in terms of these spatial categories, there may also be perceptual influences on the results. Good candidates for such effects are the tilt effect and the oblique effect. As was made plausible in Section 4.2, it is not necessarily the case that either the category effects or the perceptual effects are causal for the results. Both may have an effect. Additionally the possibility exists that the perceptual effects are causing the spatial categories. Not to be excluded either is the possibility that the bias effects are caused by weighting with prototypes. The spatial prototypes would then however be the central values of the secondary spatial quadrant categories that emerge from the primary orthogonal oriented regional oppositions. If a location is coded on two dimensions, the dimensions may effectively combine to spatial quadrant categories.

This interpretation complies with the view described in Chapter 2 that a location needs to be coded on two dimensions regarding memory for (intrinsic) location relative to objects. When a participant is asked to reproduce the position of a Figure as exactly as possible, it does not suffice for the participant to remember that the Figure was *above* the Referent (defined as either a spatial category and/or as a linguistic category), but also *where above* the Referent the Figure is located. This interpretation is appealing for another reason. In this way, two kinds of memory traces in spatial location reproduction tasks can be assumed: One fine-grain value on each dimension, and a categorical interpretation on each dimension. A specific value (**x**) is thus defined on the **[+X]** or **[–X]** dimension and another specific value (**y**) is defined on the **[+Y]** or **[–Y]** dimension. Similar to Huttenlocher, Hedges, and Duncan (1991), fine-grain values and category values are defined.

Chapter 5. Intrinsic Locations, Language, and Memory

When considering the connection between the linguistic description of Directional Relations and their (non-linguistic) spatial representation, it can be asked how this connection evolved. One possibility is that perceptual and/or spatial representations provide a vast amount of spatial distinctions, while some of these are described (referred to) by the linguistic categories that are available in a language (Clark, 1973; Landau and Jackendoff, 1993; Li and Gleitman, 2002). Another possibility is that language defines which spatial representational content is made readily available for linguistic expression as well as for non-linguistic goals (Levinson, Kita, Haun, and Rasch, 2002).[75] In any case, however, if spatial representations shape linguistic categories or if linguistic behaviour shapes spatial categories, then there should be similarities in their respective structure. To find out if such is the case, some researchers have decided to administer spatial language tasks and non-linguistic spatial tasks relative to the same spatial configurations and compare the results for similar patterns (Crawford, Regier, and Huttenlocher, 2000; Hayward and Tarr, 1995; Munnich, Landau, and Dosher, 2001).

Like these researchers, the non-linguistic spatial task of the experiment described in Chapter 6 is a memory task. However, assuming that in a spatial memory task, the task is only solved spatially and not at all linguistically is nothing more than that: An assumption. It is perfectly well possible that in a spatial memory task linguistic labels are used to remember a location. This is not necessarily a problem, however. If linguistic labels and/or conceptual categories are used in the spatial memory task, it is still possible to consider results on these tasks for category influences and compare

[75] Levinson, Kita, Haun, and Rasch (2002) do not promote a complete 'linguistic relativity' view. They suggest that there are “universal computational primitives (axes, angles, vectors) which have bases in perceptual motor systems” (p. 184).

these to linguistic data. Thus, one may compare results from the same linguistic spatial categories, only obtained on different tasks, and involving different data. The potential use of linguistic labels in assumed non-linguistic spatial tasks may even be unavoidable. What use would it be to investigate spatial representations in order to find similarities to linguistic behaviour, if participants could not have linguistically labelled the spatial categories that one finds in a spatial task? That is, it may be hard to find a spatial task with which spatial representations are investigated that could be the basis for linguistic behaviour, but that excludes the possibility that participants use linguistic labels in the task itself. Given that both the linguistic task and the memory task are spatial in nature, it is assumed that they both tap on the same underlying perceptual and/or spatial representations. Otherwise, that is, if the two types of tasks use different representations, any similarity in patterns of results over the types of tasks would simply be coincidentally.

It is thus assumed that an underlying representation is used to remember an Intrinsic Location and to describe a Spatial Relation in an Intrinsic Object Centred Frame of Reference. In particular, there is an intrinsic description of a Referent that can be used to define a location and that can be used to categorise a Spatial Relation. The question is not simply if linguistic data and location memory reports show exactly the same pattern. Rather, it needs to be specified how the assumed underlying intrinsic representation of a Referent is used to define Intrinsic Locations that can be remembered on the hand and used to categorise a Spatial Relation as a Directional Relation on the other hand. If the same underlying representation is used for two different tasks, the results on both tasks should provide a better insight in the character of the underlying representation than one of the tasks on its own.

5.1. Memory, Language, and Locations relative to Objects

The relation between the effects of Spatial Relations on spatial memory tasks and the effects of Spatial Relations on spatial language tasks has not yet been considered with respect to a purely Intrinsic Object Centred Frame of Reference. Research has however been done on situations with superimposed Frames of Reference. First, therefore, the relations proposed in those situations will be considered because the insights obtained there may be helpful to formulate hypotheses with respect to the present subject.

5.1.1. Direct Correspondence

The main rationale of Hayward and Tarr's (1995) research is that if particular Spatial Relations can be shown to have an effect on a non-linguistic spatial task such as the reproduction memory task, then this is evidence for the organisation of spatial representations that is independent of the use of spatial prepositions. Because the same distribution of effects is –according to their interpretation– found in a linguistic (see Chapter 3) as well as a non-linguistic spatial task (see Chapter 4), Hayward and Tarr make the assumption that “Spatial Relations in non-linguistic systems and spatial predicates in language both encode spatial forms as prototypes” (p. 76) and that this correspondence is not accidental. Hayward and Tarr conjecture that spatial information represented as axial prototypes causes the same pattern of results on linguistic as well as non-linguistic spatial tasks.

Munnich, Landau, and Dosher (2001) also observe a correspondence between the results of the linguistic and the non-linguistic tasks in their experiments. This correspondence, however, appears not as perfect as in the experiments of Hayward and Tarr, which is directly due to the use of more locations within the direct regions. The clear axial pattern found in the linguistic data was not reflected in a similarly clear axial pattern in the non-linguistic memory data (i.e., identity or same/different judgements).

They still conclude however that spatial memory and spatial language similarly engage axial structure, although this property is not mandatory across the two tasks.

The relevant question regarding Munnich *et al.*'s results is if a single representation of directional spatial information (whether represented as axial prototypes or in a different format) can account for a regional pattern on a non-linguistic spatial task, and an axial pattern on a linguistic spatial task. Their results at least weaken the simple equation 'the better the reproduction, the more linguistic prototypical the location'. It is possible therefore to question the presumed link between better memory performance and prototypicality of linguistic expressions that both Hayward and Tarr and Munnich *et al*. assume (see also Eshuis, 2003).

As explained in Chapter 3, the interpretation of the Spatial Relation description tasks is primarily based on the particular manner in which the data were analysed, that is, by only considering the first Directional Preposition in a description (Hayward and Tarr) or by considering only those descriptions in which a single Directional Preposition was used (Munnich *et al*.). Also, the interpretation of the Spatial Relation rating tasks and especially the relevance of rating to the goal of describing Spatial Relation with Directional Preposition, that is, providing the addressee with a means to quickly locate the Figure, was questioned.

5.1.2. An Inverse Relation

Crawford, Regier, and Huttenlocher (2000) interpret their findings as pointing to an inverse relation between spatial language and spatial representation. In particular, they find that boundaries on the spatial level (i.e., the cardinal axes) are reflected in spatial language as prototypes. Hence, they suggest an inverse relation between spatial language and spatial representation. According to Crawford *et al*., a single structure may underlie categorisation in non-linguistic and linguistic spatial tasks; the structure plays a different role in the two tasks, however. This sounds strange: An underlying representation with a structure that reveals itself with prototypical cardinal axes in language tasks and with bounding cardinal axes in memory tasks. This claim asks for a more detailed explanation. However, except for pointing out that the results are not be predicted by both camps on the evolvement of the relation between spatial representations and spatial language mentioned at the beginning of this Chapter, no further specification of how an inverse relation would have evolved is given. The question remains therefore how an underlying representation can produce such opposite effects and what use a representation is that gives a structure to memory that cannot be directly expressed in language. What is needed to give some credibility to their claim is a specification of how a Frame of Reference can be used to encode locations as well as categorise Spatial Relations, and whereby differences in data patterns over spatial language and spatial memory tasks must be explainable from this specification.

One reason why Crawford *et al*. come to this unconventional relation is their (implicit) assumption of four mutually exclusive regions. However, although, e.g., *above* is opposed to *below* and mutually exclusive regions may be necessary at an underlying non-linguistic level to account for this, *above* is not necessarily opposed to *to the left of*. Thus, the regions that *above* and *to the left of* refer to may be partially overlapping. *Left* versus *right* and *above* versus *below* may refer to two pairs of mutually exclusive half-planes oriented in an orthogonal manner. The four quadrant spatial categories that Crawford *et al*. find may thus be the result of a combination of directional and/or regional oppositions.

One more aspect of the model of Huttenlocher, Hedges, and Duncan (1991), that diminishes its application to the present subject, has not yet been discussed. Within the model, fine-grain values and category values are not directly linked, but instead specific locations (fine-grain values) are encoded and categories are encoded. The category simply defines a range of values (locations) and the two memory traces are therefore only implicitly linked. The side on which a location is relative to the boundary value defines its category encoding, but the location is encoded neither by a deviation from the boundary, nor by a deviation from the prototype. The specification of the fine-grain value like this is contradictory to the (see Chapter 1) suggestion that location is always defined relative to some reference. Location has no (pair of) values as such, but always needs a Frame of Reference (co-ordinate system) in order to be defined. The need to explicitly link fine-grain values to category or boundary values is even clearer when considering Intrinsic Locations. The locations around a Referent that belong to an Intrinsic Region depend on the Referent's orientation. Participants need to take this orientation in space into account. Therefore, there can be no definition of an Intrinsic Location except for when the encoding of the location is defined relative to the Referent's orientation and its intrinsic directions (see Chapter 2). The experimental method of the experiment in Chapter 6 involves an orientation change of the Referent between the encoding phase and the recollection phase. If the location to be remembered is not explicitly linked to one or more of the Referent's intrinsic directionality parameters at encoding, correct reproduction of the Figure location will not be possible in the reporting phase.

5.1.3. Direct Correspondence, Independent Orthogonal Dimensions

The present interpretation for the connection of results on spatial memory and spatial language tasks regarding situations with overlapping Frames of Reference will stress results concerning the description of Spatial Relations. These results show that a single Directional Preposition is used only within (a part of) the direct region. Figures at other locations around the Referent are described with two Directional Prepositions. This is taken as an indication that the content of the spatial representation that the Directional Representation refers to is regional rather than axial. It is thus assumed that a directional opposition (e.g. *above* as opposed to *below*) is defined more widely than in the direct region (at least including the oblique region). A Frame of Reference (any of the superimposed possibilities) is centred on the Referent, the *top* and *bottom* parts of the Referent are contrasted, and the space surrounding the Referent is associated with this contrast. The *left-right* axis bounds the resulting Directional Region opposition. A similar contrast is made by means of the *left* and *right* parts and the *above-below* axis bounds this Directional Regional opposition.

If the Figure is located on or close to the *top* half-axis, i.e., in the direct region for *above*, then it is also located on or close to the *left-right* boundary, and it suffices for the speaker to use only *above* to describe the Figure location in order for the addressee to easily find it. The Figure location on the orthogonal dimension is neutral (on the axis) or can be ignored (close to the axis). If the Figure is located in an oblique region for *above*, then it is also located in the oblique region for, e.g., *to the left of*, and the speaker usually uses *above and to the left* to signal the location of the Figure to the addressee. A Spatial Relation will thus be described with a single Directional Preposition if the orientation component of the Spatial Relation is *similar* enough to one of the half-axes (that is, similar enough to the boundary of the orthogonal directional opposition) and with two Directional Prepositions otherwise. A Figure location on the *above* half-axis will be rated with the highest applicability while it is located on the boundary between *left* and *right*. It is therefore the best example for *above*. Figure location away from the half-axis will be rated lower while the Figure is also located in the *left* or *right* region.

The same contrasting structure on the Referent can be used to explain findings on spatial memory tasks. A location is always defined on both dimensions, except when it is exactly on the boundary of a directional opposition. If a Figure is located exactly on the *above* half-axis, only *above* needs to be remembered (and of course a fine-grain coding specifying where exactly on the half-axis the Figure is), but no *left* or *right*. Reports for location on the axes appear to be accurate. Although I just now described the category encoding by means of Directional Prepositions, this does not necessarily need to be the coding that participants actually use. They could use any linguistic labelling or a kind of marking as, e.g., **[+Y]**. The point is simply that they differentiate somehow between opposing regions, and might even use language for this. If a Figure location now is close to the *above* half-axis, then, in contrast to description, the location cannot only be coded by *above* (or some spatial equivalent) for accurate reporting. Instead, participants also need to code the fine-grain deviation from the half-axis together with a categorical specification *contrasting left* (alternatively **[+X]**) versus *right* (**[-X]**). Reports from such locations appear to be less accurate and to show an exaggeration of the encoded deviation (bias).

A Frame of Reference may thus define structure on and around a Referent that explains both spatial language and spatial memory. The two tasks use the same structure somewhat differently however (similarity versus contrast for locations close to axes). Because the same structure is used, the spatial distinctions are similar over the tasks. It cannot be excluded that labels used in spatial language are also used in spatial memory.

The present view has some commonalties and some differences with the views of Hayward and Tarr (1995) and Crawford, Regier, and Huttenlocher (2000). Axes do function as boundaries (as in Crawford *et al*.), but as boundaries between half-planes, and not between quadrants. Half-axes do have a function as well in the correspondence between the representation of directional Spatial Relations and linguistic reference to such relations. Positions on half-axes (vectors coinciding with half-axes) are the best examples of Directional Prepositions (instead of prototypes, but similar to Hayward and Tarr). These positions are categorised only in terms of one of two spatial dichotomies.

Using axes as boundaries to establish spatial dichotomies is an example of a feature model. Being located on one or the other side of an axis is necessary and sufficient for categorisation. At first glance this seems in sharp contrast to Hayward and Tarr who propose a purely prototypical model in which goodness-of-fit measures determine categorisation. See Talmy (1983) and Hayward and Tarr for a discussion of prototype and feature models in the present domain. However, the feature aspect of the present interpretation applies to categorisation within a dimension (i.e., categorising a Spatial Relation as one Directional Relation or as the opposite Directional Relation). Therefore, the present approach does not exclude that goodness-of-fit measures are used to determine if a Spatial Relation matches more with one half-axis or with a half-axis of another dimension. Prototype-like effects in linguistic behaviour, such as the *graded* effects in applicability ratings, may thus occur when the orientation of a vector is compared with two half-axes.

5.2. Intrinsic Reference: Memory and Language

Intrinsic Object Centred Reference for language as well as memory is assumed to be based on the same intrinsic description of the Referent. The present specification holds that – in the 2D object centred situation – intrinsic axes are boundaries between pairs of regions and half-axes serve as the best examples of regions. Bounding axes separate the Directional Parts of the Referent and the contrast between pairs of opposed Directional Parts is extended to surrounding space. If Directional Parts are contrasted by a bounding axis, the bounding axis at the same time contrasts the half-axes of the orthogonal axis. These contrasted half-axes become the best examples of the Directional Regions.

This present view is illustrated in more detail by considering how an Intrinsic Object Centred Frame of Reference might be imposed on a Referent. It is assumed that establishing an intrinsic Frame of Reference is an active process requiring attention (Logan, 1995) and that the frame has to be extracted from the Referent's structure. Considering the extraction is also important given the experiments described in Chapter 5. The experimental task involves reproduction of an intrinsic Spatial Relation while the Referent changes its orientation between encoding and reproduction of the Spatial Relation. Therefore, a Frame of Reference has to be extracted during the encoding of the Spatial Relation (in order to remember the Figure's location relative to the Referent's intrinsic structure) as well as during the reproduction of the Spatial Relation (in order to apply the remembered information to the Referent's changed orientation). The ordered extraction of directionality for linguistic purposes is shown to be applicable on the coding and reporting of Figure locations as well.

First, the use of intrinsic structure for spatial memory is described. Then the use of the same structure for spatial language is considered. Finally, effects of the ordered assignment of directionality are discussed for both spatial memory and spatial language.

5.2.1. Intrinsic Structure and Spatial Memory

Figure 5.1.A1 shows a possible Referent (the egg) with a Figure (the small circle). The Referent was used before in Chapter 3. Based on the Referent's features the Figure's location has to be assigned to regional categories and therefore the space surrounding the Referent has to be divided. The only features of this Referent are shape features. An interpretation of the shape structure has to be extended outwards into regions around the Referent. Two axes can be defined on the Referent, one being an axis of symmetry (axis **[Y]**) and the other oriented orthogonal to this axis (axis **[X]**). See Figure 5.1.A2. It is assumed here that (reflection) symmetry is a strong perceptual grouping principle (see, e.g., Wagemans, 1995) and that axis **[Y]** is represented on the perceptual object because of perceptual processing. As shown in Chapter 4, an axis of symmetry can be used as a reference axis and/or as a boundary.

The status of axis **[X]** is less clear. Here axis **[X]** is positioned in such a way that it intersects the contour at its greatest width. Other positioning is possible: Axis **[X]** might intersect axis **[Y]** at the Referent's centre of gravity or at axis **[Y]**'s midpoint. Axis **[X]** may be represented less precisely as suggested in Figure 5.1. Boundaries in the model of Huttenlocher, Hedges, and Duncan (1991) can be imposed with degrees of inexactness. This could be the case for axis **[X]** as well. Finally, axis **[X]** may not be represented at all yet, and may instead be constructed as a result of contrasting object parts as described below.

No directional information is available at this point. The presence of an axis of symmetry only signals that the Referent is reflection invariant about axis **[Y]**. It is important to acknowledge the difference between axes (dimensions) and the sign attached to half-axes (directions; see Landau (2003) for some interesting observations regarding the independence of the representation of axes and the representation of directionality assigned to axes). Using or imposing axis **[X]** as a boundary, the two object parts separated by this axis can be differentiated by their shape (Part **[+Y]** versus Part **[-Y]**). See Figure 5.1.A3. In the Figure, the parts are sharply bounded by the axis. This is not necessarily the case. There may be a less sharp boundary between the parts, but some contrast between the parts is definitely needed. Two half-planes as well as the two half-axes of axis **[Y]** are also separated by axis **[X]** and can be associated with the differently shaped object parts. When the part difference is extended to the half-planes, a first pair of regions can be distinguished (Region **[+Y]** versus Region **[-Y]**). When the part difference is extended to the half-axes of axis **[Y]**, half-axes can be distinguished (Half-axis **[+Y]** versus Half-axis **[-Y]**) and the axis becomes directed.[76] See Figure 5.1.A4. Importantly, it has to be established first that object parts are different before the difference can be extended to regions outside the object and to half-axes, because intrinsic reference has to be based on the Referent's structure. Intrinsic reference is only possible when distinctions within the Referent's structure can be made. In this example, the distinctions are within the shape structure. Making spatial distinctions in object structure precedes spatial categorisation as well as linguistic labelling.

Representing axis **[Y]** as a boundary in the same way as was done with axis **[X]** above does not suffice to distinguish another pair of regions and half-axes. The mirror

[76] In the present case, the directionality can be assigned to the half-axes while there is an axis of symmetry to begin with. In case without axes of symmetry, directionality can be assigned to the dimension orthogonal to the bounding axis. See also Section 2.5.

symmetry of the two object parts separated by axis **[Y]** allows no direct discrimination between them (i.e., they have the same shape). However, the acquired directionality of axis **[Y]** makes it possible to distinguish the object parts, regions and half-axes on either side of axis **[Y]**. The explicit interpretation of the symmetry axis as, e.g., the '**[-Y]-to-[+Y]**'-Perspective, allows for the indexing of one part separated by axis **[Y]** as the **[+X]** part and the opposite part as the **[-X]** part and a similar indexing of the half-planes and half-axes as well (by using some conventional or private marking or labelling). In this way axis **[X]** becomes directed. See Figure 5.1.A5. Note that the object parts do not necessarily have to be differentiated before the regions and half-axes can be distinguished (all distinctions can be based on the '**[-Y]-to-[+Y]**'-Perspective).

In Figure 5.1, the fine-grained encoding of the relation between Figure and Referent is defined with a vector. Here, the vector is based on the proximal distance between the objects. This definition of fine-grained vector information suffices for the present example. However, vectors may be defined in other ways (see Carlson, Regier, and Covey, 2003). Within the present context, the vector has to be linked to the intrinsic Reference Frame, so that the location of the Figure can be interpreted relative to the Referent’s structure. This may be done by decomposing the vector into an orientation (α) and a distance (**d**). The orientation is defined relative to one of the Referent’s (half-) axes while the (proximal) distance between Figure and Referent has to be defined relative to some aspect of the Referent’s extendedness.

In the process of Reference Frame extraction the orientation of the vector may consecutively be linked to, respectively, axis **[Y]**, half-axis **[+Y]** and finally to half-axis **[+X]** and/or region **[+X]** as well. A spatial representation may then result which links the specific location of the Figure to the Reference Frame of the Referent and which may be described with, e.g., the Figure is at distance **d**, oriented α away from half-axis **[+Y]** and towards half-axis **[+X]** (or in region **[+X]**). The fine-grain values **d** and α are thus linked to the primary categorical divisions **[+X]** and **[+Y]**. As a result, the Figure is effectively encoded in the secondary region **[+X]** ∩ **[+Y]**. The fine-grain coding is not mandatory. Alternatively, the Figure location could have been coded by a fine-grain value β defined from half-axis **[+X]** and towards half-axis **[+Y]** (or in region **[+Y]**).

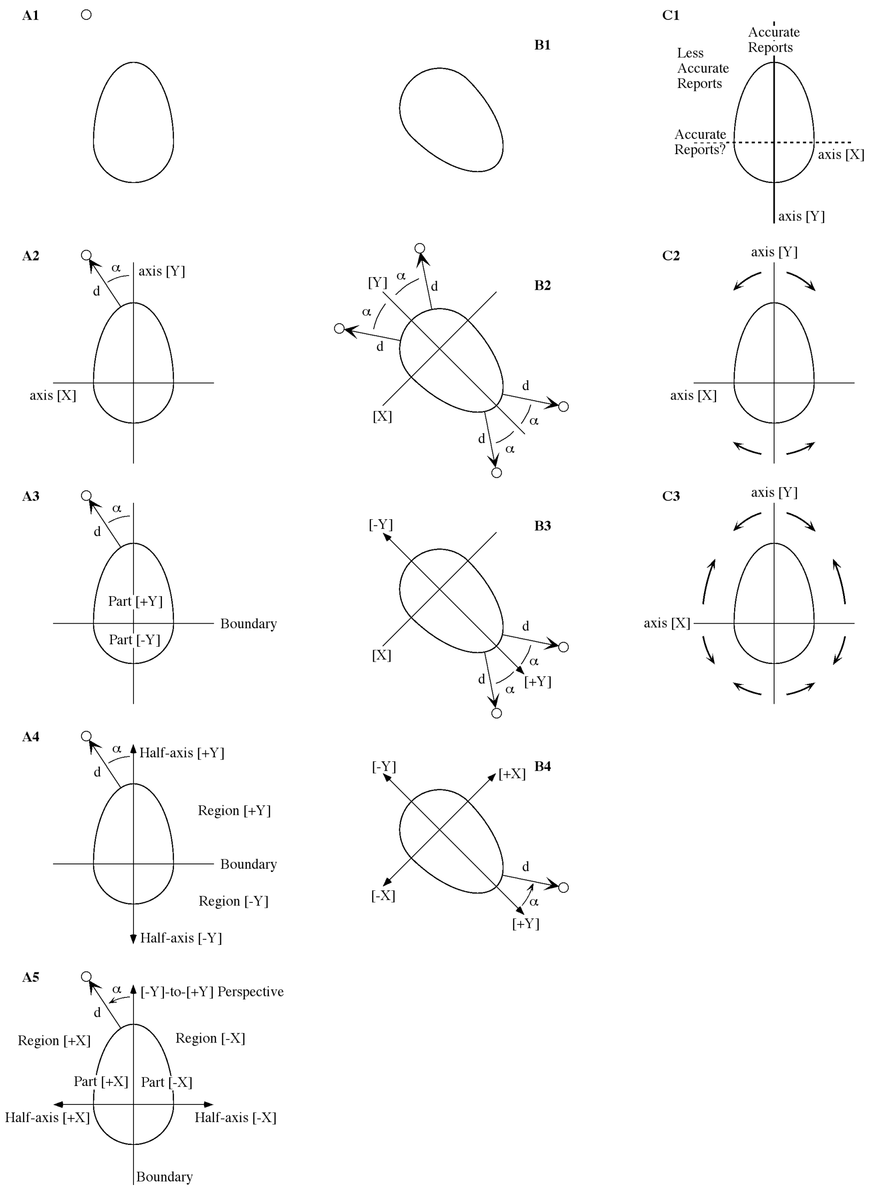

Figure 5.1. Intrinsic spatial reference for memory. A. Encoding of an Intrinsic Location. B. Reproduction of an Intrinsic Location. C. Characteristics of memory reports. See text for details.

Progressively linking the vector during Reference Frame extraction may also occur during the recall of an intrinsic position. Figure 5.1.B1 shows the Referent in a different orientation without the Figure. If axis **[X]** and axis **[Y]** are represented (alternatively, if only axis **[X]** is defined) four vectors with α and **d** can be specified. See Figure 5.1.B2. When the **[+Y]** and **[-Y]** parts and – thereafter – the **[+Y]** and **[-Y]** regions and/or half-axes are differentiated, two vectors can still be defined (Figure 5.1.B3). If, finally, the **[+X]** and **[-X]** half-axes and/or regions are distinguished, the vector and therefore the former position of the Figure can be determined unambiguously (Figure 5.1.B4). **[+X]** versus **[-X]** is thus defined only after **[+Y]** versus **[-Y]** in the encoding phase as well as the reporting phase. Effects of ordered extraction of directionality are discussed below.

In case of reproduction from memory, the effects on reproduction reports could be the following. Reproduction may be more accurate on the axes than anywhere else (see Figure 5.1.C1). In the example used, the axis of symmetry (**[Y]**) would certainly function as a clear reference axis and therefore increased accuracy of reports is expected there. The case for the orthogonal axis **(**[X]) is not that clear. The position of the axis could be different from the position assumed in the example, and the position might even vary between participants. Additionally, whereas the axis of symmetry can be defined exactly, this is not necessarily so for the orthogonal axis (also depending on the assumed position of the axis). The precision and constancy with which a Figure location can be defined on this axis, also determines the accuracy of reports. Figure locations that are not on an axis are encoded by means of a deviation from an axis. Reports may show an exaggeration of this deviation. Note that the expected bias pattern then depends upon the half-axis relative to which the deviation is defined. If locations were only defined with respect to half-axes **[+Y]** and **[-Y]**, the resulting bias pattern would be towards **[+X]** and **[-X]** as illustrated in Figure 5.1.C2. If, on the other hand, deviations would be defined relative to the half-axis that is closest in orientation to the orientation component of the Figure location, then the resulting bias pattern would be towards an orientation in between the axes (i.e. towards oblique orientations; see Figure 5.1.C3).

Franklin, Henkel, and Zangas (1995) investigate memory for direction in the intrinsic Ego Centred Frame of Reference. They find bias away from the *front* and *back* half-axes and towards the *left* and *right* half-axes. If the above characterisation is correct, then this suggests that participants in their experiment primarily code direction in the intrinsic Ego Centred frame as a deviation from the *front* and *back* direction.

5.2.2. Intrinsic Structure and Spatial Language

If the above-mentioned spatial distinctions (i.e., the intrinsic structure of the Referent) also constitute the information that is represented for Intrinsic Object Centred Frames of Reference for language, then the question becomes how the structural description corresponds to Directional Prepositions. The global correspondence between the intrinsic structure of the Referent and linguistic labelling is assumed to be relatively simple: **[+Y]** versus **[-Y]** correspond to, e.g., the *above* versus *below* directionality, and **[+X]** versus **[-X]** to the *left* versus *right* directionality. Directional Regions and Directional Parts can be referred to with the corresponding terms (e.g., *above* for a region and *the top* for a part). Next to this simple global correspondence of intrinsic structure and linguistic labels, the question is how the structure of the Referent is actually used when Spatial Relations are described.

The Figure in Figure 5.2.A is in region **[+Y]** and in region **[+X]**. The vector defining the Figure location deviates clearly from both the **[Y]** axis and the **[X]** axis. Therefore, the relation can be described with two prepositions such as *above and to the left of*. In Figure 5.2.B, the Figure's location is on an axis (the vector coincides with the axis), in this case on half-axis **[+Y]**. Only *above* will be used to describe the Spatial Relation because axis **[Y]** is neutral with respect to the other directional opposition (axis **[Y]** is neither in region **[+X]** nor in region **[-X]**). This has as a consequence that a Spatial Relation in which a Figure's location can be characterised with a vector that coincides with a half-axis is the best example of a Directional Preposition.

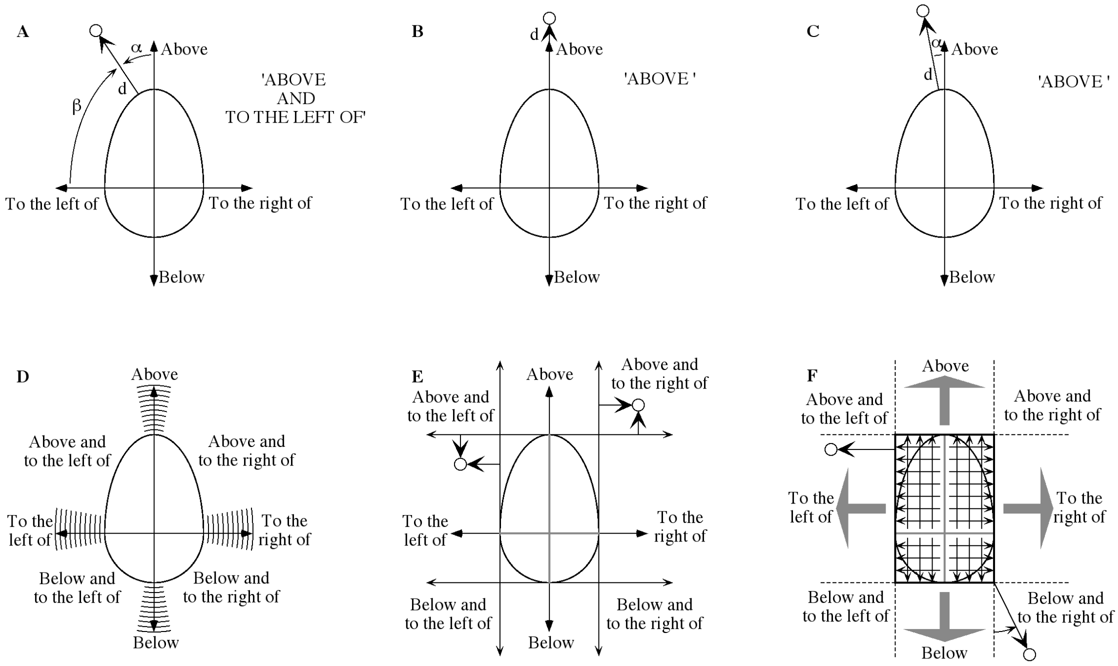

Figure 5.2. Intrinsic spatial reference for language. See text for details.

As mentioned before, in Spatial Relation description experiments the question is not necessarily where, e.g., *above* ends and *to the left of* begins. Instead, the question might be where a single Directional Preposition or where a combination of Directional Prepositions is used. Thus, as illustrated in Figure 5.2.C, if a Figure is not on a half-axis, but nevertheless close to it, then a speaker may decide to ignore categorisation on the orthogonal dimension and only refer to the Figure location as if the Figure were on the half-axis. Given enough similarity of the orientation component with the half-axis, the deviation from the half-axis may be omitted in spatial language. The purpose of a speaker explaining the location of a Figure to an addressee is that the addressee can quickly locate the Figure. It is therefore assumed here that when the addressee can find the Figure by directing his/her attention from the Referent in accordance with a Directional Part contrast (and therefore in the direct region, see Section 3.2.3) which is also the case when the Figure deviates slightly from the half-axis, that the speaker will show a preference for using a single Directional Preposition. If the addressee cannot find the Figure in this way, the speaker will show a preference for two Directional Prepositions. For a similar view, see Zimmer, Speiser, Baus, Blocher, and Stopp (1998) (but see findings by Munnich, Landau, and Dosher, 2001). See also Figure 5.2.D.

Note that the resulting regions in Figure 5.2.D are clearly different from those that are apparent in Section 2.5 and Section 3.2.3. The present regions are the direct result of defining regions for language with the same inventory of distinctions used for spatial memory. In particular, the regions result from defining the Spatial Relations based on proximal distance to the Referent and relative to some reference half-axis. In Section 3.2.3, it was suggested that the choice for one or two Directional Prepositions could be based on whether or not the Figure can be found by directing attention away from the Referent according to a Directional Part opposition. If a speaker were to use spatial language along this strategy, then the speaker needs to define regions around the Referent on the basis of the Referent's structure, and the Figure's location relative to these regions (see Figure 5.2.E). In Section 2.5, it was suggested that a Spatial Relation (vector) may not be defined from the Referent itself but from the bounding axis between Directional Parts that is extended to the outermost points of the Referent (thus constructing grazing lines). In effect, a bounding box around the Referent is specified from which the Spatial Relations are defined. If the Spatial Relations (vectors) comply with (are parallel to) dimensional orientation, then a single Directional Preposition is used; if they do not, then two Directional Prepositions are used (see Figure 5.2.F).

Which of these three possibilities is closest to the truth, I do not know. There is simply not enough Spatial Relation description data available to make a good guess. However, in all three cases, an intrinsic description of the Referent in terms of independent orthogonal dimensions can be used. The point made is simply that the same intrinsic structure of the Referent can be used, but that there may be a difference in the exact manner that the structure is used in spatial memory and in spatial language, which is caused by task demands. Whereas in spatial language it is sometimes possible to rely on the similarity between a Figure's location and a reference direction, in spatial memory this is not possible when it comes to exact reporting of the Figure's location.

5.3. Ordered Extraction of Dimensions

Above it was argued that the same intrinsic representation of a Referent could be instrumental in the definition of Intrinsic Location and in the categorisation of Spatial Relations as Directional Relations. Explicitly discussed regarding memory for location, but necessary for spatial language as well, was the assignment of directionality to the dimensions. This reference frame extraction was ordered in the example because of a spatial property of the Referent: Bilateral symmetry. The ordered extraction was explained in Chapter 2 and was shown to have parallels to the intrinsic computation analysis of Bryant and Tversky (1999; see Chapter 3). One parallel between the intrinsic computation analysis and the present view is that in the intrinsic computation analysis the distinction between *left* and *right* cannot be made unless the distinction between *top* and *bottom* has already been made, while in the present view the spatial distinction **[+X]** versus **[-X]** can not be made unless the distinction **[+Y]** versus **[-Y]** has already been made. The intrinsic computation analysis particularly stresses intrinsic object axes. Here the emphasis is primarily on the differentiation between intrinsic parts that can then be transferred to regions and half-axes. The principles for assuming the ordering are similar however. The intrinsic computation analysis has thus been tested on axial directions with language. Here it is hypothesised that the ordering of assigned directionality applies to regions in both spatial language and spatial memory tasks.

The regional interpretation of the intrinsic computation analysis has not yet been tested regarding linguistic data as far as I know. This can be easily done however. It is predicted that, e.g., *top-bottom* discriminations would be faster than *left-right* discriminations regarding the same Figure locations that are somewhere between the *top-bottom* and *left-right* axes. The regional interpretation of the intrinsic computation analysis is tested regarding spatial memory data with the experiment described in the next Chapter. It is thus specifically assumed that the ordering of directionality assignment has analogous effects in spatial language and in spatial memory because the representation of the intrinsic structure of the Referent is the same in both cases. However, also regarding directionality assignment there may be some subtle differences due to task demands in both kinds of task. Again, there may be a slightly different use of the underlying representation.

In the case of spatial memory, if a Figure location is to be accurately reproduced, then faster reaction times due to earlier assignment of directionality can only be expected on an axis that is neutral with respect to a dimension whose directionality is assigned later. On this axis, directionality on only one dimension needs to be defined. In all other cases, assigned directionality on both dimensions is needed. Thus, with respect to the example presented above, if a location needs to be remembered that is on the **[Y]** axis, then only directionality has to be assigned to this axis. Directionality of the other axis is irrelevant. In all other cases, however, directionality has to be assigned to both axes, and while directionality can only be assigned to the **[X]** axis after directionality has been assigned to the **[Y]** axis, these locations are accordingly slower.

In the case of spatial language essentially the same order applies. However, there may be a small region around an axis where the directionality on the orthogonal dimension is ignored in describing a Spatial Relation. Accordingly, it may be the case that this small region around the axis whose directionality is defined first (i.e., **[Y]**) shows faster descriptions than Figure locations anywhere else. This will only be the case however when the directionality of the orthogonal dimension is ignored in the sense of not being considered. It will not be case if it is ignored in the sense of not being expressed after having been considered. In the latter case, there may even be slower responses than would be expected because of directionality being assigned to two dimensions only. In particular, there may be competition between using one or two Directional Prepositions in the description (see Zimmer *et al*., 1998).

