

# **Creativity is more than a trait – It's a relation**

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vorgelegt von Cara H. Kahl

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Erstgutachter: Prof. Dr. Erich H. Witte

Zweitgutachter: Prof. Dr. Klaus G. Troitzsch

Disputationsgutachterin: Prof. Monique Janneck

Disputationsgutachter: Prof. Alexander Redlich

Vorsitzende des Promotionsprüfungsausschusses: Prof. Sabine Trepte

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Evolution produces viable compromises,  
not perfection.

*Bernd Baldus.*



# Abstract

This dissertation begins with an investigation of recent doctoral work on creativity, and it reveals psychologists place the most emphasis on studying individuals and their traits. However, raters of some sort were always part of the studies at hand so the construct appears to emerge from more than just creating individuals. One of the fewest models accounting for contextual relations in constructing creativity is Csikszentmihalyi's (1999) systems perspective. It encompasses three interacting subsystems: *Individuals* producing variations, a *field* selecting and a *domain* retaining them. Its qualitative, longitudinal nature renders it a challenge for empirical experimentation. A methodological alternative capable of operationalising it is *agent-based modelling*, a form of computer simulation. Two agent-based models were programmed to explore the assumptions made by Csikszentmihalyi (1999), CRESY-I and CRESY-II. Experiments conducted with them reveal the relation between the domain and creating individuals is most influential when variations are not evaluated. As soon as they are, however, the field has the largest effect on variation diversity and creativity.



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# **Part I.**

## **Theory**





# Contemporary approaches in creativity research

In the very beginning of this doctoral work, a study was conducted to explore which types of approaches are used to scientifically study the phenomenon creativity. The purpose was to gain an overview of commonly used terminology, established research practices and, last but not least, popular scientific conceptualizations particularly in the domain of psychology. The study was a near-replication of a similar one conducted by Wehner, Csikszentmihalyi and Magyari-Beck (1991). Part I of this dissertation starts with a report of the study (Chapter 1) and continues with chapters (2 - 3) in which a specific theoretical model of creativity is gradually inferred.

## 1.1 Overview

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In this chapter, a study of contemporary creativity research conducted by analysing dissertation abstracts is presented<sup>1</sup>. Keywords relating to creativity were used to collect a sample from an online database. The abstracts were coded by discipline, research aspect (trait, process or product), social level of analysis (individual, group, organization or culture) and research approach (empirical vs. theoretical; quantitative vs. qualitative). Classification trees were built to explore the relationships between disciplines and their terminology, research aspect and social level of analysis. The results show the terms *creativity* and *innovation* are used interchangeably by some disciplines, and diverse creativity research in terms of aspect and social level is produced within single disciplines. Besides indicating that disciplines overlap in their activity, these findings suggest new trends in research aspects and social levels.

## 1.2 Revisiting creativity research

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Two decades ago, Wehner, Csikszentmihalyi and Magyari-Beck (1991) investigated approaches used in research on creativity. Since that time, this phenomenon, however defined, continues to fascinate scientists from around the world (Kaufman &

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<sup>1</sup>This chapter was originally published as: Kahl, C., Hermes da Fonseca, L. & Witte, E. (2009). Revisiting creativity research: An investigation of contemporary approaches. *Creativity Research Journal*, 21(1), 1-5.

Sternberg, 2006). Yet approaches to and definitions of creativity remain highly divergent even within the discipline of psychology alone (see Jarboe, 1999; Ochse, 1990; Sternberg, 1999a). Today, the meditation on creativity research by Feldhusen & Goh (1995) still appears to hold: "...those who search for the essence of creativity in current theory and research are apt to be overwhelmed by both the current breadth of conceptions of the field as well as the relative uncertainty of its fundamental components" (p. 232).

In this study, approaches to creativity were investigated by conducting an analysis of scientific contributions. Data collection was circumscribed to doctoral dissertations, because the "work of current graduates is going to shape the publications of the future" (Wehner et al., 1991, p. 262). The main goals of this study are: (a) to uncover current directions and gaps in creativity research, and (b) to determine whether research disciplines exclusively investigate particular aspects of creativity.

### 1.3 Classifying creativity research

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Magyari-Beck (1990) developed a three-dimensional taxonomy to classify creativity research and Wehner et al. (1991) slightly refined it. The first dimension is the *aspect* investigated. A study's focal aspect can be a trait, a process or a product. The second dimension is the social *level* observed, implying individual, group, organization or culture. The third dimension denotes the research *approach* and it has two subdimensions: empirical vs. theoretical and qualitative vs. quantitative. For each level type, there is one aspect type. Within each combination of level and aspect, there are four subcategories to classify the research approach: Empirical Quantitative, Empirical Qualitative, Theoretical Quantitative and Theoretical Qualitative (see Wehner et al., p. 262).

### 1.4 Method

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#### 1.4.1. Design

##### Database

Analogous to the procedures used by Wehner et al. (1991) in their 1986 sample, data were collected in Dissertation Abstracts Online, an information service provided by ProQuest Dissertations and Theses ("PQDT", 2007). Only dissertations were reviewed, because they are assumed to be similar in their length and research depth. See the Doctoral Dissertation Agreement Form D Intl (ProQuest Information and Learning, 2004) for an overview of disciplines. All data retrieved were published at PQDT from January 2005 to April 2007.

### Search terms

Table 1.1 displays the search terms used in both studies, grouped according to their truncations. Search terms in the cells "successful others" and "unsuccessful others" were labelled according to whether relevant dissertations were retrieved with them. In this study, scientifically recognized synonyms published in psychology (compare Amabile, 1996; Finke et al., 1996; Paulus & Nijstad, 2003; Runco, 1991; Sawyer, 2006; Sternberg, 1999a; Sternberg & Davidson, 1995) were included to more thoroughly assess research within this discipline.

Table 1.1.: *Search Terms Used by Wehner et al. (1991) and in This Study*

Search Terms	Wehner et al. (1991)	This Study
Creativ*	✓ <sup>1</sup>	✓
Innovat*	✓	✓
Scien*	✓	✓
Entrepreneur*	✓	
Successful others	invention, publishing, publication, success	brainstorming, complex problem solving, creative problem solving, curiosity, divergent thinking, group creativity, idea generation, ideation, inspiration, novelty, originality, resourcefulness
Unsuccessful others	discovery, ideas, novelty, originality	convergent thinking, discovery, discovery orientation, genius, group productivity, ideas, imaginativeness, ingeniousness, ingenuity, insight, invention, inventiveness, productiveness, productivity, talent

<sup>1</sup> Checked cells indicate used search terms and their truncations, empty cells indicate their omission.

### 1.4.2. Procedure

#### Search method

Only titles and index terms of English-language dissertations were searched synchronously over all disciplines. No abstracts were searched because that "usually yields a high proportion of irrelevant material" (Wehner et al., 1991, p. 263). "Relevant" dissertations are characterized by the investigation and operationalization of creativity as a scientifically observed phenomenon.

### Sampling

The retrievals obtained per search term yielded amounts up to 400 abstracts. Therefore, a sampling procedure was devised to reduce labour: Three lists of abstracts were made according to search term (*creative\**, *innovat\** and *successful others*; see Table 1.1). Each list was ordered by year and last name, and every fifth abstract was selected from each list to form the entire sample. Not all successful search terms listed in Table 1.1 are included in the data selected by this method, because each only retrieved a few abstracts.

### Coding abstracts

Firstly, each abstract was classified by its search term and discipline. Analogous to the method used by Wehner et al. (1991), a search term was given one point for an abstract it retrieved, and if more than one term retrieved the same abstract, the point was divided. The same procedure holds for disciplines.

Secondly, each abstract was coded using the typology developed by Magyari-Beck (1990) and later refined and published by Wehner et al. (1991). For *aspect*: The *trait* category was checked when human features were the focus and *process* if an abstract dealt with the way humans produce a creative outcome. *Product* was chosen if creative output was the main issue, no matter whether attributes or production was meant. Under *level*, the *individual* category was chosen when the social unit investigated was no larger than one person, even if the study dealt with particular groups of people such as teachers or managers. *Group* was checked when small units of people assembled for a common purpose were studied, for example music bands or students' groups. *Organization* was checked when more than one type of group was investigated and contrasted, for instance executives and employees, or teachers and students. *Culture* was checked when the work focused on a particular culture or cross-cultural comparisons, for example Japanese literature or a comparison of Hungarian and Polish music. When considering *approach*, an abstract was labelled *empirical* if its research background was only based such findings, and *theoretical* if an abstract model backing up the study was mentioned. Additionally, an abstract was rated *quantitative* if such analyses were conducted and *qualitative* if only those kinds of analyses were mentioned.