Next to ordering in directionality assignment, normalisation effects were discussed in Chapter 3. Those effects are observed in linguistic direction judgements. Does normalisation also occur in spatial memory? Because an intrinsic description of the Referent is assumed to underlie both spatial language and spatial memory, it is thought so. Normalisation is expected on both dimensions, and the effect is stronger on the *left-right* dimension. Normalisation should occur relative to the (stored) upright orientation of the Referent. This applies of course only if an object has an Intrinsic Object Centred Frame for Language. Intrinsic Location may also be possible without such a frame (see below). Because the experiment described in the next Chapter is not designed to investigate normalisation effects relative to the upright, it is not possible to consider them however.

5.4. Objects used in the Experiment

Intrinsic Object Centred Frames of Reference for language were found to be based on knowledge associated with the Referent's object category. The possibility to define an Intrinsic Location was found to be based solely on the Referent's spatial structure. In the experiment described in the next Chapter, one Referent will be used that allows to define an Intrinsic Frame based on knowledge about the object category, while also another Referent will be used that does not allow such a frame because it is a 'meaningless' shape and therefore there can be no knowledge about its object category.

The object that allows an intrinsic frame for language to be defined is the same as one of the Referents used by Hayward and Tarr (1995). It is the Referent illustrated in Figure 3.3. The data that Hayward and Tarr obtained with this Referent were collected under conditions of superimposed Frames of Reference. It will simply be assumed that the linguistic data they found would also have been found if the same Referent were used in a situation in which only its Intrinsic Frame would have been available for describing Spatial Relations. Spatial memory data in a purely intrinsic frame are obtained in the next Chapter. The participants in the experiments of Hayward and Tarr were native English speakers, while the participants of the experiment in the next Chapter are native German speakers. It is assumed that no relevant differences exist between (speakers of) these languages that would make a comparison between the spatial language task and the spatial memory task improper (whatever the causal relation assumed between the representations used in the task and the native language of the participants).

The chosen object without meaning is bilateral symmetric. As argued in Chapter 2, an object with such a spatial structure will necessarily be used in a way that makes it comparable to Frames of Reference for language. It was argued that if an intrinsic description of such an object is represented, that it must then involve a dimension along the axis of symmetry and another orthogonal to it, and that directionality needs to be assigned to the dimension along the axis of symmetry first. However, no Intrinsic Object Centred Frame of Reference for language is available for the object beforehand, and therefore no category dependent labelling of Directional Parts. Thus, there is only one way to define Directional Parts, but no pre-defined way to label these parts. Similarities in results between the object with knowledge and the object without knowledge do not indicate that the availability of Intrinsic Object Centred Frames of Reference in West-European languages influences the spatial representational content that is readily available for non-linguistic goals (but neither can this be excluded).

The spatial memory data obtained with the abstract object in the next Chapter can be compared with linguistic data even when there can be no pre-defined Frame of Reference based on category information. Linguistic data in a purely Intrinsic Object Centred Frame of Reference have been obtained from native Dutch speakers and are reported in Van der Zee and Eshuis (2003; see also Van der Zee, Rypkema, and Busser, 1996; Eshuis, 1995). It is assumed that there are no relevant differences between (speakers of) Dutch, English, and German regarding the present topic. In Van der Zee and Eshuis, participants were not asked to describe a given Spatial Relation with respect to objects (as in Hayward and Tarr), but to produce as exactly as possible a Spatial Relation by means of a given description by marking it on a circle around the Referent. It is assumed that the combinations of descriptions and Spatial Relations obtained by Van der Zee and Eshuis and by Hayward and Tarr are equivalent regarding their predictive power for the experiment described in the next Chapter.

5.4.1. Spatial Relations relative to Meaningless Objects

Van der Zee, Rypkema, and Busser (1996; see also Van der Zee and Eshuis, 2003) used six 3D objects as Referents in their experiments. The Referents were examples of so-called geons, that is, abstract geometric shapes defined by an axis and a cross-section that are used as explanatory primitives in object recognition (see Biederman, 1987). Of particular importance to the present experiment is the experiment they report on intrinsic reference. In this experiment, participants were instructed to specify as accurately as possible (on a circle on a round table with one of the geons on the middle of the table) the places corresponding to ‘links van’ (*to the left of*) and ‘rechts van’ (*to the right of*) or ‘voor’ (*in front of*) and ‘achter’ (*behind*) the geon *in an Intrinsic Object Centred manner*. Van der Zee *et al*. also report the Relative Ego Centred equivalent of this experiment. In both experiments, varying the Referent’s orientation controlled for possible effects of the Environment Centred Frame of Reference based on the room. The Referents are shown in Figure 5.3.

A hypothesis on how participants would define Intrinsic Spatial Relations with respect to these ‘category-free’ objects can be (partially) based on the discussions in Chapter 2. The object at the left of the top row in Figure 5.3 is a cuboid, and will be called Geon 1. Geon 1 is an object whose structure allows to define three different dimensions but not to assign directionality to any of these (an example of the symmetry point group D_{2h}; see also Figure 2.12.B1). Geon 1 happens not to be suited for intrinsic reference at all. Three of the Referents, that is, the others in the top row of Figure 5.3 (Geons 3 and 5) and the left one in the bottom row (Geon 2) are members of the point symmetry group C_{2v} (see also Figure 2.12.D1). They also have three dimensions. One of these may obtain directionality, however. Locations on their 2-fold rotation axis have a unique intrinsic definition. The remaining two Referents (Geons 4 and 6) are bilateral symmetric 3D objects (point group C_s; see also Figure 2.14). One directed dimension is defined perpendicular to their plane of symmetry, and needs to be the *left-right* dimension. Two other directed dimensions can be defined as well; the symmetry characteristics do not restrict their orientation however.

If participants would need to define a full Intrinsic Object Centred Frame of Reference on these objects, then the following might be expected. On Geon 1, *top-bottom*, *front-back* and *left-right* dimensions might be defined on the basis of axis length, which is the only spatial characteristic that allows differentiating the dimensions. Any assigned directionality would be accidental because it cannot be differentiated from the opposed directionality.

On Geons 2, 3, and 5, one directed dimension is oriented along the rotation axis and is a dimension that allows differentiating between Directional Parts within the spatial structure and should therefore be the *top-bottom* or *front-back* dimension. If the order of directionality assignment identified in Chapter 3 applies here as well, it should be the *top-bottom* directed dimension. What part is considered the *top* (*front*) and what part is considered the *bottom* (*back*) is not restricted by the symmetry characteristics but needs to be based on other spatial characteristics, e.g., what participants would define to be suited as a 'base' (*bottom*) or what participants would consider to be the 'aerodynamic direction of motion' (*front*). Which of the other dimensions would become the front-back (top-bottom) dimension and which one the left-right dimension has to depend on the spatial characteristics axis length and/or the presence or absence of curvature. Any directionality assignment to these dimensions would be accidental.

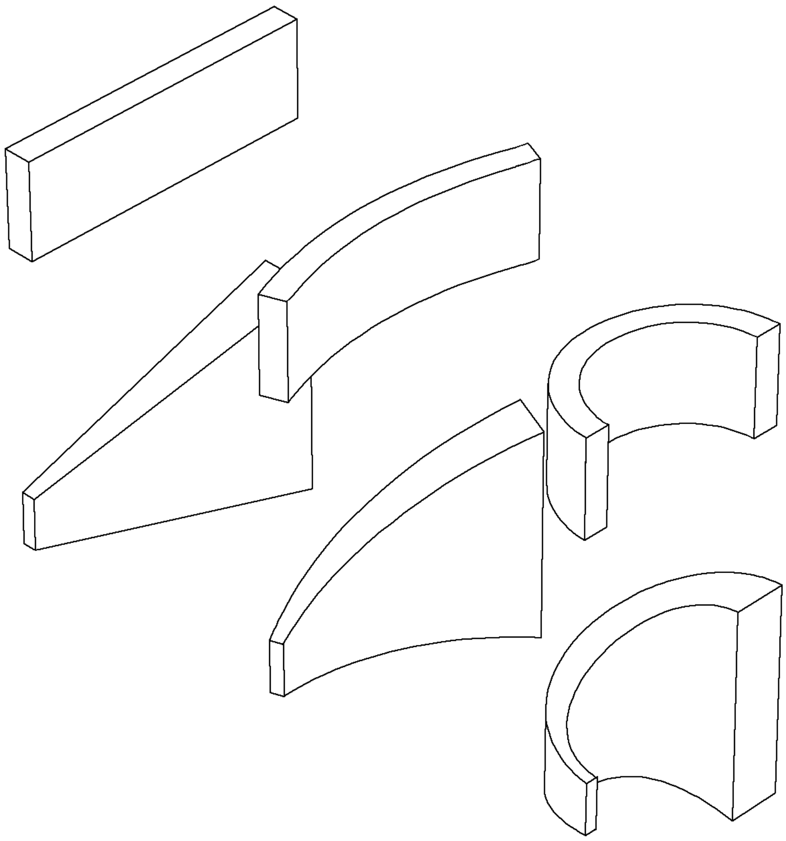

Figure 5.3. The Referents used by Van der Zee, Rypkema, and Busser (1996).

On Geons 4 and 6, the *top-bottom* and *front-back* directed dimensions are aligned with the plane of symmetry whereas the *left-right* dimension is oriented orthogonal to it. The orientation of the *top-bottom* and *front-back* axis is not determined by the symmetry characteristics but needs to depend on the spatial characteristics expansion, curvature and/or axis length. The same spatial characteristics must be instrumental in defining directionality to these dimensions. There is no intrinsic differentiation between the *left* and *right* Directional Parts. Assignment of directionality has to await the assignment of the other directionality.

The definition of Spatial Relations in the experiment was however restricted by the Directional Prepositions that were asked for and the orientation of the Geons on the table. Thus, Directional Parts of the Referents are oriented vertically that are not the *top* and *bottom* according to the above specification. Similarly the Directional Parts in the horizontal plane relative to which the Spatial Relations *in front of* and *behind* or *to the left of* and *to the right of* had to be defined are not necessarily the corresponding Directional Parts in the above specification. The preferred categorisation of dimensions (i.e., the axis labelling produced by a majority of the participants) is shown in Figure 5.4 relative to the cross-section of the Geons in the horizontal plane.

Figure 5.4 shows (closest-fitting) bounding boxes with the objects and axis localisation seems to confirm the specification of the bounding boxes (see Van der Zee, 1996). The bounding boxes can either be a representation that is used to define Directional Relations or their emergence can be a consequence of participants searching for a spatial realisation of directional oppositions for pairs of Directional Prepositions on the one hand and the orthogonal orientation of dimensions on the other hand (see also Eshuis, 2003). The orientation of the bounding boxes and/or the localisation of axes by participants regarding Geons 1, 2, 3, and 5 are according to the objects' spatial structure. Regarding Geons 4 and 6, the spatial structure does not determine the orientation, but still the closest-fitting bounding box is apparent.

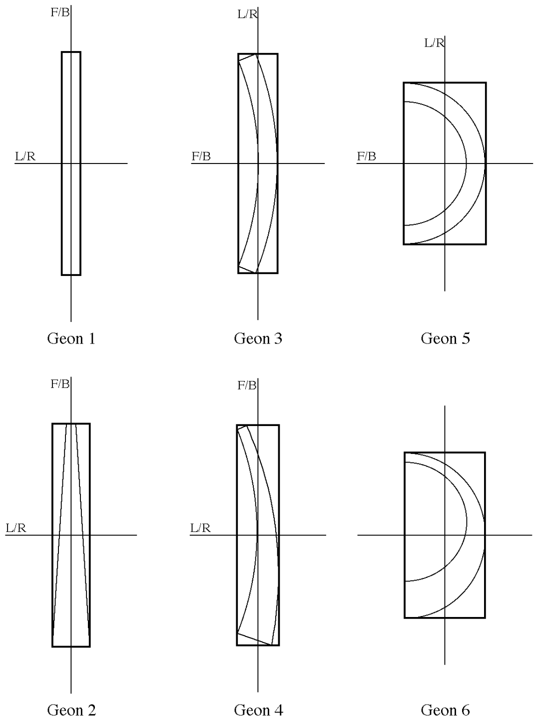

Figure 5.4. Preferred intrinsic axial labelling on the Referents used by Van der Zee, Rypkema, and Busser (1996).

The longest axis of Geon 1 is considered the *front-back* axis and the smaller axis the *left-right* axis. The reasons for this labelling are unclear, but it is consistent to a suggestion by Miller and Johnson-Laird (1973) regarding the definition of (unspecified) *sides* on an elongated object (as opposed to *ends*). The localisation and categorisation of the axes of Geons 2, 3, and 5 are in agreement with the specification given before. The only intrinsic definable locations become (usually) categorised as *in front of* and *behind*. On this dimension, an intrinsic difference between parts can be defined. The remaining axis, where no parts can be intrinsically differentiated, is consequently labelled as the *left-right* axis. The localisation and categorisation of axes on Geons 4 and 6 involve labelling in a plane that according to the specification above should involve the *top-bottom* and *front-back* axes. However, spatial relations corresponding to *to the left of* and *to the right of* or *in front of* and *behind* need to be defined. It is assumed here that, within the horizontal plane, the least distinctive object parts will be labelled as the *left* and *right side*, while the more distinctive object parts will be labelled as the *front* and the *back*. The slight curvature of Geon 4 that defines a 'concave side' and a 'convex side', is apparently less a difference between parts to the participants than the expansion that defines an 'apex part' and a 'base part'. The higher curvature of Geon 6 seems to create a greater difference than the slighter curvature as is evidenced by this object not showing a preferred labelling of sides.

Labelling of an axis may thus depend on the relative distinctiveness of the object parts an axis intersects or, to describe it in line with the last section, the relative distinctiveness of the object parts the orthogonal axis separates. Similar principles of relative (a-) symmetry have also been derived by Van der Zee and Eshuis (2003; see also Eshuis, 2003) in order to explain the categorisation of axes of the Geons and some other objects. Van der Zee and Eshuis find that axes along which expansion occurs and axes oriented orthogonal to a curved axial plane are most directionally marked. According to their Spatial Feature Categorisation model an axis that is most directionally marked is categorised as the *above-below* axis, the intermediate directionally marked axis is the *front-back* axis and the least directionally marked axis is the *left-right* axis. The axes that are most directionally marked as evidenced by their categorisation must obtain this marking from spatial features. The mentioned axes have something in common: They intersect two different (and thus distinguishable) sides. An axis along which expansion occurs intersects a relatively small and a relatively big side. An axis oriented orthogonal to a curved axial plane intersects a convex and a concave side. The orthogonal axis thus bounds distinctive object parts.

Regarding bilateral symmetric cross-sections (Geons 2, 3, and 5) in the horizontal plane, it is thus clearly confirmed that symmetric sides are labelled as the *left side* and the *right side* and that sides that can be differentiated are labelled as the *front* and the *back*. Harris and Strommen (1974) present similar results. If participants are asked to draw a line in a bilateral symmetric object that separates the front from the back, then participants typically draw a line perpendicular to the axis of symmetry that has different object parts on either side of it. The abstract object used in the experiment is the cross-section of Geon 2. The labelling of directions assumed in the experiment is *top-bottom* and *left-right* (for reasons described above). Figure 6.1 shows the object superimposed with the Hayward and Tarr Referent and their intrinsic directions. Geon 2 will be referred to as the Van der Zee and Eshuis Referent.

5.4.2. Differences between the Referents

There are a number of differences between the Hayward and Tarr Referent and the Van der Zee and Eshuis Referent. For instance, the latter is bilateral symmetric, has an elongated shape, and is not an instance of a category with an Intrinsic Frame. The former is almost bilateral symmetric, has a square shape, and is an instance of a category with an Intrinsic Frame. It would not be surprising if there were a number of differences between the Referents when they are used in an experiment on memory for Intrinsic Location. Still it is expected that the results in the experiment are qualitatively the same for both objects.

Regarding the Hayward and Tarr Referent, it is expected that an Intrinsic Location be coded by the Intrinsic Frame of Reference that can also be used to categorise Spatial Relations as Directional Relations. An intrinsic description is thus given to the Referent, whereby the *top-bottom* directionality is assigned before the *left-right* directionality. The Intrinsic Location is encoded on these directional oppositions and reproduced by the same oppositions as well. Regarding the Van der Zee and Eshuis Referent it is expected that an Intrinsic Location be coded by the Intrinsic Frame of Reference that follows as a matter of course out of the Referent’s spatial structure. An intrinsic description is thus given to the Referent whereby directionality is assigned to the dimension along the axis of symmetry before directionality is assigned to the orthogonal dimension. The Intrinsic Location is encoded on these directional oppositions and reproduced by the same oppositions as well.

Some differences between the objects can however be considered beforehand. One obvious example is the different perimeter of the Referents, which may have an effect on memory reports. Thus, the *top-bottom* elongation as opposed to the *left-right* narrowness of the Van der Zee and Eshuis Referent may influence accuracy of reports as compared to the equal-sized *top-bottom* and *left-right* dimensionality of the Hayward and Tarr Referent. In addition, the Hayward and Tarr Referent opens up the possibility that the assignment of *left-right* directionality is facilitated by its small asymmetric feature (see also Section 2.5), while such facilitation cannot be expected with regard to the Van der Zee and Eshuis Referent because of its perfect bilateral symmetry.

One interesting question regarding differences between the Referents concerns the question if normalisation occurs and the presence or absence of category knowledge. The identity of the Hayward and Tarr Referent allows to define a *top-bottom* directed dimension first that depends on the object's canonical orientation. Thereafter *left-right* directionality can be conventionally defined to the (facing) Referent. Normalisation effects, if found, would be to the upright orientation of the Referent, and *left-right* normalisation would show a steeper slope than *top-bottom* normalisation. Finding normalisation relative to upright in a memory task would indicate that participants indeed do use the Intrinsic Object Centred Frame of Reference that is also being used for linguistic categorisation. In the memory task, it is possible to use one of many possible intrinsic feature descriptions of the Referent and define Intrinsic Location relative to the description. If normalisation relative to upright is observed, then this thus suggests that participants employ the same category knowledge as they use to describe Spatial Relations. With respect to the remembered *left-right* position of the Figure, any normalisation relative to upright only shows that *left-right* directionality is defined dependent on *top-bottom* directionality, but not if the Referent is correctly used as a facing or an aligning Referent. In the memory task, participants can choose to assign *left-right* directionality one way or the opposite way. This is not relevant to correct reproduction of the Figure on the *left-right* dimension provided the same assignment is used during encoding as well as reporting.

The Van der Zee and Eshuis Referent does not have a canonical orientation. The way intrinsic directions are set to be equal to those of the Hayward and Tarr Referent are based on the preferred Spatial Relation production in the experiment of Van der Zee, Rypkema, and Busser (1996) described above. There is no stored orientation relative to which the object can be normalised in order to define dimensional directionality. It could be the case that a participant quickly adopts an ad hoc '*top-bottom*' orientation relative to which Intrinsic Locations are defined first (and with it the secondary '*left-right*' directionality as well). This could be the one assumed in Figure 6.1, or it could be the opposite orientation. Alternatively, participants could use both orientations on an accidental basis, or they could define directional oppositions by spatial distinctions only, that is, without the using some object orientation as a reference. In exploration of this question, the occurrence of normalisation effects with respect to the Hayward and Tarr Referent (if any) needs to be considered, and in what respect the Van der Zee and Eshuis Referent deviates from it. Again, note that the experiment has not been designed to provoke normalisation effects relative to the upright. An experiment involving a different set of trials as the experiment described in the next Chapter is needed for this.

Chapter 6. An Experiment

The experiment described in this chapter has been conducted with two aspects of intrinsic object centred reference that were discussed in previous Chapters in mind. One of these aspects concerns the difference in the time required to access or to establish different intrinsic directions (i.e., the intrinsic computation analysis). The other aspect is the possible difference in accuracy associated with the reporting of different intrinsic locations. It is the explicit goal of the experiment to elicit both aspects in a memory task in a purely Intrinsic Object Centred Frame of Reference. The Referents used in the experiment were described earlier.

The experiment elaborates on previous research in several respects. The applicability of the intrinsic computation analysis is tested in a memory task where there is no explicit need to label Intrinsic Directions. Also, non-cardinal directions (off-axis directions) are used in the experiment. Previous findings of accuracy differences over directions are tested for their generality by employing only a single Frame of Reference instead of the superimposed Frames of Reference used in other research. It is however necessary to compare the contribution of the intrinsic frame to accuracy with that of other frames present. The collection of reaction time data as well as reporting accuracy data in one experiment makes sure both are obtained with respect to the same Referents and over the same conditions. Obtaining both may make it possible to explore which of these spatial data (if not both) is suited to investigate the connection between non-linguistic spatial behaviour and linguistic spatial behaviour.

The intrinsic computation analysis predicts faster responses on the *top-bottom* on-axis directions than on the *left-right* on-axis directions. The regional interpretation of the analysis as developed before would predict responses for off-axis directions that are about as fast (or slow) as responses for the *left-right* on-axis directions. The accuracy data obtained in situations with superimposed Frames of Reference would predict a pattern different from response times if transferred to the purely intrinsic case. Both the *top-bottom* and *left-right* on-axis directions should show superior accuracy compared to off-axis directions.

6.1. Experimental Method and Hypotheses

The experiment employs a spatial memory task involving an Intrinsic Object Centred Frame of Reference. A Referent is presented during the encoding phase of the experiment. A dot (i.e., the Figure) is presented together with the Referent. The participants in the experiment are explicitly instructed to remember the location of the dot relative to the Referent, that is, with respect to the Referent's Intrinsic Frame. During the reporting phase, participants reproduce the Spatial Relation by putting the dot back on its former location, whereby 'former' is to be understood relative to the Referent's frame. The use of information in the scene other than information based upon intrinsic characteristics of the Referent is made ineffective by changing the orientation of the Referent between the encoding of the Spatial Relation and the subsequent reporting of this relation. Between the encoding of the relation and its reporting the Referent‘s orientation changes 0, 45, 90 or 135 degrees. Because of the Referent's change in orientation, a correct response depends on actually using the Referent's Intrinsic Frame. In this way the Intrinsic Object Centred Frame of Reference can be investigated exclusively regarding its effects on reporting performance.

Eight directions are defined around the Referents (4 on-axis and 4 off-axis directions), and four distances in each direction (32 dot locations per Referent in total, see Figure 6.1). Participants perform a double task in the reporting phase: First, they visually determine the former position of the dot relative to the Referent as quickly as possible and press a key. Thereafter they indicate this position as accurately as possible with the mouse cursor. Reaction time respectively reported co-ordinates are recorded.

The procedure thus explicitly aims at eliciting responses based on Intrinsic Frames of Reference. There is an additional advantage with this experimental method. The superimposition of the Referent's axial directions with the screen and/or perceptual axial directions can be varied over the encoding and reporting phases of different trials. The accuracy of memory reports may be different at different screen directions and/or perceptual directions. It may thus be possible to consider the relative influence of intrinsic axes and perceptual and/or screen axes on accuracy. Screen axes and perceptual axes are not differentiated in the experiment. Because the task is explicitly aimed at the Intrinsic Frame of Reference, it can be argued that any additional effects are primarily perceptual or reflect the rectangular geometry of the screen, but are not caused by explicitly coded ego or screen centred co-ordinates. Note that varying the superimposition of the Referent's axes with screen and/or perceptual axes at encoding and varying this superimposition at reporting is necessarily confounded with the degree of Orientation Change.

The Referent's change of orientation between encoding and reporting may allow estimating perceptual effects on encoding accuracy and reporting accuracy. The location of the Figure will be varied between the cardinal perceptual axes (horizontal and vertical) and the oblique perceptual axes in the encoding as well as reporting phase. Previously it has been suggested that perceptual effects may influence the accuracy with which a location can be encoded and reported. If solely the on- or off-axis character of Intrinsic Directions is responsible for reporting accuracy, then whether a Figure is presented on cardinal or on oblique perceptual axes at encoding and whether the Figure is to be reported on cardinal or on oblique perceptual axes would make no difference. If, on the other hand, the perceptual on- or off-axis directions are influencing accuracy, then where the Figure is in perceptual co-ordinates at encoding and whether the Figure location is on the cardinal perceptual axes or on the oblique perceptual axes determines reporting accuracy, while there would be no effect of intrinsic direction. Of course, both possibilities may happen simultaneously.[77]

The experimental procedure also allows controlling for mental rotation and/or other normalisation effects. It is assumed that participants use an intrinsic description of the Referent in the task and that Intrinsic Location is defined relative to this representation of the Referent. An intrinsic description of location is thus derived during the encoding phase and the retained intrinsic description is applied to the Referent's changed orientation during the reporting phase. However, an alternative possibility would be that participants use mental imagery in the experimental task (see, e.g., Kosslyn, 1990; 1994). Participants could store an image of the Referent-Figure constellation at encoding and mentally rotate the image into accordance with the Referent in the reporting phase to define a response. A third possibility would be that the Figure location is encoded relative to some intrinsic aspect of the Referent, but that the orientation of the Referent itself is encoded with respect to the screen or another reference direction such as the vertical. That is, an orientation of an intrinsic aspect of the Referent could be coded relative to the screen or ego centred co-ordinates, and the Figure's location coded relative to that Referent's intrinsic aspect.

In the first case, no linear effect of Orientation Change is expected, but only differences in response time between Intrinsic Directions. However, a difference between no Orientation Change and higher degrees of Orientation Change is possible, because in the former case an encoding of the Figure's screen location may be helpful, even when such non-intrinsic coding is usually not instrumental for the task to be performed. If the intrinsic description of the Figure location involves a description of the Referent referring to its canonical *top-bottom* orientation, then normalisation effects relative to upright could occur. As mentioned before, the experiment has not been

[77] The present experiment does not contrast Referents with Intrinsic Directions orthogonal to sides and Intrinsic Directions orthogonal to corners. A research report that (also) addresses this is in preparation.

designed to take such effects into account. In the second case (mental rotation), a linear effect of Orientation Change is expected. The mental rotation procedure would be similar for each Figure location and therefore no differences between Intrinsic Directions are expected. In the third case, effects of both Intrinsic Directions and Orientation Change would occur. The intrinsic aspect relative to which the orientation of the Referent is coded is expected to be the *top-bottom* axis. Orientation Change can be overcome by normalisation between the *top-bottom* orientations at encoding and reporting, and a linear effect of Orientation Change would thus be expected. The Figure location can be determined after the normalisation. The *top* and *bottom* intrinsic directions would be defined before *left*, *right*, and off-axis directions.

Reaction time results are thus compared with the intrinsic computation analysis of Bryant and Tversky (1999): With respect to Intrinsic Frames of Reference, the poles of the *top-bottom* axis can be determined (or accessed) faster than those of the *left-right* axis. According to the regional interpretation, off-axis directions show reaction times similar to the *left-right* axis. The reported Figure locations allow a comparison with the results of Hayward and Tarr (1995): They found smaller error on the on-axis locations in the direction orthogonal to the axes in their situation with superimposed frames of reference. The results on the Van der Zee and Eshuis Referent can be compared with the results on the Hayward and Tarr Referent. It is considered if the preferred linguistic categorisation found with the abstract Van der Zee and Eshuis Referent and with the non-abstract Hayward and Tarr Referent is accompanied by parallel results in a task that does not require the explicit categorisation and labelling of Intrinsic Directions.

The most relevant experimental questions and the hypotheses are the following:

(Q1) Are similar effects found for the Hayward and Tarr Referent (a stimulus depicting an existing object) and the Van der Zee and Eshuis Referent (an abstract stimulus)?

(H1) Experimental effects will be comparable over the two Referents although not necessarily identical.

(Q2) Can the intrinsic computation analysis be extended to the present situation?

(H2) The intrinsic computation analysis can be transferred to a spatial memory situation where there is no explicit need to label axes.

(Q3) Is the regional interpretation of the intrinsic computation analysis a valid extension?

(H3) Off-axis locations show effects comparable to the slowest on-axis locations.

Reaction time is thus expected to be faster on the *top-bottom* axis than on the *left-right* axis and on the off-axis directions. Reaction time on the *left-right* axis is comparable to those on the off-axes: Locations in the overlapping parts of, e.g., *to the left of* and *in front of* can only be determined unambiguously when the *left-right* dimension is extracted. As a consequence, only locations on the *above* and *below* half-axes should be determined faster than other directions. This is expected for both Referents.

(Q4) Are results obtained with exclusive Intrinsic Frames of Reference similar to results obtained with superimposed Frames of Reference?

(H4) Similar effects will be found and the effects are independent of environment centred (i.e., the screen) and relative ego centred Frames of Reference.

The error on the intrinsic axes is thus expected to be smaller than on the other locations; in particular the angular error will be smaller (i.e., the error in the direction orthogonal to the axes). This expectation however explicitly takes the shape characteristics of the Referents into account as well. The issue if the Frame of Reference as such is responsible for differences in accuracy, or if the coincidence of sides and axes of symmetry with on-axis directions and of corners with off-axis directions is responsible, is left to future research. The angular component of reports for on-axis directions is thus expected to be more accurate than for off-axis directions.

(Q5) Are effects founds that do not depend on the Intrinsic Frame of Reference?

(H5) The Figure position at encoding and reporting influences accuracy of reports.

Differences in encoding accuracy over cardinal and oblique perceptual axes have been discussed previously. It would be remarkable –given the well-documented oblique effect– if effects of perceptual axes do not show up in the present experiment. The encoding and reporting accuracy of Figure location is thus expected to be better on the cardinal axes than on the oblique axes (next to the expected effects of the intrinsic Frames of Reference). However, if such effects are found, then it is not possible to separate perceptual effects from effects due to screen geometry.

Participants thus report the intrinsic location of dots with respect to the Referents from memory. To assure intrinsic reference, the Referent‘s orientation changes between the encoding of the relation and reporting it (0, 45, 90, or 135 degrees Orientation Change, counter-clockwise only). Eight Intrinsic Directions are defined around the Referents, four on-axis directions and four off-axis directions. The on-axis directions are the *top-bottom* and *left-right* Intrinsic Directions whereas the off-axis directions are the oblique directions in between these. Four distances are defined in each direction. In total there are thus 32 dot locations for each Referent. During the encoding phase, each intrinsic dot location is shown in each of two directions on the screen (the Screen Encoding Direction). Participants thus have to report each Intrinsic Location relative to a Referent twice, which adds up to the total of 128 experimental trials for each participant. Each of the four Distances of each Intrinsic Direction presented in a Screen Encoding Direction is paired randomly with each of the four Orientation Changes. Figure 6.1 shows the two Referents superimposed on one another in their canonical orientation together with the tested Intrinsic Locations.

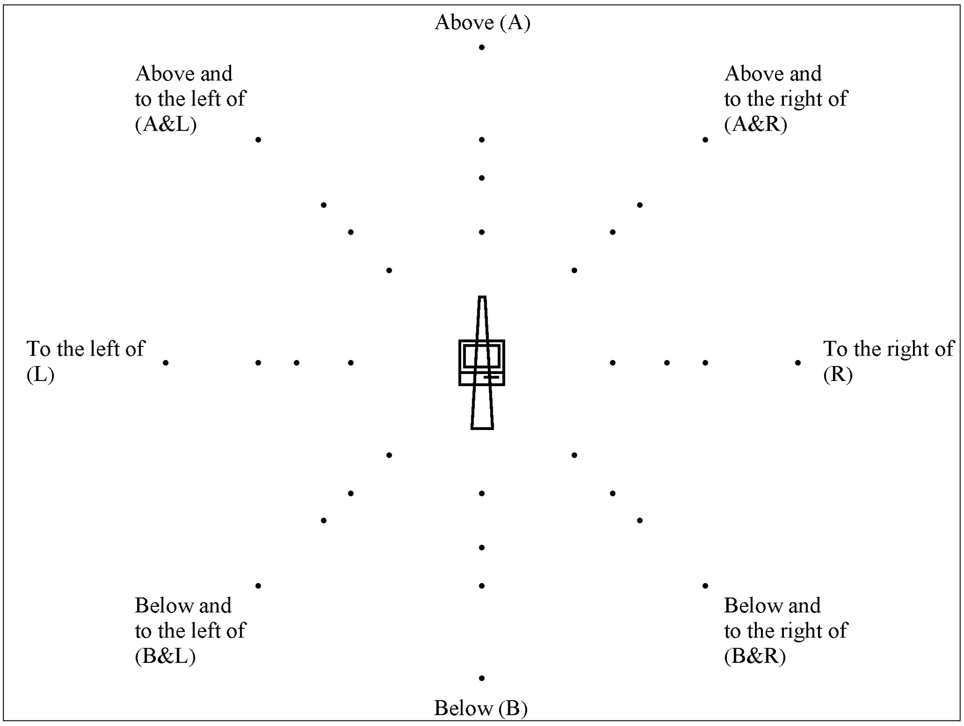

Figure 6.1. The superimposed Referents and the Intrinsic Locations used in the experiment. Black dots represent the tested intrinsic locations (not the screen locations; the surrounding frame does represent the relative size of the screen). The labels illustrate the linguistic reference to the directions for both Referents as reported by Hayward and Tarr (1995) and van der Zee and Eshuis (2003).

6.2. Experimental Procedure, Materials, and Design

6.2.1. Participants

36 persons, all native German speakers, and primarily students from the University of Hamburg, participated in the experiment in return for course credit or a small payment.

6.2.2. Materials

Stimulus material is constructed that show the two Referents in 8 different orientations. For the reporting phase, they are shown on their own (2 x 8 = 16 reporting stimuli). For the encoding phase, each of the Referents in a specific orientation is shown together with a dot located at one of 4 distances from the middle of the Referent and screen (140, 198, 239, and 338 pixels) and in one of two different Screen Encoding Directions (2 x 8 x 4 x 2 = 128 encoding stimuli). Either the dot is (ego centred) above the Referent on the Screen (the Vertical Screen Encoding Direction) or the dot is (ego centred) above and to the left of the Referent on the Screen (the Oblique Screen Encoding Direction). The Hayward and Tarr stimulus consists of 48 x 48 pixels, its ‘screen’ of 32 x 40 pixels. The Van der Zee and Eshuis Referent's mid-section is 144 pixels in height, the small end is 6 pixels in width, and the other end 24 pixels in width. Its centre is set halfway its height. The Referents surface areas are of comparable size.

Stimuli are presented by means of Psyscope 1.2 (Cohen, MacWhinney, Flatt and Provost, 1993) with a Powermacintosh on an AppleVision screen with a resolution of 1024 x 768 pixels (32 x 24 cm), and a refreshing rate of 75 Hz. Participants are seated about 80 cm away from the screen.

Participants are tested on memory for intrinsic location on each Referent in separate blocks. The order of the Referent blocks is randomised across participants. Between Referent blocks, participants could take a break if they wanted. Each participant sees each Distance in each Intrinsic Direction relative to an object twice, once in each Screen Encoding Direction. Each of the four Distances in an Intrinsic Direction relative to the Referent and in each of the Screen Encoding Directions is paired with a different Orientation Change of the Referent randomly. As a result there were 2 (Referent) x 8 (Intrinsic Direction) x 2 (Screen Encoding Direction) x 4 (Distance - Orientation Change combinations) = 128 conditions for each participant. The practice trials and the experiment took between 45 minutes and an hour in total.

6.2.3. Procedure

Participants are first trained in the handling on the mouse, in particular, to be sure that they know what location they are actually 'pointing at' when clicking the mouse (i.e., the tip of the arrow cursor). Participants are then explained that they have to remember the position of a dot with respect to an object. The experimenter (i.e., the present author) confers the general idea by means of a triangle (90, 60 and 30 degree angle) on a piece of paper. The participants are explained that the location of a dot has to be remembered and reproduced relative to the Referent (i.e., the triangle in the example that has no Intrinsic Frame of Reference for language and no unambiguous frame based on shape). The participants are explained that when the Referent changes its orientation, that the to-be-remembered Intrinsic Location changes along with the Referent’s orientation. The use of Directional Prepositions is avoided in the instructions. Participants are also explained that the Referent changes its orientation in the plane only and never flips out of the plane. Then, three sets of 12 practice trials are given in order to be sure the participants understood the task well.

The first practice set is conducted on the computer with another triangle (with angles of 75, 60, and 45 degrees). The mouse cursor is not used in this set and put into a corner of the screen. In this set of practice trials, participants are confronted with this triangle in the middle the computer screen in one of 36 orientations, with a dot (vertically) above it for two seconds. This constellation disappears, and the screen goes blank for a short time. Thereafter the triangle reappears in a different orientation accompanied by two dots. Of these two dots, one dot is in the same position with respect to the triangle as the dot presented before. The other dot is a few degrees away from this dot. Upon being presented with the rotated triangle with the two dots, participants have to decide as quickly as possible which of the two dots is in the same position as the previously seen dot by pressing one of two keys. Participants then hear a tone that signals to them if their response is correct. To start a new practice trial, participants have to press another key. A trial starts with the presentation of a small fixation circle centred in the middle of the screen for a short period of time.

The second set of practice trials uses the same set of triangle, dot combinations and possible Orientation Change. Instead of using keys for their responses, participants now have to indicate the dot they think was in the same location by clicking on one of the two dots. The procedure is somewhat different as well. To start a trial, participants now have to click the mouse in a small circle at the extreme right of the horizontal midline of the screen. Upon clicking there the small fixation circle appears. Participants are instructed to immediately take their hand of the mouse after clicking inside the circle and lay this hand at the [SPACE]-bar (key board and mousepad are positioned according to handedness of the participants; only 2 participants are left-handers). The stimuli then reappear as described above. After the rotated triangle accompanied by the two dots appears, participants are instructed first to decide for themselves which of the two dots is in the original dot location as fast as possible and press the [SPACE]-bar upon this decision. After pressing the space bar, the participants can take the mouse again and click on the dot they had decided upon. When clicking on a dot, a tone tells them if they made the correct response. If the mouse is moved between the encoding appearance of the triangle and the pressing of the [SPACE]-bar (i.e. after the triangle reappears), the participant hears another tone, and the trial is aborted.

In the third and last set of practice trials, the task and stimuli are the same as in the second set, with one mayor difference. When the triangle reappears, there is no dot accompanying it. The task of the participant is, first, to decide as quickly as possible where the dot was and press the [SPACE]-bar, and, second, to indicate as accurately as possible the location of the previously seen dot by means of the mouse cursor. Again, the participant has to let go of the mouse upon starting a trial and not to move the mouse before the space bar is pressed, otherwise the trial is aborted. When participant indicate the location of the dot, they would again hear a tone, but its sound is neutral with respect to the (relative) correctness of the response

During all the practice trials, the experimenter (i.e., the present author) is sitting next to the participant and corrects her/his behaviour if necessary and in that case explains what he/she does wrong. When the practice trials are finished, the instructor explains the differences between the final practice trials and the actual experiment, asks the participant if all is clear, and, if so, leave the room.

The task of the participants in the actual experiment is exactly the same as the task in the last set of practice trials. Participants are however explained that there are two different Referents and that these are not triangles. Participants are also told that the two different Referents are presented separately within each half of the experiment, that they receive a message when the first half is finished, as well as when the second half is finished. After the second Referent block, trials that have been aborted during the experiment are repeated. Finally, participants are told that the duration of the initial presentation of Referent and dot is somewhat shorter than during the practice trials and that there is more variation in the distance between object and dot, which participants have to take into account in reporting the locations.

A trial in the experiment thus proceeds as follows (see also Figure 6.2). At first a blank screen is presented with a circle at the right of the screen. Participants need to click within this circle to start the trial. If the trial gets started by means of the click, then a small fixation circle appears in the middle of the screen for 1500 ms. During this preparation time, participants have to let go of mouse and put their hand at the [SPACE]-bar, and concentrate on the fixation circle. With this procedure the mouse cursor is well away from the screen area in which the stimulus is presented and can therefore not interfere with it. From this point on participants are not allowed to move the mouse until later in the trial when the remembered location is to be reported. If participants accidentally move the mouse before that phase in the trial, then the trial is aborted (and repeated at the end of the experiment).

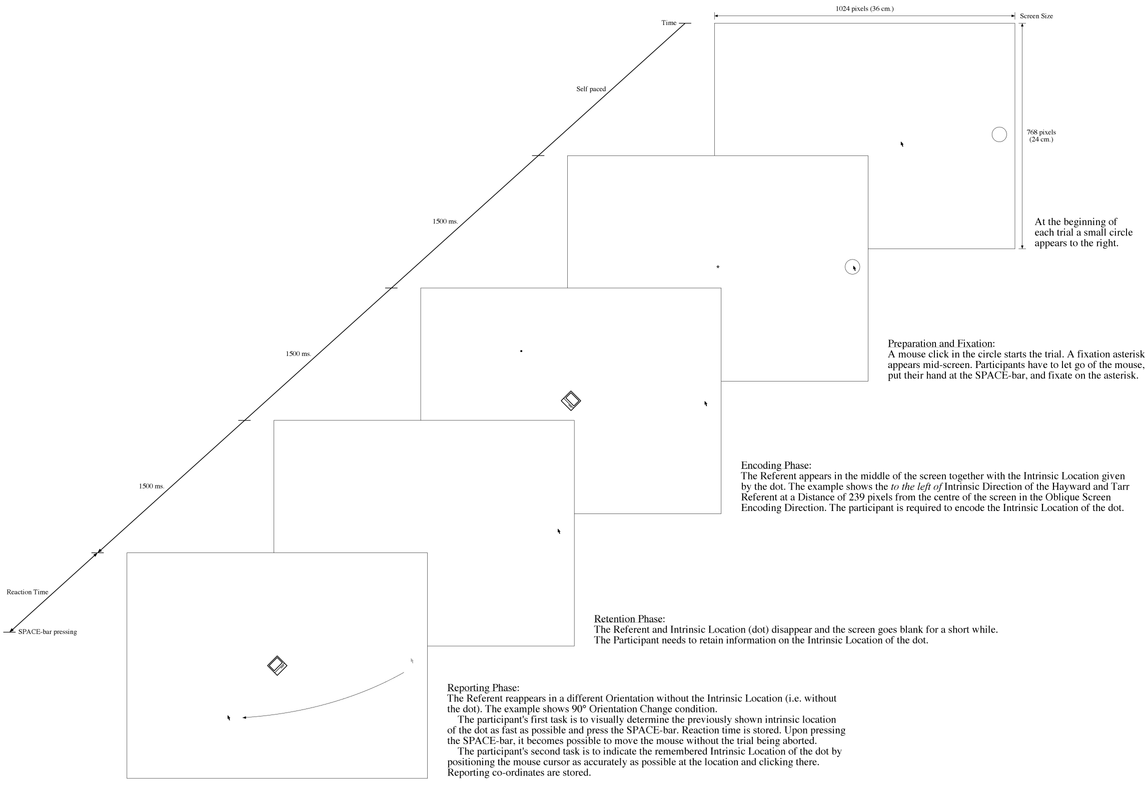

Figure 6.2. Illustration of a trial in the experiment.

In the encoding phase the Referent and Figure (a dot) are presented for 1500 ms. During this phase the participants need to encode the location of the Figure (the dot) with respect to the Referent's Intrinsic Frame of Reference. In the retention phase, the screen goes blank for 1500 ms. In the reporting phase, the Referent is presented again without the Figure. Participants have to do two things. They first have to visually find the intrinsic location of the Figure as quickly as possible and press the [SPACE]-bar. After participants have pressed the [SPACE]-bar in the reporting phase, a trial will not be aborted anymore if the mouse is moved. The second thing that participants need to do is to take the mouse and indicate Figure location as accurately as possible by clicking at the remembered intrinsic location. After the location report is given, the screen goes blank except for the circle to the right in which the participants need to click in order to start the next trial.

Pressing the [SPACE]-bar during the reporting phase triggers the registration of the time elapsed since the on-set of the reporting phase (Reaction Time). Clicking the mouse triggers registration of the mouse cursor's (x, y) co-ordinates on the screen. The reported screen co-ordinates can be transformed to Referent-based co-ordinates.

6.2.4. Data Treatment

Due to some unknown programming or technical error, some participants did not receive the full set of trials. The data of these participants have still been included in the analysis, because all participants in the end had some invalid cases for one of a few reasons (see below). About 1.5% of the planned reports was not obtained.

During the course of the experiment it became clear that participants made many errors. These errors are made in the reporting of the Figure location and are by no means random. In particular, the errors appear to be reports in the wrong region, especially Intrinsic Locations in the *left* region are reported in the *right* region and *vice versa*. Even though the region is mistaken in these errors, the fine-grain report in the wrong region still appears to reflect the actual fine-grain location as it would have been in the correct region. These errors constitute another dependent variable for which no hypotheses have been stated. A method is required to separate 'Correct' reports from 'Regional Error' reports. This method is illustrated in Figure 6.3.

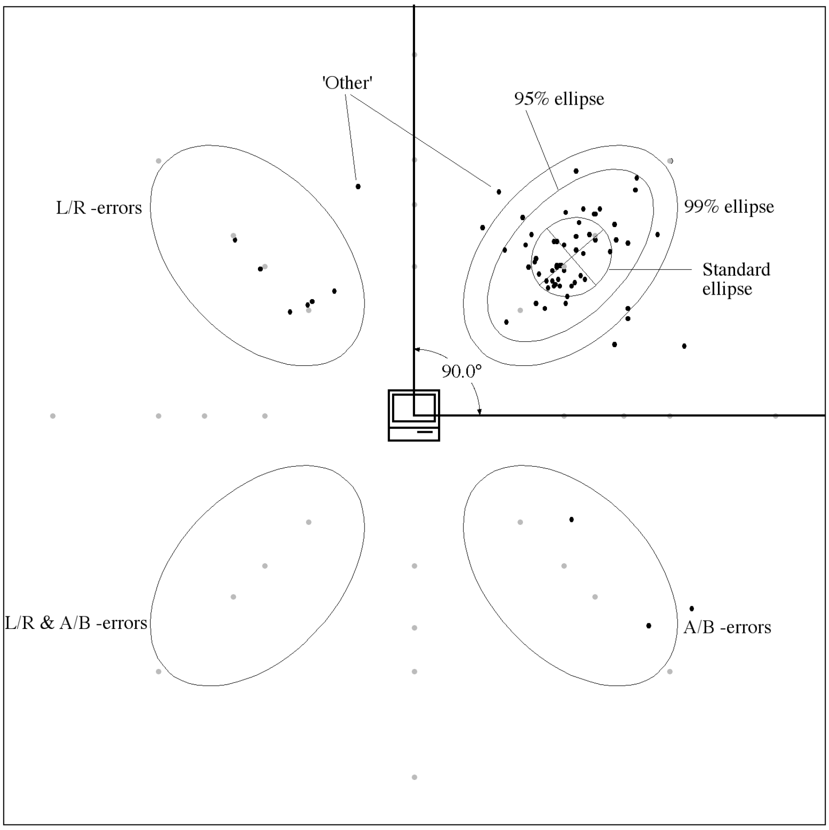

Figure 6.3. Defining 'Correct' reports and 'Regional Error' reports. The treatment of Figure location estimates is shown. The estimates within the correct 90° area around the true location are used to compute an ellipse that fits 99% of the estimates (assuming a Cartesian bivariate normal distribution). The estimates within this ellipse are considered to be 'Correct.' The ellipsoid areas are mirrored over the *top-bottom* and *left-right* axes to define the areas for 'Regional Error' estimates. Reports within these ellipses are '*Left-Right*' (L/R), '*Above-Below*' (A/B) or '*Left-Right and Above-Below*' (L/R & A/B) errors. Regarding on-axis true locations, an ellipsoid area can only be mirrored once over the orthogonal axis. The 95% ellipse in the 90° area functions as a filter to remove extreme scores. Only estimates within this ellipse are used for the analysis of accuracy of reports. The standard ellipse based on these estimates is drawn. Standard ellipses are a descriptive tool (a kind of 2-dimensional standard deviation) and contain about 40% of the estimates with which they are defined (see Batschelet, 1981).

The procedure shown in Figure 6.3 assures that the a priori chances are equal that an estimate will be considered a 'Correct' report or a 'Regional Error' report. It also assures that similar percentages of estimates within the 90° area around the true location are considered 'Correct.' The a priori chances that a report is considered 'Correct' or a 'Regional Error' as opposed to 'Other' is different for each intrinsic location however.

Referent	Axis	Regional Error Category

		Correct	L/R-error	A/B-error	A/B+L/R-error	Other
Hayward and Tarr	Top-Bottom	94.4	N/A	1.7	N/A	3.8
	Left-Right	89.7	4.0	N/A	N/A	6.3
	Off	87.7	5.1	1.8	1.0	4.5
Van der Zee and Eshuis	Top-Bottom	97.7	N/A	0.0	N/A	2.1
	Left-Right	87.2	8.5	N/A	N/A	4.3
	Off	86.3	7.6	1.5	0.7	3.9

Table 6.1. Percentages of 'Correct' reports and 'Regional Error' reports for each Referent and direction category.[78]

Regional error as defined in Figure 6.3 was not observed in the experiments on memory for location relative to Referent discussed in Chapter 4. The errors found here can be considered regional and/or categorical: Instead of, e.g., Region **[+X]** (*to the left of)*, the opposite Region **[-X]** (*to the right of)* has been the region in which reporting takes place. However, although the wrong region is chosen, fine-grained information does not appear to be impaired more for locations reported in an 'Incorrect' region than for locations reported in the 'Correct' region. As can be seen in Figure 6.3, the same local variability is allowed for estimates in the 'Correct' region and in the 'Incorrect' regions. Table 6.1 shows percentages regional error for each Referent together with the percentage of error not captured by any of the regional error categories.

[78] The table presented in Eshuis (2003) for the same data differs from the present one. Erroneously in Eshuis (2003) the table is based on ellipses defining reports that are in a stricter region than the 90° area exemplified in Figure 6.3. Table 6.1 presents the correct percentages.

6.3. Results

The presence of many independent variables (Referent, Intrinsic Direction, Distance, Orientation Change, and Screen Encoding Direction, that is, 512 cells in total) allows for many possible effects and interactions. Also, these effects can emerge on several dependent variables (2D reporting co-ordinates that require consideration of constant and variable error, Reaction Time and Regional Error). Moreover, participants were only tested on 128 conditions each and missing values are frequent. Therefore, in order to consider effects of independent variables properly, collapsing over other variables will be performed. With respect to the analyses in general, I will of course concentrate on effects of Intrinsic Directions and its interaction with the Referent (the Intrinsic Frames of Reference). When possible, effects of the other independent variables will also be considered (that is, Distance, Screen Encoding Direction, and Orientation Change which together determine Screen Reporting Location) as well as interactions with the Intrinsic Frames of Reference.

Four dependent variables will be considered separately. Of these, two are considered for both constant and variable error. Moreover, due to the structure of the resulting data set (participants are not tested on all combinations of independent variables and the occurrence of missing values) several analyses will be performed for each dependent variable. Therefore, to decrease the probability of Type I errors (i.e., concluding that an effect is significant when in fact the H_0 hypothesis of no effect is true) alpha is set somewhat stricter than is usually done. For all effects that I consider significant, it is the case that $p < .01$. Effects reaching a significance level between $p < 0.5$ and $p > 0.1$ are considered only marginally significant.

Below, reaction time, regional error, angular error, and distance error are considered separately. The latter two variables are considered for both constant error and variable error. In all cases, at first an informal repeated measures analysis of variance is performed over all independent variable simultaneously. To this end, the missing values and the conditions not tested with a participant are replaced by the mean of a participant. This informal analysis only serves to trace the (possible) significant effects within the data set and is not used to report any test statistics or significance levels. Effects identified in this way are then considered closer by means of repeated measures analysis while collapsing over variables that are not involved and over Intrinsic Directions that appear not to be different in the effect. If a participant still has missing values when data are collapsed, then the data for this participant are not included in the formal analysis.

To see which Intrinsic Directions are not different in an effect and over which collapsing apparently may be performed, a contrast set is constructed for the eight values of Intrinsic Direction. Regarding, for instance, reaction time, a set of orthogonal (i.e. independent) contrasts is constructed. The set compares the on- and off-axis directions (to test for Hayward-and-Tarr-like effects), the *top-bottom* and *left-right* axes (to test the intrinsic computation analysis), the *above* and *below* directions, the *left* and *right* directions, as well as the oblique axes, the left and right off-axis directions, and the above and below off-axis directions (to check if a pair of off-axis directions differs from the other pair). In the case of reaction time, however, two additional (non-orthogonal) contrasts are used to test the regional interpretation of the intrinsic computation analysis. The *top-bottom* axis is compared all other directions and the *left-right* axis is compared with the off-axis directions. Other contrast sets may be used when data are collapsed over directions. Thus, if data are collapsed over the *top-bottom* axis, *left-right* axis, and each of the oblique axes, then an orthogonal set contrasting on-axis and off-axis directions, *top-bottom* and *left-right* axes, and the oblique axes can be used.

With respect to the Orientation Change variable different contrast sets are constructed as well. One set comprises the well-known trend analysis and tests for linear, quadratic, and cubic trends over Orientation Change. A second set is used to test if Orientation Change is only mattering because of a difference between the Referent not changing its orientation (0°) and the Referent actually changing its orientation (45°, 90°, and 135°). The set thus contrasts this difference as well as the difference between 45° Orientation Change and higher degrees of Orientation Change (90° and 135°), and between 90° Orientation Change and 135° Orientation Change (these are thus Helmert contrast). The latter two contrasts serve as a check on the first one, if the first contrast happens to be significant. A final contrast set serves to consider that it is not the amount of orientation change that is important for the results, but instead if the to be reported location coincides with a screen axis or not. To this end, 0° and 90° Orientation Change is contrasted with 45° and 135° Orientation Change. The other contrasts in this set compare 0° and 90° Orientation Change, and 45° and 135° Orientation Change. Note that the goal of this set requires interaction with Screen Encoding Direction. Regarding the Distance Variable, no specific contrast sets are constructed. Here, the trend analysis is used throughout.

Between participant variables (e.g., sex, order of Referent blocks, and handedness) will be ignored. These have not been controlled for explicitly.

6.3.1. Reaction Time

For the analysis of reaction times, those trials are used that go together with a reported location in the ‘correct region’ (99% ellipse) described above. See Table 6.1. Some exclusion of extreme values appears necessary however. First, obvious extreme scores are removed, that is, reaction times less than 250 ms (2 trials) and reaction times over 7 seconds (2 trials). The remaining scores are transformed to z-values for each participant. These z-values are again –over participants– transformed to z-values for each Referent and Intrinsic Direction. Of these, values below or over –3 respectively 3 are considered outlyers. This results in the exclusion of 1.8% of the otherwise correct responses.

6.3.1.1 Results

Because there is not a response for each combination of independent variables of each participant, initially a repeated measures analysis of variance is conducted with all independent variables whereby missing values are replaced with the mean reaction time of a participant. This analysis is conducted to estimate the most important effects, and not to report any of the statistics. This analysis reveals significant main effects of Intrinsic Direction, Distance, and Orientation Change, two-way interaction effects between Referent and Intrinsic Direction and between Intrinsic Direction and Orientation Change, and a three-way interaction between Referent, Intrinsic Direction, and Orientation Change. Additionally a possible significant three-way interaction involving on- versus off-axis directions, Orientation Change, and Screen Encoding Direction is observed.

As will be the case with all other dependent variables, the effects of Referent and its interaction with Intrinsic Direction is considered first. Thereafter the effects of Orientation Change and Referent over collapsed Intrinsic Directions are discussed. Then, the effect of on- versus off-axis directions, Orientation Change, and Screen Encoding Direction is discussed (which serves also as a comparison with regional error). The effect of Distance is finally discussed by considering it together with Referent and collapsed directions.

6.3.1.1.1. Referent and Intrinsic Directions

To consider the Intrinsic Frames of Reference, data are collapsed onto participant's mean reaction time for each combination of Referent and Intrinsic Direction. Mean reaction time over Referent and Intrinsic Direction is shown in Figure 6.4.[79] The

[79] The data depicted in this and all following graphs are summaries of all valid observations from the sample. The analyses however are usually based on data summarised for each participant while not all participants are necessarily included in the analysis (as indicated in the text).

repeated measures Analysis of Variance reveals significant effects of the interaction of Referent and Intrinsic Direction [$F(4.92, 172.33) = 5.56$, $p < .01$][80] and of the main effect of Intrinsic Direction [$F(4.76, 166.57) = 27.29$, $p < .01$]. The main effect of Referent is not significant [$F(1, 35) = 1.89$, n.s.].

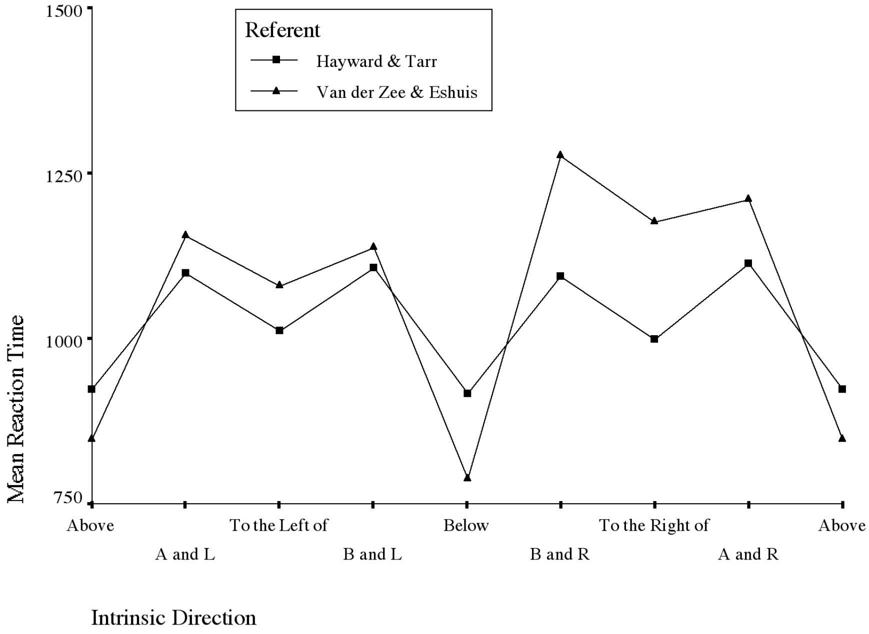

Figure 6.4. Mean reaction time for Referent and Intrinsic Direction. Abbreviations as defined in Figure 6.1. The *above* direction is presented twice for illustrative purposes.

The planned comparisons show the following significant contrasts with the Intrinsic Direction main effect. Responses are faster for on-axis directions than for off-axis directions [$t(35) = 6.73$, $p < .00112$][81], faster for the *top-bottom* axis than for the *left-right* axis [$t(35) = 8.82$, $p < .00112$], faster for the *top-bottom* axis than for all other directions [$t(35) = 9.38$, $p < .00112$], and tendentially faster for the *left-right* axis than

[80] In this and all other cases Huynh-Feldt adjustments to the degrees of freedom are made to correct for violations of the sphericity assumption.

[81] The familywise error rate (α_{FW}) is kept at .01. The per-comparison error rate (α_{PC}) is therefore adjusted depending on the number of comparisons (c) made. The Dunn-Sidak test is used here, where the Bonferroni inequality [$\alpha_{PC} \geq 1 - (1 - \alpha_{FW})^{1/c}$] is applied. In the present case with 9 comparisons, α_{PC} equals or is greater than .00112, and so the alpha per comparison is set at .00112. The alpha level for marginally significant comparisons is likewise set at .00568.

for the off-axis directions [t(35) = 3.32, p < .00568]. The *above* versus *below* contrast fails to reach marginal significance and so does the left versus right off-axis directions contrast [t(35) = -2.61 respectively 2.60, .05 > p > .00568].[82] The other planned contrasts (*left* versus *right*, oblique axis versus other oblique axis, above versus below off-axis directions) also fail to reach significance [t(35)'s respectively 1.41, -.35, and .41, all p's > .05].

The planned comparisons show the following significant and non-significant contrasts for the interaction effect of Referent and Intrinsic Direction. The reaction time difference between on-axis and off-axis directions does not differ significantly over Referents [t(35) = 2.19, .05 > p > .00568] nor does the marginally significant difference between the *left-right* axis and the off-axis directions [t(35) = -1.38, n.s.]. The difference between the *top-bottom* axis and the *left-right* axis does differ over the Referents [t(35) = 5.19, p < .00112] and so does the difference between the *top-bottom* axis and all other directions [t(35) = 4.84, p < .00112]. The other non-significant main effect contrasts of Intrinsic Direction (*above* versus *below*, *left* versus *right*, oblique axis versus other oblique axis, above versus below off-axis directions, and left versus right off-axis directions) do not differ over the Referents either [t(35)'s respectively -1.04, 1.93, -.78, .52, and 2.03, all p's > .05]. Figure 6.4 show that responses are faster for the *top-bottom* axis of the Van der Zee and Eshuis Referent than for the *top-bottom* axis of the Hayward and Tarr Referent while responses are slower for the other directions of the Van der Zee and Eshuis Referent.

In order to consider the interaction effect more closely, separate repeated measures Analyses of Variance for each Referent are performed. Intrinsic Direction is significant with the Hayward and Tarr Referent [F(4.71, 164.89) = 8.21, p < .01]. The tested contrasts show significant effects of on- versus off-axis directions, *top-bottom*

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[82] The *above* versus *below* contrast and the left versus right off-axis directions contrast would thus have reached marginally significance if α_{PC} had not been adjusted downwards (see previous Note; both p's < .05). Such cases will be separately mentioned.

versus *left-right* axes, *top-bottom* axis versus the other directions, and *left-right* axis versus off-axis directions [t(35) = 6.06, 3.64, 6.84 respectively 4.12, all p's < .00112]. Responses are thus faster on the *top-bottom* axis than on the *left-right* axis, for which responses are faster than on the off-axis directions. The other contrasts (*above* versus *below*, *left* versus *right*, oblique axis versus other oblique axis, above versus below off-axis directions, and left versus right off-axis directions) fail to reach significance [t(35) = -.23, -.46, .48, -.03 respectively -.42, all p's > .05].

Intrinsic Direction is also significant with the Van der Zee and Eshuis Referent [F(4.41, 154.47) = 21.18, p < .01]. The tested contrasts show significant effects of on- versus off-axis directions, *top-bottom* versus *left-right* axes, and *top-bottom* axis versus the other directions, [t(35) = 5.82, 7.97 respectively 8.25, all p's < .00112]. Differing from the Hayward and Tarr Referent, the *left-right* axis versus off-axis directions contrast does not appear significant [t(35) = 1.81, n.s.]. Responses are thus faster on the *top-bottom* axis than all other directions, while responses are not faster on the *left-right* axis than on the off-axis directions. Another difference is that the left versus right off-axis directions contrast does reach marginal significance [t(35) = 3.30, p < .00568]. Responses are thus tendentially faster on the left off-axis directions than on the right off-axis directions. The other contrasts (*above* versus *below*, *left* versus *right*, oblique axis versus other oblique axis, and above versus below off-axis directions) fail to reach significance with this Referent [t(35) = -2.05, 2.03, -.70 respectively .65, all p's > .05 except for the p for *above* versus *below* which is slightly below .05].

6.3.1.1.2. Effects of Orientation Change

The informal analysis reveals an interaction effect of Orientation Change, Intrinsic Direction, and Referent. The effect appears (mostly) due to differences between the *top-bottom* axis, the *left-right* axis, and off-axis directions. Data are collapsed to obtain the mean reaction time of each participant on the *top-bottom* axis, the *left-right* axis, and the left and right off-axis directions for each Referent and Orientation Change. This choice of off-axis collapsing is solely based on the above finding of a marginal difference between left and right off-axis directions on the Van der Zee and Eshuis Referent. Collapsing data like this results in valid cases (no missing values) of 33 participants.

The contrasts used are the following. For collapsed Intrinsic Direction, the orthogonal set *top-bottom* axis versus the other Directions, the *left-right* axis versus the off-axis directions, and the left versus the right off-axis directions is used as well as the additional (non-orthogonal) contrast *top-bottom* versus left-right axes. For the Orientation Change variable the trend analysis is used. The mean reaction time on Orientation Change for the *above-below* dimension, the *left-right* dimension, and the off-axis directions for each Referent are illustrated in Figure 6.5.

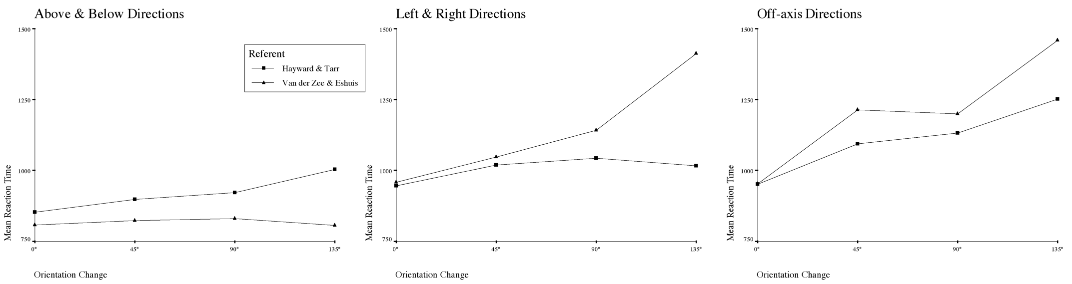

Figure 6.5. Mean reaction time for Referent, Intrinsic Direction, and Orientation Change.

Figure 6.5 shows that an increase in Orientation Change (more or less) goes together with an increase in reaction time. The repeated measures Analysis of Variance reveals a marginally significant effect of the three-way interaction of Referent, Intrinsic Direction, and Intrinsic Direction [$F(5.09, 162.87) = 2.94$, $p < .05$].[83] Significant two-

[83] The informal analysis suggests stronger significance of the interaction effect. This is due to the involvement of a difference between the *left* and *right* directions which are collapsed in the present case. This effect seems predominantly caused by slow reaction time for the *right* direction of the Van der Zee and Eshuis Referent when Orientation Change is 135°. This is an effect that allows no collapsing over Directions. Therefore, the effect can not be considered in the present case together with all other Intrinsic Directions, because too many participants would show one or more missing values. The effect can be checked by considering only the scores on the respective Directions whereby it will be pretended that an orthogonal set of contrasts involving all Intrinsic Directions is used, and the per-comparison alpha is

way interaction effects are observed of Referent and Orientation Change [F(2.68, 85.77) = 4.44, p < .01], and of Intrinsic Direction and Orientation Change [F(6.60, 211.11) = 4.21, p < .01]. A significant main effect of Orientation Change is observed [F(2.13, 68.09) = 28.69, p < .01]. Other main effects and interactions are ignored here, because they were already discussed above.

The trend analysis of the main effect of Orientation Change reveals that the linear trend is significant [t(32) = 6.94, p < .00334], while the quadratic and cubic trends are not [t(32) = -.61, n.s. respectively t(32) = 2.44, 0.05 > p > .01695].

The interaction of Referent and Orientation Change shows a marginally significant linear trend [t(32) = 3.09, p < .01695], which means that the linear orientation effect is somewhat steeper for the Van der Zee and Eshuis Referent than for the Hayward and Tarr Referent (see Figure 6.5 and keep in mind that the analysis uses two off-axis categories which are shown together). The quadratic and cubic trends are not significant [t(32) = 1.34 respectively 1.32, n.s.].

The interaction between Intrinsic Direction and Orientation Change shows that the linear trend for the *top-bottom* axis is different from the linear trends for the other directions. The comparisons between the *top-bottom* axis and all other directions respectively only the *left-right* axis show a significant difference in the linear trend [t(32) = 6.13 respectively 3.87, both p's < .00084]. The comparisons between the *left-right* axis and the off-axis directions and between the left and right off-axis directions show no such difference [t(32) = 1.05 respectively 1.19, n.s.]. The linear trend of

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adjusted accordingly. The repeated measures analysis of variance involving Referent, *left* versus *right* directions, and Orientation Change is performed with the data of 24 participants. The three-way interaction is significant [F(2.81, 64.65) = 9.34, p < .01]. The trend analysis on this effect reveals that the linear trend is significant [t(23) = 4.34, p < .00048], but that the quadratic [t(23) = 2.34, 0.5 > p > .00243] and cubic [t(23) = -1.01, n.s.] trends are not. A separate analysis on the Hayward and Tarr Referent (data of 33 participants) reveals that the interaction between *left* versus *right* directions and Orientation Change fails to reach significance [F(2.88, 92.26) = 2.64, p > .05]. A separate analysis on the Van der Zee and Eshuis Referent (data of 26 participants) reveals that the interaction between *left* versus *right* directions and Orientation Change does reach significance [F(2.23, 55.78) = 8.94, p < .01]. Trend analysis revealed that the linear trend is marginally significant [t(25) = 3.69, p < .00243], while both the quadratic trend [t(25) = 2.30, 0.5 > p > .00243] and the cubic trend [t(25) = -.33, n.s.] are not.

reaction time over degrees of Orientation Change is thus weaker on the *top-bottom* axis (if any) than on any of the other directions (consider the steepness of the slopes in Figure 6.5). Quadratic and cubic trends show no difference over the Intrinsic Directions [t(32)'s varied between -1.06 and 1.60, n.s.].

The (marginally significant) three-way interaction seems also primarily due to the linear trend for the *top-bottom* axis. The difference of this linear trend with the linear trend for all other directions or linear trend for only the *left-right* axis differs over Referents [$t(32) = 4.54$ respectively 4.42, p's < .00084]. Additionally, however, the difference of the quadratic trend for the *top-bottom* axis with the quadratic trend for the *left-right* axis is also significant over the Referents [$t(32) = 4.00$, $p < .00084$]. The other comparisons did not show significant effects [t(32)'s for all but 2 contrasts range between -1.76 and 1.61, n.s.; t(32) for the quadratic trend difference between *top-bottom* and all other directions and between Referents is 2.29, $.05 > p > .00427$; t(32) for the quadratic trend difference between *left-right* and off-axis directions and between Referents is -2.28, $.05 > p > .00427$]. Inspection of Figure 6.5 suggests that there could be a quadratic trend of reaction time over Orientation Change on the *left-right* axis of the Hayward and Tarr Referent, but not on its *top-bottom* axis. In contrast, there could be a quadratic trend of reaction time over Orientation Change on the *top-bottom* axis of the Van der Zee and Eshuis Referent, but not on its *left-right* axis. To investigate the interaction closer the Referents are each subjected to a separate Analysis of Variance.

The analysis for the Hayward and Tarr Referent is performed with the data of all 36 participants. The repeated measures Analysis of Variance shows a significant effect of Orientation Change [$F(2.14, 74.95) = 13.77$, $p < .01$] and a marginally significant effect of Orientation Change and Intrinsic Direction [$F(6.28, 219.84) = 2.49$, $p < .05$]. The trend analysis for the Orientation Change effect shows a significant linear trend [$t(35) = 5.06$, $p < .00334$]. The quadratic and cubic trends are not significant [t(35) = -.70 respectively 1.40, n.s.]. The planned comparisons on the interaction effect do not reach significance [t(35) for the linear trend difference between the *left-right* axis and the off-axis directions is 2.80, .05 > p > .00427; t(35)'s for all other comparisons range between -1.98 and 1.59, n.s.]. The lack of (marginally) significant comparisons although the omnibus F shows a marginal significant effect indicates that the difference between conditions is probably elsewhere in some contrast(s) not tested at present. This possibility is not followed up here any further.

The analysis for the Van der Zee and Eshuis Referent is performed with the data of 33 participants. The repeated measures Analysis of Variance shows a significant effect of Orientation Change [F(2.48, 79.42) = 23.94, p < .01] and of Orientation Change and Intrinsic Direction [F(5.39, 172.45) = 4.55, p < .01]. The trend analysis for the Orientation Change effect shows a significant linear trend [t(32) = 7.08, p < .00334]. The quadratic and cubic trends are not significant [quadratic: t(32) = .41, n.s.; cubic: t(32) = 2.07, .05 > p > .01695]. With this Referent, two comparisons made on the interaction effect reach significance. The linear trend for the *top-bottom* axis (if any) differs from the linear trend for the *left-right* axis as well as from the linear trend for all other directions together [t(32) = 4.86 respectively 6.26, p's < .00084]. The other comparisons for the interaction effect do not reach significance [t(32)'s for all but two comparisons range between -.40 and 1.85, n.s.; t(32) for the quadratic trend difference between the *left-right* axis and the off-axis directions is -2.04, .05 > p > .00427; t(32) for the quadratic trend difference between the *top-bottom* axis and the *left-right* axis is 2.12, .05 > p > .00427].

These separate analyses show that the linear trend of reaction time over Orientation Change is different (weaker) on the *top-bottom* axis of the Van der Zee and Eshuis Referent than on its other directions and that this trend fails to be different on corresponding directions of the Hayward and Tarr Referent. Two of the three observed significant contrasts in the three-way interaction above are thus clear by these separate analyses for each Referent. The differences in the quadratic trend over Orientation

Change between the *top-bottom* and *left-right* axes and between the Referents can also be explained. This quadratic trend difference between the *top-bottom* and *left-right* axes for the Hayward and Tarr Referent shows a t(35) of -1.98, while for the Van der Zee and Eshuis Referent it shows a t(32) of 2.12. Thus while the difference between the *top-bottom* and *left-right* axes is not strong enough to be significant on each of the Referents separately, the difference between the values is strong enough to produce significant in the three-way interaction.

The orientation Change effect does not seem to compromise the main effect of Intrinsic Direction. Responses on *top-bottom* axis appear faster than on any other direction over each level of Orientation Change (although to different degrees).

6.3.1.1.3. On- or off-axis, Screen Encoding Direction, and Orientation Change

The informal analysis does not clearly show a three-way interaction effect of Intrinsic Direction, Screen Encoding Direction, and Orientation Change, but does show a quite strong contrast involving the comparison between on- and off-axis directions. To allow comparison with the regional error analysis, the possible significant contrast is considered more closely. The mean reaction time of each participant is calculated for each combination of Screen Encoding Direction, on- versus off-axis directions, and Orientation Change (valid data from 36 participants). The repeated measures analysis reveals –apart from effects described before[84]– a significant interaction effect of on- versus off-axis directions and Orientation Change [$F(3.00, 105.00) = 10.59$, $p < .01$], and a marginally significant three-way interaction [$F(2.21, 77.23) = 4.09$, $p < .05$]. No other (marginally) significant effects are observed of Screen Encoding Direction [$F(1, 35) = .43$, $p > .05$], its interaction with on- versus off-axis directions [$F(1, 35) = 1.50$, p

[84] The on- versus off-axis directions variable was not tested before in comparison to Orientation Change, but is implicit in some of the comparisons tested before. The main effect of Orientation Change was tested before. In this case, however, the cubic trend (next to the significant linear trend) reaches marginal significance ($t(35) = 2.88$, $p < .01695$). This difference is caused by the differences in collapsing the data. The trend is significant when only off-axis directions are considered [$t(35) = 3.04$, $p < .00334$], but not when on-axis Directions are considered [$t(35) = 1.17$, n.s.]. See also Figure 6.6.