## 1.5 Results

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A total of  $N = 119$  abstracts were examined. The majority (94%) was submitted by institutions within the United States; the remaining contributions were from Canada, Finland, the Netherlands, Sweden and the United Kingdom. Two raters categorized a randomly selected subsample ( $n = 20$ ) to measure reliability. The overall percentage of agreement ( $P$ ), kappa ( $\kappa$ ) and the maximum attainable kappa ( $\kappa_{max}$ ; Sim & Wright, 2005) were calculated for each dimension: aspect ( $P = 95\%$ ;  $\kappa = .92$ ;  $p = .00$ ;  $\kappa_{max} = .92$ ), social level ( $P = 70\%$ ;  $\kappa = .61$ ;  $p = .00$ ;  $\kappa_{max} = .81$ ), empirical

vs. theoretical ( $P = 85\%$ ;  $\kappa = .77$ ;  $p = .00$ ;  $\kappa_{max} = .77$ ), and quantitative vs. qualitative ( $P = 80\%$ ;  $\kappa = .67$ ;  $p = .00$ ;  $\kappa_{max} = .67$ )<sup>2</sup>.

### 1.5.1. Disciplines

The disciplines retrieved were aggregated to six categories (percentages in parentheses): Psychology (25%), Education (24%), Business Administration & Economics (29%), Social Sciences (29%), Sciences & Engineering (18%) and Miscellaneous (21%). The *miscellaneous* category represents disciplines sparsely contributing to the sample: a) Communications & The Arts, b) Language, Literature, & Linguistics and c) Philosophy, Religion, & Theology. Figure 1.1 displays the frequency distributions for aspects and social levels separately for each subject category.

### 1.5.2. Search terms

The terms *innovat\** (52%), *creativ\** (34%) and the successful others *brainstorming*, *creative problem solving*, *inspiration*, *novelty*, *resourcefulness*, *ideation* and *invention* (14%) returned the  $N = 119$ . Only three abstracts (2%) contained multiple keywords. These findings raise two questions: (a) Are search terms specific to disciplines? (b) Do different disciplines produce non-overlapping research in terms of level-aspect classifications? To explore these ideas, classification trees were built with SPSS 15.0 using the QUEST split selection method (Loh & Shih, 1997) and Bonferonni-adjusted  $p$ -values. Abstracts were reassigned to a single discipline, and those with a score of 0.75 or higher were allocated to that respective subject, all others were labelled *interdisciplinary* (2-3 subjects). Abstracts retrieved by *successful* other keywords ( $n = 15$ ) were excluded from these analyses.

### Classifying disciplines by terminology

A tree model was built with *discipline* as the predictor and *search term* as the dependent variable. Two child nodes were constructed, *innovat\** and *creativ\** ( $\chi^2(6, 101) = 20.93$ ;  $p_{adj} = .00$ ). The *innovat\** node is predicted by the disciplines Sciences & Engineering, Social Sciences and Business Administration & Economics. The *creativ\** node is predicted by the disciplines Interdisciplinary, Miscellaneous, Education and Psychology. The misclassification cost after 10-fold cross validation is 42.6%.

<sup>2</sup>The significance tests calculated for  $\kappa$  were one-tailed ( $\alpha = .05$ ;  $H_0 : \kappa \neq 0$ ). Confidence limits for each dimension are the following. *Aspect*: .76. *Level*: .40. *Empirical vs. theoretical*: .56. *Quantitative vs. qualitative*: .43. Testing the reliability of a random subsample ( $n = 20$ ) is therefore enough to detect  $\kappa$  as large as  $\kappa = .40$ . The largest confidence interval serves only as a guideline because there is no sample size estimation for  $\kappa$  with non-dichotomous variables (Sim & Wright, 2005). However,  $n = 20$  proves to be sufficient to detect any deviation from at least "moderate" reliability. The authors would like to thank Hans Hansen for his help on this issue.

## CHAPTER 1. CONTEMPORARY APPROACHES IN CREATIVITY RESEARCH

Psychology ( <i>n</i> = 30)			
	Trait	Process	Product
Individual	40%	20%	3%
Group	3%	20%	3%
Organization	3%	7%	
Culture			

Education ( <i>n</i> = 29)			
	Trait	Process	Product
Individual	46%	18%	
Group		4%	11%
Organization		14%	7%
Culture			

Business Admin. & Economics ( <i>n</i> = 35)			
	Trait	Process	Product
Individual		13%	10%
Group		6%	10%
Organization	6%	16%	37%
Culture		3%	3%

Social Sciences ( <i>n</i> = 34)			
	Trait	Process	Product
Individual	15%	24%	9%
Group	6%	15%	9%
Organization		6%	3%
Culture			15%

Sciences & Engineering ( <i>n</i> = 21)			
	Trait	Process	Product
Individual	31%	25%	
Group		6%	6%
Organization		13%	19%
Culture			

Miscellaneous ( <i>n</i> = 25)			
	Trait	Process	Product
Individual		35%	35%
Group			9%
Organization			
Culture			23%

Figure 1.1.: *Aspect and social level by discipline: Cells represent percentages of scores. The sample size (*n*) indicates the number of abstracts from the entire sample (*N* = 119).*

### Classifying disciplines by research aspect

A tree model was built with *discipline* as the predictor and *aspect* as the dependent variable. Three child nodes were constructed, *trait*, *process* and *product* ( $\chi^2(12, 99) = 53.12; p_{adj} = .00$ ). The *trait* node is predicted by the disciplines Education and Psychology. The *process* node is predicted by the disciplines Interdisciplinary, Sciences & Engineering and Social Sciences while the *product* node is predicted by the disciplines Miscellaneous and Business Administration & Economics. The misclassification cost after 10-fold cross validation is 46.5%.

### Classifying disciplines by social level

A tree model was built with *discipline* as the predictor and *social level* as the dependent variable. Only two child nodes were constructed, *organization* and *individual* ( $\chi^2(18, 94) = 29.24; p_{adj} = .05$ ). The *organization* node is predicted by the disci-

plines Business Administration and Sciences & Engineering. The *individual* node is predicted by the disciplines Interdisciplinary, Miscellaneous, Social Sciences, Education and Psychology. No nodes were constructed for *group* and *culture*; notice the social *level* categories are unevenly distributed (see Figure 1.2). The misclassification cost after 10-fold cross validation is 54.3%.

### 1.5.3. Comparing samples

#### Research aspect

Figure 1.2 displays the absolute cell and relative marginal frequencies across aspect and level dimensions for the entire sample ( $\chi^2(2, 117) = 5.13; p = .08$ ). *Other* was added to code abstracts not classifiable with the given categories. Comparing this distribution with the one reported by Wehner et al. (1991, p. 267) yielded a significant result ( $\chi^2(2) = 28.69; p = .00; V = .37; e = .14$ ; for *e* see Cohen, 1969, p. 217).

	Traits	Processes	Products	Other	
Individual	25	17	12	0	45%
Group	2	9	9	0	17%
Organization	2	11	14	0	23%
Culture	0	1	7	0	7%
Other	0	1	7	2	8%
	24%	33%	41%	2%	

Figure 1.2.: The classification of the entire sample ( $N = 119$ ) across aspect and level dimensions. Cells depict absolute and margins relative frequencies.

### Social level

See Figure 1.2 for the distribution of investigated social levels ( $\chi^2(3, 109) = 41.79; p = .00$ ). A comparison with Wehner et al. (1991, p. 267) 1986 sample yielded a significant result ( $\chi^2(3) = 16.74; p = .00; V = .28; e = .08$ ; for  $e$  see Cohen, 1969, p. 217).