> .05], or its interaction with Orientation Change [F(2.40, 83.87) = 1.11, p > .05]. Figure 6.6 shows the effect.

Trend analysis for the two-way interaction of on- versus off-axis directions with Orientation Change shows a clear linear trend [t(35) = 4.80, p < .00334], no quadratic trend [t(35) = -1.18, n.s.], and a cubic trend that fails to reach marginally significance [t(35) = 2.28, 0.5 > p > .01695]. Reaction time thus displays a steeper slope over Orientation Change on off-axis directions than on-axis directions. See Figure 6.6.

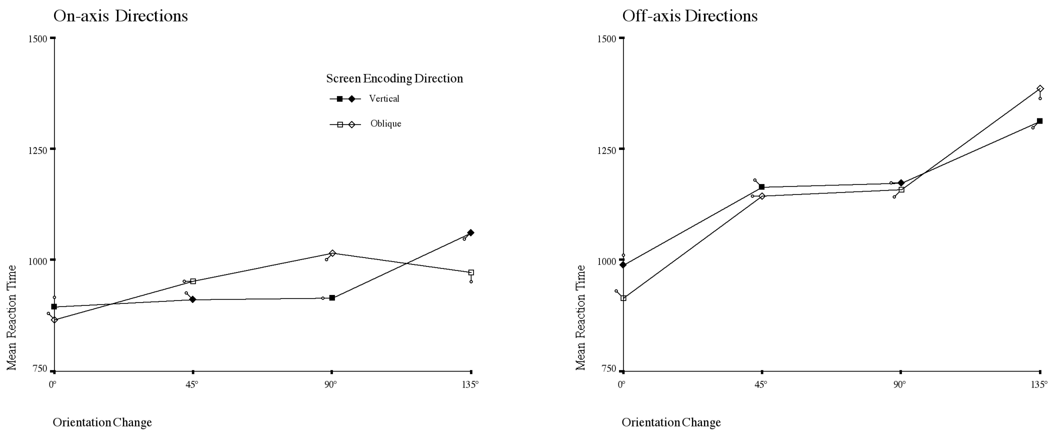

Figure 6.6. Mean reaction time for Intrinsic Direction, Screen Encoding Direction, and Orientation Change.

Trend analysis for the three-way interaction reveals that the linear component just fails to reach marginal significance [t(35) = 2.41, 0.5 > p > .01695], whereas the quadratic trend is marginally significant [t(35) = 2.64, p < .01695]. The cubic trend shows no sign of significance [t(35) = 1.13, n.s.]. A separate analysis for the on-axis directions shows a significant interaction of Screen Encoding Direction and Orientation Change [F(2.89, 101.28) = 5.82, p < .01]. The linear and cubic trends do not show significance [t(35) = -1.05 respectively -1.56, n.s.], but the quadratic trend does [t(35) = -3.47, p < .00334]. A separate analysis for the off-axis directions does not show a significant interaction of Screen Encoding Direction and Orientation Change [F(1.95, 68.16) = 1.73, p > .05]. As can be seen in Figure 6.6, the reaction time pattern over Orientation Change is about similar in both Screen Encoding Directions on the off-axis directions, while the pattern is different for the on-axis directions.

6.3.1.1.4. Distance

The final variable to be considered is Distance. The informal analysis shows Distance to have a significant influence on reaction time but not to interact with any of the other dependent variables. To illustrate this for the Intrinsic Frames of Reference, the final repeated measures analysis of variance for reaction time uses Referent, Intrinsic Direction (collapsed over *top-bottom* axis, *left-right* axis, above off-axis directions, and below off-axis directions)[85], and Distance as explanatory factors. The data of 33 participants are included in this analysis.

Ignoring already familiar effects, only the main effect of Distance appears significant [$F(2.99, 95.54) = 8.71$, $p < .01$]. The interactions of Distance with Referent [$F(2.43, 77.75) = .54$, $p > .05$] and with Intrinsic Direction [$F(5.13, 164.15) = .56$, $p > .05$] are not significant, and neither is the three-way interaction [$F(4.41, 141.27) = .72$, $p > .05$]. The effect of Distance from the centre of the object (or screen) on reaction time is shown in Figure 6.7.

The trend analysis reveals a significant linear trend [$t(32) = 4.88$, $p < .00334$]. The quadratic and cubic trends are not significant [$t(32) = -1.32$ respectively 1.26, n.s]. Reaction time thus increases with Distance from the Referents.

[85] This collapsing of Intrinsic Direction is chosen here to capture the difference in outline of the Referents in order to increase the possibility of finding effects if it is the distance of the dot location to the Referent's outline that (also) influences reaction time.

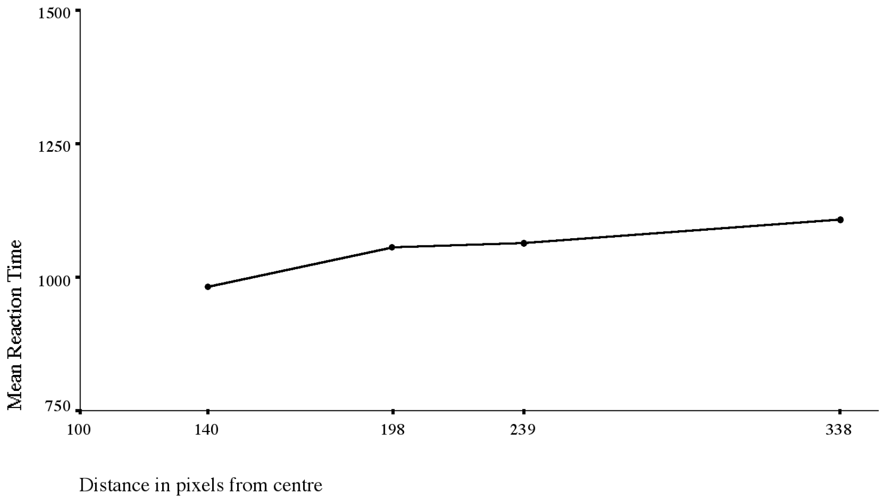

Figure 6.7. Mean reaction time for Distance. The Figure shows Distance as measured from the screen or object centre. The significant effect obtained in the analysis codes Distance on an ordinal scale (e.g., 1, 2, 3, and 4 depending on the relative proximity to the centre).

6.3.1.2. Reaction Time Discussion

As can be seen from the figures some differences exist between the two Referents, although both follow more or less the same pattern. Over both objects the *above-below* direction is responded to faster than the *left-right* direction, which is responded to faster than the off-axis directions. The difference between the *left-right* axis and the off-axis directions is significant for the Hayward and Tarr Referent only. These findings are in line with the intrinsic computation analysis for the on-axis directions. The slower responses on the off-axis directions and the *left-right* axis are in line with the regional interpretation because it shows that all locations in the *left* and *right* regions show slower reaction times than the locations on the *above-below* axis. It was not expected that responses on the off-axis locations are slower than responses on the *left-right* axis (over both Referents simultaneously and confirmed for one of them when considered separate). This finding is not necessarily contradicting a regional pattern. Off-axis locations are in two regions, which may lead to a somewhat higher memory load if memory is based on regions. Off-axis locations require that values on two directional oppositions are remembered (say, **a+** & **b+** corresponding to *above and to the left of*) whereas on-axis locations only require one directional opposition (say, **b+** corresponding to *to the left of*). Alternatively, the reporting of off-axis locations may demand an additional orienting of a vector relative to the axes.

Normalisation effects are observed whereby the slope of the normalisation function is flatter for the *top-bottom* axis than it is for the other directions. The normalisation is not normalisation relative to upright (which was not explicitly tested in the experiment; i.e., it was not designed to test this), but relative to the orientation of the Referent seen at encoding. Although not relative to the upright, the different normalisation slopes resemble the findings discussed in Chapter 3. Those findings did not involve directional decisions relative to a Referent with experimental trials involving a previously seen encoding orientation of the Referent, but with experimental trials in which there is only a single Referent orientation. The present findings suggest that both the encoding orientation of the Referent and the Intrinsic Location of the dot are retained in memory. The encoding orientation is coded by defining the *top-bottom* axis relative to an extrinsic reference orientation such as the environment or ego centred vertical. Normalisation between the reporting orientation and the retained encoding orientation would explain the Orientation Change effect. The intrinsic location is coded in terms of the primary *top-bottom* distinction and the secondary *left-right* distinction. This explains the faster responses for the *top-bottom* axis directions and the slower responses for the other directions. The findings also show that the normalisation is faster for the *top-bottom* axis than for the other directions. In Chapter 3 it was suggested that the slower normalisation rate for the locations that are not on the *top-bottom* axis is due to the normalisation being guided by the *top-bottom* axis. However, the line of reasoning in Chapter 3 still leaves quite some room for alternative views.

The pattern for the reaction time data can thus be linked with the establishment of intrinsic dimensions even when explicit linguistic labelling of directions is not required. The reaction time pattern of the intrinsic computation analysis is found for the axial directions and the data point to its regional interpretation regarding the off-axis directions. Reaction time for off-axis directions in the experiment point to a regional underlying structure. The different normalisation rates of the dimensions suggest that one dimension is defined only after the other. In particular the establishment of the *left-right* dimension is dependent on the establishment of the *top-bottom* dimension. It can thus be proposed that reaction time reflects the establishment of the poles of dimensions during the reporting phase.

On the other hand, the findings may not be solely attributable to reference frame extraction during the reporting phase of a trial. The Intrinsic Frame of Reference has to be extracted during the encoding phase as well. If there is an insufficient extraction of the reference frame during encoding, then an incomplete memory trace for the Figure's location may be the result. If so, this would lead to uncertainty during the reporting phase, which is accompanied by longer reaction time. Reference frame extraction is assumed to be similar for both phases of a trial. Because of the restricted encoding time, the relative occurrence of insufficient encoding for a particular dimension should follow the order in which the dimensions are extracted. If there is an effect of the encoding phase on the reaction time at reporting, then the findings should thus show a pattern that reflects an exaggeration of reference frame extraction.

The (marginally) significant three-way interaction between the on- versus off-axis directions, Screen Encoding Direction, and Orientation Change is difficult to interpret. The Screen Encoding Direction and Orientation Change jointly determine the Screen Reporting Direction, off- versus on-axis directions and Screen encoding direction jointly define if Referent axes and Screen axes are aligned or misaligned at encoding, and together with orientation Change if they are aligned or misaligned at reporting. Due to these interpretation difficulties that are inherent to the present experimental task and because the effect was only marginally significant, the reasons for the effect will not be considered any further.

The effect of Distance shows that locations farther from the Referents go together with slower responses. This suggests that the participants in the experiment took the double task they were given in the experiment seriously. The instruction to first find the location of the dot visually and press a key as fast as possible thus lead participants to first find the correct direction by focussing on the Referent at reporting and then moving their attention outward to the retained Distance from there.

6.3.2. Regional Error

The error analysis includes the 'Correct' scores and the three kinds of regional error scores ('A/B-error', L/R-error', and 'A/B+L/R-error'; see Table 6.1). Within the analysis, no differentiation is made between the different kinds of error. On-axis directions allow only one kind of error, and the proportion of the *above-below* errors and of the combines *above-below* and *left-right* errors is too small to allow a separate analysis.

The percentage regional error pattern follows (more or less) the reaction time pattern. Directions where relative more regional errors are made are directions that show relative long reaction time. No hypotheses were defined for regional error as this kind of error was not expected (similar errors have not been found in memory experiments with superimposed frames of reference). It is possible to argue, however, that the explanations invoked for reaction time differences can also be employed for differences in the occurrence of regional error. Longer reaction time may point to more uncertainty on behalf of the participant and this uncertainty could also be linked to a higher prevalence of Regional error. Alternatively, longer reaction time could point to a more time-consuming procedure to define a response. The longer and/or complicated this procedure, the more regional error could occur during its course.

Regional error is quite interesting from a theoretic point of view as well. This kind of error may also reveal something about how spatial information characterising Directional Relations is represented. There are now two measures with which the correspondence between spatial representation and spatial language can be investigated. On the one hand, Directional Prepositions may correspond to axial prototypes that have an influence on the (local) accuracy of reporting a location. If this is the case the *above-below* axis produces similar results as the *left-right* axis. This correspondence is suggested by Hayward and Tarr: Axial prototypes exert an influence in linguistic as well as non-linguistic spatial tasks. On the other hand, the correspondence between spatial representation and spatial language can also be investigated with the proportion regional error. In that case there is a difference between the *above-below* and the *left-right* dimension, and the errors reflect a regional pattern.

6.3.2.1. Results

As with reaction time, the proportion of regional error (that is, the reported locations that are in one of the Regional Error ellipses compared to those in the Correct 99% ellipse) is first subjected to an informal analysis with missing values replaced. This analysis reveals some effects that are comparable to the effects found on reaction time. In particular, significant main effects are found of Intrinsic Direction and Orientation Change, as well as an interaction effect of Referent and Intrinsic Direction and of Intrinsic Direction and Orientation Change. The three-way interaction of Referent, Intrinsic Direction, and Orientation Change shows no significant effect on regional error, however. The three-way interaction of Intrinsic Direction (on- versus off-axis directions), Orientation Change, and Screen Encoding Direction does show a significant effect. Additionally, for regional error a three-way interaction between Direction, Distance and Screen Encoding Direction is found. The main effect of Distance is not found on regional error.[86]

To be able to compare results with those on reaction time, contrast sets similar to those used there will be used here. Below, I will discuss the (non-significant) three-way interaction between Referent, Intrinsic Direction, and Orientation Change (and lower order effects). Also, as with reaction time, the interaction between on- versus off-axis directions, Orientation Change, and Screen Encoding Direction is considered. Additionally, the interaction between Intrinsic Direction, Distance, and Screen encoding Direction is explored.

6.3.2.1.1. Referent and Intrinsic Direction

At first (as usual) the interaction between Referent and Intrinsic Direction is considered. Figure 6.8 shows regional error for each Referent and Intrinsic Direction. If the data are collapsed onto each participant's mean proportion Regional Error for each Referent and Intrinsic Direction, a repeated measures analysis of variance reveals significant effects of Intrinsic Direction [$F(5.19, 181.80) = 9.65$, $p < .01$] and of the interaction of Referent and Intrinsic Direction [$F(5.95, 208.23) = 3.31$, $p < .01$]. The main effect of Referent is not significant [$F(1, 35) = 1.70$, $p > .05$].

Planned comparisons for the main effect of Intrinsic Direction reveal significant effects of on- versus off-axis directions [$t(35) = 6.27$, $p < .00112$], *top-bottom* versus *left-right* axes [$t(35) = 4.80$, $p < .00112$], and *top-bottom* axis versus all other directions [$t(35) = 6.86$, $p < .00112$]. The comparison between the *left-right* axis and off-axis directions only comes close to marginal significance [$t(35) = 2.78$, $.05 > p > .00568$].

[86] The informal analysis also reveals that the four-way interaction between Referent, Distance, Orientation Change, and Screen Encoding Direction might approach (marginal) significance. With the data resulting from the present design it is not possible to consider if there is an effect or not. Next to already mentioned sources of missing data, the effect involves both Distance and Orientation Change, whose levels are randomly paired for an Intrinsic Direction. They are not systematically varied. The resulting variation for a given participant is therefore accidental and not all levels may be paired within a participant. The interaction has no evident theoretical importance for present purposes and is ignored.

The remaining contrasts (*above* versus *below*, *left* versus *right*, oblique axis versus other oblique axis, above versus below off-axis directions, and left versus right off-axis directions) all fail to come anywhere near significance [t(35)'s range from -1.20 to 1.50, n.s.]. Fewer errors are made on the *top-bottom* axis than on any of the other Directions.

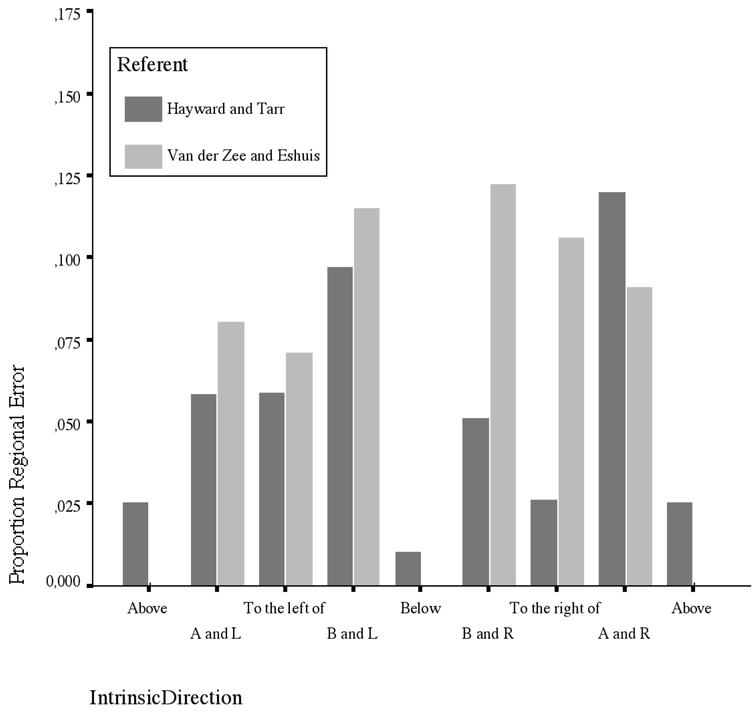

Figure 6.8. Proportion regional error for Referent and Intrinsic Direction.

The same planned comparisons for the interaction of Intrinsic Direction and Referent however fails to provide any significant contrasts with the present set although the omnibus F-statistic proves significant. The contrasts between the *top-bottom* and *left-right* axes, between the *top-bottom* axis and the other directions, and between the "topleft-bottomright" and "topright-bottomleft" oblique axes can be considered quite close to marginal significance [t(35) = 2.72, 2.58, respectively -2.48, 0.5 > p's > .00568]. The contrasts between above and below off-axis directions and between *left* and *right* are less close to significance [t(35) = 2.03 respectively 1.99, 0.5 > p's >

.00568]. The other contrasts (on- versus off-axis directions, *left-right* axis versus off-axis directions, *top* versus *bottom*, and left versus right off-axis directions) do not come close to significance at all [t(35)'s range between -1.27 and 1.20, n.s.]. The significant difference over Referents and Intrinsic Directions is apparently not captured well by the comparisons used at present.

A separate analysis for the Hayward and Tarr Referent reveals a significant effect of Intrinsic Direction [F(4.48, 156.85) = 6.25, p < .01]. The comparisons between on- versus off-axis directions and between *top-bottom* axis and the other directions prove to be significant [t(35) = 4.22 respectively 4.93, both p < .00112]. The contrasts between *left-right* axis and off-axis directions and between the "topleft-bottomright" and "topright-bottomleft" oblique axes come quite close to marginal significance [t(35) = 2.82 respectively 2.86, 0.5 > p's > .00568], while the contrast between the *top-bottom* and *left-right* axes comes less close [t(35) = 2.35, 0.5 > p > .00568]. The comparisons between *above* and *below*, between *left* and *right*, between above and below off-axis directions, and between left and right off-axis directions are not significant at all [t(35) ranges from -1.45 to .59, n.s.]. Fewer errors are thus made on the *top-bottom* axis if compared with all other directions and on the on-axis directions when compared with the off-axis directions. There are not significantly fewer errors on the *top-bottom* axis than on the *left-right* axis.

A separate analysis on the Van der Zee and Eshuis Referent has one obvious problem: No regional error has been found on the *top-bottom* axis, that is, there is no variance at these directions. The analysis may suffer from ceiling (in this case: floor) effects. Nonetheless the analysis is performed and reveals a significant effect of Intrinsic Direction [F(5.33, 186.67) = 6.86, p < .01]. The lack of regional errors on the *top-bottom* axis is clearly responsible for this effect. Comparisons between the *top-bottom* and left-right axes, between the *top-bottom* axis and all other directions, and between on- and off-axis directions all show significant effects [t(35) = 4.21, 5.65

respectively 5.30, all p < .00112]. None of the comparisons contrasting the *left-right* axis and the off-axis directions, the *left* and *right* directions, the oblique and other oblique axes, the above and below off-axis directions, and the left and right off-axis directions are significant [t(35)'s range from -.26 to 1.64, n.s.]. The comparison between the *above* and *below* directions cannot show a significant difference as on both directions no regional errors are found. Regarding the Van der Zee and Eshuis Referent, fewer errors are thus made on the *top-bottom* axis than on any of the other directions, while no difference between the other directions is apparent.

6.3.2.1.2. Effects of Orientation Change

The data are collapsed onto each participant's mean proportion of regional error for each combination of Referent, Intrinsic Direction (i.e., top-bottom axis, left-right axis, above off-axis, and below off-axis directions[87]), and Orientation Change. The proportion regional error for the *top-bottom* axis, the *left-right* axis, and the off-axis directions for each Referent and degree of Orientation Change is illustrated in Figure 6.9.

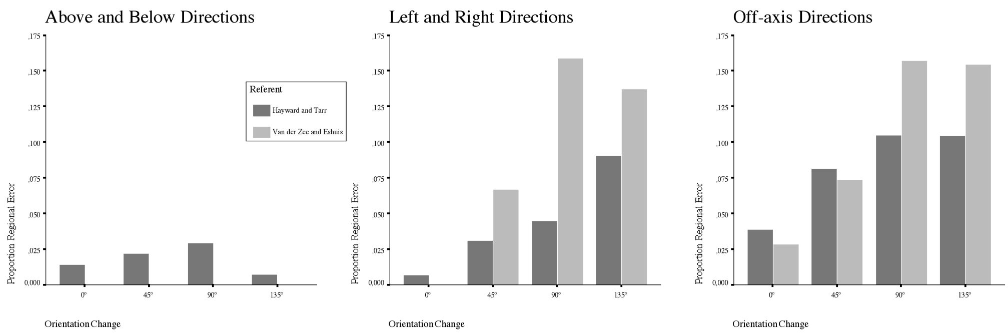

Figure 6.9. Proportion regional error for Referent, Intrinsic Direction, and Orientation Change.

A repeated measures analysis of variance with the data of 34 participants is performed. Except for effects discussed before, a significant main effect of Orientation Change is

[87] The choice for this pairing of off-axis directions follows the informal analysis, where the difference between above and below off-axis directions appears close to significance in the three-way interaction.

observed [$F(3.00, 99.00) = 16.76$, $p < .01$]. Additionally, the interaction of Orientation Change and Intrinsic Direction displays significance [$F(7.34, 242.32) = 2.84$, $p < .01$]. The interaction of Referent with Orientation Change [$F(2.95, 97.22) = 1.73$, $p > .05$] and the three-way interaction [$F(6.43, 212.28) = 1.14$, $p > .05$] are not significant.

Trend analysis on the Orientation Change main effect reveals a significant linear component [$t(33) = 6.46$, $p < .00334$]. The quadratic and cubic trends are not significant [$t(33) = -1.87$ respectively -1.05, both $p > .05$]. Proportion regional error thus linearly increases with degree of Orientation Change. Visual inspection of Figure 6.9 however suggests that the increase applies mainly to Orientation Change up to 90°.

Orientation Change interacts with the Intrinsic Directions involved. The planned comparisons reveal that the linear trend differs significantly between the *top-bottom* and *left-right* axes [$t(33) = 4.51$, $p < .00084$] and between the *top-bottom* axis and all other directions [$t(33) = 5.55$, $p < .00084$]. No differences in linear trend were observed between the *left-right* axis and the off-axis directions [$t(33) = -.28$, n.s.], or between the above and below off-axis directions [$t(33) = 1.51$, n.s.]. Quadratic and cubic trends display no differences between the compared directions [$t(33)$ ranges from $-.92$ to $.53$, n.s.]. This shows that the proportion regional error is much less affected by Orientation Change on the *top-bottom* axis than on any other direction and that there is no difference between the *left-right* axis and off-axis directions regarding the effect of Orientation Change.

6.3.2.1.3. On- or off-axis, Screen Encoding Direction, and Orientation Change

The informal analysis reveals a three-way interaction of Intrinsic Direction, Screen Encoding Direction, and Orientation Change that appears to involve the difference between on- and off-axis directions. Intrinsic Direction is dichotomised as an on- versus off-axis direction variable, and participant's mean proportion of regional error is calculated for each Screen Encoding Direction and Orientation Change. The data of all

36 participants can be used in a repeated measures analysis of variance. Apart from already familiar effects[88], the analysis shows a marginally significant interaction effect of Screen Encoding Direction and on- versus off-axis directions [$F(1, 35) = 4.79$, $p < .05$], and a significant effect of the three-way interaction between on- versus off-axis directions, Orientation Change, and Screen Encoding Direction [$F(2.43, 85.02) = 5.97$, $p < .01$]. The main effect of Screen Encoding Direction is not significant [$F(1,35) = 1.72$, $p > .05$] and neither is its interaction with Orientation Change [$F(2.29, 80.24) = .74$, $p > .05$]. The interaction between Orientation Change and on- versus off-axis directions is not significant either [$F(3.00, 105.00) = 2.20$, $p > .05$][89]. The three-way interaction is shown in Figure 6.10. Note that the on-axis directions include the *above* and *below* directions, which were shown to produce very little regional error. Therefore, the proportion of regional error is relatively low for on-axis directions.

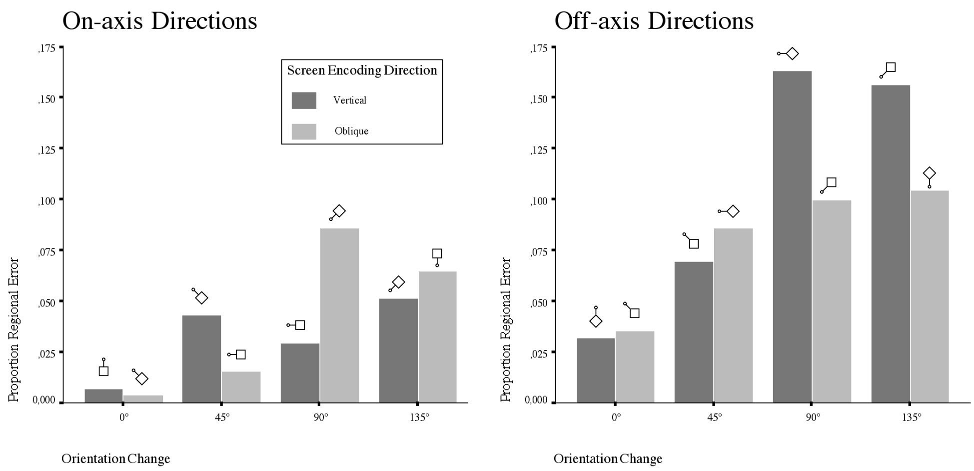

Figure 6.10. Proportion regional error for Intrinsic Direction, Screen Encoding Direction, and Orientation Change.

From the Figure it can be inferred that the marginal two-way interaction of Screen Encoding Direction and on- versus of directions is caused by a higher occurrence of

[88] The main effects of on- versus off-axis directions and Orientation Change were discussed above but not yet their interaction.
[89] Even though the linear trend on Orientation Change appears marginally different between on- and off-axis directions [$t(35) = 2.75$, $p < .01695$].

regional error with the vertical Screen Encoding Direction than with the oblique Screen Encoding Direction for the off-axis directions and a reversed pattern for the on-axis directions. Regarding the on-axis directions the difference is quite small though.

Trend analysis on the three-way interaction shows marginally significant linear and cubic trends [$t(35) = -2.96$ respectively 2.95, both $p < .01695$]. The quadratic trend is not significant [$t(35) = .34$, n.s.]. A separate analysis on the on-axis directions shows no main effect of Screen Encoding Direction [$F(1, 35) = 1.80$, $p > .05$], but a significant interaction of Screen Encoding Direction and Orientation Change [$F(2.35, 82.11) = 5.99$, $p < .01$]. The trend analysis shows a significant cubic trend [$t(35) = -3.55$, $p < .00334$]. The linear and quadratic trends are not significant [$t(35) = 1.93$ respectively $-.92$, both $p > .05$]. Inspection of Figure 6.10 shows that particularly the vertical Screen Encoding Direction displays a cubic pattern and that the oblique Screen Encoding Direction differs mostly at 45° and 90° Orientation Change.

A separate analysis on the off-axis directions shows a marginally significant effect of Screen Encoding Direction [$F(1, 35) = 4.96$, $p < .05$] and a marginally significant interaction of Screen Encoding Direction and Orientation Change [$F(2.59, 90.79) = 2.98$, $p < .05$]. The trend analysis shows a marginally significant linear trend [$t(35) = -2.61$, $p < .01695$]. The quadratic and cubic trends are not significant [$t(35) = -.17$ respectively 1.65, both $p > .05$]. Inspection of Figure 6.10 shows that the proportion of regional error is somewhat smaller in the oblique Screen Encoding Direction than in the vertical Screen Encoding Direction. Because the somewhat higher proportion in the vertical Screen Encoding Direction is particularly due to the conditions of 90° and 135° of Orientation Change, the linear trend is somewhat stronger for this Screen Encoding Direction. Fewer regional errors are made when off-axis directions encoded in the oblique Screen Encoding Direction than in the vertical Screen Encoding Direction.

6.3.2.1.4. Distance and Screen Encoding Direction

The informal analysis points to an effect that includes Intrinsic Direction, Distance, and Screen Encoding Direction. Most important within the effect appears the difference between left and right off-axis directions. Participant's mean proportion regional error is thus calculated for the *top-bottom* axis, *left-right* axis, left off-axis directions and right off-axis directions in each combination of Screen Encoding Direction and Distance. A repeated measured analysis of variance can be performed with the data of all 36 participants. Except for the already discussed effects, only the three-way interaction proves significant [$F(6.59, 230.79) = 2.94$, $p < .01$]. The main effect of Distance is not significant [$F(3.00, 105.00) = 1.00$, $p > .05$]. The two-way interactions of Intrinsic Direction and Distance, Intrinsic Direction and Screen Encoding Direction[90], and Distance and Screen Encoding Direction all fail to reach significance as well [$F(7.31, 255.90) = .68$, $F(2.26, 79.13) = 2.31$, respectively $F(2.96, 103.77) = .14$, all $p > .05$]. The three-way effect is shown in Figure 6.11.

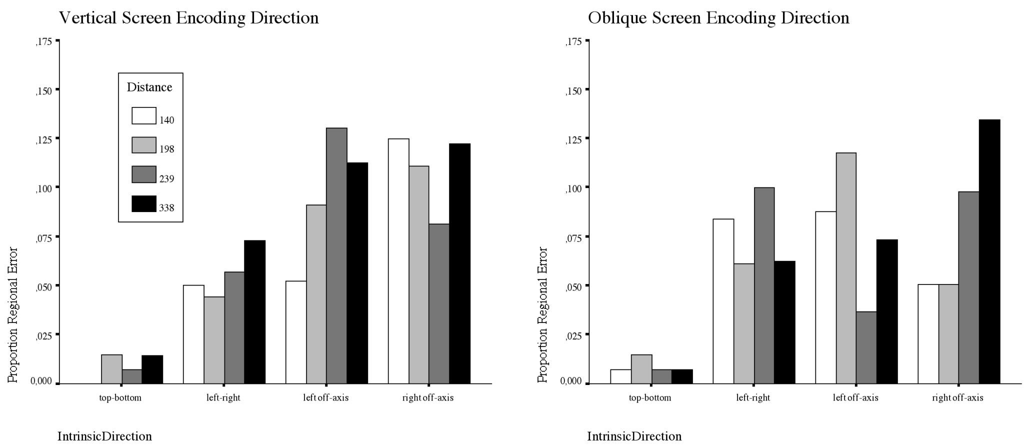

Figure 6.11. Proportion regional error for Intrinsic Direction, Screen Encoding Direction, and Distance.

[90] The previous encounter with this interaction involved the dichotomy on- versus off-axis directions and proved marginally significant. With respect to the present four-valued Intrinsic Direction no significance is observed.

The difference in proportion regional error displayed in the figure does not appear to exhibit any clear pattern. This is also clear from the trend analysis. The only comparison that comes near to but still fails to reach marginal significance is the difference in linear trend between left and right off-axis directions over Screen Encoding Direction [$t(35) = 2.79$, $0.5 > p > .00427$]. The corresponding quadratic and cubic trends and all trends in the comparisons between *top-bottom* and *left-right* axes, between *top-bottom* axis and all other directions, and between *left-right* axis and off-axis direction over Screen Encoding Direction fail to reach significance [$t(35)$ ranges between -1.86 and 1.64, all $p > .05$]. The trend analysis therefore does not appear to capture the significant differences. If separate analyses are conducted on each Screen Encoding Direction, then the interaction between Intrinsic Direction and Distance fails to reach significance in both cases [vertical Screen Encoding Direction: $F(6.84, 239.57) = 1.21$, $p > .05$; oblique Screen Encoding Direction: $F(5.80, 202.96) = 2.15$, $p > .05$]. Because there appears to be no clear pattern in the data for this effect, because the choice of off-axis direction collapsing is driven by the data, and because there is no explanation for the effect, it will be ignored.

6.3.2.2. Discussion of Regional Error

The suggestion made previously that similar reasons might be invoked to explain the proportion of regional error as have been invoked for reaction time seems confirmed. Many of the effects found for regional error parallel those found for reaction time. Although the commonalties are not perfect, similarities can be discovered in the interaction between Referent and Intrinsic Direction, in the interaction of Intrinsic Direction and Orientation Change, and in the interaction of on- versus off-axis directions, Screen Encoding Direction, and Orientation Change.

The proportion of regional error is smaller on the *top-bottom* axis than on the *left-right* axis (significant for one Referent only) or on all other directions together.

Between the *left-right* axis and the off-axis directions no clear difference is established. These data point to a similar occurrence of primarily *left-right* errors for the *left-right* axis as well as the left and right off-axis directions, that is, over the whole *left* and *right* regions. Regional errors thus appear to reflect a regional pattern in that they are made between one region and the opposite region. Regional error for off-axis directions points to a regional underlying structure.

Regional error can be linked with the establishment of intrinsic dimensions. The different proportions of regional error over different degrees of Orientation Change suggest that one dimension is defined only after the other. Both the *left-right* axis and the off-axis directions exhibit a strong increase of regional error with Orientation Change whereas the *top-bottom* axis does not (at least not that strong). This shows that the occurrence of regional error may be due in part to the establishment of the poles of a dimension whereby the *above* and *below* regions are defined before the left and right regions can be defined. The *left-right* opposition is more vulnerable to error because it depends on the *top-bottom* opposition. Higher degrees of Orientation Change heighten the proportion regional error because the chance of incorrectly imposing the *left* and *right* regions relative to the *top-bottom* opposition increases. The pattern suggests that the coding of a location is defined in an intrinsic Frame of Reference, and that the frame itself is defined by means of the encoding orientation relative to some extrinsic reference orientation.

These findings may not be solely attributable to Reference Frame extraction during the reporting phase of a trial. A Frame of Reference has to be extracted during the encoding phase as well. Insufficient extraction of the Reference Frame during encoding may result in an incomplete memory trace for the Figure's location. This may then lead to uncertainty during the reporting phase, which may produce regional error. However, Reference Frame extraction is the same for both phases. Because of the restricted encoding time, the relative occurrence of insufficient encoding for a particular dimension should follow the order in which the dimensions are extracted. The regional error findings may thus show an exaggerated extraction pattern. Additionally, because the *left-right* aspect of an encoded location depends upon the *top-bottom* axis, *left* and *right* regions need to be explicitly encoded relative to the *top-bottom* distinction (at least for the bilateral symmetric Van der Zee and Eshuis Referent). Any insufficiency in explicitly defining this dependency relation during the encoding phase leads to more regional *left-right* errors during the reporting phase.

The marginally significant interaction between on- versus off-axis directions and Screen Encoding Direction comes about because, on the one hand, on-axis directions in the vertical Screen Encoding Direction produce a smaller proportion error than On-axis Directions in the oblique Screen Encoding Direction. A smaller proportion of error is thus made when Referent axes coincide with screen axes at encoding than when Referent axes are not aligned with screen axes. On the other hand, off-axis directions in the vertical Screen Encoding Direction produce a higher proportion of errors than off-axis Directions in the oblique Screen Encoding Direction. Also here, a smaller proportion of error is thus made when Referent axes coincide with screen axes at encoding than when Referent axes are not aligned with screen axes.

The three-way interaction between on- versus off-axis directions, Screen Encoding Direction, and Orientation Change necessarily confounds different explanatory factors in the present experimental method. The interaction is thus difficult to interpret because Screen Encoding Direction, Screen Reporting Direction, Orientation Change, axes alignment at encoding, and axis alignment at reporting all may have an influence on the effect.

6.3.2.3. Comparison of Reaction Time and Regional Error

Because the pattern is similar to that found for the reaction time data, regional error can be linked with the establishment of intrinsic dimensions even when explicit linguistic labelling of directions is not required. The reaction time pattern of the intrinsic computation analysis is found for the axial directions and the data point to its regional interpretation regarding the off-axis directions. Reaction times appear correlated with the proportion of error between the poles of the dimensions. The different normalisation rates of the dimensions as well as the proportions of regional error over different degrees of Orientation Change suggest that one dimension is defined only after the other. This shows that the occurrence of regional error may be due in part to the establishment of the poles of a dimension. The reaction time data suggest that the coding of a location is defined in an Intrinsic Frame of Reference, and that the frame itself is defined by means of the encoding orientation relative to some extrinsic reference orientation. The question regarding axial or regional structure of the underlying representation is not definitely solved by the experiment. However, regional error and reaction time for off-axis directions in the experiment do point to a regional underlying structure.

Some differences were observed between reaction time and regional error. No three-way interaction between Referent, Intrinsic Direction, and Orientation Change is found for regional error. The patterns over the two dependent variables are similar though (compare Figure 6.5 and Figure 6.9). Regional error seems somewhat more volatile over conditions involved than reaction time. Also no difference in *left* and *right* directions over Referent and Orientation Change observed for reaction time (see Note 83) is observed for regional error. Finally no three-way effect of Screen Encoding Direction, Intrinsic Direction, and Distance for reaction time has been observed. There is no explanation for these effects at present.

A three-way effect of on- versus off-axis directions, Screen Encoding Direction, and Intrinsic Direction is observed on reaction time as well as regional error. At present, it is not clear what causes the effect. The interaction is difficult to interpret because Screen Encoding Direction, Screen Reporting Direction, Orientation Change, axes alignment at encoding, and axis alignment at reporting all may have an influence on the effect. Speculation makes no sense at this point bur has to await that such an effect is replicated preferably with a more balanced combination of experimental factors. The parallels are interesting though. In particular regarding the on-axis directions, reaction time and regional error about follow a similar pattern over Orientation Change in each Screen Encoding Direction (compare Figure 6.6 and Figure 6.10).

A main effect of Distance is found for reaction time, but not for regional error. For this difference between the dependent variables, a straightforward explanation can be presented. The reaction time effect points to the instruction of first visually finding the location of the dot. Directing attention from the Referent to the dot would take some time to complete. This time-consuming behaviour does not influence regional error though, because regional error probably only depends on the direction chosen to move attention along and not on how far it needs to be moved.

6.3.3. Reported Locations

Not all reported locations that are considered 'Correct' (see Table 6.1) are used in the analysis of location reporting accuracy. To remove extreme values, instead of the 99% ellipse, the 95% ellipse exemplified in Figure 6.3 serves to select the scores used in the analysis. This procedure results in the removal of (indeed) 4.0% of the otherwise 'Correct' scores. The standard ellipses for each Intrinsic Direction and Distance are shown in Figure 6.12 for the Hayward and Tarr Referent and in Figure 6.13 for the Van der Zee and Eshuis Referent.

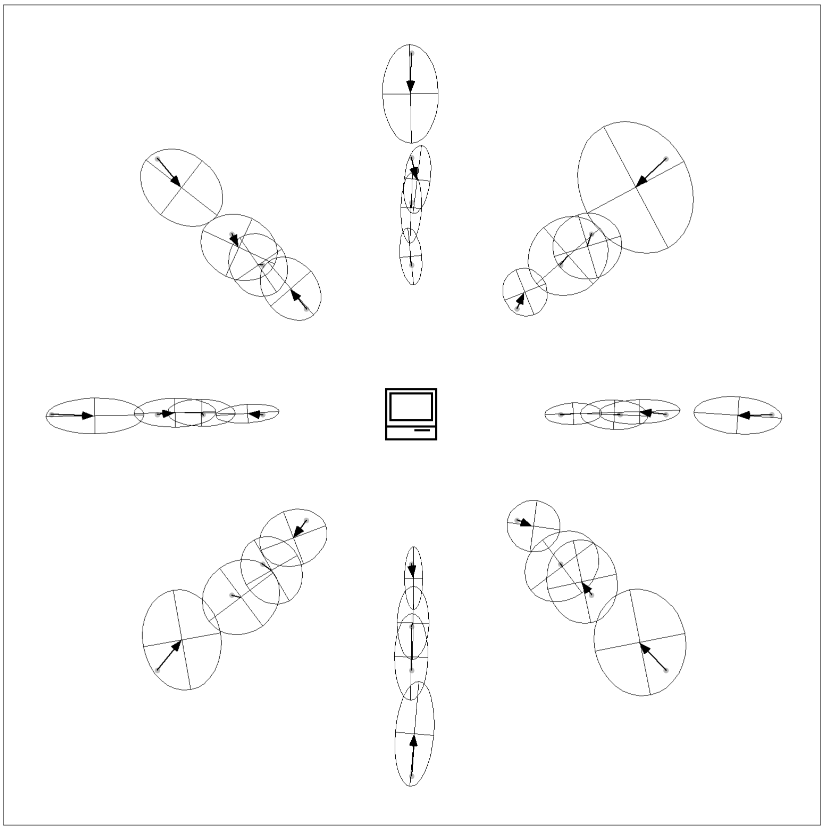

Figure 6.12. Standard ellipses for each Intrinsic Location relative to the Hayward and Tarr Referent. Arrows denote the bias from the true location to the mean of reports.

The planned contrasts used for reporting accuracy and bias differ somewhat from those used for reaction time and regional error. In this case no trend analysis is invoked for Orientation Change. The findings of Hayward and Tarr (1995) point to accuracy depending on- versus off-axis directions, but not on *top-bottom* versus *left-right* axes, nor on *top-bottom* axis versus all other directions. Regarding Intrinsic Direction the orthogonal set of contrasts comparing the on- and off-axis directions, the *top-bottom* and *left-right* axes, the *top* and *bottom* directions, the *left* and *right* directions, the oblique axes, the above and below off-axis directions, and the left and right off-axis directions is used. The contrasts will also be used to see if bias occurs.

On the other hand, the findings of Hayward and Tarr (accuracy of reports) may depend on the screen axis on which encoding respectively reporting takes place. Thus, Screen Reporting Direction may show differences in bias and accuracy. The Screen Reporting Direction depends on the combination of Screen Encoding Direction and Orientation Change. Therefore, if a significant interaction effect is observed that includes both Screen Encoding Direction and Orientation Change, then the planned contrasts for Orientation Change are the following. One comparison contrasts the 0° and 90° Orientation Change with the 45° and 135° Orientation Change. Another comparison contrasts 0° Orientation Change with 90° Orientation Change. The third comparison contrasts 45° Orientation Change with 135° Orientation Change. This set of contrasts is orthogonal. For example, if accuracy depends on the Screen Reporting Direction, then the first comparison should prove significant in the interaction of Screen Encoding Direction and Orientation Change, but the others should not. Of course, it is possible that accuracy is relatively increased if there is no Orientation Change in which case the second comparison could be significant as well. As another example, if bias is in opposite directions on oblique screen axes, then the second and third comparison should be significant in the interaction of Screen Encoding Direction and Orientation Change.

Of course, Orientation Change as such may influence results. No orientation change (0°) offering more than one frame of reference to base the response upon, than if there is actual Orientation Change (45°, 90°, and 135°). If a significant effect includes Orientation Change, but does not include Screen Encoding Direction, then this comparison and the other two Helmert contrast (45° with 90° and 135° Orientation Change, and 90° with 135° Orientation Change) are used. If accuracy is higher under the condition of no Orientation Change, then the first contrast should be significant while the others should not. Similarly, if (Intrinsic Direction) bias effects occur only if there is Orientation Change, then also the first contrast should be significant while the others should not in the interaction with Intrinsic Direction.

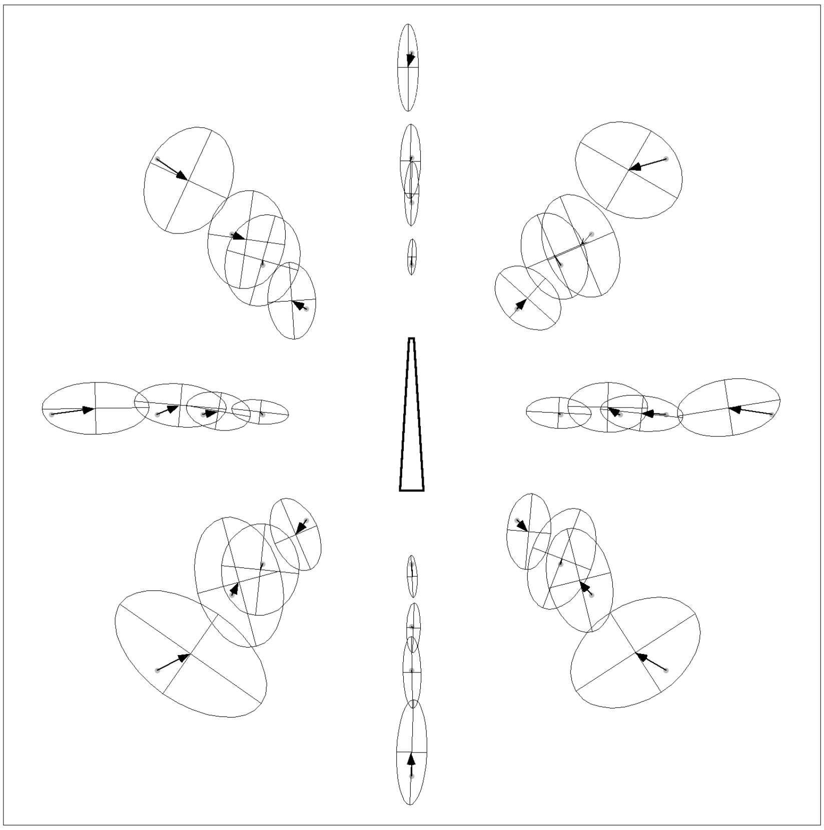

Figure 6.13. Standard ellipses for each Intrinsic Location relative to the Van der Zee and Eshuis Referent. Arrows denote the bias from the true location to the mean of reports.

6.3.3.1. Constant Angular Error Results

First, as usual, an informal analysis is performed. Unfortunately, this analysis shows that there might be a four-way interaction between Referent, Intrinsic Direction, Screen Encoding Direction and Orientation Change. Due to the occurrence of missing values, the significance of the effect cannot be determined with any certainty, although it appears that the interaction only comes close to significance. The direction comparisons show that the difference in angular error between above and below off-axis directions, between *left* and *right* directions, and between on- and off-axis directions are closest to varying significantly over Referent, Screen Encoding Direction, and Orientation Change. The possible effect is ignored, but the angular error over the conditions involved is shown in Figure 6.14. As can be seen, the pattern is not easy to interpret.

Other effects clearly apparent from the informal analysis are three three-way interactions and some of their lower order interactions. These are the interactions between Referent, Intrinsic Direction, and Screen Encoding Direction, between Referent, Intrinsic Direction, and Orientation Change, and between Intrinsic Direction, Screen Encoding Direction, and Orientation Change. The effects are considered below. At first, the interaction between Referent and Intrinsic Direction will be considered.

6.3.3.1.1. Referent and Intrinsic Direction

The data are collapsed onto participant's mean angular error for each Referent and Intrinsic Direction. The data of all 36 participants are subjected to a repeated measures analysis of variance. No significant effects are found of Intrinsic Direction [$F(2.83, 99.11) = 1.80$, $p > .05$], of Referent [$F(1, 35) = 1.26$, $p > .05$], and of the interaction of Referent and Intrinsic Direction [$F(2.89, 101.23) = 1.72$, $p > .05$]. Only the grand mean shows marginal significance [$F(1, 35) = 6.27$, $p < .05$], indicating that angular error is slightly biased in the positive direction (i.e., counter-clockwise). The mean angular error over Referent and Intrinsic Direction is shown in Figure 6.15.

6.3.3.1.2. Referent, Intrinsic Direction, and Screen Encoding Direction

The data are collapsed onto the mean angular error of participants for each combination of Referent, Intrinsic Direction, and Screen Encoding Direction. The repeated measure analysis of variance is performed with the data of 32 participants. Except for the already familiar effects, the three-way interaction is found to be significant [$F(4.59, 142.25) = 7.88$, $p < .01$] as is the two-way interaction between Intrinsic Direction and Screen Encoding Direction [$F(4.78, 148.17) = 6.19$, $p < .01$]. The main effect of Screen Encoding Direction reaches marginal significance [$F(1, 31) = .87$, $p < .05$]. The two-way effect of Referent and Screen Encoding Direction fails to reach significance [$F(1, 31) = .87$, $p > .05$]. The three-way interaction is shown in Figure 6.16.

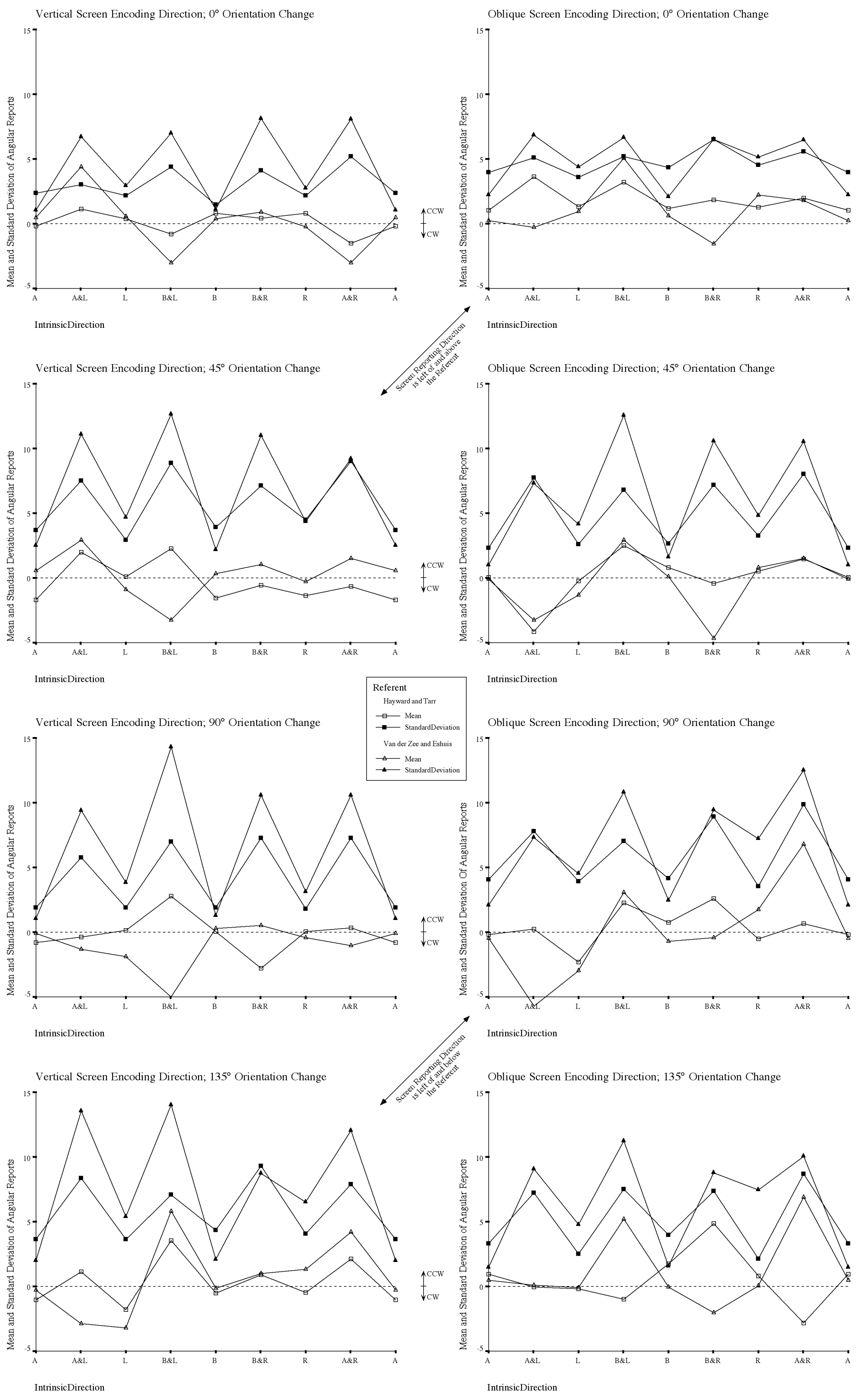

Figure 6.14. Mean and standard deviation of angular reports for Referent, Intrinsic Direction, Screen Encoding Direction, and Orientation Change.

The set of planned orthogonal contrasts reveals that the comparison between the oblique axes proves significantly different over Referent and Screen Encoding direction [t(31) = 4.61, p < .00143] as well as over Screen Encoding Direction [t(31) = 4.20, p < .00143]. The comparison between the *top-bottom* an *left-right* axes closely fails to reach marginal significance over Referent and Screen Encoding Direction [t(31) = 2.75, 0.05 > p > .00730]. All other planned comparisons show no significant effects for both the three-way and the two-way interaction [t(31) ranges from -2.02 to .82 for the three-way effect and from -.36 to 1.69 for the two-way effect, n.s.].

Separate analyses are performed for each Referent. Regarding the Hayward and Tarr Referent (36 valid cases) the interaction between Intrinsic Direction and Screen Encoding Direction shortly fails to reach significance [F(4.39, 153.59) = 2.34, p > .05]. The analysis for the Van der Zee and Eshuis Referent (32 valid cases) does show a significant interaction of Intrinsic Direction and Screen Encoding Direction [F(5.25, 162.83) = 11.28, p < .01]. Here, the difference between the oblique axes is significant over Screen Encoding Direction [t(31) = 6.78, p < .00143]. The difference between the *top-bottom* and *left-right* axes fails to reach significance [t(31) = 2.74, 0.05 > p > .00730]. All other comparisons are not significant [t(31) ranges from -.95 to 1.27, n.s.].

There is a tendency to counter-clockwise bias on oblique Screen Encoding Direction. In this Encoding Direction also the strongest bias is found, particularly on the off-axis directions of the Van der Zee and Eshuis Referent. On its *above and to the left* and its *below and to the right* directions clockwise bias is found, whereas on its *above and to the right* and its *below and to the left* directions counter-clockwise bias is found. Bias is thus away from the *top-bottom* axis (and towards the *left-right* axis). In the vertical Screen Encoding Direction, on the other hand, the bias for this Referent is not so pointed, and even seems more in opposite directions (see Figure 6.16). Bias for on-axis directions appears to be zero. Regarding the Hayward and Tarr Referent no significant bias is observed.

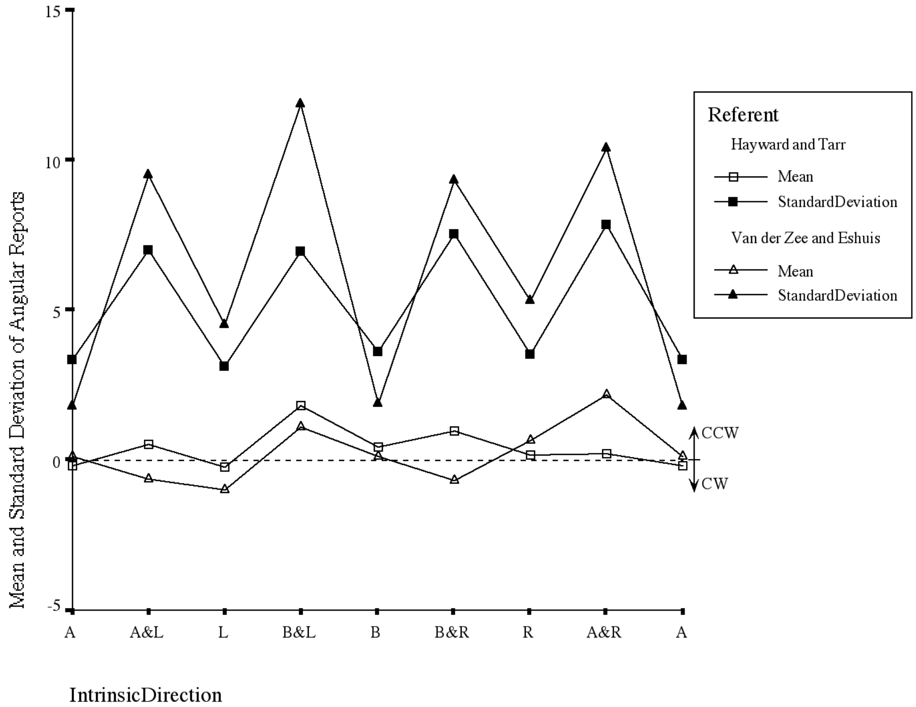

Figure 6.15. Mean and standard deviation of angular reports for Referent and Intrinsic Direction.

6.3.3.1.3. Effects of Orientation Change

The informal analysis suggests a three-way interaction effect of Referent, Intrinsic Direction, and Orientation Change, where the contrasts between the oblique axes and between on- and off-axis directions are the effect-determining factor levels. Therefore, the mean angular error of each participant for each combination of *top-bottom* axis, *left-right* axis, and each of the oblique axes and Orientation Change and Referent is calculated. A repeated measures analysis with the data of 31 participants is performed. Planned contrasts involve the comparisons between on- and off-axis directions, between *top-bottom* and *left-right* axes, and between the oblique axes for Intrinsic Direction. Because the analysis does not include Screen Encoding Direction, Helmert contrasts are used for Orientation Change.

Next to effects already mentioned above, the three-way interaction proves to be significant at a level on the boundary between significance and marginal significance [F(6.02, 180.69) = 2.89, p ≈ .01]. The two-way interaction between Intrinsic Direction and Orientation Change is marginally significant [F(6.67, 200.01) = 2.51, p < .05], and just so is the interaction between Referent and Orientation Change [F(2.44, 73.32) = 2.98, p < .05]. The main effect of Orientation Change does not reach significance [F(2.66, 97.68) = 2.02, p > .05]. The three-way interaction is shown in Figure 6.17.

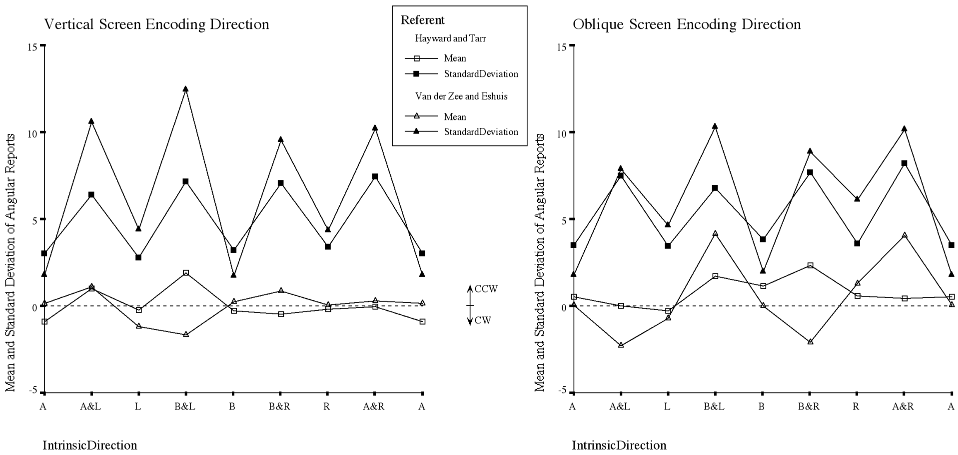

Figure 6.16. Mean and standard deviation of angular reports for Referent, Intrinsic Direction, and Screen Encoding Direction.

With respect to the two-way interaction between Intrinsic Direction and Orientation Change, only the difference between the oblique axes regarding the comparison between 0° and higher degrees of Orientation Change comes close to significance [t(30) = 2.72, .05 > p > .00568]. The other tested contrasts show no significance [t(30) varies between -1.87 and 1.60, n.s.]. Concerning the two-way interaction between Referent and Orientation Change, only the comparison between 90° and 135° Orientation Change comes close to significance [t(30) = 2.26, .05 > p > .01695]. The contrasts between 0° and higher degrees of Orientation Change and between 45° and higher degrees of Orientation Change are not significant [t(30) = 1.15 respectively .23, both p > .05].

Regarding the three-way interaction, only the planned comparison between 45° and higher degrees of Orientation Change comes close to marginal significance between the oblique axes and between Referents [t(30) = 2.86, .05 > p > .00568]. The same comparison for the difference between on- and off-axis directions fails to vary significantly over the Referents [t(30) = 1.96, p > .05]. Between the *top-bottom* and *left-right* axes there is no similar Orientation Change difference over the Referents either [t(30) =.41, p > .05]. The six other tested contrasts also show no significance [t(30) varies between -.68 and 1.71, n.s.].

A separate analysis for the Hayward and Tarr Referent (35 valid cases) shows a marginally significant two-way interaction [F(7.47, 253.94) = 2.53, p < .05]. The main effect of Orientation Change is not significant with this Referent [F(2.52, 85.72) = 2.07, p > .05].[91] The planned comparisons for the interaction fail to show a marginally significant difference between 90° and 135° Orientation Change for the difference between the oblique axes [t(34) = -2.20, .05 > p > .00568]. Regarding the same direction comparison, the contrast between 45° and higher degrees of Orientation Change also fails to reach marginal significance [t(34) = -2.07, .05 > p > .00568], while the contrast between 0° and higher degrees of Orientation also is not significant [t(34) = 1.86, p > .05]. Additionally, the contrast between the 45° and higher degrees of Orientation Change comes close to significance for the comparison between the *top-bottom* and *left-right* axes [t(34) = -2.71, .05 > p > .00568]. None of the other comparisons reaches significance [t(34) ranges from -.53 to .73, n.s.]. Inspection of Figure 6.17 shows that the difference between the oblique axes may be more or less a difference in their quadratic trends, which the contrast set does not accurately capture.

A separate analysis for the Van der Zee and Eshuis Referent (32 valid cases) shows a significant two-way interaction [F(6.12, 189.61) = 3.36, p < .01]. The main effect of Orientation Change is marginally significant with this Referent [F(3.00, 93.00)

[91] Even though the contrast between 0° and higher degrees of orientation Change appears marginally significant [t(34) = -2.77, p < .01695].

= 2.88, $p < .05$]. Planned comparisons for the interaction however show that none of the contrasts reaches significance. The comparisons for the difference between the oblique axes show that the contrast between 0° and higher degrees of Orientation Change is closest to significance [$t(31) = 2.60$, $.05 > p > .00568$], while the contrast between 45° and higher degrees of Orientation Change is less close [$t(31) = 2.24$, $.05 > p > .00568$], and the contrast between 90° and 135° Orientation Change is even further away [$t(31) = 1.22$, $p > .05$]. Note that the contrasts all point in the same direction and that between the oblique axis there could be a difference in their respective linear trends (see Figure 6.17). The remaining contrasts do not show significance [$t(31)$ ranges from -1.70 to 1.82, n.s.]. The comparison between 90° and 135° Orientation Change for the Orientation Change main effect reaches marginally significance [$t(31) = 2.69$, $p < .01695$], whereas the others do not [$t(31) = -.59$ and .46, n.s.]. This marginal effect might be caused by the relatively high counter-clockwise bias on the *above and to the right* and the *below and to the left* directions when there is 135° Orientation Change.

There thus appear to be some differences between the Referents regarding the bias displayed on different directions over different degrees of Orientation Change. The differences are however difficult to capture by the used comparisons. Moreover, the pattern displayed in Figure 6.17 is not easy to interpret.

6.3.3.1.4. Intrinsic Direction, Screen Encoding Direction, and Orientation Change

Finally, the informal analysis suggests a significant three-way interaction between Intrinsic Direction, Screen Encoding Direction, and Orientation Change, which again seems to involve differences between the oblique axes and between on-axis and off-axis directions. The mean angular error of each participant is thus calculated for each combination of the Intrinsic Directions *top-bottom* axis, *left-right* axis, and each oblique axis, and Screen Encoding Direction, and Orientation Change. For effects including both Screen Encoding Direction and Orientation Change, the contrast set involves comparisons between 0° plus 90° and 45° plus 135°, between 0° and 90°, and between 45° and 135° Orientation Change. A repeated measures analysis of variance is conducted with the data of 31 participants. Two effects were not considered before. The three-way interaction proves significant [$F(5.98, 179.37) = 4.70$, $p < .01$], while the two-way interaction between Screen Encoding Direction and Orientation Change is not significant [$F(2.91, 87.27) = .73$, $p > .05$]. The three-way interaction is shown in Figure 6.18. Note that the data are plotted against the Screen *Reporting* Direction, whereby the vertical Screen Encoding Direction starts at 0° and increases with Orientation Change whereas the oblique Screen Encoding Direction starts at 45°.

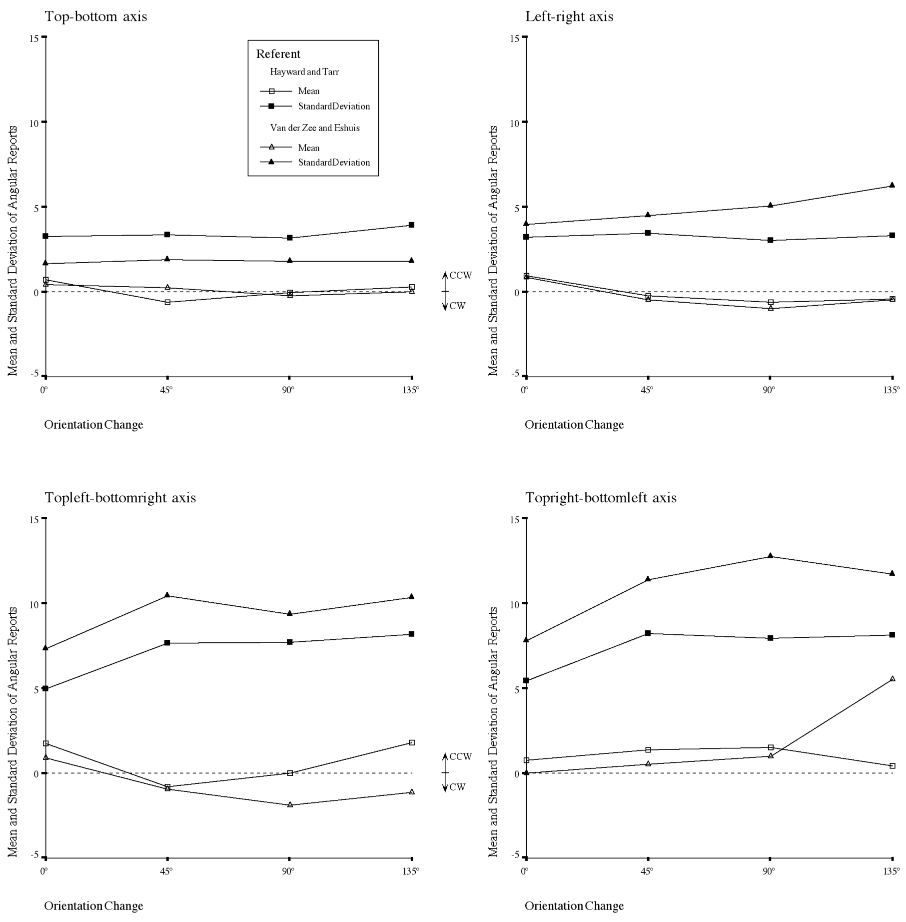

Figure 6.17. Mean and standard deviation of angular reports for Referent, Intrinsic Direction, and Orientation Change.

The planned comparisons show that the contrast between 45° and 135° Orientation Change between the oblique axes is significantly different over Screen Encoding Direction [$t(30) = -3.65$, $p < .00112$]. Additionally, a marginally significant effect is found on the on- versus off-axis directions when comparing the 0° and the 90° with the 45° and 135° Orientation Change over Screen Encoding Directions [$t(30) = -3.34$, $p < .00568$]. All other contrasts fail to display significance [$t(30)$ ranges between -1.37 and .19, all $p > .05$].

Separate analyses are conducted for each Screen Encoding Direction. On the vertical Screen Encoding Direction (34 valid cases), the two-way interaction between Intrinsic Direction and Orientation Change proves significant [$F(5.79, 191.04) = 5.09$, $p < .01$]. The comparison of 45° and 135° Orientation Change between the oblique axes produces almost a marginally significant difference [$t(33) = 2.91$, $.05 > p > .00568$]. Additionally, a marginally significant effect is found on the on- versus off-axis directions when comparing the 0° and 90° with the 45° and 135° Orientation Change [$t(33) = 3.27$, $p < .00568$]. All other comparisons fail to display significance [$t(33)$ ranges between -.91 and 1.91, all $p > .05$].

On the oblique Screen Encoding Direction (32 valid cases), the two-way interaction between Intrinsic Direction and Orientation Change proves only marginally significant [$F(6.90, 213.90) = 2.42$, $p < .05$]. The comparison of 45° and 135° Orientation Change between the oblique axes fails to produce a marginally significant difference [$t(31) = -2.41$, $.05 > p > .00568$]. No significant effect is found on the on- versus off-axis directions when comparing the 0° and the 90° with the 45° and 135° Orientation Change [$t(31) = -1.22$, $p > .05$]. Also, on- versus off-axis directions almost show some significance when the 45° and 135° Orientation Change conditions are compared [$t(31) = 2.13$, $.05 > p > .00568$]. All other comparisons fail to display significance [$t(31)$ ranges between -1.85 and 1.52, all $p > .05$].

Although the used contrast do not seem to capture the significancies very well, it can be argued that effects are mostly caused by, on the one hand, the relatively strong clockwise bias found at 45° Orientation Change compared to the other degrees of Orientation Change on the *above and to the left* and the *below and to the right* directions in the oblique Screen Encoding Direction. This is thus at the 90° Screen Reporting Direction. On the other hand, relatively strong counter-clockwise bias is found at the 135° Orientation Change compared to lower degrees of Orientation Change on the *above and to the right* and the *below and to the left* directions in the vertical Screen Encoding Direction (see Figure 6.18).

6.3.3.2. Constant Angular Error Discussion

For on-axis directions bias in angular reports seems small, for off-axis directions it seems strongest for the Van der Zee and Eshuis Referent. However, notwithstanding this differential susceptibility to angular deviation from the true location, no clear pattern can be discerned over the different conditions and different off-axis directions. The interpretation of the results is difficult. In particular, there does not appear to be a bias pattern that can be ascribed to the Intrinsic Frames of Reference and that does not depend on any of the other variables. In addition, there is not a clear bias pattern that can be ascribed to Screen Direction either. However, because the tested directions involve only on-axis directions or off-axis directions exactly in between, no clear bias pattern has necessarily been expected in the first place.

6.3.3.3. Variable Angular Error Results

In the previous sections on constant angular error, it was shown that constant error depends to some extent on each of the independent variables Referent, Intrinsic Direction, Screen Encoding Direction, and Orientation Change. Importantly, no effect of Distance on constant angular error is observed. In order to consider variable angular error, an absolute angular error measure is chosen as a variable. However, this measure is not absolute angular error from the true location, but instead the absolute angular deviation of a response from the mean of responses obtained on each combination of Referent, Intrinsic Direction, Screen Encoding Direction, and Orientation Change. These means are referred to as the 'observed cell means.' This measure should give an impression of the variability in responses independent of constant error and can be used as a measure of variability without having obtained the within-participant variability for a given condition (without having obtained several responses of a participant for the same condition). If possible, that is, in case of simple enough effects for which several responses from each participant have been obtained, the standard deviation of participant's angular responses will additionally be used as a dependent variable.[92] For instance, there are up to 8 valid responses of a participant for each Intrinsic Direction of each Referent and standard deviation can be used with this interaction.

The informal analysis (of the absolute deviation of mean of responses) reveals some three-way interactions that approach (marginal) significance. Upon closer inspection, i.e., under collapsing, none of these interactions prove significant in a formal analysis. There are several significant two-way interactions, however. As usual, I will start by considering the interaction of Referent and Intrinsic Direction. Then, in order to keep in line with previous analyses, the three-way interaction and simpler terms of Referent, Intrinsic Direction, and Screen Encoding Direction, and of Referent, Intrinsic Direction and Orientation Change will be considered. Finally, the interaction between Screen Encoding Direction and Orientation Change will be considered, that is, an effect that does not depend on the Intrinsic Frames of Reference. No effect involving the independent variable Distance is observed.

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[92] Test statistics may differ over the two methods to estimate variable error. One measure involves the variability in sample responses and the other the variability in participant responses. The measures may differ for instance when the variability of the responses of each participant is about equal but when their means differ. In such a case the variability in the sample is bigger than in the participant. The use of both measures in the present analysis serves to assure that the basic effects in one measure (sample variability) can also be found in the other measure (participant variability).