### Research approach

Table 1.2 shows the frequencies for research approaches. Due to their scarcity, abstracts classified as *mixture* (featuring combinations) were excluded from analyses. The scientific rationales provided in the abstracts were predominantly based on empirical work ( $\chi^2(1, 116) = 23.31; p = .00$ ); whereas the methods were similarly distributed (45%;  $\chi^2(1, 105) = 1.15; p = .33$ ). A comparison with the sample in Wehner et al. (1991, p. 270) yielded a significant result ( $\chi^2(3) = 10.54; p = .01; V = .23; e = .05$ ; for  $e$  see Cohen, 1969, p. 217).

Table 1.2.: *Frequencies for Research Approaches (N = 119)*

Research Analysis	Research Type			Total (%)
	Empirical (%)	Theoretical (%)	Mixture (%)	
Quantitative	33	17	1	51
Qualitative	32	10		42
Mixture	7	1		8
Total	72	28	1	100

## 1.6 Discussion

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### Trends and gaps in creativity research

Recent postgraduates place more emphasis on investigating creative products compared to their predecessors in the 1986 sample (Wehner et al., 1991); however, research on creative processes is less substantial in the current sample. The focus on individual creativity continues; whereas the lack of research on group creativity commented by Wehner et al. (1991) was not reconfirmed in this study. Additionally, the results show a drop in creativity research on the cultural level. None of the disciplines presented here focus starkly on this social level, perhaps indicating opportunities to research the intracultural and intercultural understanding and production of creativity and innovation. The distributions of empirical vs. theoretical groundwork are very similar, and today empirical rationales still outweigh. Dissertations submitted in 2005-2007 reveal a decrease in qualitative work and today, the kind research analyses



conducted on dissertation data is equally distributed among both forms. Most noteworthy, three times as many theoretical-quantitative dissertations were found in the 2005-2007 sample compared with the 1986 one. Balancing scientific activity among all approach cells within and among level-aspect cells would be necessary to enhance construct validity.

### **Transparency within creativity research**

While coding abstracts with the dimensions used by Wehner et al. (1991), it became apparent that the taxonomy reveals more similarities between disciplines than differences. The classification tree models relay significant descriptions of the research landscape on creativity. Research conducted within a particular discipline is not restricted to a certain aspect. A similar interpretation applies to social level classifications. The misclassification costs obtained with all three tree models are high, implying that the disciplines cannot be easily categorized. In effect, this means the disciplines overlap in their research types. Creativity research can profit from a higher awareness of different approaches to better communicate what part of the whole is being studied. Continuous effort in surveying research could facilitate the exchange of knowledge between and within scientific communities.



## Creativity is more than a trait: It's a relation

In this chapter, a compact introduction to the established conception of creativity as a trait is given (Section 2.2). It is followed by an explanation of how this construct can also be conceived in terms of social relations (Section 2.3). The chapter was originally published<sup>1</sup> in an online quarterly magazine for social psychology. One of the journal's goals is to present social psychological research in a manner which is accessible and entertaining to the broad academic public.

### 2.1 Introduction

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What is all the commotion about creativity? Whatever definition this vogue expression is dressed in, it has apparently captured the awareness of countless authorities for educational, economical, governmental and last but not least, scientific issues. Moreover, the media is filled with references to creativity or its synonyms. Ochse (1990), the author of a renowned book on the determinants of creative genius, contested that "our quality of life, perhaps our very survival as a species, depends on promoting creativity" (p. 33).

Within the discipline of psychology, research on creativity was initiated after an influential speech given by J.P. Guilford in 1950 to commence his election as president of the American Psychological Association (APA). Guilford (1950), until that time known for his work on psychometrics and intelligence, foretold the arrival of a "second industrial revolution" which would make humankind's "brains relatively useless" (p. 446). The economic value of our minds would be jeopardized, as he predicted, by the emergence of "remarkable new thinking machines" (ibid.).

During the same period, the U.S. American society began to search for ways to ease the "age of conformity" (Savelle, 1957) and concurrently, the Sputnik shock was interpreted by the authorities and the public alike as the price for not cultivating creativity in individuals from early in life onwards (Preisendörfer, 2007). In essence, creativity became something valuable to society as a whole and the question was how to go about producing more of it.

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<sup>1</sup>Kahl, C. (2008, January 27). Creativity is more than a trait: It's a relation. The INquisitive MIND, 6. Retrieved July 30, 2010, from [<http://beta.in-mind.org/node/130>].

## CHAPTER 2. CREATIVITY IS MORE THAN A TRAIT: IT'S A RELATION

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Today, we find ourselves in the initial decades of what Guilford (1950) implied. Our self-made information society is challenging the global workforce to find new ways to earn a living. Germany's federal chancellor Angela Merkel (2006) made a similar call as Guilford did when she spoke of the country's need for a creative imperative. She explained that novel ideas and their implementation are the key to securing standards of living and prosperity in this globalized world.

### **Creativity B.C.R. (Before Creativity Research)**

Of course, creativity was an acknowledged phenomenon before Guilford's speech in 1950, but its interpretation has been subjected to various historical and societal movements. Studying how the word has been used in the past can help us understand why there are so many different perspectives on creativity today.

In ancient Greece, there was no word to describe the action of creating something. The verb *poiein* (to make) existed, but it was solely reserved for what poets did: They invented poetry and did so freely, i.e. with no limitations due to laws (of nature). All other crafts and technologies were interpreted as acts of imitation or discovery, because they were subdued to principles of some kind (Tatarkiewicz, 1980). Therefore, the verb *poiein* was semantically similar to what many today consider *to create* to mean. In ancient Rome, poets as well as painters were free "to make" as they pleased (ibid.). The Romans had two words to describe such action: (a) *facere* (to make, to perform, to bring about) and (b) *creare* (to create, to make).

In the Christian period, the act of creating became one solely attributed to God. This verb no longer designated the realm of human action, because only the divine could produce a "creation from nothing" (*creatio ex nihilo*). Yet later in the Renaissance, an air of freedom and independence characterized European societies and the act of creating became something inspired humans could do. It was from this period onwards that creativity became connected to science, eventually leading to the study of eminent scholars from all disciplines (Albert & Runco, 1999).

## 2.2 The Great Trait

---

Sir Francis Galton (1822-1911), a cousin of Charles Darwin and a jack-of-all-trades in the sciences, believed that the variation observed in human intellect was controlled by genetically-determined, biological processes. To test his hypothesis, he investigated men of distinguished talent and counted the number of eminent male relatives they had (Galton, 1865). Assuming "talent and character" are only passed on from fathers to sons, he proposed that if intellectual ability is indeed hereditary, such men must have more prominent relatives than found distributed in the general population. Although Galton did not speak of creativity, he used the synonym genius which stood for all intellectual capacities and perseverance.

About a century later and without hereditary reasoning, Guilford (1950) began working on a concept to describe intelligence as a multi-dimensional, non-hierarchical

trait. The resulting structure of intellect (Guilford, 1956) encompasses three main dimensions describing the (a) input, (b) operations and (c) output of intellectual abilities. The operations include divergent production, the mental process of generating more than one solution to a given task. This mental process is similar to what many researchers call creativity. Guilford (1950) planned to test divergent production, or divergent thinking as it is often called, with paper-and-pencil tests. Although admitting this kind of behaviour represents "lower degrees of distinction" (ibid., p. 445), it would be an opportunity to collect larger samples than the ones of eminent creators previously investigated.

The noteworthy contributions made by Galton and Guilford are exemplary for two kinds of individual, or trait, perspectives on creativity, "big C" and "small c" creativity (see Amabile, 1996; Sawyer, 2006). The term "big C" is used to describe eminent creators. These are people who have literally gone down in history for their achievements, such as Nobel Prize winners and renowned musicians. However, the world is full of people who do creative work without large-scale public recognition, and the term "small c" is reserved for describing such creators. Boden (2004) makes a similar distinction when she defines historical and individual creativity. A historical creative act is one which has never occurred before to humankind's knowledge, and individual creativity is reserved for acts which are new to the person creating, but not necessarily new to humankind in general.

Apart from intellectual abilities, certain personality characteristics have been consistently related to creative performance, such as openness to experience, impulsivity, ambition, nonconformity, flexibility and autonomy (Feist, 1999). Openness to experience is one of five major personality traits (McCrae & John, 1992) and it correlates with performance in divergent thinking tests (McCrae, 1987). Individuals open to experience are, for example, intellectually curious, imaginative, sensitive to their inner feelings, aesthetically oriented and flexible in thought.