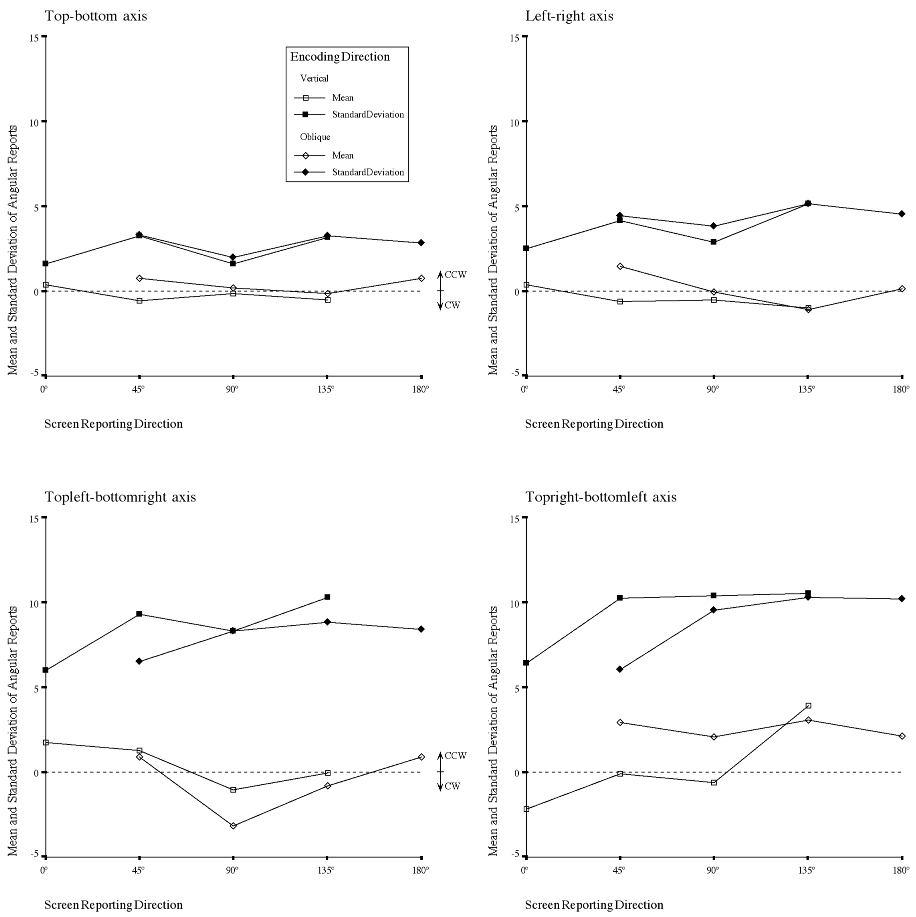

Figure 6.18. Mean and standard deviation of angular reports for Intrinsic Direction, Screen Encoding Direction, and Orientation Change.

6.3.3.3.1. Referent and Intrinsic Direction

If only Referent and Intrinsic Direction are considered (with the data of all 36 participants), then the absolute deviation of observed means shows significant effects of Referent [$F(1, 35) = 32.63$, $p < .01$], Intrinsic Direction [$F(4.58, 160.29) = 94.64$, $p < .01$], and the interaction of Referent and Intrinsic Direction [$F(4.76, 166.62) = 19.25$, $p < .01$]. Accuracy overall is higher for the Hayward and Tarr Referent than for the Van der Zee and Eshuis Referent. The standard deviation of all observations of the sample is shown in Figure 6.15.

Planned comparisons for the main effect of Intrinsic Direction show significant effects of the contrasts for on- versus off-axis directions [t(35) = 16.97, p < .00143] and for *top-bottom* versus *left-right* axes [t(35) = 7.80, p < .00143]. The *left* versus *right* directions contrast quite closely misses marginally significance [t(35) = 2.85, .05 > p > .00730], while the oblique axes contrast misses marginal significance by a somewhat higher degree [t(35) = 2.46, .05 > p > .00730]. All other contrast are not significant [t(35) between -.18 and 1.26, n.s.]. Angular accuracy is higher for on-axis directions than for off-axis directions, and higher for the *top-bottom* axis than for the *left-right* axis if Intrinsic Direction is considered independent of Referent.

Planned comparisons for the interaction of Referent and Intrinsic Direction show significant effects of the contrasts for on- versus off-axis directions [t(35) = 7.20, p < .00143] and for *top-bottom* versus *left-right* axes [t(35) = 9.44, p < .00143]. The oblique axes contrast misses marginal significance [t(35) = 2.60, .05 > p > .00730]. The *left* versus *right* directions contrast and all other contrasts are not significant [t(35) between -1.76 and .93, n.s.]. The on-axis directions advantage relative to the off-axis directions thus varies over the Referents, as does the *top-bottom* axis advantage relative to the *left-right* axis.

A separate analysis for the Hayward and Tarr Referent reveals a significant effect of Intrinsic Direction [F(4.02, 140.63) = 39.40, p < .01]. Planned comparisons show a significant effect of on- versus off-axis directions [t(35) = 10.77, p < .00143]. The *left* versus *right* directions contrast misses marginally significance [t(35) = 2.12, .05 > p > .00730]. The *top-bottom* versus *left-right* axes contrast, the oblique axes contrast and all other contrasts are not significant [t(35) between -1.46 and 1.28, n.s.]. Regarding the Hayward and Tarr Referent, there is thus an on-axis directions accuracy advantage over off-axis directions, but no *top-bottom* axis advantage over the *left-right* axis.

A separate analysis for the Van der Zee and Eshuis Referent reveals a significant effect of Intrinsic Direction [F(4.92, 172.08) = 77.45, p < .01]. Planned comparisons show significant effects of on- versus off-axis directions [t(35) = 16.91, p < .00143] and of *top-bottom* versus *left-right* axes [t(35) = 9.93, p < .00143]. The oblique axes contrast is at the boundary of significance and marginal significance [t(35) = 3.46, p ≈ .00143]. The *left* versus *right* directions contrast misses marginal significance [t(35) = 2.19, .05 > p > .00730]. The other contrasts are not significant [t(35) between -1.10 and .83, n.s.]. Regarding the Van der Zee and Eshuis Referent, there is thus also on-axis directions accuracy advantage over off-axis Directions, but additionally a *top-bottom* axis advantage over the *left-right* axis and a difference between the oblique axes.

This analysis can be repeated with the standard deviation of a participant for each Referent and Intrinsic Direction (with the data of 35 participants). The repeated measures analysis of variance on participant's standard deviation shows significant effects of Referent [F(1, 34) = 26.69, p < .01], Intrinsic Direction [F(4.36, 148.20) = 69.94, p < .01], and the interaction of Referent and Intrinsic Direction [F(4.61, 156.73) = 13.14, p < .01]. Accuracy overall is higher for the Hayward and Tarr Referent than for the Van der Zee and Eshuis Referent.

Planned comparisons for the main effect of Intrinsic Direction show significant effects of the on- versus off-axis directions contrast [t(34) = 19.34, p < .00143] and of *top-bottom* versus *left-right* axes contrast [t(34) = 6.40, p < .00143]. The other contrasts are not significant [t(34) between .01 and 1.21, n.s.]. Planned comparisons for the interaction of Referent and Intrinsic Direction show significant effects of the on- versus off-axis directions contrast [t(34) = 7.59, p < .00143] and of the *top-bottom* versus left-*right* axes contrast [t(34) = 9.72, p < .00143]. All other contrasts are not significant [t(34) between -.87 and 1.25, n.s.].

A separate analysis for the Hayward and Tarr Referent (36 participants) reveals a significant effect of Intrinsic Direction [F(4.47, 156.29) = 28.51, p < .01]. Planned comparisons show a significant effect of the contrast between on- and off-axis directions [t(35) = 10.97, p < .00143]. Other contrasts are not significant [t(35) between

-.80 and 1.50, n.s.]. A separate analysis for the Van der Zee and Eshuis Referent (35 participants) reveals a significant effect of Intrinsic Direction [$F(5.00, 169.99) = 57.35$, $p < .01$]. Planned comparisons show significant effects of the contrasts for on- versus off-axis directions [$t(34) = 20.26$, $p < .00143$] and for *top-bottom* versus *left-right* axes [$t(34) = 9.93$, $p < .00143$]. The other comparisons are not significant [$t(34)$ between -.32 and 1.45, n.s.]. The analysis with standard deviation thus about confirms the analysis with the absolute deviation from observed cell means.

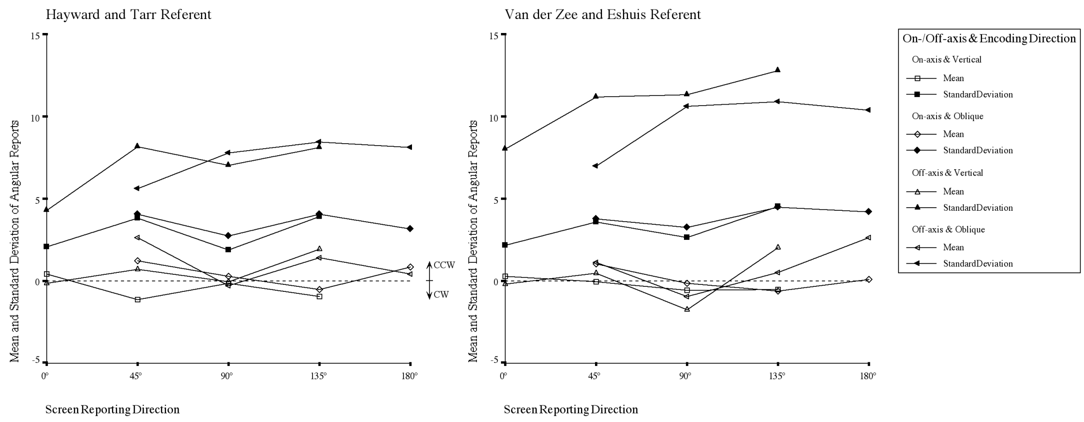

Figure 6.19. Mean and standard deviation of angular reports for Referent, On/Off-axis, Screen Encoding Direction, and Orientation Change.

6.3.3.3.2. Referent, Intrinsic Direction, and Screen Encoding Direction

For this analysis, data are collapsed onto each participant's mean absolute angular deviation from observed cell means for each combination of Referent, Intrinsic Direction, and Screen Encoding Direction. Repeated measures analysis is performed with the data of 32 participants. Next to the effects discussed above, the analysis reveals a marginally significant effect of the interaction of Intrinsic Direction and Screen Encoding Direction [$F(4.51, 139.85) = 2.71$, $p < .05$] and of the interaction of Referent and Screen Encoding Direction [$F(1, 31) = 4.91$, $p < .05$]. The three-way interaction is not significant [F(3.75, 116.16) = 1.41, $p > .05$][93] and neither is the main effect of Screen Encoding Direction [F(1, 31) = .00, $p > .05$].

Planned comparisons for the Intrinsic Direction and Screen Encoding Direction interaction show a marginally significant effect of the contrast between on- and off-axis directions [t(31) = -3.40, $p < .00730$]. The contrast between *top-bottom* and *left-right* axes fails to reach significance [t(31) = 2.26, $.05 > p > .00730$]. All other comparisons show no significant effect [t(31) between .05 and 1.76, n.s.].

Angular accuracy for the on-axis directions is thus influenced different by Screen Encoding Direction than off-axis directions. In particular, angular accuracy is higher for off-axis directions in the oblique Screen Encoding Direction than in the vertical Screen Encoding Direction. This difference is clear for the Van der Zee and Eshuis Referent but not for the Hayward and Tarr Referent (see Figure 6.16 and also Note 93). Angular accuracy for on-axis directions is slightly higher in the vertical Screen Encoding Direction than in the oblique Screen Encoding Direction. This effect is clear for the *left-right* axis of the Van der Zee and Eshuis Referent, less clear for the on-axis directions of the Hayward and Tarr Referent, and not visible for the *top-bottom* axis of the Van der Zee and Eshuis Referent (see Figure 6.16 and also Note 93).

The interaction between Referent and Screen Encoding Direction shows that angular accuracy is increased for the Van der Zee and Eshuis Referent in the oblique Screen Encoding Direction compared to the vertical Screen Encoding Direction. This is particularly due to the off-axis directions. The pattern (if any) is reversed for the Hayward and Tarr Referent.

The interaction between Intrinsic Direction and Screen Encoding Direction can be repeated by using the participant's standard deviations for each combination of the variable levels. The analysis performed with the data of 35 participants also reveals a

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[93] Despite the omnibus F not being significant, regarding the three-way interaction both the comparison between on- and off-axis directions and the comparison between *top-bottom* and *left-right* axes appear marginally significant [t(31) = -3.16 respectively 2.94, both $p < .00730$].

marginally significant effect of the interaction of Intrinsic Direction and Screen Encoding Direction [F(4.46, 151.50) = 3.11, p < .05]. The main effect of Screen Encoding Direction is not significant [F(1, 34) = .01, p > .05]. Planned comparisons for the interaction show a marginally significant effect of the contrast between on- and off-axis directions [t(34) = -3.48, p < .00730]. The contrast between the oblique axes fails to reach significance [t(34) = -2.04, .05 > p > .00730]. All other comparisons show no significant effect [t(34) between -.18 and 1.56, n.s.]. Again, the analysis with participant's standard deviation about confirms the previous analysis.

6.3.3.3.3. Effects of Orientation Change

For this analysis, data are collapsed onto each participant's mean absolute angular deviation from observed cell means for each combination of Referent, Intrinsic Direction (i.e., collapsed onto *top-bottom* axis, *left-right* axis, and each of the oblique axes), and Orientation Change. A repeated measures analysis is performed with the data of 31 participants. Next to the effects discussed above, the analysis reveals a significant main effect of Orientation Change [F(3.00, 90.00) = 20.73, p < .01], and a significant interaction of Intrinsic Direction and Orientation Change [F(4.94, 148.15) = 4.65, p < .01]. The interaction between Referent and Orientation Change is not significant [F(2.47, 74.02) = 2.32, p > .05], and neither is the three-way interaction [F(5.34, 160.28) = 1.79, p > .05].[94] The effect is shown in Figure 6.17.

The planned Helmert contrasts for the main effect of Orientation Change shows that accuracy is significantly increased for 0° Orientation Change compared to higher degrees of Orientation Changes [t(30) = 7.37, p < .00334]. The comparisons contrasting 45° with higher degrees of Orientation Change and 90° with 135° Orientation Change are not significant [t(30) = .89 respectively 1.40, n.s.]. The corresponding contrasts for the Intrinsic Direction and Orientation Change interaction shows that the comparison

[94] Despite the omnibus F not being significant, the comparison between oblique axes and 0° and higher degrees of Orientation Change appears marginally significant over Referent [t(30) = 3.38, p < .00568].

between the 0° and higher degrees of Orientation Change is significantly affected by the on- versus off-axis directions [t(30) = 6.51, p < .00112], but fails to reach significance between the *top-bottom* and *left-right* axes [t(30) = 2.10, .05 > p > .00568] and between the oblique axes [t(30) = 1.50, p > .05]. All other contrasts are not significant either [t(30) between -1.38 and 1.37, n.s.].

It is thus the case that accuracy is increased if there is no Orientation Change than when there is some higher degree of Orientation Change. Additionally, the relative increase in accuracy is greater if off-axis directions are involved than if on-axis directions are involved. The accuracy for on-axis directions is always greater than accuracy for off-axis Directions. On-axis directions do not seem to be influenced much by Orientation Change. See Figure 6.17.

The two-way interaction between Intrinsic Direction and Orientation Change can also be investigated by using the participant's standard deviation as the dependent variable. This analysis is performed with the data of 35 participants. Also in this analysis the main effect of Orientation Change is significant [F(2.72, 92.39) = 27.80, p < .01], and also the interaction between Intrinsic Direction and Orientation Change [F(4.44, 151.08) = 4.70, p < .01]. The planned Helmert contrasts for the main effect of Orientation Change show that the accuracy is significantly increased for 0° when compared with higher degrees of Orientation Change [t(34) = 8.08, p < .00334]. The comparisons contrasting 45° with higher degrees of Orientation Change is not significant [t(34) = .30, n.s.], whereas the comparison contrasting 90° with 135° Orientation Change is marginally significant [t(34) = 2.85, p < .01695]. The corresponding contrasts for the Intrinsic Direction and Orientation Change interaction show that the comparison between the 0° and higher degrees of Orientation Changes is significantly affected by the on- versus off-axis directions [t(34) = 6.74, p < .00112], but fails to be influenced by the *top-bottom* versus *left-right* axes [t(34) = 1.73, p > .05], and does not differ between the oblique axes either [t(34) = .34, p > .05]. All other contrasts are not significant [t(34) between -1.37 and 1.26, n.s.]. The analysis with participant's standard deviation thus about confirms the previous analysis except for the marginally significant difference between 90° and 135° Orientation Change.

6.3.3.3.4. Effects of Screen Direction

For this analysis, the data are collapsed onto each participant's mean absolute angular deviation from observed cell means for each combination of Screen Encoding Direction and Orientation Change. The analysis thus considers only screen effects. The effects can be inferred from Figure 6.18 and Figure 6.19 (although they are broken down there by direction and Referent; no interaction of Screen Encoding Direction, Orientation Change, and either Intrinsic Direction or Referent is observed however). Repeated measures analysis is performed with the data of 36 participants. Next to the main effects already discussed above, the analysis reveals a significant interaction effect of Screen Encoding Direction and Orientation Change [F(2.64, 92.36) = 12.67, p < .01]. Planned comparisons show that only the contrast between 0° and 90° Orientation Changes and the 45° and 135° Orientation Changes is significant between Screen Encoding Direction [t(35) = -5.05, p < .00334]. The comparisons of 0° with 90° Orientation Change and of 45° with 135° Orientation Change do not show significance [t(35) = .46 respectively -.22, n.s.]. These results point to an axial pattern of the Screen *Reporting* Direction whereby angular accuracy is greater on the screen's cardinal axes than it is on the screen's oblique axes.

This analysis can also be repeated by using participant's standard deviation over each of the conditions involved (with the data of all 36 participants). The interaction term only reaches marginal significance in this case, however [F(2.59, 90.78) = 3.12, p < .05]. The contrast between 0° and 90° Orientation Changes and the 45° and 135° Orientation Changes fails to be significant between Screen Encoding Direction [t(35) = -2.19, .05 > p > .01695]. Both other contrasts are not significant either [0° versus 90°:

t(35) = 1.17, n.s.; 45° versus 135°: t(35) = -1.18, n.s.]. In this case, the analysis with participant's standard deviation does not exactly follow the previous analysis although the direction of the differences measured by the contrasts is similar.

6.3.3.3.5. A Comparison

A final analysis is performed with the Hayward and Tarr Referent for reasons of comparison with the findings of Hayward and Tarr (1995). Because there is no difference between the *top-bottom* and *left-right* axes with this Referent (as Hayward and Tarr also found), it is possible to consider the relative influences of Intrinsic Directions and Screen Directions on angular accuracy simultaneously. The data are collapsed onto on- and off-axis directions for each Screen Encoding Direction and Orientation Change. Each participant's mean absolute angular deviation from observed cell means is calculated and the data of 31 participants can be used for the analysis. Significant main effects are found of on- versus off-axis directions [$F(1, 30) = 93.22$, $p < .01$], Orientation Change [$F(2.78, 83.25) = 8.48$, $p < .01$], and Screen Encoding Direction [$F(1, 30) = 9.61$, $p < .01$]. Significant two-way interaction effects are found of on- versus off-axis directions and Orientation Change [$F(2.97, 89.12) = 5.83$, $p < .01$] and of Screen Encoding Direction and Orientation Change [$F(3.00, 90.00) = 9.82$, $p < .01$]. The two-way interaction of on- versus off-axis directions and Screen Encoding Direction is not significant [$F(1, 30) = .27$, $p > .05$] and neither is the three-way interaction [$F(3.00, 90.00) = 1.15$, $p > .05$]. The conditions are illustrated in Figure 6.19 together with the data for the Van der Zee and Eshuis Referent.

Regarding the main effect of Orientation Change, the planned comparisons show that the contrast between 0° and higher degrees of Orientation Change is significant [$t(30) = 4.40$, $p < .00334$]. The same contrast is also significant in the on- versus off-axis directions and Orientation Change interaction [$t(30) = 4.10$, $p < .00334$]. The contrast comparing 0° and 90° with 45° and 135° Orientation Change is significant in the interaction of Screen Encoding Direction and Orientation Change [$t(30) = -4.82$, $p < .00334$]. None of the other comparisons tested for these effects is significant [$t(30)$ between -1.09 and .75, n.s.].

In Figure 6.19 it can be seen that angular accuracy is clearly increased for on-axis directions relative to off-axis directions. Angular accuracy is somewhat higher for the vertical Screen Encoding Direction than for the oblique Screen Encoding Direction. Also, angular accuracy is improved for 0° Orientation Change compared to higher degrees of Orientation Change, whereby this difference is clear for the off-axis directions only. Finally, angular accuracy is enhanced for reporting on a cardinal screen axis compared to reporting on an oblique screen axis.

6.3.3.4. Variable Angular Error Discussion

Previous experiments on spatial memory for location used experimental situations with superimposed Frames of Reference. Accuracy has been found to be higher on on-axis directions than on off-axis directions. These results can be attributed to an Intrinsic Frame of Reference, the screen-based Frame of Reference, or both. The present results do clearly show, on the one hand, that increased accuracy for on-axis directions is found in the exclusive Intrinsic Frame of Reference as well. On the other hand, however, the results also show differences between the Referents. Regarding the Hayward and Tarr Referent, an on-axis directions accuracy advantage over off-axis directions is found. Regarding the Van der Zee and Eshuis Referent, there is also an on-axis directions accuracy advantage over off-axis Directions, but additionally a *top-bottom* axis advantage over the *left-right* axis and a difference between the oblique axes is found (the latter effect is however not found if standard deviation is used as a dependent variable). The situation is thus somewhat more complicated than a simple difference between on- and off-axis directions. The difference between the Referents can tentatively be linked to their respective geometric structures, that is, the findings could reflect the global square shape of the Hayward and Tarr Referent and the elongated global shape of the Van der Zee and Eshuis Referent.

Other effects are found as well. For instance, angular accuracy for the on-axis directions is influenced differently by Screen Encoding Direction than off-axis directions. In particular, angular accuracy is higher for off-axis directions in the oblique Screen Encoding Direction than in the vertical Screen Encoding Direction. This difference is clear for the Van der Zee and Eshuis Referent but not for the Hayward and Tarr Referent. Again it can be proposed that this difference between the Referents is due to their respective shape characteristics. Off-axis locations relative to the Hayward and Tarr Referent can always be encoded as being located in the extension of a line between two corners of the Referent. For off-axis locations relative to the Van der Zee and Eshuis Referent this is not the case. It appears that in encoding situations where the intrinsic axes of the Referent align with the axes of the screen, in particularly, when off-axis directions are encoded in the oblique Screen Encoding Direction, that the encoding of the off-axis directions relative to the Referent's axes is more accurate.

Not surprisingly, it is the case that accuracy is increased if there is no Orientation Change than when there is some higher degree of Orientation Change. The relative increase in accuracy is stronger if off-axis directions are involved than if on-axis directions are involved. The accuracy for on-axis directions is always higher than accuracy for off-axis Directions however. On-axis directions do not seem to be influenced that much by Orientation Change.

Finally, effects have also been found of the screen-based frame of reference. These results point to an axial pattern of the Screen *Reporting* Direction whereby angular accuracy is higher on the screen's cardinal axes than it is on the screen's oblique axes. Thus, not only intrinsic axes influence the results, but also the screen axes even when reporting is required on an intrinsic basis only. Apparently, reporting is improved when it is performed along an axis of the screen. It is possible to ascribe this influence to the perceptual oblique effect although the screen's geometry could also play a role.

An extra analysis has been performed for the Hayward and Tarr Referent only to consider the relative influences of different effects. Angular accuracy is clearly increased for on-axis directions relative to off-axis directions and this is by far the strongest effect. Another effect is that angular accuracy is somewhat higher for the vertical Screen Encoding Direction than for the oblique Screen Encoding Direction. There may thus be a small influence of the oblique effect (or screen axes) at encoding as well. Also, angular accuracy is improved for 0° Orientation Change compared to higher degrees of Orientation Change, whereby this difference is clear for the off-axis directions only. Finally, angular accuracy is enhanced for reporting on a cardinal screen axis compared to reporting on an oblique screen axis.

6.3.3.5. Comparison of Constant and Variable Angular Error

No clear pattern of constant variable error has been found, whereas the pattern of variable error appears more straightforward. Although the pattern of constant angular error can not be interpreted clearly, it appears that those Intrinsic Directions that have relatively high angular accuracy (small variability) are not that susceptible to constant angular error. On the other hand, those Intrinsic Directions that have relatively low angular accuracy (more variability) appear more prone to angular bias.

6.3.3.6. Constant Distance Error Results

Not much was said before about expectations regarding distance error. The magnitude of the error that participants can be expected to make is naturally restricted between the outline of the Referent and the boundaries of the screen. At encoding this space is more restricted at the vertical Screen Encoding Direction than at the oblique Screen Encoding Direction. At reporting the space is similar restricted by the Screen Reporting Direction following from the combination of Screen Encoding Direction and Orientation Change. Vertical *above* and *below* the Referent in the screen-based Frame of Reference shows the same and the strongest restriction. On the oblique screen axes, the restriction is weaker as is also the case with the reporting direction horizontal *to the left of* the Referent on the Screen. The outline of the Referent and the Screen Reporting Direction may thus jointly influence the space that participants report within.

Extrapolating from experimental results discussed before such as those reported by Huttenlocher, Hedges, and Duncan (1991), it can be hypothesised that there is a tendency towards the central value of this space of varying extent. If so, it can be theorised that a kind of cubic pattern is to be found in distance bias. For instance, if encoding and reporting take place on the vertical screen encoding direction, then no bias would be expected at the screen boundary and at the Referent's outline, which both function as actual available landmarks close to which reporting can be accurate. For other locations, there should be stronger effects of central tendency, whereby reports are biased towards some central value. On the route from Referent outline to screen boundary, bias would start at zero, increase to some amount of bias away from the Referent, become zero again at the central vale, decrease to some amount of bias towards the Referent, and become zero again at the screen boundary.

As another example, if the location is again encoded at the vertical Screen Encoding Direction, but –after 90° Orientation Change– the Screen Reporting Direction is *to the left of* the Referent in screen-based terms, then the story can be hypothesised to be slightly different. While the contour of the Referent is still available as a reference point or landmark to base a distance estimate upon, the previous boundary of the screen is not available anymore (another screen boundary is available, that is clearly further away). Maybe participants impose a subjective reference point or participants use only the Referent's contour in the distance estimation.

It remains to be seen however if a cubic pattern is actually found in the present experiment, because locations very close to the Referent have not been used, and only on the vertical Screen Encoding Direction is one location quite close to the screen boundary (see Figure 6.1). Decrease of bias close to the Referent and screen boundary may thus not be observed, and only a linear effect could be visible in the data.

Variability in the reports may also be influenced by the availability of objective and subjective landmarks. Variability should be smaller if a location is closer to a landmark. For dots closest to the Referent an objective landmark is thus always available in relative proximity, whereas for the farthest dots this depends on the Screen Encoding Direction and Orientation Change.

The following set of contrasts is therefore used in the analysis. For Distance the trend analysis is used. For Intrinsic Direction the already familiar orthogonal set is used. If there is collapsing over Intrinsic Direction, the outlines of the Referents suggest collapsing on *top-bottom* axis, *left-right* axis, above off-axis directions, and below off-axis directions. Regarding the Hayward and Tarr Referent, the outline is only different between on-axis (*top-bottom* and *left-right* axis) and off-axis (above and below off-axis) directions. The difference between the respective extendedness of the contour of the collapsed directions is not big if compared to the variation in true Distance of dot location. Regarding the Van der Zee and Eshuis Referent, the outline is different between all of the four collapsed Intrinsic Directions. In particular, there is a strong difference between the *top-bottom* and *left-right* axes regarding the extendedness of the Referent's contour. If distance is estimated from the corners (closest point on the contour) of the Referent if off-axis directions are concerned, then the difference between the *top-bottom* axis and the off-axis direction may be minimal for the Van der Zee and Eshuis Referent. Between the Referents the extension of the contour is clearly different for different Intrinsic Directions as well.

The informal analysis shows that a three-way interaction of Referent, Intrinsic Direction, and Screen Encoding Direction could be the case. Other three-way Directions on occasion came close to significance in the informal analysis but fail to reach it when data were formally collapsed. Several two-way interactions appear significant and all but one of the main effects. In contrast to many of the previous analyses, the Distance independent variable plays an important role.

6.3.3.6.1. Referent and Intrinsic Direction

As usual, the data are first collapsed onto participant's mean distance error for each Referent and Intrinsic Direction. The data of all 36 participants can be used in the repeated measures analysis of variance. The grand mean is significant [$F(1, 35) = 10.39$, $p < .01$], which shows overall that locations are reported as being closer to the Referent than they actually were. The main effect of Referent is not significant [$F(1, 35) = 1.14$, $p > .05$]. The main effect of Intrinsic Direction is significant [$F(6.38, 223.44) = 13.54$, $p < .01$] and so is the interaction of Referent and Intrinsic Direction [F(6.46, 226.05, $p < .01$]. Mean distance error for Referent and Intrinsic Direction is shown in Figure 6.20.

Planned comparisons on the interaction effect show that only the contrast between the *top-bottom* and *left-right* axes is different over the Referents [$t(35) = -6.46$, $p < .00143$]. All other contrasts are not significant [$t(35)$ between -1.40 and 1.67, n.s.]. The planned comparisons for the main Intrinsic Direction effect show significant effects of the on- versus off-axis directions contrast [$t(35) = 5.38$, $p < .00143$] and the *top-bottom* versus *left-right* axes contrast [$t(35) = -6.71$, $p < .00143$]. The contrast between the oblique axes fails to reach significance [$t(35) = 2.38$, $.05 > p > .00730$]. The other contrasts do not show significance [$t(35)$ between -1.27 and -.20, n.s.].

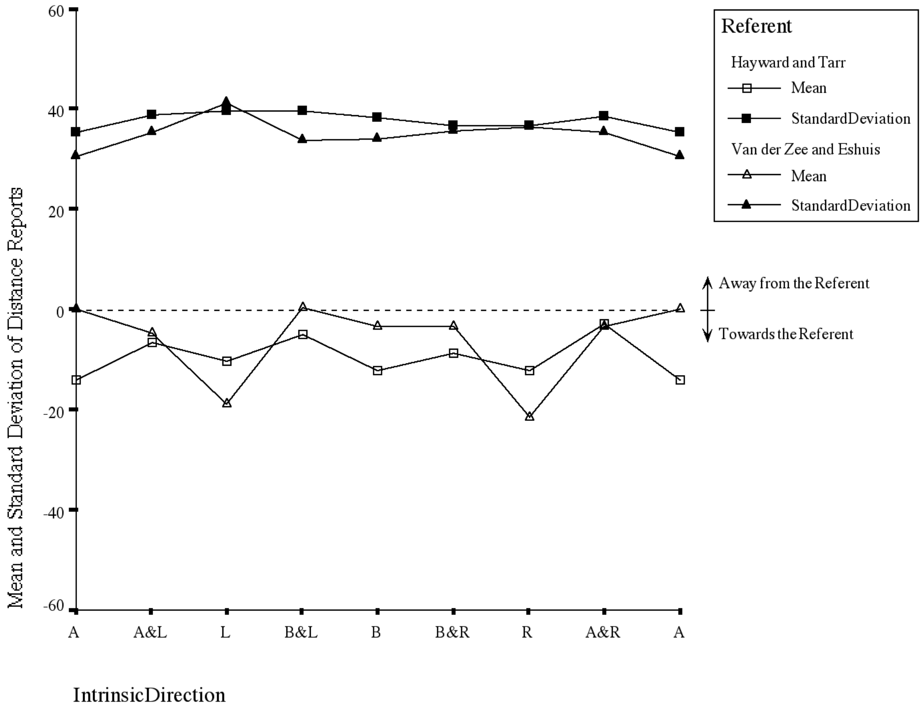

Figure 6.20. Mean and standard deviation of distance reports for Referent and Intrinsic Direction.

A separate analysis for the Hayward and Tarr Referent reveals a significant effect of Intrinsic Direction [$F(6.46, 226.22) = 4.57$, $p < .01$]. The contrast comparing the on- and off-axis directions is significant [$t(35) = 3.80$, $p < .00143$], the contrast comparing the *top-bottom* and *left-right* axes is not significant [$t(35) = 1.33$, $p > .05$], and the contrast comparing the oblique axes closely fails to reach marginal significance [$t(35) = 2.74$, $.05 > p > .00730$]. The other contrasts are not significant [$t(35)$ between -1.32 and .83, n.s.]. On-axis directions are biased more towards the Referent than off-axis directions (see Figure 6.20).

A separate analysis for the Van der Zee and Eshuis Referent also shows a significant effect of Intrinsic Direction [$F(6.64, 232.55) = 18.32$, $p < .01$]. The contrast comparing on- and off-axis directions is significant [$t(35) = 5.34$, $p < .00143$] as is the contrast comparing the *top-bottom* and *left-right* axes [$t(35) = -7.94$, $p < .00143$]. The contrast comparing the oblique axes is not significant [$t(35) = .57$, $p > .05$]. The other contrasts are not significant [t(35) between -1.39 and .98, n.s.]. Figure 6.20 shows that the *left-right* axis is more strongly biased towards the Referent than the other directions, whereas the *top-bottom* axis and the off-axis directions do not show a clear difference.

6.3.3.6.2. Referent, Intrinsic Direction, and Screen Encoding Direction

The informal analysis suggests a three-way interaction between Referent, Intrinsic Direction, and Screen Encoding Direction. The data are thus collapsed on participant's mean distance error for each combination of Referent, Intrinsic Direction, and Screen Encoding Direction. A repeated measures analysis is performed with the data of 32 participants. This reveals the following additional effects. The main effect of Screen Encoding Direction is significant [$F(1, 31) = 18.10$, $p < .01$]. The two-way interaction effects of Referent and Screen Encoding Direction [$F(1, 31) = 15.58$, $p < .01$] and of Intrinsic Direction and Screen Encoding Direction [$F(6.63, 205.43) = 3.17$, $p < .01$] are significant as well. The three-way interaction is also significant [$F(7.00, 217.00) = 3.99$, $p < .01$]. The effect is shown in Figure 6.21.

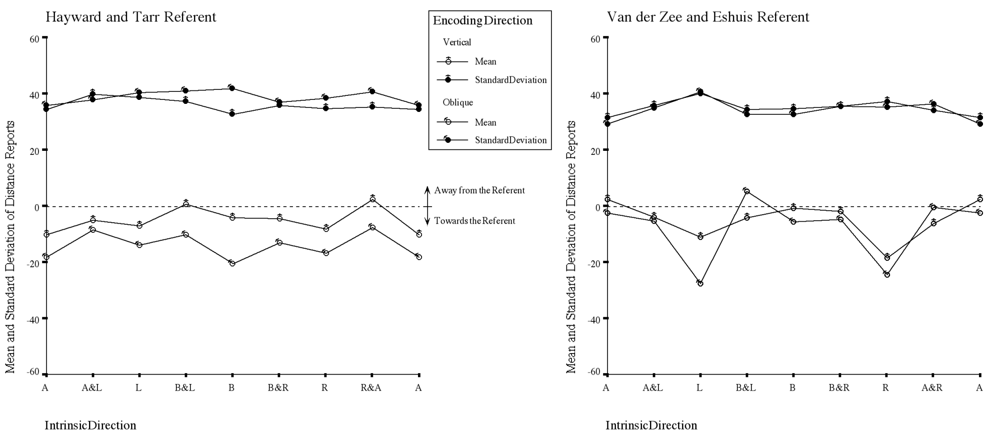

Figure 6.21. Mean and standard deviation of distance reports for Referent, Intrinsic Direction, and Screen Encoding Direction.

Planned contrasts on the three-way interaction reveal marginally significant effects of the on- versus off-axis directions comparison [t(31) = 3.02, p < .00730] and of the comparison between the oblique axes [t(31) = 2.99, p < .00730]. The comparison between the *top-bottom* and *left-right* axes fails to reach significance [t(31) = -2.08, .05 > p > .00730] as does the comparison between the *left* and *right* directions [t(31) = 2.52, .05 > p > .00730]. The other planned comparisons are not significant [t(31) between .27 and 1.74, p > .05]. Planned comparisons for the two-way interaction between Intrinsic Direction and Screen Encoding Direction show marginally significant contrasts between on- and off-axis directions [t(31) = 3.42, p < .00730] and between *above* and *below* [t(31) = -2.88, p < .00730]. All other comparisons are not significant [t(31) between -.32 and .76, n.s.].

A separate analysis for the Hayward and Tarr Referent (with the data of all 36 participants) reveals a significant effect of Screen Encoding Direction [F(1, 35) = 23.71, p < .01]. The interaction of Intrinsic Direction and Screen Encoding Direction is not significant [F(6.89, 241.27) = 1.20, p > .05]. A separate analysis for the Van der Zee and Eshuis Referent (with the data of 32 participants) shows that the effect of Screen Encoding Direction is not significant [F(1, 31) = 3.37, p > .05]. The interaction between Intrinsic Direction and Screen Encoding Direction is significant [F(6.51, 201.73) = 5.77, p < .01]. The planned comparisons for the interaction show that the contrast between on- and off-axis directions is significant [t(31) = 4.27, p < .00143]. The contrast between the oblique axes fails to reach marginal significance [t(31) = 2.69, .05 > p > .00730] as does the contrast between the *left* and *right* directions [t(31) = 2.22, .05 > p > .00730]. The other contrasts are not significant [t(31) between -1.57 and .70, n.s.].