### **From the Great Trait to more individuality**

Before the turn of the century, Feldhusen & Goh (1995) remarked, "...those who search for the essence of creativity in current theory and research are apt to be overwhelmed by both the current breadth of conceptions of the field as well as the relative uncertainty of its fundamental components" (p. 232). After the era of personality psychology approaches to creativity, a cognitive psychology wave advanced (Sawyer, 2006), and creativity research was no longer restricted to unravelling the creative personality. The scientific focus turned from the creative person to the creative process. Creating individuals were still central in studies, but now the way they created was investigated. The process is commonly divided into four stages (see Csikszentmihalyi & Sawyer, 1995; Finke et al., 1996): (a) preparation (b) incubation (c) insight or illumination and (d) verification. This stage model of creativity is still quite popular in pragmatic approaches (Nölke, 2006) and much research has been conducted on incubation and insight. In contemporary research, it is viewed as a heuristic model characterized by overlapping and iterative stages (Sawyer, 2006).

In the relay to unravel creativity, cognitive psychology passed the stick to neurological approaches to creativity (Martindale, 1999; Sawyer, 2006). This research trend did not only evolve due to technological advancements in medical imaging, but also because psychological methods were unable to clearly account for what actually happens during incubation, the phase right before insight, i.e. the moment a creator perceives the outcome of this mental process. The neurological approach has led to attempts to localize the so-called "creative drive" (Flaherty, 2005) and the realm of creativity and innovation production (Vandervort et al., 2007).

Creativity scholars started with the individual and moved on to examining the process. Other scientists have made attempts to describe the outcomes, or products, of creative behaviour (Amabile, 1996; Gruber & Wallace, 1999). Although only a fraction of creativity definitions have been mentioned here, they have one thing in common: their trait or individual character. Creativity is interpreted as a potential outcome of either a) intellectual, personality and/or neurological attributes or b) individual cognitive skills. Although the latter skills are not inherent and may be trained to improve creative performance, they are particular to the individual. This implies creativity is either attributed to a stable trait (Mayer, 1999) or individual skills. However, such attributions result from others observing and evaluating individual behaviour, be it on personality or performance tests. Yet who is responsible for this decision?

### 2.3 The relation

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Think of a creative person you admire. What makes you believe this person is creative? An educated guess is that you have seen something he or she has made, e.g. an art performance, a new recipe or an organizational change at your workplace. This thought experiment introduces the first necessity in the relational definition of creativity: the product (Amabile, 1996; Westmeyer, 2001). Before deeming someone creative, we must recognize what type of behaviour this person exhibited to be considered so, and behaviour is manifested in an observable outcome. This is the basis of numerous approaches to creativity, including the ones by Galton (1865) and Guilford (1950) sketched earlier. Yet in deeming someone or something creative, we are not, as often assumed, only recognizing their traits or skills. Instead, we are observing a behavioural outcome and adopting a position on it (Amabile, 1996; Nicholls, 1972; Westmeyer, 2001). This postulate is not as novel as it may sound; the same thing occurs when psychologists assess creativity with psychometric tests (Hocevar & Bachelor, 1989; Csikszentmihalyi, 1999).

Csikszentmihalyi (1999) developed a model to describe how this observation and judgement process proceeds. Instead of viewing creativity as an objective property of a person, process or product, he saw it as the effect something is able to produce on others. Similar to an audience's fanatic reaction to a concert, creativity is the judgemental outcome of people witnessing and implicitly or explicitly evaluating a particular focal output. According to Csikszentmihalyi, this relational approach is

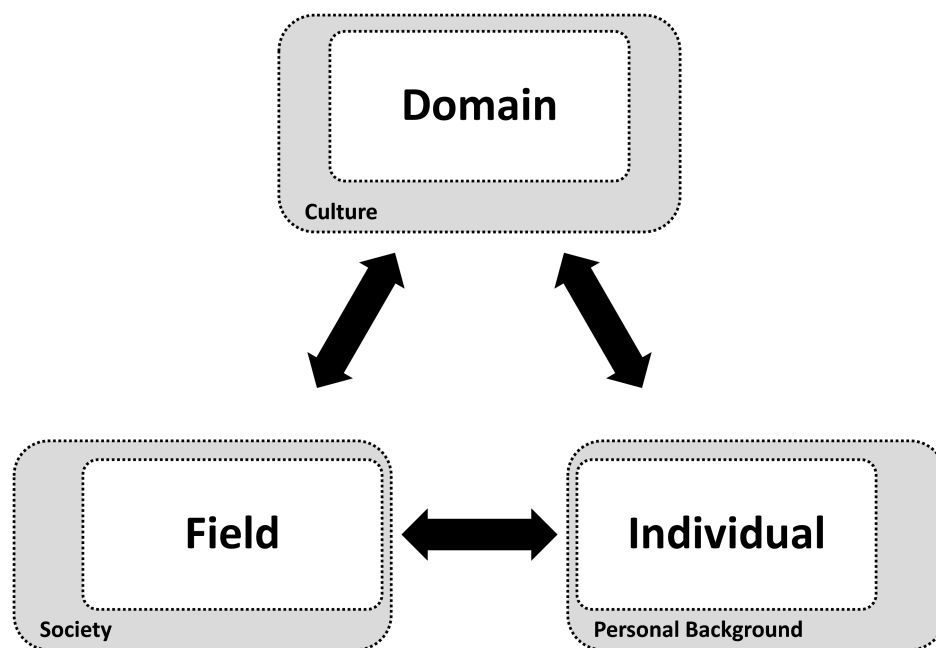


Figure 2.1.: A reproduction of Csikszentmihalyi's (1999) systems model of creativity. Creativity evolves as a product of social interaction. The domain (a part of a culture) transmits information to its members: the field (a part of society) and among the latter individuals (with specific personal backgrounds). Individuals create novel products, and the field selects products "worthy" of being retained in the domain. By selecting and transmitting novel products, the field and ultimately the domain stimulate the production and evaluation of future novelty.

based on the interaction between three social systems: the individual, the field and the domain.

The field and the domain constitute an individual's environment. The field represents a part of society, i.e. a social group in the position to decide how much impact individual creative output will have. The domain represents a part of the individual's and the field's culture. It is a symbolic system including ideas, behaviours, styles, etc. Csikszentmihalyi (1999) used the term *meme* to describe these symbols. Furthermore, a society can have many fields just as a culture can be composed of more than one domain. To illustrate the model in Figure 2.1, think of schoolchildren (individuals with specific backgrounds and experiences) participating in an art contest to decorate the walls of their otherwise dismal school hallways. The school art teachers (a field) will select the most creative pictures to put on display, so their vote will decide which types of art will go down in this school's history (domain). Even though parents or the children themselves (other fields) could disagree with the art

## CHAPTER 2. CREATIVITY IS MORE THAN A TRAIT: IT'S A RELATION

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teachers' selection, the latter social group is the relevant field for deciding on which art types (memes, e.g. motifs, color choice, material) are deemed creative enough for the school's hallways. In representing different fields, parents and art teachers can use varying judgement criteria for deciding on the creativity of schoolchildren's artwork, and their decisions affect how long and where a creative product spends its life (domains, culture). For example, even if a particular work of art does not make school (hallway) history, it could very easily make it on the family's refrigerator door. Several researchers, such as Hargreaves et al. (1996) as well as Hennessey (2003), have investigated the evaluation of schoolchildren's artwork from different social group perspectives.

In Csikszentmihalyi's (1999) model, creativity occurs when a change in the domain is made. For this to happen, an individual must first produce something new, and this is done on the basis of the existing memes in the domain. A child participating in the art contest, for example, could study the existing pictures in the school's hallways and decide to deviate from all the landscape pieces by painting a space scene. Once an individual produces a new meme, it is judged by the field and either rejected or accepted into the domain, e.g. the school's art teachers may find the space scene totally revolutionary compared with the previous pictures.