These results show that on the oblique Screen Encoding Direction the distance estimates are more biased towards the Hayward and Tarr Referent than on the vertical Screen Encoding Direction. Regarding the Van der Zee and Eshuis Referent the same pattern is observed for the on-axis directions while for the off-axis directions it is rather reversed (see Figure 6.21).

6.3.3.6.3. Effects of Orientation Change

For the following analysis, the data are collapsed onto each participant's mean distance error for each combination of Referent, Intrinsic Direction (i.e., *top-bottom* axis, *left-right* axis, above off-axis directions, and below off-axis directions), and Orientation Change. A repeated measures analysis of variance can be performed with the data of 31 participants. Except for effects already mentioned before, the main effect of Orientation Change is significant [$F(2.73, 81.84, p < .01$]. Neither the interaction of Referent and Orientation Change is significant [$F(1.99, 59.83) = .62$, $p > .05$] nor the interaction of Intrinsic Direction and Orientation Change [$F(7.49, 224.62) = 1.55$, $p > .05$]. The three-way interaction fails to reach marginal significance [$F(8.56, 256.66) = 1.81$, $p > .05$] but comes close. The quadratic trend of Orientation Change is significant [$t(30) = -6.00$, $p < .00334$]. Both the linear trend and the cubic trend are not [$t(30) = -.64$ respectively -1.10, both $p > .05$]. Distance error for Referent, Intrinsic Direction, and Orientation Change is shown in Figure 6.22. On 0° and 135° Orientation Change distance error is biased more towards the Referent than on 45° and 90° Orientation Change.

6.3.3.6.4. Referent, Intrinsic Direction, and Distance

For the next analysis, the data are collapsed upon participant's mean distance error for each combination of Referent, Intrinsic Direction (*top-bottom* axis, *left-right* axis, above off-axis directions, and below off-axis directions), and Distance. A repeated measures analysis is performed with the data of 30 participants. Except for effects discussed above, a significant main effect of Distance is observed [$F(1.89, 54.92) = 127.67$, $p < .01$]. The interaction of Referent and Distance is marginally significant [$F(3.00, 87.00) = 3.11$, $p < .05$]. The interaction of Intrinsic Direction and Distance is significant

[F(8.46, 245.41) = 3.35, p < .01]. The three-way interaction is not significant [F(7.58, 219.96) = 1.34, p > .05]. Distance estimates over the conditions involved are shown in Figure 6.23.

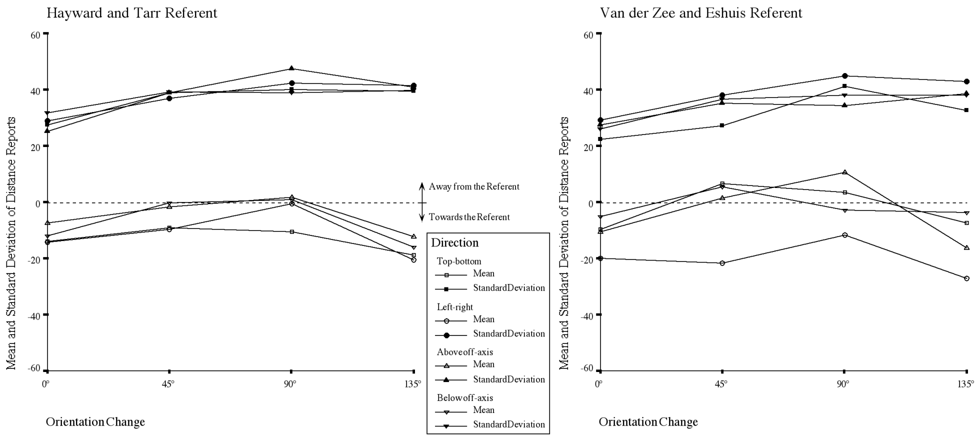

Figure 6.22. Mean and standard deviation of distance reports for Referent, Intrinsic Direction, and Orientation Change.

The planned comparisons for the main effect of Distance show a significant linear trend [t(29) = -13.81, p < .00334]. The quadratic trend closely fails to reach marginal significance [t(29) = -2.53, .05 > p > .01695]. The cubic trend is not significant [t(29) = -.68, p > .05]. Distance estimates for the nearest dot locations are biased away from the Referent (with the exception of those on the *left-right* axis of the Van der Zee and Eshuis Referent) while those for the farthest dot locations are biased towards the Referent. The other dot locations show intermediate bias in a linear pattern.

Planned comparisons for the interaction of Referent and Distance show that there is a marginally significant difference in the linear trend between the Referents [t(29) = 2.94, p < .01695]. The quadratic and cubic trends show no such difference [t(29) = .05 respectively -.27, n.s.]. The slope describing constant distance error against true Distance tends to be steeper for the Hayward and Tarr Referent.

Planned comparisons for the interaction of Intrinsic Direction and Distance show a significant difference between the linear trend at the on-axis directions and the linear trend at the off-axis directions [t(29) = -3.71, p < .00112]. There is a steeper slope of distance error on true Distance for the off-axis directions than for the on-axis directions. A difference between the *top-bottom* and *left-right* axes regarding their quadratic trend fails to reach marginal significance [t(29) = 2.15, .05 > p > .00568]. All other tested contrasts are not significant [t(29) between -1.87 and 1.37, n.s.].

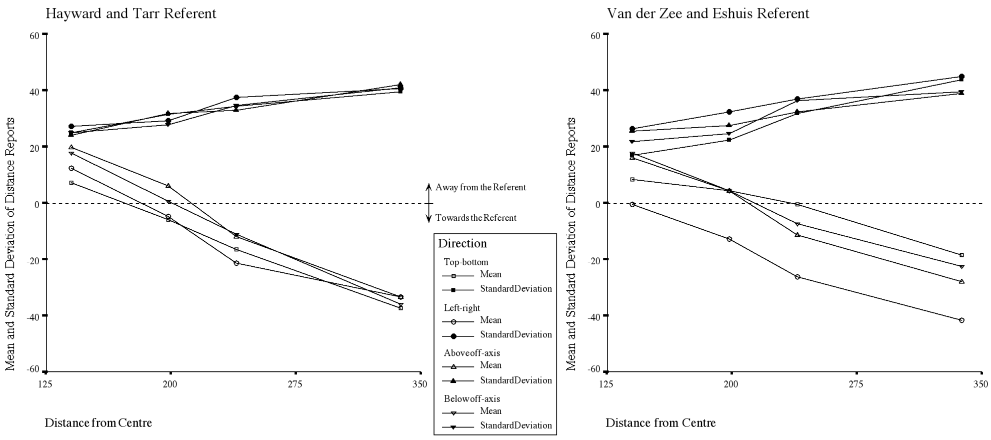

Figure 6.23. Mean and standard deviation of distance reports for Referent, Intrinsic Direction, and Distance.

6.3.3.6.5. Effects of Screen Location

Several two-way interactions are suggested by the informal analysis. Of these, the interactions between Screen Encoding Direction and Orientation Change, between Distance and Screen Encoding Direction, and between Distance and Orientation Change have not yet been discussed in detail. The distance error for each true Distance over Screen Encoding Direction and Orientation Change is shown in Figure 6.24. The three-way effect does not appear to be significant, although this is hard to estimate for sure given the present design (because Distance and Orientation Change have not been systematically varied within participants).

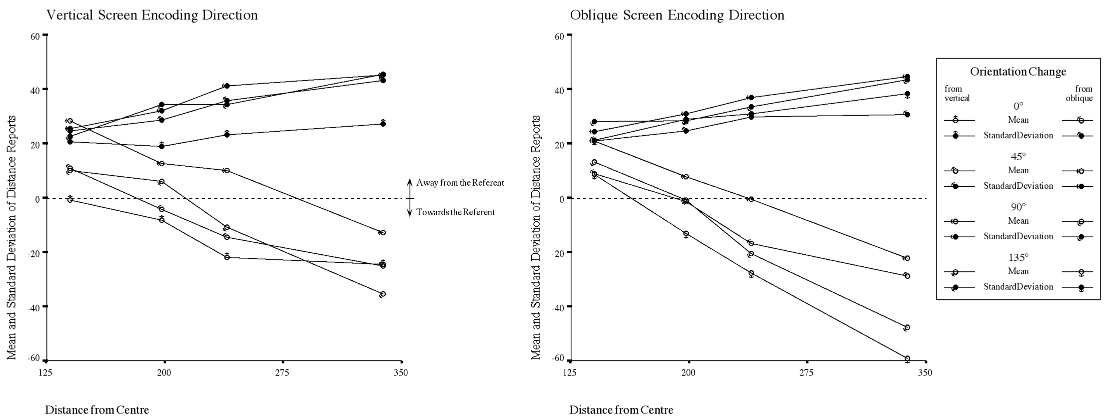

Figure 6.24. Mean and standard deviation of distance reports for Screen Encoding Direction, Orientation Change, and Distance.

To consider the interaction effect of Screen Encoding Direction and Orientation Change, data are collapsed onto the participant's mean distance error for each combination of these variables. Repeated measures analysis is performed with the data of all 36 participants. The two-way interaction turns out to be significant [$F(2.78, 97.40) = 38.80$, $p < .01$]. Planned comparisons show that there is no difference in the quadratic trend over Orientation Change between Screen Encoding Direction [$t(35) = .92$, $p > .05$]. However, both the linear [$t(35) = -8.68$, $p < .00334$] and the cubic trends [$t(35) = 6.51$, $p < .00334$] do significantly differ between Screen Encoding Direction.

Inspection of the results shows that with regard to the vertical Screen Encoding Direction at 0° Orientation Change the distance bias is strongest towards the Referent, at 45° Orientation Change bias is less strongly so, at 90° Orientation Change bias is away from the Referent, and at 135° Orientation Change bias again is towards the Referent (of comparable strength to 45° Orientation Change). On the other hand, for the oblique Screen Encoding Direction, distance bias is towards the Referent at 0° Orientation Change, slightly away from the Referent at 45° Orientation Change, again towards the Referent at 90° Orientation Change (of comparable strength to 0°), and strongest towards the Referent at 135°. This pattern clearly points to an effect of the Screen *Reporting* Direction, and because this direction is jointly determined by Screen Encoding Direction and Orientation Change, the significant trends in the interaction effect can be explained.

A separate analysis for the vertical Screen Encoding Direction shows a significant effect of Orientation Change [F(2.74, 95.73) = 27.23, p < .01]. The linear trend is significant [t(35) = 3.55, p < .00334] and shows that the linear slope is positive overall. The already considered quadratic trend is significant as well [t(35) = -6.40, p < .00334] and so is the cubic trend [t(35) = -5.89, p < .00334] that can be explained by the peak in the bias pattern at 90° Orientation Change. A separate analysis for the oblique Screen Encoding Direction shows a significant effect of Orientation Change [F(2.93, 102.51) = 35.45, p < .01]. The linear trend is significant [t(35) = -8.66, p < .00334] and shows that the linear slope is negative overall. The already considered quadratic trend is significant as well [t(35) = -5.39, p < .00334] and so is the cubic trend [t(35) = 3.70, p < .00334] that can be explained by the peak in the bias pattern at 45° Orientation Change.

The data are collapsed on each participant's mean distance estimate for each combination of Distance and Screen Encoding Direction. The data of all 36 participants are used in the repeated measures analysis. The interaction effect turns out to be significant [F(2.21, 77.52) = 9.83, p < .01]. Trend analysis shows that the linear effect over true Distance is different over Screen Encoding Direction [t(35) = -4.82, p < .00334]. It is clear from Figure 6.24 that the slope of distance error over true Distance is steeper on the oblique Screen Encoding Direction than on the vertical Screen Encoding Direction. The quadratic and cubic trends are not different over Screen Encoding Direction [t(35) = -.78 respectively .41, n.s.].

For the final analysis the data are collapsed onto participant's mean distance error for each combination of Distance and Orientation Change. The data of all 36 participants are used in the repeated measures analysis of variance. The interaction turns out to be significant [$F(6.72, 235.18) = 4.75$, $p < .01$]. The planned comparisons show that the linear trend over true Distance interacts with the linear trend over Orientation Change [$t(35) = -6.56$, $p < .00112$]. Inspection of the data (and visible in Figure 6.24 as well) reveals that the slope of distance error over true Distance decreases (gets more negative) with increasing values of Orientation Change. The interaction of the quadratic trend over true Distance and the linear trend over Orientation Change fails to reach marginal significance [$t(35) = -2.11$, $.05 > p > .00568$]. All other planned comparisons are not significant [$t(35)$ between -.49 and 1.00, n.s.].

6.3.3.7. Constant Distance Error Discussion

The strongest influence on constant distance error is clearly exerted by Distance from the Referent. The bias found for locations nearest to the Referent tends away from the Referent, whereas the bias found for the locations farthest from the Referent tends towards the Referent. The bias displays a linear pattern towards some central value. This pattern is reminiscent of results by Huttenlocher, Hedges, and Duncan (1991). One explanation would thus invoke a fine-grain memory trace that is influenced by a prototype value, in this case a central value constructed from the experimental set. It is hypothesised here that the linear pattern that has been found in fact is a part of a cubic pattern. A cubic pattern would be the result if locations are tested that are far more closer to the Referent.

Additional influences would have to be incorporated in a central-tendency explanation though. One of these would invoke that distance is estimated from the outline of the Referent, in such a way that the same dot location is biased differently depending on its distance from the Referent outline. If a dot location is closer to the outline its biased estimate will be relatively farther from the Referent than if the same dot location is more distant from the outline. Another influence that needs to be explained is the effect of the screen direction that might be caused by the space available for reporting, that is, if there is an objective outer boundary given by the screen. In the vertical Screen Reporting Directions the bias is most clearly towards the Referent whereas in the horizontal Screen Reporting Direction bias is predominantly away from the Referent. Similarly the oblique Screen Encoding Direction leads to bias that is more away from the Referent than the vertical Screen Encoding Direction.

Although the explication of a theory that incorporates these influences and a few others would be an interesting task, it is only a side-issue to the present topic. I will not undertake an attempt to do that here.

6.3.3.8. Variable Distance Error Results

The previous construction of a measure for variable angular error was made relatively easy due to the lack of an effect of Distance on constant angular error. In the case of distance error, however, all independent variables are involved in constant distance error to some degree. Because not all combinations of independent variables have been tested with all participants (in fact, far from it), it makes no sense to use the sample mean on each condition to construct a variable error measure. However, with respect to the Distance independent variable, only significant linear trends are observed. Therefore, for each combination of the other independent variables, the linear regression line for constant distance error over true Distance is computed. The predicted value for each true Distance is then used to compute the absolute deviation of a distance estimate from this value as a measure of variable error.

However, there is one potential problem here. The observed linear trend of estimated distance over true Distance (and the lack of quadratic and cubic trends) has been established by using the different true Distances on an ordinal scale. Regarding regression the use of the distance values on a ratio scale seems more straightforward. Accordingly the linear regression line is estimated by using the actual distance on the ratio scale to estimate distance error. The absolute value of the residuals from this fitted line is used as a measure of variable error. To be sure, if ordinal values would have been used instead, then only minor differences to the presented results would occur.

At first, as always, an informal analysis is performed. This analysis reveals that there could be significant three-way interactions of Referent, Intrinsic Direction, and Orientation Change, and of Referent, Intrinsic Direction and Distance. Additionally a clear two-way interaction of Screen Encoding Direction and Orientation Change is apparent, and possibly of Distance and Orientation Change. Clear main effects of Orientation Change, Distance and Intrinsic Directions are obvious from the informal analysis as well.

6.3.3.8.1. Referent and Intrinsic Direction

Although not appearing significant from the informal analysis, again first the interaction of Referent and Intrinsic Direction is considered. Data are thus collapsed on participant's mean absolute deviation from fitted regression lines for each Referent and Intrinsic Direction. The data of all 36 participants can be used in this analysis. Only the main effect of Intrinsic Direction proves significant [$F(6.97, 243.87) = 4.10$, $p < .01$]. The main effect of Referent is not significant [$F(1, 35) = 2.18$, $p > .05$], nor is its interaction with Intrinsic Direction [$F(7.00, 245.00) = .57$, $p > .05$]. Planned contrasts for the main effect of Intrinsic Direction show that only the comparison between the *top-bottom* and *left-right* axes is significant [$t(35) = 4.94$, $p < .00143$]. Over both Referents, the variable distance error is smaller on the *top-bottom* axis than it is on the *left-right* axis. The comparison between on- and off-axis directions fails to reach marginal significance [$t(35) = -2.09$, $.05 > p > .00730$]. Other contrasts are not significant [$t(35)$ between -1.12 and 1.29, n.s.]. The standard deviation of distance error for each Referent and Intrinsic Direction is shown in Figure 6.20 but does not clearly depict the present effect.

The previous analysis can be repeated by using the participant's standard deviation of their distance error for each Referent and Intrinsic Direction. Note however that this involves collapsing over the estimates for different true Distances where strong bias effects are observed. The bias slope may influence the variability of the responses of a participant. This slope was only found to be different between on- and off-axis directions and tendentially different between Referents though (see above). The data of 35 participants can be used for this analysis.

In this case, the repeated measures analysis of variance shows a significant main effect of Referent [$F(1, 34) = 9.47$, $p < .01$]. Participant's variability in distance errors is lower with the Van der Zee and Eshuis Referent. The main effect of Intrinsic Direction is only marginally significant [$F(6.63, 225.51) = 2.44$, $p < .05$]. Planned comparisons show a marginally significant difference between *above* and *below* [$t(34) = 3.13$, $p < .00730$]. The *above* direction thus tends to have smaller variability in distance error than the *below* direction. The comparison between the *top-bottom* and *left-right* axes fails to reach marginal significance [$t(34) = 2.31$, $.05 > p > .00730$], as does the comparison between *left* and *right* [$t(34) = -2.32$, $.05 > p > .00730$]. Other contrasts are not significant [$t(34)$ between -1.16 and .92, n.s.]. The interaction of Referent and Intrinsic Direction is not significant [$F(6.47, 219.84) = .89$, $p > .05$]. This analysis thus only partially parallels the previous analysis.

6.3.3.8.2. Effects of Orientation Change

The informal analysis suggests that there could be a three-way interaction between Referent, Intrinsic Direction and Orientation Change. However, from the informal analysis it is not immediately clear whether differences between above and below off-axis directions or between left and right off-axis directions are involved (next to possible differences between the *top-bottom* and *left-right* axis). I have chosen to present the former option.[95] Data are thus collapsed on participant's mean absolute deviation from fitted regression lines for each combination of Intrinsic Direction (i.e., *top-bottom* axis, *left-right* axis, above off-axis directions, and below off-axis direction), Referent and Orientation Change. A repeated measures analysis of variance is conducted with the data of 31 participants.

Except for effects already discussed above, there is a main effect of Orientation Change [$F(3.00, 90.00) = 21.44$, $p < .01$]. The interaction between Referent and Orientation Change is not significant [$F(3.00, 90.00) = 1.29$, $p > .05$] and neither is the interaction between Intrinsic Direction and Orientation Change [$F(7.68, 230.41) = 1.53$, $p > .05$]. The three-way interaction comes close to marginal significance, but does not reach it [$F(7.86, 235.80) = 1.94$, $p > .05$]. Planned comparisons for the Orientation Change main effect show that both the linear trend and the quadratic trend are significant [$t(30) = 5.76$ respectively -5.68, both $p < .00334$]. The cubic trend is not significant [$t(30) = .94$, $p > .05$]. As can be seen in Figure 6.22 the standard deviation shows an increase from 0° to 90° Orientation Change, and a small decrease at 135° compared to 90° Orientation Change. This pattern explains both the linear effect and the quadratic effect. The differences between the different Intrinsic Directions within this general pattern fail to be significant.

6.3.3.8.3. Referent, Intrinsic Direction, and Distance

The informal analysis also suggests a three-way interaction between Referent, Intrinsic Direction, and Distance, whereby the difference between above and below off-axis directions (next to differences between the *top-bottom* and *left-right* axis) could play a

[95] If the latter option would be chosen, and data are collapsed onto *top-bottom* axis, *left-right* axis, left off-axis directions and right off-axis directions for each Referent and Orientation Change, then an analysis with the data of 31 participants would also fail to produce a significant three-way interaction [$F(7.84, 235.32) = 1.89$, $p > .05$].

role.[96] Data are thus collapsed on participant's mean absolute deviation from fitted regression lines for each combination of Intrinsic Direction (i.e., *top-bottom* axis, *left-right* axis, above off-axis, and below off-axis direction), Referent, and Distance. A repeated measures analysis of variance is conducted with the data of 30 participants.

Next to effects already mentioned above, the main effect of Distance turns out to be significant [F(2.20, 63.87) = 46.97, p < .01]. Trend analysis reveals only a significant linear trend [t(29) = 10.15, p < .00334]; the quadratic and cubic trends are not significant [t(29) = -.27 respectively -1.15, n.s.]. Variability of distance estimates thus increases with increasing distance from the Referent. The two-interaction of Referent and Distance is not significant [F(3.00, 87.00) = 1.36, p > .05] and neither is the two-way interaction of Intrinsic Direction and Distance [F(6.94, 201.23) = .88, p > .05]. The three-way interaction between Referent, Intrinsic Direction and Distance proves marginally significant [F(7.63, 221.37) = 2.08, p < .05]. However, none of the tested comparisons reaches marginal significance. The contrast for the difference of the linear trend over true Distance between the *top-bottom* and *left-right* axes and between Referent comes closest to significance [t(29) = -2.56, .05 > p > .00568]. All other contrasts are not significant [t(29) between -1.76 and 1.14, n.s.].

A separate analysis for the Hayward and Tarr Referent with the data of 32 participants shows that the interaction between Intrinsic Direction and Distance is marginally significant [F(7.49, 232.32) = 2.17, p < .05]. Planned comparisons show that also in this case none of the contrasts reaches marginal significance. The contrast for the difference in linear trend over true Distance between the *top-bottom* and *left-right* axes

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[96] Additionally there is a difference between the *left* and *right* direction that varies over Referent and Distance. If only *left* and *right* directions are considered (in order to have enough valid data), the three-way interaction between Referent, *left* versus *right*, and Distance is marginally significant [data of 23 participants; F(2.62, 57.66) = 3.17, p < .05]. For the Hayward and Tarr Referent, the interaction between *left* versus *right* and Distance is not significant [data of 30 participants; F(2.79, 80.92) = .44, p > .05]; for the Van der Zee and Eshuis Referent it is [data of 26 participants; F(2.79, 69.74) = 6.08, p < .01]. The cubic trend is the only significant comparison [t(25) = 3.41, p < .00334]. The trend would be marginally significant if it is pretended that all directions are tested simultaneously, and the alpha level is adjusted accordingly [p < .00243]. An explanation for this difference is not available.

comes close [$t(31) = 2.05$, $.05 > p > .00568$]. The other trends are not significant [$t(31)$ between -1.85 and 1.77, n.s.]. The difference between the conditions obviously is not captured by the tested contrasts. The marginally significant effect is not considered relevant. A separate analysis for the Van der Zee and Eshuis Referent with the data of 33 participants shows that the interaction between Intrinsic Direction and Distance is not significant [$F(6.91, 221.10) = 1.37$, $p > .05$].

6.3.3.8.4. Effects of Screen Location

The informal analysis suggests an interaction between Screen Encoding Direction and Orientation Change. Accordingly data are collapsed on participant's mean absolute deviation from fitted regression lines for each combination of Screen Encoding Direction and Orientation Change. The data of all 36 participants are used in the analysis. Effects not mentioned before are the main effect of Screen Encoding Direction which is not significant [$F(1, 35) = 2.23$, $p > .05$] and the interaction effect of Screen Encoding Direction and Orientation Change which is significant [$F(2.83, 99.04) = 7.71$, $p < .01$]. Trend analysis reveals a significant difference in the linear trend [$t(35) = -5.56$, $p < .00334$] over Orientation Change between the vertical and oblique Screen Encoding Direction. The quadratic and cubic trends are not significantly different [$t(35) = .37$ respectively .90, $p > .05$].

A separate analysis for the vertical Screen Encoding Direction shows a significant effect of Orientation Change [$F(2.85, 99.70) = 27.02$, $p < .01$]. The linear trend as well as the quadratic trend are significant [$t(35) = 8.57$ respectively -3.99, both $p < .00334$] and the cubic trend is not [$t(35) = .14$, $p > .05$] as they were on the main effect of Orientation Change discussed previously. A separate analysis for the oblique Screen Encoding Direction also shows a significant effect of Orientation Change [$F(2.97, 103.90) = 6.36$, $p < .01$]. In this case only the quadratic trend is significant [$t(35) = -4.19$, $p < .00334$] whereas the linear and cubic trends are not [$t(35) = 1.25$

respectively 1.15, $p > .05$]. A close look upon Figure 6.24 shows for the Vertical Screen Encoding Direction that the variability in distance error increases relatively strongly from 0° to 45° Orientation Change, increases still slightly towards 90° Orientation, but decreases from there slightly at 135° Orientation Change. This pattern produces both the linear effect and the quadratic effect. The oblique Screen Encoding Direction, on the other hand, shows also the smallest variability for 0° Orientation Change, a somewhat higher variability for 45° and 90° Orientation Change, and intermediate variability for 135° Orientation Change. There is thus only a quadratic trend. The results probably reflect a difference between 0° and higher degrees of Orientation Change and differences between the Screen *Reporting* Directions.

The previous analysis can be repeated by using the participant's standard deviation of their distance error for each Screen Encoding Direction and Orientation Change. Note again, however, that this involves collapsing over estimates for different true Distances where strong bias effects were observed. The bias slope may influence variability of responses from a participant. The slope proved different over the vertical and oblique Screen Encoding Directions as well as over different degrees of Orientation Change (see above). The data of 36 participants can be used for this analysis.

In this case, the main effect of Screen Encoding Direction does prove significant [$F(1, 35) = 12.55$, $p < .01$] as does the main effect of Orientation Change [$F(3.00, 104.93) = 33.19$, $p < .01$]. The interaction is not significant [$F(2.86, 100.26) = .61$, $p > .05$]. The effect of Screen Encoding Direction shows that the variability of distance estimates is higher in the vertical Screen Encoding Direction. Trend analysis for the main effect of Orientation Change shows significant linear and quadratic trends [$t(35) = 10.77$ respectively -4.07, both $p < .00334$]. The cubic trend is not significant [$t(35) = .79$, $p > .05$].

It is possible that the discrepancies between this analysis and the previous one are caused by differences in the bias slopes over true Distance for the different conditions in this analysis. The conditions do not include the Distance independent variable. However, if a distance bias slope over true Distance is steeper for one condition than it is for another condition, then the difference in bias between the near and far true Distances will be greater. Following, if the standard deviation is computed while the Distance variable is ignored, then the standard deviation will be higher as a consequence of this difference in bias slope. The present standard deviation analysis may reflect this mechanism by showing an effect of Screen Encoding Direction, which has a direction that complies with the difference in bias slope over true Distance for each Screen Encoding Direction (the difference was shown previously). Similarly, the previous finding that the bias slope gets steeper with increasing degrees of Orientation Change may be reflected here in finding no difference in the linear trends for Screen Encoding Direction. Therefore, the interaction effect found in the previous analysis is not found in the present analysis.

The informal analysis also suggests an interaction between Distance and Orientation Change. Accordingly, data are collapsed on participant's mean absolute deviation from fitted regression lines for each combination of Distance and Orientation Change. The data of all 36 participants are used in the analysis. The only effect not mentioned before is the interaction between these variables which proves to be marginally significant [$F(8.18, 285.15) = 2.48$, $p < .05$]. 'Double' trend analysis shows that the linear trend over true Distance by the linear trend over Orientation Change very closely fails to reach marginal significance [$t(35) = 2.94$, $.05 > p > .00568$]. The cubic trend over true Distance by the quadratic trend over Orientation Change misses marginal significance less close [$t(35) = 2.70$, $.05 > p > .00568$]. Other trends are not significant [$t(35)$ between -1.78 and 1.74, n.s.]. Inspection of Figure 6.24 shows that the increase in variability with increasing Distance from the Referent is weaker in case of 0° Orientation Change than it is in case of higher degrees of Orientation Change. This probably causes the marginal significant effect and the almost marginal significant linear by linear trend.

Also here, the analysis can be repeated by using the participant's standard deviation of distance error for each of the combinations of Distance and Orientation Change. Because Distance is included in the effect, there should be no large discrepancies with the previous analysis. The data of 32 participants are included in the analysis. The main effect of Distance proves significant [F(2.84, 88.05) = 50.97, p < .01]. Trend analysis reveals a significant linear trend [t(31) = 11.87, p < .00334]. The quadratic and cubic trends are not significant [t(31) = 1.46 respectively 1.61, both p > .05]. Variability increases with increasing Distance from the Referent. The main effect of Orientation Change proves significant as well [F(2.77, 85.73) = 23.77, p < .01]. Trend analysis reveals significant linear and quadratic trends [t(31) = 6.44 respectively -5.32, both p < .00334]. The cubic trend is not significant [t(31) = .10, p > .05]. Note that in this case the Orientation Change effect strength and the strength of the linear and quadratic trends are more in line with the corresponding Orientation Change effect on the corrected absolute error measure discussed earlier and differ from the previous Orientation Change effect on the standard deviation measure. The interaction between Distance and Orientation Change proves to be marginally significant [F(7.76, 240.65) = 2.02, p < .05]. The 'double' trend analysis again reveals that the linear trend over true Distance by the linear trend over Orientation Change closely fails to reach marginal significance [t(31) = 2.95, .05 > p > .00568]. The cubic trend over true Distance by the linear trend over Orientation Change misses marginal significance less close [t(31) = 2.23, .05 > p > .00568]. Other trends are not significant [t(31) between -1.73 and 1.47, n.s.]. This analysis thus quite closely follows the previous one.

6.3.3.9. Variable Distance Error Discussion

The main finding is that the variability of distance estimates increases with increasing distance from the Referent. This suggest that distance is estimated from the Referent and not (or only to a lesser extent) from any other reference point that may be available in some conditions. Some effects do indicate however that the increase in variability with increasing Distance from the Referent is weaker in case of 0° Orientation Change than it is in case of higher degrees of Orientation Change. Under the 0° Orientation Change condition, reference points other than the Referent may thus also have been used to estimate distance. Next to the difference between 0° and higher degrees of Orientation Change, there appear to be differences depending on the Screen *Reporting* Direction. If the space available for reporting is more restricted, then the variability of distance estimates is smaller than when the space available to report is less restricted.

Finally, some effects are observed involving Referent, Intrinsic Direction, and Distance. For instance, the variable distance error is smaller on the *top-bottom* axis than it is on the *left-right* axis. Also, the three-way interaction between Referent, Intrinsic Direction and Distance proves marginally significant. However, the effects are not really clear and so there is no clear interpretation for these effects either.

6.3.3.10. Comparison of Constant and Variable Distance Error

Ignoring all other independent variables, the strongest findings are caused by true Distance. The general pattern is that the constant error of distance estimates follows a linear pattern whereby near locations are biased away from the Referent and far locations are biased towards the Referent. On the other hand, the variable error of the distance estimates increases with increasing Distance from the Referent. This pattern suggests a central tendency of estimates, for instance, because a central value for the Distances used in the experimental set is constructed by the participants. In case of uncertainty, the central value could be used to adjust fine-grain values along similar lines as hypothesised by Huttenlocher, Hedges, and Duncan (1991). The variable error pattern suggests that the distance report is estimated from the Referent. Increasing Distance could thus cause an increased uncertainty of the recollected fine-grain distance value. Locations far from the Referent would therefore be more susceptible to adjustment by the central value than locations close to the Referent. The findings do show that bias away from the Referent at near Distance is smaller than bias towards the Referent at far Distance. A more detailed explanation of distance reports would need to take into account the effects of other independent variables as well, in particular the extendedness of the Referent in different Directions and the restrictions of the distance range available in the direction in which Distance is encoded and reported.

6.3.3.11. Comparison of Angular and Distance Error

One quite important finding regarding angular error (constant as well as variable) is that there is no effect of Distance. This is one indication that the analysis of reported locations by means of separate angular and distance co-ordinates is sensible. It has been implicitly assumed that participants estimate both an angle and a distance in reporting, and thus that these components are independent. If the direction and distance components in location reports are not independent, then effects of distance on angular error would have been probable.

However, effects of direction (intrinsic as well as screen-based) are observed on distance estimates. These effects can be directly linked to Referent perimeter and Screen Reporting Direction, and therefore are not opposing independent co-ordinates. In fact, no apparent deviations from linear distance effects (central tendency) are observed over different Intrinsic Directions and Screen Reporting Directions. It is thus concluded that the choice to separate the analyses of distance and angular estimates is supported by the results.[97] Direction and distance estimates are probably independent.

[97] It could be the case that the co-ordinates that are used by the participants are not exactly those that are used in the analysis. For instance, it is possible that direction and distance are estimated from the corners

6.4. General Discussion

In discussing the results of the experiments, I will concentrate on the findings that bear direct relevance to the discussions in previous chapters. A subjective selection of the experimental results will thus be considered and the other results are considered as depending on the particulars of the used experimental procedure. First, the most relevant results are summarised.

6.4.1. Summary of Findings

Fewer regional errors are made on the *top-bottom* dimension than on the *left-right* dimension. Regional errors on both dimensions simultaneously are more infrequent than regional errors on the *top-bottom* dimension. Errors are particularly made from the *left* to the *right* region or *vice versa*. If a location is on- or off-axis within these regions does not appear influential. The fine-grain information for the reports, that is, the location along the *top-bottom* dimension and distance information, does not appear to be impaired any further. The errors are thus hypothesised to be an error in the *left* or *right* category or pole of the encoded memory trace that is similarly encoded for any location in the *left* respectively *right* half-planes.

Responses are faster for the *top-bottom* dimension than for the *left-right* dimension. Responses for off-axis directions are slightly slower than for the *left-right* dimension in general, but not so for the Van der Zee and Eshuis Referent in particular. The pattern more or less reflects the regional interpretation of the intrinsic computation analysis. All directions in the *left* and *right* regions show longer reaction times than the *top-bottom* dimension.

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of the Referents for off-axis directions. Regarding the Van der Zee and Eshuis Referent, this would mean that the co-ordinate system used by the participants is slightly different from the co-ordinate system used to analyse the data. It is however assumed here that the co-ordinate system used for the analysis approaches the co-ordinate system used by the participants sufficiently for the conclusions to be valid.

Both regional error and reaction time thus point to a regional pattern. Reaction time and regional error differences can both be attributed to uncertainty on the participant's behalf, or to a more complicated or longer process to determine a response (during which more errors can be expected as well).

There are normalisation effects in reaction time. Reaction time increases with increasing degrees of Orientation Change, i.e., the difference between the orientation seen at encoding and the orientation seen when reporting. An analogous effect is seen in the proportion regional error. This proportion also increases with increasing degrees of Orientation Change. Normalisation occurs between the Referent's orientation presented at encoding and its orientation at reporting. This suggests that the memory trace that is constructed during the encoding phase includes an encoding of the orientation of the Referent relative to some reference orientation.

Variable angular error is found to be smaller on on-axis directions than it is on off-axis directions. The results are not that straightforward as the results of Hayward and Tarr (1995) though. In particular, there is a clear difference between on-axis *left-right* directions and on-axis *top-bottom* directions on the Van der Zee and Eshuis Referent. Differences in angular accuracy are also found that depend on the Screen Reporting Direction. Both effects can be hypothesised to depend on geometric features, of the Referent and the screen respectively.

6.4.2. Discussion of Hypotheses

If a quick look back to the hypotheses stated at the beginning of the Chapter is taken, then it becomes clear that most hypotheses are at least partially confirmed by the findings. The experimental effects are quite comparable over the two Referents although in various respects not identical and in some respects different (H1). Particularly regarding reaction time and regional error are the results comparable for both Referents. Regarding angular error accuracy, however, there are clear differences between the Referents.

Reaction time effects similar to the intrinsic computation analysis are found. The intrinsic computation analysis can thus be transferred to a spatial memory situation where there is no explicit need to label axes (H2). This does not necessarily mean that participants did not use linguistic labels to remember a location, but only that they did not have to. Interestingly, regarding reaction time, off-axis locations show about comparable results as the *left-right* axis. This confirms the regional interpretation of the intrinsic computation analysis: Off-axis locations show effects comparable to the slowest on-axis locations (H3). Regarding the Hayward and Tarr Referent, reaction time for the off-axis directions is somewhat longer that those for the *left-right* axis.

The angular accuracy of reports do show that within an exclusive Intrinsic Object Centred Frame of Reference similar effects to those of Hayward and Tarr are found and the effects are independent of environment centred (i.e., the screen) and relative ego centred Frames of Reference (H4). However, regarding the Van der Zee and Eshuis Referent there is a difference between the *left-right* and *top-bottom* axis.

Effects of the Screen Direction at encoding and Reporting do also influence the accuracy of angular reports (H5). In particular, the Figure position at reporting influences accuracy of reports. This is clearest for the Hayward and Tarr Referent. An interesting encoding effect is observed regarding the Van der Zee and Eshuis Referent. Off-axis directions are reported more accurate in the angular respect when they have been encoded on the oblique Screen Encoding Direction. It was suggested that, because in that condition the Referent axes coincide with screen axes, that off-axis direction can be better encoded relative to the Referent axes and reported with higher accuracy as a consequence.