In returning to the relational definition of creativity, this means behavioural outcomes must be socially validated in order to be deemed creative. However, this does not mean to say individuals are only productive when the outcome is creative. Their behavioural outcomes may be numerous as well as original, but if they are to be considered creative, i.e. novel and useful or valuable to the social environment, these products must be accepted by the field (see Amabile, 1996; Sternberg, 1999b). This is what makes up the relational definition of creativity. It refers to social evaluation processes after an individual has produced some behavioral outcome, and these are made on the basis of what already exists in the referential domain. Once deemed creative by a respective field, a behavioural outcome turns into cultural input, because it is accepted into the pool of memes existing in a particular domain. In our example, the space scene will make school hallway history and it could influence future artists in next year's contest.

In defining creativity relationally, the scientific focus moves from solely assessing individual, process, product or environmental properties to a higher, more dynamic level of observation. We define creativity as the variable outcome of an evaluative process conducted by a relevant social group or field. Reducing creativity to a trait or skill, i.e. an individual quality existent or not, means overlooking what this phenomenon could be for social scientists: a research topic undoubtedly modelled by socio-environmental parameters. Furthermore, the influence of social variables is spiral. In resuming the children's artwork example, the art teacher jury (relevant field) decides which kinds of pictures are creative enough for the school's hallways. In doing so, they are using judgemental criteria based on information already available in their domain, e.g. the quality of children's artwork they have seen before. Yet at the same time, they are reshaping the domain by making their present selection. If,



for instance, the teachers find pictures with abstract motifs to be the most creative, this socially-produced information will shape the way children design their pictures in the future, thereby influencing the personal background of those creating individuals. In the artwork example, the relevant domain is children's art culture at a particular school. Domains could also be represented by existing cultures, such as the Eastern and Western described in an earlier In-Mind article by Chiu & Leung (2007), and just as the evaluations of school art teachers may differ, so may those of differing cultures when it comes to tasting innovative food.

Social groups play an integral part in establishing creativity. Their perception and evaluation processes may be hard to decipher in an increasingly networked world, but ignoring this complexity does not necessarily facilitate scientific comprehension of creativity. This notion implies adopting a relational approach to investigating it. And taking the phenomenon for what we make of it: a dynamical construct based on social stimulation and judgement processes.



## Modeling a social environment to investigate creativity

In this chapter, a concept of creativity as a phenomenon emerging from the interaction between three subsystems is elaborated. The subsystems, creators, evaluators and a so-called domain, refer to the systems model of creativity published by Csikszentmihalyi (1988, 1999) and described in Chapter 2. The majority of this chapter (Sections 3.1 - 3.5) is an excerpt from a contribution published in the proceedings of an annual symposium<sup>1</sup>.

### 3.1 Defining creativity

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Although people seem to know creativity when they see it (Amabile, 1996; Plucker & Renzulli, 1999), scientists defining this phenomenon offer a variety of meanings depending on their research perspective (Dresler & Baudson, 2008; Kaufman & Sternberg, 2006; Sternberg, 1999a). Broadly, social scientific definitions of creativity vary depending on a) the social unit of analysis observed, b) the specific aspects of this unit under investigation, c) the behavioural outcomes literally assessed, and d) the concrete measure of creativity used to discriminate between the latter. For example, the social unit of analysis could be individuals, say potential candidates for a position as a campaign designer in an advertising agency. The specific aspect under investigation could be their creative talent, and it could be observed in an assessment center by having the candidates design a campaign for a fictive customer. The measure used to discriminate how creative each candidate's campaign could be the observers' subjective judgements based on their knowledge and experience (Amabile & Mueller, 2007). In a typical laboratory setting within the domain of social psychology, the unit of analysis could be a group of students asked to participate in a brainstorming experiment. Their creative performance as a group would be under investigation as they produced ideas together on a particular task, for instance how to improve their university (Paulus & Brown, 2003). The measure of creativity to discriminate this group's performance from other tested groups' outcomes could be the number of ideas they produced, or *fluency* (Guilford, 1950).

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<sup>1</sup>Kahl, C. (2009). Modeling a social environment to investigate creativity: An agent-based model. In E. Witte & Kahl, C. (Eds.), *Sozialpsychologie der Kreativität und Innovation* [Social psychology of creativity and innovation] (pp. 27-52). Lengerich, Germany: Pabst Science Publishers.

There is no single, authoritative definition of creativity and no standardized, universally accepted measurement technique for its assessment (Sternberg, 1999b). Yet no matter which social unit of analysis and particular aspects of it are investigated, researching creativity ultimately results in observing the outcome of prior processes (Schuler & Görlich, 2006; Westmeyer, 2009) and comparing it to a specific definition of creativity, regardless of whether this definition is explicitly or implicitly stated. Therefore, creativity can be described as at least encompassing a) production and b) evaluation processes (Csikszentmihalyi, 1988, 1999; Streicher et al., 2009). Furthermore, many researchers argue that these two processes do not occur "in a vacuum" (Guilford, 1950; Styhre, 2006), but are embedded in a culture or a particular *domain* (Csikszentmihalyi, 1988, 1999; Westmeyer, 2008). The following sections (3.2 - 3.4) will illuminate the processes of production and evaluation within the study of creativity and subsequently describe how both are embedded within a particular context, the domain.

### 3.2 Production

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Early psychological research on creativity (for an overview see Sawyer, 2006; Sternberg, 1999b) aimed to explain the quantity and quality of creative output by discriminating their makers from one another. Regardless of output type, creativity was attributed to particular features creators of various aptitude exhibit. These features could be, for instance, personality traits, behavioural styles or cognitive processes. Such assessments, however, are indirectly made. The observer does not see a person's cognitions or traits. She rather witnesses something a creator has produced e.g. a piece of music, a scientific breakthrough, or a technology innovation. A necessity in deriving a definition of creativity is the *product*<sup>2</sup> (Amabile, 1996; Westmeyer, 2009). Before deeming someone creative, the behaviour to be considered so must be perceived by others. This is the basis of numerous approaches to creativity, including for instance a very early one on "talent and character" by Galton (1865). In line with this notion, Amabile & Mueller (2007) summarized creativity as "a process resulting in a product; it is the production of a novel and appropriate response, product, or solution to an open-ended task" (p. 35). MacKinnon (1978, p. 187, in Plucker & Renzulli, 1999, p. 44) stated that "the starting point, indeed the bedrock of all studies of creativity is an analysis of creative products, a determination of what it is that makes them different from more mundane products". In determining human creativity, the manifest outcomes of people's behaviour must first be distinguished by observers, and such outcomes "can be any observable product, performance, response, or idea, such as a poem, a new software program, a dance, a market research project, a new drug, a training course, a scientific experiment or a completed consulting engagement" (Amabile & Mueller, 2007, p. 38)<sup>3</sup>. Psychological interpretations

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<sup>2</sup>In this thesis, the terms *outcome*, *product* and *artefact* are used interchangeably to denote observed behaviour resulting from a creative production process.

<sup>3</sup>Lubart (1999) noted that the necessity of an observable product for determining creativity is a particular feature of Western civilizations, as are the dimensions novelty and appropriateness for

of individual creativity therefore refer to a behaviour or product possessing particular qualities considered indicative of creativity.

In distinguishing creative products, the attributes *novelty* and *appropriateness* are commonly cited in creativity research literature (Amabile & Mueller, 2007; Lubart, 1999; Metzger, 1986; Schuler & Görlich, 2006; Styhre, 2006; Preiser, 2006; Zysno & Bosse, 2009). Ward et al. (1999) called them the "twin criteria of creative products" (p. 190) and the "crucial birthmarks of creativity" (p. 191). Sometimes synonyms for these two dimensions are used, for example Couger et al. (1989) spoke of *newness*, *uniqueness* and *freshness* for novelty as well as of *value* and *utility* for appropriateness concerning inventions and patents (see also El-Murad & West, 2004; Gruber, 1988)<sup>4</sup>. Shalley & Zhou (2007, p. 6) described that "novel ideas are those that are unique compared to other ideas currently available" and "useful or appropriate ideas are those that have the potential to add value in either short or long term". Similarly, Lubart (1999, p. 339) stated that novel work is "distinct from previous work" and "appropriate work satisfies the problem constraints, is useful or fulfils a need".

Schuler & Görlich (2006) argued that these two dimensions are "relatively independent" from each other (p. 8). Evidence for this only appears in the form of how others conduct research on creative products using these dimensions (Amabile & Mueller, 2007). Shalley & Zhou (2007) distinguished that these two dimensions are commonly used in organizational research, whereas in psychology research sometimes other attributes prevail (Sternberg, 1999b): *fluency* (total number of relevant responses), *flexibility* (number of different categories of relevant responses), *originality* (statistical rarity of responses) and *elaboration* (amount of detail). Other authors use more than the dimensions of novelty and appropriateness, for instance Boden (2004) emphasized the importance of surprise as a vital part of creativity. Other criteria used to discriminate creative outcomes, and therewith their makers, have been "statistical deviations of scores on tests, number of citations or number of lines devoted to famous people in literature, judgements of professionally qualified people, generally acknowledged eminence, number of products defined as creative, pursuit of activities assumed to require creative talent, peer/supervisor ratings, promotion rate, number of patents, number of publications" (Taylor, 1975, p. 313).

Aiming to characterize another quality of creative output, Sternberg (1999b) devised seven categories of creative contributions in his propulsion model of creativity: *replication*, *redefinition*, *forward incrementation*, *advance forward incrementation*, *redirection*, *reconstruction/redirection* and *reinitiation*. The first four types

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evaluating it.

<sup>4</sup>In creativity research literature, many synonyms can be found for these attributes. For example, novelty is also called *originality*, *newness* or *unexpectedness* (Sternberg, 1999b). Appropriateness is interchanged with words such as *usefulness*, *utility*, *value*, *adaptiveness* and *practicality* (ibid.). Both terms do not seem to have been explicitly discriminated from their respective synonyms within creativity research literature. Rather, there appears to be an implicit scientific agreement that they more or less refer to the same latent dimensions of creativity (as a quality of behaviour or products) which are labelled novelty and appropriateness in this thesis.

are considered to accept current paradigms, while the latter three categories reject, or drive, current paradigms. The differentiation between *paradigm-preserving* and *paradigm-modifying* contributions, as another quality of creative performance, has been expressed by others in the domain of creativity research (Satzinger et al., 1999). Boden (2004), for instance, described the difference between *exploring* and *transforming* conceptual space, a structured style of thought or "any disciplined way of thinking that is familiar to (and valued by) a certain social group" (p. 4). Other authors have illustrated how creative output is the result of combining things into something new or in unfamiliar ways (Sawyer, 2006; Schuler & Görlich, 2006). Finke et al. (1996), for instance, described creative output as the result of *association*, *synthesis*, *transformation*, *analogical transfer* and *categorical reduction* processes.

In essence, the observation of some particular outcome or performance is necessary to assess and judge creativity, no matter what assumed construct leads to it. As Csikszentmihalyi (1988, 1999) and Westmeyer (2009) have described, the product of creative behaviour only represents the starting point for assessing creativity, and there is more to the story: The quality of a product, described by a set of implicit or explicit characteristics, is often literally translated into the corresponding creator's traits. The product therefore represents a medium which facilitates communication between creator and evaluator: The evaluator refers to the product in judging the creator's creativity, and the creator may refer to this evaluation when assessing his or her own quality of work. In Section 3.3, the evaluator's role in the process of defining creativity is elucidated.

### 3.3 Evaluation

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In deeming someone or something creative, people are not, as often assumed, only viewing their traits or skills. Instead, they are observing a behavioural outcome and adopting a position on it (Amabile, 1996; Hennessey, 2003; Nicholls, 1972; Westmeyer, 2001, 2009). This postulate is not as novel as it may sound; the same thing occurs when, for instance, psychologists assess creativity with psychometric tests (Csikszentmihalyi, 1999; Hocevar & Bachelor, 1989). As Styhre (2006) asserted, "creativity is above all what is regarded so by peers; no creativity subsists in a vacuum" (p. 147). In other words, the phenomenon creativity emerges from a social system; it evolves from the communication between actor (creator) and observer (evaluator). Creators alone cannot account for creativity. Instead, social systems contribute to its emergence by producing judgements about manifest behaviour. Consequently, creative work, or production, is not equal to the acceptance of this work, social valuation processes are always a component to any definition of creativity. As Csikszentmihalyi (1999) argued, "there is no way...to separate the reaction of society from the person's contribution: The two are inseparable" (p. 321). Westmeyer (2008, 2009) elegantly defined the connection between creator and evaluator as a process of constructing creativity. From his perspective, creativity can be perceived as a relation with four elements. A particular object  $y$  is constructed as  $z$  by a certain

evaluator  $e$  at time  $t$ . The object  $y$  represents something evaluator  $e$  perceives, and  $z$  is the unique meaning evaluator  $e$  attributes to  $y$ . This approach, very similar to the one defended by Csikszentmihalyi (1988, 1999), highlights the notion that there is no objective reality containing creative objects. It is impossible to isolate the evaluator from the process of creative distinction. As Westmeyer (2009) accentuated, a product is not creative, it is regarded as creative! One other important feature Westmeyer (2008) incorporated in his approach to creativity is time. Although time has implicitly been mentioned by other creativity researchers (Amabile & Mueller, 2007; Csikszentmihalyi, 1999), it is seldom explicitly considered as a variable relevant to investigating creativity. Evaluators can judge a product differently at various time periods, as Sawyer (2006) described concerning the careers of renowned artists.

Opposed to these ideas, many definitions of creativity imply that it is an objective quality exhibited by certain products. For instance, Amabile & Mueller (2007) defined creativity as "a process resulting in a product; it is the production of novel and appropriate response, product or solution to an open-ended task" (p. 35). To this day, however, there is no universal standard by which to evaluate creative responses. Even if, for example, the attributes novelty and appropriateness are commonly mentioned in creativity research literature as necessary characteristics of creative output (Amabile & Mueller, 2007; Lubart, 1999; Metzger, 1986; Schuler & Görlich, 2006; Styhre, 2006; Preiser, 2006; Zysno & Bosse, 2009), their assessment relies on individual subjective judgements often aggregated to form one general assertion about a person's or an product's creativity (Amabile & Mueller, 2007). Plucker & Renzulli (1999) admonished that the evaluative component has not been the focus of creativity research, although it is put into effect whenever people express a preference for something they consider creative.

When creativity is attributed to a person or a product, therefore, it is relationally defined (Kahl, 2008; Westmeyer, 2009). In addition to the work creators produce, there are evaluators "measuring" how creative the work is. The people responsible for defining what is creative have an important feature: They are "relevant" judges. This means they are people socially entitled to make evaluations about someone's or something's creativity. Such people could be, for instance, peers, supervisors or experts in a particular domain. In fact, these kinds of ratings are commonly used in many assessments of creativity (Runco et al., 1994), Nijstad et al. (2003) commented, "...an idea will be called creative only if significant others agree that it is" (p. 157). For instance, Csikszentmihalyi & Getzels (1971) conducted a study in which drawings produced by art students were evaluated by artists and art critics on the dimensions craftsmanship, originality and aesthetic value. Csikszentmihalyi (1988, 1999) called such relevant judges *gatekeepers* or in terms of his systems perspective of creativity the *field*. In other words, those people with the right to define what is creative are collectively designated the field.

In adapting this *relational* perspective of creativity (Csikszentmihalyi, 1988, 1999; Westmeyer, 2008, 2009), it obviously follows that the field possesses great power in navigating what is produced and accepted. As a gatekeeper, the field – put

simply – adds or subtracts what is retained in a domain. The field is not necessarily homogeneous, meaning opinions about and preferences for products may diverge, and products may enter a domain without being consistently praised for their creativity. On a similar note, Amabile (1996) deemed outcomes as creative if appropriate, independent judges reliably agree on their creativity. How open a field is to change is one factor determining how versatile and flexible its corresponding domain will be. As Csikszentmihalyi (1999) contemplated, "if one wishes to increase the frequency of creativity, it may be more advantageous to work at the level of fields than at the level of individuals" (p. 327). In defining creativity relationally, the scientific focus moves from solely assessing individual, process, product or environmental properties to a higher, more dynamic level of observation. Creativity can therefore also be defined as the variable outcome of an evaluative process conducted by a relevant social group or field regarding a certain product. Alternately, if creativity is reduced to a trait or skill, i.e. an individual quality existent or not, the socio-environmental parameters modelling the phenomenon are undoubtedly overlooked. Once a product is accepted by relevant judges as novel and appropriate, a creative outcome has been generated (Amabile & Mueller, 2007).