6.4.3. General Discussion

The majority of the regional errors are *left-right* errors. Errors between the *above* and the *below* regions happen less often. Errors between *above* and *below* regions and *left* and *right* regions at the same time are very rare. Regional errors are thus typically made from a region at one side of an axial boundary to the region at the opposite side of the boundary. The two pairs of half-planar regions are susceptible to regional error to a different degree. The difference in frequency of the kinds of regional error may point to the relative independence of the respective dimensions. This is in line with the axis-as-boundary point of view as well as an ordered extraction of regions. The regional interpretation of the reaction time data seems to support this option.

It is possible to object that regional error primarily indicates that participants just have difficulties with symmetry. However, symmetrical properties of a Referent determine how the Referent is spatially structured. Extrapolating from that structure or from axes oriented in line with the structure, such properties determine how surrounding space is carved up. It is rather the case that bilateral symmetry and the definition of intrinsic *left* and *right* are closely connected.

The normalisation effects for reaction time and the parallel finding of an increase in regional error over increasing degrees of Orientation Change is interesting and informative. First, these effects appear to depend on Orientation Change, that is, the difference between the orientation of the Referent at encoding and the orientation of the Referent at reporting. This suggests that the orientation of the Referent at encoding is stored, and that normalisation occurs to correct for the orientation difference at reporting. An orientation can be stored at encoding by defining the orientation of an intrinsic axis (presumably the *top-bottom* axis) relative to some non-intrinsic axis or orientation (presumably upright).

Second, normalisation is slower and the increase of regional error is stronger for locations in the *left* and *right* regions than for locations on the *top-bottom* axis. This suggests that normalisation can proceed quickly for the *top-bottom* axis because the normalisation is guided by the Referent features that distinguish the *top* from the *bottom*. The normalisation for locations in the *left* and the *right* regions is slower, because there are no features that distinguish the *left side* from the *right side* and that can be used for normalisation. In order to define the *left* and *right* regions at reporting, a normalisation is required that depends on the *top-bottom* axis. This process is slow and difficult as evidenced by the errors. This suggests that descriptions (or encodings) of sides and corresponding directions happens usually in terms of an intrinsic description that employs independent dimensions. However, in the experiment the *left-right* coding needs to be made dependent on the *top-bottom* coding. It is not possible to encode intrinsic *left* and *right* for memory by intrinsic structure when the *left side* and the *right side* are symmetric. Consider the analogy with linguistic labelling.

It is not possible to define intrinsic *left* and *right* for language even when the *left side* and *right side* are not symmetric. Differences in *left-right* structure do not indicate which is *left* and which is *right*. *Left* and *right* linguistic labelling is defined by convention and needs to take the other directions into account. That is, it depends on the definition of the other intrinsic directions what is *left* and what is *right* and therefore *left-right* cannot be defined unless the others are defined. The case is similar with respect to coding a Figure location for memory relative to a bilateral symmetric object. If the Figure does not happen to be located on the axis of symmetry (on the *top-bottom* axis), then the half-plane in which the Figure is located cannot be defined unless by reference to the Referent's structure along the axis of symmetry. That is, the half-plane cannot be coded unless a kind of Perspective is laid upon the axis of symmetry and the half-planes are labelled by conventional *left* and *right* or some other private labelling.

The reasoning above explains the slower normalisation rates for *left* and *right* in the experiment and it may explain differences in both reaction time and error-proneness of the different dimensions as well. An alternative source for regional error might be that the explicit coding of the *left* and *right* regions relative to and dependent upon the orthogonal dimension is neglected at encoding.

The accuracy of angular reports is better at on-axis directions than it is at off-axis directions. Regarding the Van der Zee and Eshuis Referent there however exists a difference between the *above-below* and the *left-right* axis. The experiment reproduces the accuracy results of Hayward and Tarr (1995) in the Intrinsic Object Centred Frame of Reference regarding the Hayward and Tarr Referent. The difference in reporting accuracy between the *above-below* and the *left-right* on-axis locations of the Van der Zee and Eshuis Referent seems to question the generality of the finding. However, a variety of reasons can be thought of to account for this difference: For instance, the assumed position of the *left-right* axis may have been wrong, or the *above-below* axis (being an axis of symmetry) may be represented more exactly than the *left-right* axis. It is also possible to consider the geometry of the Referents in order to account for the differences between the Referents regarding angular reporting accuracy. In that case, the findings of Hayward and Tarr do not so much reflect (in part at least) the effect of an Intrinsic Object Centred Frame of Reference, but instead the primarily square shape of the Referents and also the availability of other Frames of Reference, perceptual effects, and the geometry of the reporting situation. However, more research is required for a definite answer.

One interesting observation that has been made regarding accuracy of reporting is that relatively high accuracy is not restricted to axes, but can be seen as well (a) at locations close to axes, and – possibly – (b) at locations on imagined extensions of the Referent’s contour. See the findings of Munnich, Landau, and Dosher (2001; see also Landau, 2003; Eshuis, 2003) where the findings of Hayward and Tarr are replicated with respect to linguistic and non-linguistic data for locations on axes and locations that are relatively far away from axes. Differences however appear between these kinds of data for locations closer to the axes. Whereas the linguistic task produces strong axial effects, the non-linguistic task (identity judgement) produces more graded effects with no apparent difference between locations on axes and locations that are close to the axes but still within the area between extensions of the Referent's contour. Such finding allow to question if accuracy of reporting is the suited measure to investigate representations that are assumed to play a role in spatial language and in spatial tasks such as spatial memory.

Whether or not axes are the primary determinant of local accuracy of spatial reproduction (or of identity judgement performance) is one issue. Another issue is what such axial effects have to do with spatial language. For one thing, the axial accuracy effects in non-linguistic spatial tasks do not show any effect of half-axes and not even axes[98] whereas the linguistic spatial tasks do (see also Landau, 2003). The experiment reported in this chapter does show directionality effects in that regional errors occur from one half-plane to the complementary half-plane (half-planes separated by an axial boundary) and that the frequency of the errors depends on the dimension involved. This suggests that axes (functioning as boundaries) are at most responsible for accuracy of reporting, but that the categorisation of regions (and directionality assigned to half-axes) is responsible for the regional error in the non-linguistic spatial task reported here. Categorised regions are natural candidates for involvement in spatial language.

One may argue that with two axes, four mutually exclusive regions are constructed where the half-axes function as boundaries (as in Crawford, Regier & Huttenlocher, 2000). In that case one would expect that regional errors should occur more or less randomly over these four quadrants. This, however, does not appear to be the case. On the one hand, regional errors are typically made from a half-plane at one

[98] If accuracy is considered by analysing both horizontal and vertical error, then it is possible to hold that a difference exists between axes. However, if accuracy is considered by analysing both direction and distance error, then no difference exists between axes.

side of an axis to the half-plane at the other side of the axis with seemingly intact fine-grain information (these errors are thus between neighbouring quadrants). Errors from one quadrant to the opposing (non-neighbouring) quadrant hardly ever happen. Moreover, it can be shown that the amount of errors made from one half-plane to the opposing one is different from the amount of errors between the orthogonally oriented pair of half-planes. This signals that the individual axes are the main organising entities carving up space into regions and that the two axes (and the dimensions they separate) might be relatively independent.

Although axes do function as boundaries, this is only a part of the story. A *front-back* axis does not only function as the boundary between *left* and *right*, its half-axes also function as the best examples of *front* and *back*, just because the axis is neutral with respect to *left* and *right*. Thus, although axes, and perhaps an enhanced acuity for directional information associated with the axes, may be at the basis of the categorisation of space, their prime function at the spatial level may be to function as boundaries between half-planes. Linguistically, one may refer to a direction unambiguously when this direction coincides with a half-axis. The spatial representation of Intrinsic Directions is considered here as a combination of space categories (regional oppositions) and vector information. Activation of all spatial oppositions allows the vector to be oriented and shows which directions are the best examples of a given spatial dimension.

Effects of Intrinsic Frames of Reference have been found for the Hayward and Tarr Referent as well as for the Van der Zee and Eshuis Referent. Similar dimensions lead to comparable effects with respect to both Referents. The different ways of linguistic labelling directions in the experiments of Hayward and Tarr (1995) and Van der Zee, Rypkema, and Busser (1996) prove to be equivalent with respect to the present task. Effects of other Frames of Reference have also been found; this, however, only leads to an improvement in accuracy that is minor compared to the effect of the Intrinsic Frames of Reference. It remains to be established if screen- or ego-based accuracy differences are due to the employment of the respective Frames of Reference, or if they are solely due to perceptual effects (i.e., the oblique effect) or to screen geometry.

Concluding, it appears that the experimental method is successful and that changing the orientation of Referent is an effective way of avoiding interference of other Frames of Reference in a memory task.

Chapter 7. Summary and Conclusions

In this thesis I have considered the use of Intrinsic Object Centred Frames of Reference in defining and categorising the location, direction, and/or region of one object (the Figure) in the space surrounding another object (the Referent). Intrinsic Object Centred Frames of Reference are well-known as one of several frames of reference with which the location of a Figure can be defined relative to a Referent and expressed by means of a Directional Preposition (i.e., *above*, *below*, *in front of*, *behind*, *to the left of*, and *to the right of*). Frames of Reference for spatial language have been discussed by, e.g., Levelt (1984), Levinson (1996), Retz-Schmidt (1988), and Talmy (1983).

Intrinsic Frames of Reference for Language are investigated regarding the so-called 'accessibility' of different axial directions. Bryant and Tversky (1999) developed the 'intrinsic computation analysis' (see also Bryant, 1998; Bryant, Tversky, and Lanca, 2001; Logan, 1995). According to this analysis, the *top-bottom* axis is accessed before the *front-back* axis, which is accessed before the *left-right* axis. The time to identify or verify the linguistic label for an Intrinsic Direction reflects this ordering.

Intrinsic Frames of Reference for Language have also been investigated in another subject area (partly accidentally), namely within the topic of Object Recognition. One interesting effect in object recognition is that the time to recognise an object increases with the degree of deviation of an object from its canonical upright (Jolicoeur, 1985). The reasons for orientation dependency are controversial, but some explanatory models propose an involvement of the *top* or *top-bottom* axis of the object (e.g., Rock, 1973). Following from this line of thinking experiments have been conducted to investigate the identification of the *top* and *bottom* on disoriented objects. Some experiments also investigate the identification of the *front* and *back* or of the *left side* and *right side* of a disoriented object. The results of these experiments are in line with the intrinsic computation analysis on the one hand, but show additional effects on the other. In particular, analogous to reaction time in object recognition, time to identify an object part depends on deviation from upright (see Corballis and Cullen, 1986; McMullen and Jolicoeur, 1990; 1992; Jolicoeur, Ingleton, Bartram, and Booth, 1993). The so-called 'normalisation' of object orientation relative to upright is comparable to object recognition for the *top* and *bottom* identification, but is much slower for the identification of the *left side* and *right side* (i.e., the slope of the line describing reaction time against deviation from upright is steeper).

Another line of research concerning Frames of Reference seeks to find evidence on the dependence of linguistic spatial expressions on non-linguistic spatial representations (see Hayward and Tarr, 1995; Landau and Jackendoff, 1996; Li and Gleitman, 2002; Munnich, Landau, and Dosher, 2001; but see Levinson, Kita, Haun, and Rasch, 2002, for a different view). Unfortunately, experimental research into this subject area usually does not restrict itself to a single Frame of Reference, but instead uses experimental material in which several Frames of Reference may play a role. One example of such research is that of Hayward and Tarr (1995). The same experimental configurations are used in spatial language experiments and in spatial memory experiments. The basic findings are that locations relative to a Referent where memory for location is relatively accurate are the locations where participants use a single Directional Preposition to describe the location relative to the Referent. These locations exhibit an axial structure. This leads Hayward and Tarr to hypothesise that axial prototypes are responsible for the effects in both the spatial memory experiment and the spatial language experiment. They thus conclude that there is a direct correspondence between spatial representation and spatial language.

In sharp contrast to this conclusion is the conclusion of Crawford, Regier, and Huttenlocher (2000) although they use a similar approach in their experiments. They find a bias in reports from memory away from those locations that are rated with the highest applicability for a Directional Preposition. The memory results are interpreted with the spatial category model of Huttenlocher, Hedges, and Duncan (1991), on the basis of which they conclude that the highest-applicability locations are on a boundary for spatial categories, and that prototypes of spatial categories are half-way between the highest-applicability locations for different Directional Prepositions. Hence they conclude that there is an inverse relation between spatial representation and spatial language. Locations acting as prototypes in spatial memory act as boundaries in spatial language and *vice versa*. The experimental results of both Hayward and Tarr and Crawford *et al* are obtained with several superimposed Frames of Reference that might be responsible for the findings.

In the thesis, I have attempted to integrate several parts of the above mentioned approaches, and tested several of their aspects in an experiment on memory for Intrinsic Location, that is, locations defined from inherent features of a Referent. To this end, both the time required to identify an Intrinsic Direction and the accuracy of memory for intrinsic location is investigated in a single spatial memory experiment. The experiment does not explicitly require the linguistic labelling of any directions (although it cannot be excluded that participants use these). Two Referents are used of which the Intrinsic Frame of Reference for Language is known. One of these is similar to one of the Referents of Hayward and Tarr (1995) and depicts an existing object for which object category information is available (the Hayward and Tarr Referent). The other object is a cross-section of an object used by Van der Zee and Eshuis (2003) and is an abstract object for which no object category information is available (the Van der Zee and Eshuis Referent). Van der Zee and Eshuis have however determined participants' preferred Intrinsic Directional labelling despite the object not depicting a known object.

The experiment thus tries to elicit the intrinsic computation analysis as well as possible normalisation effects in a spatial memory situation in which there is no requirement to use information on the labelling of sides and directions. At the same time, it tries to elicit data on the accuracy of spatial memory in an exclusively Intrinsic Frame of Reference. The joint gathering of reaction time and spatial accuracy data in the Intrinsic Object Centred Frame of Reference may also provide new insights in the connection of (non-linguistic) spatial representations and spatial language.

7.1. Summary

In Chapter 1 of the thesis the subject is introduced and some relevant questions are stated. Also, the general assumptions regarding human information-processing structures are explicated. Further, the concept of Frame of Reference is elaborated and so is its connection to percepts and concepts. Finally, the different Frames of Reference for language are shortly considered.

In Chapter 2, the concept of an intrinsic description of an object is identified as a good candidate to base an Intrinsic Frame of Reference upon (see Hinton, 1979; Marr and Nishihara, 1978; Palmer, 1977). The intrinsic description that is preferred for obvious reasons defines an object along the *top-bottom*, *front-back*, and *left-right* dimensions (or some non-linguistic equivalents). The suitability of such intrinsic descriptions is discussed by considering to what extent they are able to define intrinsic locations and directions around Referents with different spatial structures (independent of any labelling actually being used for locations and directions around the Referents in a language).

Thereafter the relation between the spatial structure of a perceptual Referent and the spatial structure of the Referent's object category is considered and so is the relation between the object category and the Intrinsic Object Centred Frame of Reference for Language. The Referent's object category determines the suitability of a Referent for

Intrinsic Reference in language, while it is the structure of the actual (or perceptual) Referent that determines if Intrinsic Locations can be defined.

Then, the different sources of information associated with object categories that determine if and which intrinsic dimensions can be defined are considered (such as canonical orientation, canonical encounter, and canonical use). It is concluded that intrinsic descriptions of objects can act in part as the basis for Intrinsic Directions for language. If an object category can be used as an intrinsic Referent, then each of its instances has a spatial structure that allows an intrinsic description of the perceptual Referent that captures the relevant structural distinctions of two intrinsic dimensions. The distinction between *top* and *bottom* requires a differentiation in object structure and so does the distinction between *front* and *back*; an intrinsic description may specify these. *Left side* and *right side* on the other hand do not depend on a structural differentiation in the object's category structure and need to be imposed conventionally upon the perceptual Referent. The lack of structural differentiation between the *left side* and the *right side* of an object category makes the object effectively *left-right* symmetric, while intrinsic descriptions can not differentiate between mirror images. It can be argued that differentiation between *left* and *right* is only possible after other intrinsic dimensions have been identified.

Finally, it is considered how a Spatial Relation is categorised, that is, how it is determined that the specific relation a Figure has with respect to the Referent belongs to some region to which one may refer with a Directional Preposition. Although there are not necessarily clear answers to all questions concerning categorisation, it can be concluded that there is an important difference in the definition of an Intrinsic Location for memory and its definition for language. If the same intrinsic description of a Referent is employed for language and memory, then the categorisation of a Spatial Relation for language can be based on similarity to some reference direction (i.e. the figure location can be associated with the pole of one dimension or with the orientation orthogonal to the object-part differentiation that specifies the dimension). However, the specification of an Intrinsic Location for memory in most cases requires not only an association with one dimension but an appreciation of the location on the other dimensions as well (i.e. in order to be able to retrieve an accurate memory report for the greater part of space surrounding a Referent, the Figure location needs to be valued on all dimensions).

In Chapter 3, the processing required for Intrinsic Object Centred Reference for Language is discussed. At first the recognition of a Referent is considered and the effect of deviation from upright on recognition time (Jolicoeur, 1985). It is argued that the orientation effect is a rotate-to-orient effect and not a rotate-to-recognise effect (see DeCaro and Reeves, 2000). Within object recognition, the orientation effect is thought to occur as a check on the identity of the object (see Corballis, 1988). The orientation effect (the 'normalisation') determines the orientation of the perceptual object relative to upright. Therefore, by means of this normalisation the *top-bottom* dimension is established on the perceptual object as well. In other words, an intrinsic description of the perceptual object is defined regarding its *top-bottom* structure.

After the *top-bottom* dimension is thus established by means of normalisation, the *front* and *back* can be defined on the perceptual object. It is not assumed that there is normalisation with respect to this dimension, but it cannot be excluded either. Finally, the *left side* and *right side* can be defined. In this case, because there is no structural differentiation between *left* and *right*, a normalisation is required with respect to an orientation of the object in which *left* and *right* can be conventionally defined (i.e. with respect to an orientation in which the observer knows how the label the sides). The normalisation required for defining *left* and *right* thus needs to be guided by another dimension. Experimental research is reviewed and the relation of the present approach to the intrinsic computation analysis is discussed.

Finally, the categorisation of Spatial Relations is considered, and some of the relevant literature on the linguistic description of Spatial Relations and the applicability ratings of Directional Prepositions with respect to Spatial Relations is reviewed. With such spatial language research, most experimental situations involve superimposed Frames of Reference. It is argued that the Hayward and Tarr (1995) linguistic data can be interpreted as reflecting a regional pattern and not necessarily an axial pattern. The area where a single Directional Preposition is used is quite small, whereas two Directional Prepositions are used in the remainder of surrounding space (see Zimmer, Speiser, Baus, Blocher, and Stopp, 1998). With respect to rating data it is unknown if the spatial constellation against which the applicability of a Directional Preposition has to be rated is considered only for this Preposition on its own or if it also considered for the suitability of alternative Directional Prepositions (i.e., lexical competition).

In Chapter 4 spatial memory is considered. Several aspects are identified that could have an effect on reports from memory. In particular, perceptual effects may have an effect on the accuracy of reports (e.g., the oblique effect, see Appelle, 1972) and on bias observed in memory reports (e.g., the tilt effect, see Bouma and Andriessen, 1970). Another possible influencing factor is spatial categories, for example, as they are specified in great detail in the model of Huttenlocher, Hedges, and Duncan (1991). A review of some literature on the reporting of lines within frames shows that both perceptual and category factors seem to be involved in the accuracy and bias of reports and that it may be difficult to tell them apart.

Thereafter the spatial category model is considered in relation to memory for location in bounded spaces. According to Huttenlocher *et al.* bias in reports from memory is bias towards prototypes, bias away from boundaries, or both. Attneave (1955) has previously published an experiment similar to the experiments by Huttenlocher, Hedges, and Duncan on memory for location in a circle. The explanatory scheme of Attneave differs strikingly however. Bias is not explained as bias towards prototypes but as bias away from reference directions. If a location is encoded explicitly by means of a deviation from some reference, then the deviation tends to be exaggerated in the report. There is thus an alternative to the Huttenlocher *et al.* explanatory scheme.

Finally, the experiments on memory for location relative to a Referent (with superimposed Frames of Reference) are considered. An alternative for the explanation that Hayward and Tarr (1995) give for their accuracy data may invoke perceptual effects. An alternative for the explanation that Crawford, Regier, and Huttenlocher (2000) give for their bias data may invoke perceptual effects as well or be re-interpreted as bias away from reference directions. Additionally, the data of Crawford *et al* show enhanced accuracy at the axial directions, which is not easily explained by the model of Huttenlocher *et al.*

Chapter 5 considers the relation between spatial representation and spatial language and presents an alternative to both the direct correspondence approach and the inverse correspondence approach. It is assumed that an underlying intrinsic description of the Referent is responsible for effects in both spatial memory and spatial language. The expression of the underlying representation may however be different due to different demands associated with each task. At the basis lays the independent definition of intrinsic dimensions on a Referent by which it is given a structural intrinsic description. To accomplish the definition of an intrinsic dimension, first an opposition between Directional Parts is defined. A spatial dichotomy is defined if the opposition is then applied to surrounding space. Such a spatial opposition is primarily regional and not axial. Note however that with the spatial dichotomy an orientation orthogonal to the boundary between the opposed object parts can be defined which could be used as a prototypical orientation or reference direction. Three pairs of opposed parts and –following– three pairs of spatial oppositions can be defined.

Confining to two dimensions, if a regional opposition is defined by means of some difference in object parts, then an axis-like entity separating the object parts is, when extended, also bounding the regional opposition. If one opposition defines, e.g., the *top* and *bottom* and from there the *above* and *below* regions (or some non-linguistic spatially marked equivalents), then the boundary between the regions is, e.g., the *left-right* axis (or a spatial equivalent). The other opposition defines the *left side* and the *right side* and from there *the to the left* of and *to the right of* regions which are bounded by the *top-bottom* axis.

In the case of memory for locations, an Intrinsic Location can be defined by a value on each of the dimensions; that is, an Intrinsic Location can be associated (categorised) by one of each of the opposite pairs of Referent parts (and some additional fine-grain information). If a location is on the *top-bottom* axis, then only the *top* or *bottom* value (or some spatial equivalent) needs to be taken into account. Locations on an axis are thus the best example of the region it intersects by virtue of the axis being the boundary of the orthogonally oriented regional opposition and therefore neutral with respect to this dimension. If a location is close to the *top-bottom* axis, but not on it, then the use of the *top* or *bottom* value does not suffice for accurate reporting. Additionally it has to be coded if the location is in the *left* or *right* region (contrasted on that dimension as well).

In the case of spatial language, if a location is on an axis, then only one Directional Preposition can be used. If the location is close to an axis (close to a boundary), then it may also be possible to use a single Directional Preposition, because in spatial language the location may be coded by similarity. The categorisation of the location on the orthogonal dimension may thus be ignored. If the location is clearly away from both axes, then two Directional Prepositions will be used.

Additionally it is argued that an ordered extraction of dimensions may apply to spatial memory as well as spatial language. It is not only the case that the *left-right* dimension can only be linguistically labelled after the other dimensions have been identified, but also that a coding of an intrinsic location for memory requires this ordering (at least when the Referent is bilateral symmetric). The regional interpretation of the intrinsic computation analysis is stated: A location that is somewhere between axial directions can be defined only as fast as the slowest of the axial directions it is in between. Normalisation effects could occur in both memory and language tasks.

Finally, the Referents used in the experiment are introduced. The reasons to assume a specific linguistic labelling (or equivalent spatial structuring) for the Van der Zee and Eshuis Referent are explained (by making use of the discussion on spatial structure and the possibility to define intrinsic directions from Chapter 2).

In Chapter 6 an experiment is described. A spatial memory task is used to obtain reaction time as well as reported location with respect to a Referent in an exclusively Intrinsic Object Centred Frame of Reference. To this end the participants remember the location of a dot (the Figure) with respect to inherent features of a Referent. Between the encoding phase and the reporting phase of a trial the Referent changes its orientation and as a consequence the to-be-reported Intrinsic Location changes along with the Referent's orientation. Participants have to perform a double task. First they visually determine the previous location of the dot as fast as possible and press a key. Thereafter they indicate this location as exactly as possible by means of the mouse. Hereby reaction times respectively reporting co-ordinates are stored.

The results (among others) are as follows. Reaction time (about) follows the regional interpretation of the intrinsic computation analysis. Responses are faster for the *top-bottom* directions than for the *left-right* directions and off-axis directions. Responses for the *left-right* directions are slightly faster than off-axis directions in general, but the difference is only confirmed for one of the Referents if these are considered separately. Normalisation effects are observed whereby the slope of the normalisation function is flatter for the *top-bottom* axis than it is for the other directions. The normalisation is not normalisation relative to upright (which was not explicitly tested in the experiment; i.e., it was not designed to test this), but relative to the orientation of the Referent seen at encoding. Variable angular error is smaller for on-axis directions than it is for off-axis directions. For the Van der Zee and Eshuis Referent there is a difference between the *top-bottom* axis and the *left-right* axis however. Variable error is also influenced by the direction on the Screen where the reporting takes place. Many regional errors are observed in the experiment. These errors are mostly errors between the *left* and *right* regions, although also some errors between the *above* and *below* regions were observed. The relative occurrence of regional errors (about) follows the reaction time pattern.

Bias and accuracy of reports from memory were previously used to investigate the connection between spatial representations and spatial language. Regional error in reports from memory is identified as an alternative measure. The two measures show different patterns of results. The accuracy of reports from memory shows a difference between on-axis directions and off-axis directions. Regional error however shows a difference between the *top-bottom* on-axis directions and the *left-right* on-axis and off-axis directions for both Referents. The regional error reflects a definition of opposite regions, in this case half-planes. Errors are predominantly made between a location in one half-plane and the corresponding location in the complementary half-plane. Orthogonal oriented pairs of opposite half-planes may thus constitute the spatial representation upon which memory reports and spatial language is based. In fact, where the accuracy of reports does not reflect the different labels that are used in the spatial language experiments, the regional error measure does exactly do that. Regional errors are predominantly made between the poles of a dimension, and differences between the dimensions exist.

Because the pattern is similar to that found for the reaction time data, regional error can be linked with the establishment of intrinsic dimensions even when explicit linguistic labelling of directions is not required. The reaction time pattern of the intrinsic computation analysis is found for the axial directions and the data point to its regional interpretation regarding the off-axis directions. Reaction times appear correlated with the proportion of errors between the poles of the dimensions. The different normalisation rates of the dimensions as well as the proportions of regional error over different degrees of Orientation Change suggest that one dimension is defined only after the other. This shows that the occurrence of regional error may be due in part to the establishment of the poles of a dimension. The reaction time data suggest that the coding of a location is defined in an Intrinsic Frame of Reference, and that the frame itself is defined by means of the encoding orientation relative to some extrinsic reference orientation. Normalisation corrects for the difference between the orientation seen at encoding and the orientation at reporting. Normalisation for the *top-bottom* directions is assumed to be guided by the features that distinguish *top* and *bottom*. This procedure is relatively fast and almost flawless. Normalisation for the *left-right* directions and the off-axis directions cannot be similarly guided by features that define *left side* and *right side*, because there are no such intrinsic features. *Left-right* decisions thus have to be made through a normalisation guided by the *top-bottom* axis. This procedure is relatively slow and error-prone.

7.2. Axes or Regions?

The question regarding axial or regional structure of the underlying representation is not definitely solved by the experiment. On the one hand, regional error and reaction time for off-axis directions in the experiment point to a regional underlying structure. On the other hand, arguments can be put forth in favour of an axial interpretation. For instance, if applicability rating data were obtained for 3D Referents with one intrinsic dimension, then the definition of an axis orthogonal to the object part distinction may be required to explain the data. A hypothesised regional structure must be extendable to explain possible axial effects. In the present case this would be performed by means of the orientation that can be defined orthogonal to the plane-like boundary between opposite object parts. Likewise, however, a hypothesised axial structure must be widened to explain regional effects such as those found in the experiment and to explain reference to Directional Parts.

To exemplify somewhat, a 3D object with one directed dimension such as a tree may have its poles defined by distinguishing the features that define *top* and *bottom* and thereby an opposition between object parts is thus made. With this distinction a planar boundary is separating the opposite parts. The planar entity may also be used to differentiate regional oppositions. However, to explain why one Figure is more *above* the Referent than another Figure, the orientation opposite to this planar bounding entity is probably required. Only in this way it is possible to explain different degrees of '*above*-ness.'

On the other side, it is possible to propose that a directed dimension is defined by means of an axial entity *along* which the *top* and *bottom* features are organised. Different degrees of agreement of a Figure position with the (extended) axis naturally explain different degrees of '*above*-ness' in this approach. In this conception, however, it is not so easy to determine when a Figure is still somehow *above* the Referent and when a Figure is not *above* the Referent anymore, that is, additionally some planar entity may be required, one that is orthogonal to the axial representation. The data presented in the previous chapter signal another reason to invoke such a planar entity: The regional errors from one region to the opposite region. A third reason is the linguistic reference to Directional Parts such as *top* and *bottom.* Having an axis where *top* and *bottom* features are organised along does not determine which of these features belong to the *top* and which belong to the *bottom*. Also here, an opposition is required, that is, a boundary needs to be set.

Using axes as boundaries to establish spatial dichotomies is an example of a feature model. Being located on one or the other side of an axis is necessary and sufficient for categorisation. At first glance this seems in sharp contrast to Hayward and Tarr who propose a prototype model in which goodness-of-fit measures determine categorisation (see Talmy, 1983, and Hayward and Tarr, 1995, for discussion of prototype and feature models in the present domain). However, the featural aspect of the present approach applies to categorisation within a dimension (categorising a Spatial Relation as one direction or as the opposite direction). Therefore the present approach does not exclude that goodness-of-fit measures are used to determine if a specific Spatial Relation matches more with one half-axis or with a half-axis of another dimension. Prototype-like effect (i.e., graded effects) in linguistic behaviour may thus occur when the orientation of a vector is compared with two half-axes, for instance, when the applicability of a Directional Preposition to specific Spatial Relations is rated.

The sharp distinction drawn between axial and regional explanations may be exaggerated or mistaken, for instance, because they always or usually go together (see, e.g., the specification by Clark, 1973). It is possible in any case to define a unique orientation orthogonal to a bounding plane. Similarly is it possible to define a uniquely oriented plane orthogonal to an axis. The empirical evidence seems indefinite to what is the correct characterization. On the one hand, it is clear that the relevant parts and/or features of a Referent need to be identified on the perceptual object to define a directed dimension. Contrasting Directional Parts seems foremost to specify a planar entity on the basis of which orthogonal orientations can be defined. On the other hand, normalisation effects may suggest that an axial structure along which object category features are organised is rotated into correspondence with features on the perceptual Referent (an instance of the object category). If so, then foremost an axial structure is defined. From such an axis, then an orthogonal plane is required to define regions (to account for regional error and opposite object parts). It would be interesting to consider if an intrinsic description explanation of Intrinsic Directions could be stated that is more about the organisation of object structure along an axis than about the discrimination between object parts.

The goal of presenting an account of Intrinsic Object Centred Frames of Reference as has been done in this thesis is to make it plausible that object axes may function as boundaries in certain spatial tasks. The presented view is limited in scope though. For one thing, the present view is restricted to Intrinsic Object Centred Frames of Reference. Regions surrounding the Referent are associated with differences between object parts. This account may not necessarily be transferable to other Frames of Reference. For instance, ego centred Frames of Reference (intrinsic or relative) may be dependent on a line of sight, which may function as a basis of defining directions that does not require any boundaries or object parts. This may also be the case with environment centred Frames of Reference in which the gravitational vertical plays a role. The relative merits of ‘axis-as-prototype’ accounts and ‘axis-as-boundary’ accounts are an empirical question. Mixtures of these approaches do seem to be possible as well. For instance, a *front-back* axis and an *above-below* axis may be defined as axial prototypes while at the same time the plane containing both axes may function as the boundary between *left* and *right* regions.

7.3. Space and Language revisited

It can be argued, in light of the mentioned contradictory suggestions on the relation between spatial memory and spatial language, that there is need of a theory that specifies in more detail the underlying representations that could play a role in both spatial language and memory. Instead of gathering data on two kinds of tasks and positing some alleged relation on the basis of a comparison of the data, it may be more worthwhile to consider how an underlying representation may be used in both tasks and how the demands of each task may determine its expression. The thesis is a first attempt to do exactly that for one specific Frame of Reference that can be used in both spatial language and spatial memory.

In the present approach there is thus a specification of intrinsic descriptions of Referents that can be used for spatial memory tasks and for spatial language tasks. The expression of the underlying representation in spatial memory and spatial language is exemplified whereby the different demands for each task are taken into account. Regarding spatial memory tasks, the expression of the underlying representation is primarily through regional effects and through an ordering in the definition of separate dimensions. Regional error and differences in reaction time are found. The present approach does not explicitly specify differences in accuracy as a consequence of the expression of the underlying representation in spatial memory.

It is not necessarily the case that accuracy of reports is not instructive at all in research regarding the spatial representations involved in spatial language. If locations are predominantly coded in terms of orthogonal dimensions, then the accuracy of reports may somehow reflect this. The basic finding of Hayward and Tarr that relative accurate reports reflect linguistic prototype directions is probably too simple however. For instance, the difference between the axial directions on the Van der Zee and Eshuis Referent speaks against it.[99] The findings of Munnich, Landau, and Dosher (2001) do also show that the correspondence between accuracy of reports and linguistic prototypicality is far from perfect. Results presented in Eshuis (2003) also speak against this simple relation.

[99] With this Referent no Frame of Reference for Language is available. Therefore, the relevance of this finding regarding alleged relations between spatial representation and spatial language may be questioned. However, if spatial language is dependent on spatial representations, then the representation of objects should be spatially similar if there is or if there is not an Intrinsic Object Centred Frame of Reference for Language.

In some cases, at least, accuracy can be associated with linguistic prototypicality. For example, it is probable that the axis of symmetry in a bilateral symmetric object (for detection of symmetry, see e.g. Wagemans, 1995) is associated with increased accuracy when considering memory reports. If a two-dimensional bilateral object has a Frame of Reference for Language, then the axis of symmetry is the best example of a dimension as explained in Chapter 2 of the thesis. This dimension is the *top-bottom* or *front-back* dimension.

7.4. Conclusions

In the first Chapter some questions were listed which the thesis would address. I will conclude the thesis by giving the answers that follow for the developed approach.

A Frame of Reference is defined by up to three pairs of regional oppositions as well as half-axes defined orthogonal to the oppositions. The Frame of Reference is centred on the Referent (A). An Intrinsic Frame of Reference refers to knowledge about the object category. Knowledge in object memory about the canonical orientation of an object and the associated difference between *top* and *bottom* is used to identify the *top* and *bottom* defining features on the perceptual instance of the category (i.e., the actual Referent) and define the *top-bottom* axis on this basis (by normalisation). Knowledge about canonical encounter, use, and/or movement of the object category and the associated difference between *front* and *back* can likewise be used to define the *front-back* dimension on the Referent. In contrast, the *left-right* dimension needs to be imposed on the Referent by convention under consideration of the other directed dimensions (A1).

A Spatial Relation is defined by a vector from the Referent to the Figure (B). A vector is defined in polar co-ordinates. The orientation co-ordinate of the vector definition may be linked to one or more directional aspects (half-axes) of the Frame of Reference (B1).

A Spatial Relation is categorised as a Directional Relation by assigning the Figure to a pole of one or more of the regional oppositions. If the Figure is close enough to one of the half-axes (or expressed alternatively: If the Figure is close to one of the boundaries between opposite regions), then categorisation on one of the spatial dichotomies can be ignored (C1). All Figure locations that can clearly assigned to one regional pole can be categorised similar with respect to that directional opposition (C2). However, because orthogonal pairs of opposite regions overlap, combinations of Directional Relations are possible.

The location of a Figure is coded for memory relative to a Referent by means of co-ordinates and categorical oppositions (D). The Figure is defined relative to the Referent's intrinsic structure by using co-ordinates and categories that are linked to the intrinsic structure (D1).

Intrinsic Locations are thus categorised in memory (E1). Those Intrinsic Locations that are on the same side of a bounding axis are categorised as being in the same region (E2). However, regions overlap with other regions.

The coding of Intrinsic Location for memory and the definition of Directional Relations for language share most aspects if a bilateral symmetric object (or a rotation invariant 3D object with one directed dimension respectively one rotation axis) is used as a Referent (F). It is actually unknown if and when the same Intrinsic Object Centred Frame of Reference is used to categorise Spatial Relations for language and to code location for memory. If the assigned directionality in memory employs the same labelling that is used for language is not known (F1). It is also unknown if the definition of a Spatial Relation employs the same co-ordinates in spatial language and spatial memory. It has been proposed, however, that in spatial language a location can be coded by similarity to a reference direction while in spatial memory it needs to be encoded by a difference to the reference direction if accurate reporting is required (F2). Bilateral symmetric objects force participants to use the same structural definition of the Referent for spatial language and spatial memory. The categorisation for language and memory is based on the same part definitions (F3).

Co-ordinates employed by participants in memory should be independent in the error along the co-ordinate components observed in memory reports. Regional errors in memory reports point to the categories used in memory (G).

Finally, the thesis suggests many topics for further research.

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