### 3.4 The domain

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Csikszentmihalyi (1988, 1999) described a systems perspective of creativity in which the individual creator is surrounded by an environment consisting of a) the field and b) the domain. While the field is a part of society, the domain represents a part of the individual's and the field's culture. It is a symbolic system including ideas, behaviours, styles, etc. Whatever elements make up the domain, they influence how people interact with their social and physical environment (Lubart, 1999). From Csikszentmihalyi's (1999) perspective, creativity can only be determined by studying the interaction between creators, their fields and corresponding domains. Basically, the dynamics of this systems perspective works in the following way: A creator produces something new, and this product must be accepted, or socially validated, by the field in order to be included in the domain, a symbolic space or frame of reference for both creators and evaluators. In this sense, "creativity occurs when a person makes a change in a domain" (Csikszentmihalyi, 1999, p. 315). A culture can host countless domains, and something or someone considered creative by the field of a particular domain does not necessarily receive kudos from the field of another (Westmeyer, 2009). The dynamics described by this systems perspective are depicted in Figure 3.1.

The concept of the domain is significant for at least two reasons: Firstly, as many creativity researchers have maintained (e.g. Guilford, 1950; Styhre, 2006), creativity does not occur in a vacuum. A domain can be compared to a memory. It retains things accepted by the field, in this case products socially deemed creative. In other words, the domain represents a frame of reference creators directly or indirectly refer to when producing work. The elements a creator has access to in the domain can be



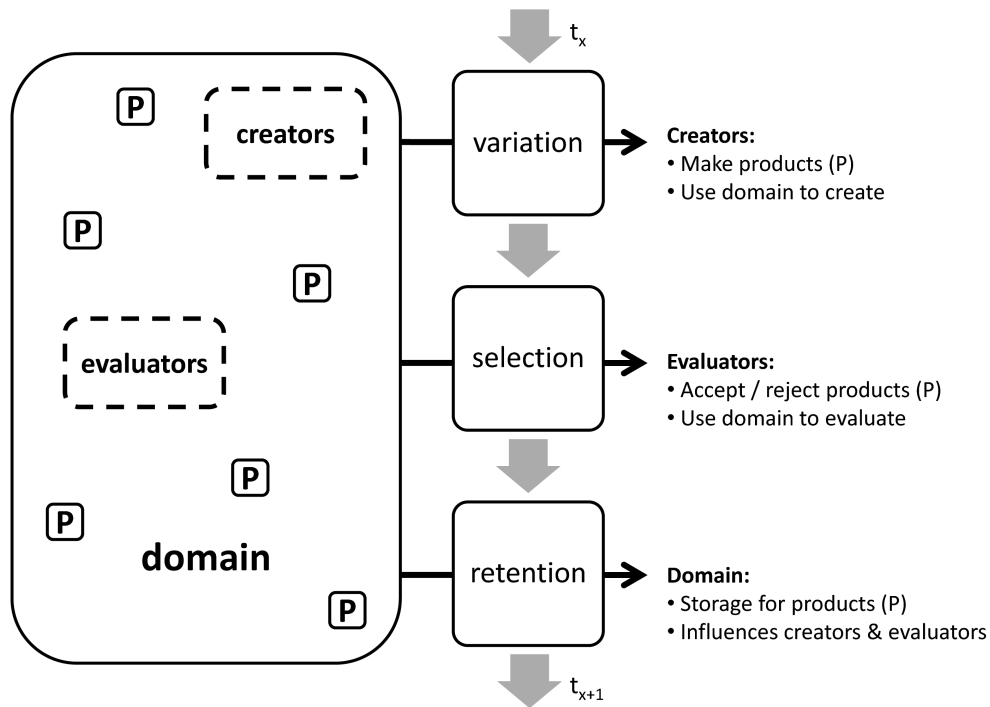


Figure 3.1.: *Illustration of Csikszentmihalyi's (1999) systems perspective of creativity: Creators and their field are embedded in a domain they produce. The purpose or goals of these subsystems (creators, evaluators, domain) resemble the evolutionary mechanism of variation, selection and retention.*

combined to generate new output (Sternberg, 1999b; Simonton, 2003). If creators want their work to be included in the domain, they require knowledge of what the domain contains, i.e. what the field prefers (Sternberg, 1999b; Westmeyer, 2008). For this reason, creativity researchers emphasize the necessity of creators having domain-specific knowledge (Amabile, 1998).

Secondly, the domain is not static. Its contents change over time as products are more or less valued by the field. Gruber (1988), for instance, explained that "...whatever we might hope to mean by novelty changes as human history moves on in time" (pp. 34). When creative work is accepted by the field, it is transmitted to and retained in the domain, therewith available to creators and their field in the future. In simple terms, the domain is updated when the field adds new things to it or reduces the significance of other things within it (Gruber, 1988). The notion of a domain and its influence on the creator as well as the field in producing and determining creativity further emphasizes the socially-determined nature of this phenomenon.

### 3.5 Integrating perspectives

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The systems perspective of creativity presented so far, i.e. the dynamics of creators producing, evaluators judging and the domain evolving, resembles the evolutionary mechanism of variation, selection and retention (VSR; see Rigney, 2001). VSR can be described as a three-phase mechanism, and it is useful in depicting action in social systems. In the initial phase, a variation occurs in some social system. It makes no difference whether the variation was planned or not, or whether it occurred randomly or according to prediction. In the second phase, a designated environment accepts or rejects the novel variation, therewith allowing it to persist in the system or reducing its chance of continuance. In the third phase, variations selected by the environment are preserved in a symbolic system, e.g. culture or domain, to be reproduced or altered in future variation phases. These three stages do not necessarily occur subsequently in practice. They may overlap and occur in any order, but when information is retrieved from, for instance, a domain in a particular phase, it happens at a distinct point in history. In applying the VSR mechanism to understanding creativity, creators produce replications or variations of things already existing in the domain when they make new output, so variations therefore correspond to contributions creators make. Evaluators, representing the field, select what is worth storing in the domain and therewith regulate what it retains and transmits to future generations of creators and evaluators. The domain therefore represents an entity storing, or retaining, what evaluators have selected. Put simply, creators perform variations, evaluators conduct selections and the actions of both collectives lead to the emergence of the domain representing the retention mechanism in VSR theorizing. The importance of time, as discussed by Westmeyer (2008), is perhaps easier to comprehend using a VSR description of creativity: The domain is not a static entity. It changes over time as creators introduce new variations to the entire system and evaluators select particular ones for retention. When creators draw upon the domain at a later time as a frame of reference, it will not be exactly the same entity that influenced them at an earlier moment.

Other researchers have used VSR theorizing to describe creativity (Campbell, 1960; Csikszentmihalyi, 1988, 1999; Ford & Kuenzi, 2007; Simonton, 2003; Ochse, 1990). Two advantages of using this metaphor are a) the interconnectedness of social action the model includes and b) the progress, or development over time, it illustrates. Creativity researchers such as Amabile & Mueller (2007), Csikszentmihalyi (1988, 1999) and Westmeyer (2008, 2009) have emphasized that these aspects require more attention to gain better comprehension of the phenomenon creativity. In adopting a VSR model to describe creativity, the aim is not to reduce social evolution to biological evolution or some technical approach. Instead, from a VSR perspective, "biological and social evolution are merely two particular manifestations of the same general evolutionary principles" (Rigney, 2001, p. 31).

## 3.6 Defining a model of creativity

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### 3.6.1. Describing creativity in evolutionary terms

A domain's contents are discovered, processed, disseminated. They constitute the informational or cultural environment creators and evaluators are surrounded by. If the acts of variation, selection and retention are observed longitudinally instead of, quite futilely, in cross-sectional studies, the concept of adaptation surfaces. The domain changes relative to how creators and evaluators behave, and creators and evaluators change depending on what information is available in the domain (Dasgupta, 2004; Gabora & Kaufman, 2010). The domain as a dynamic entity - a *diversity pool* to so speak - is characterised by change and growth, but it is not unrestricted. It co-evolves with constraints set by *its* environment (Bryson, 2009), namely in the model presented here creators and evaluators. Moreover, evaluators are viewed as *explicit* restrictors because their main purpose in the system is to filter variations, even if they do so with differential rigour. *Implicit* restrictions occur, for instance, by coincidence (e.g. which variations are discovered, imitation errors; Gabora & Kaufman, 2010) and due to internal psychological mechanisms (e.g. how information is processed, how behaviour is exhibited; Buss, 2004) regarding creators and evaluators alike.

The unit of selection is the single artefact or its comprising parts, if they can be perceived<sup>5</sup>. Additionally, it is important to note that in the evolutionary process described here, the elements of the domain are not discarded from one generation to the next (Gabora & Kaufman, 2010) as in biological evolution. They accumulate and only extinguish if they are overlooked, forgotten or actively deselected. This implies diversity can accumulate much faster than in biological evolution. The elements are "inherited" by people when they acquire them (Buss, 2004).

Finally, it should be re-emphasized that creators and evaluators *actively* participate in the generation of creativity. Even if they cannot predict their domain's contents, they can change them by performing their specific roles in the process, by creating and attributing meaning. This does not necessarily occur in linear fashion (Baldus, 2002; Csikszentmihalyi, 1988; Gabora & Kaufman, 2010), even though verbal and figural descriptions such as Figure 3.1 coerce it to this form due to their static nature.

Admittedly, VSR theorizing in creativity research is commonly used in a rhetorical rather than a substantial nature. Moreover, the purpose of this already interdisciplinary work is not to additionally close the gap between creativity research and the way this domain uses evolutionary analogies. However and in order to systematically explore the scientifically established ideas presented thus far, a model of creativity combining the systems approach illustrated by Csikszentmihalyi (1988, 1999) and VSR theorizing is further explicated in this section. There are a few reasons for taking this last step. Firstly, defining in concrete ways what actually is assumed to

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<sup>5</sup>A car, for instance, can constitute a single creative artefact, but perhaps just individual attributes such as shape, color, number of doors or tires are retained by those perceiving and reprocessing it.

(not) happen during variation, selection and retention facilitates the model's translation into an investigative and testable form. Secondly, as this is interdisciplinary work, it allows readers with more profound knowledge of evolutionary theories the chance to locate the base of this analogy in their domain. In conclusion, the following **general assumptions** about creativity are made:

### 3.6.2. Creators (Variation)

To some degree, the following appears to hold for the variation process effectuated by creators:

#### Entities

- The acting *entities* of the variation subprocess are human beings, no matter how they socially perceived or organised (e.g. individuals, groups, societies).
- Individual creators act with the underlying purpose to contribute information to the domain (Csikszentmihalyi, 1988; Sawyer, 2006).
- There is evidence, i.e. standard beliefs based on empirical research, that individuals vary in their creative potential and/or behaviour, however these constructs are defined (see Chapter 7; Plucker & Renzulli, 1999; Sawyer, 2006).
- The presumed innate differences in creative potential and/or behaviour are usually described as extremes<sup>6</sup> of some implicit, theoretical continuum.

#### Actions

- The production of variations ("raw material") is a prerequisite for evolution (Bryson, 2009; Buss, 2004).
- Individual creators acquire knowledge from their environment and use it, however implicitly or explicitly, to produce the outcomes of their creative processes (Baldus, 2002; Csikszentmihalyi & Sawyer, 1995; Kozbelt et al., 2010; Sawyer, 2006).
- In order for evolution to occur, individuals must therefore be capable of learning and storing information<sup>7</sup>.

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<sup>6</sup>For instance, Sawyer (2006) states, "Some creators are more likely to use the conventions of a traditional domain, to make works that are recognizably similar to what has come before. Other creators are more likely to innovate, to emphasize novelty, to make works that contain elements not found in any prior works" (p. 149).

<sup>7</sup>Such individual capacities not only imply creators play an *active* role in constructing evolution, they also indicate that these entities possess their own kinds of internal selection mechanisms (Baldus, 2002).

- Creators produce variations "blindly", meaning they do not know in advance if their variations will adapt to the environment by being adopted by others (Baldus, 2002; Dasgupta, 2004)<sup>8</sup>.

#### Variations, Products

- An individual entity's creativity is manifested in some observable behavioural outcome, variation or product (Dasgupta, 2004), at least according to creativity research influenced by modern Western or Anglo-American culture (Sawyer, 2006).
- Variations can be characterized by their genotypes and their phenotypes. As variations refer to inanimate objects, the genotype could refer to parts of an object (ingredients for a casserole) while the phenotype to the object's overall appearance (the final dish). If the object refers to something more abstract like a behaviour, the same can hold: A dance can appear as something whole (phenotype), yet its composition could be encoded in a dance notation (genotype).
- It is assumed creators are explicitly or implicitly familiar with the genotypes of their variations (e.g. they know what they put in the casserole or can describe the movements in their dance after being prompted).

#### 3.6.3. Evaluators (Selection)

There is more to creativity (and evolution) than simply individual production. All instances of observed creativity encompass evaluations made by a (more or less) relevant social field<sup>9</sup> (Csikszentmihalyi, 1988; Csikszentmihalyi & Sawyer, 1995; Kozbelt et al., 2010; Runco, 2007), however implicit these judgements may occur. Even psychometric tests of creativity require raters to give points for the quality (e.g. elaborateness) of answers (Amabile, 1996; Sawyer, 2006). Similar to creators making variations, evaluators also produce them in terms of concrete evaluations. Therefore and to some degree, the following appears to hold for the selection process invoked by evaluators:

#### Entities

- The acting *entities* of the evaluation subprocess are human beings, no matter how they are socially perceived or organised (e.g. individuals, groups, societies).

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<sup>8</sup>Kronfeldner (2010) indicates logical inconsistencies in using the term "blind". Here, it is meant in the following manner: Variations occur in a *guided* sense, i.e. the variation process is not independent of the selection process. They are, however, *unjustified* in that a creator does not know in advance if a particular variation will be accepted.

<sup>9</sup>For a meditation on *relevant* social fields see Westmeyer (2009).

- The evaluators are collectively called *gatekeepers* or the *field*. Csikszentmihalyi (1988, p. 327) notes the "easiest way to define a field is to say that it includes all those persons who can affect the structure of the domain".
- Evaluators possess personal experience and individual knowledge of what they have seen before in the domain (Sawyer, 2006). A variation's perceived novelty depends on this.
- In addition, evaluators have preferences for what is appropriate or valuable, depending on their personal, temporal and relevant contexts<sup>10</sup> (Cropley & Cropley, 2010; Dasgupta, 2004; Moran, 2010; Runco, 2007).
- Single members of a field are most likely not familiar with all products in their domain (Chattoe, 1998, paragraph 4.6). Instead, they know of products either directly (e.g. via their own contact with them) or indirectly (e.g. via reading or hearing about them).
- What a particular field recognizes as creative depends on temporal factors (Baldus, 2002; Csikszentmihalyi, 1988)<sup>11</sup>. Therefore, ratings a variation gets reflect (at least) the knowledge and/or preferences evaluators have at a given time, and that is subject to change as time progresses. There is no "absolute" creativity (Chattoe, 1998, paragraph 4.8).

### Actions

- Gatekeepers "determine what is accepted and disseminated" (Sawyer, 2006, p. 122), i.e. the field's task is to "select promising variations and to incorporate them into the domain" (Csikszentmihalyi, 1988, p. 327).
- Fields can differ in the way they evaluate, or *filter*, variations: Their selection mechanisms may vary in stringency, tolerance, sensitivity or fuzziness (Csikszentmihalyi, 1988; Moran, 2010; Runco, 2007).
- Although what actually happens when a variation is evaluated still lacks precise formulation, it is described as a comparison process, i.e. whether a perceived variation meets an evaluator's current, salient criteria (Dasgupta, 2004).
- The actual mechanism of selection occurs locally between a particular evaluator and a specific variation (Buss, 2004; Gabora & Kaufman, 2010).
- Evaluators' single, local selections of creators' variations lead to the emergence of the domain.

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<sup>10</sup>Sawyer (2006, p. 122) neatly summarizes Amabile's (1996) thoughts on this: "...social appropriateness could never be avoided in creativity research, not even by personality researchers who claimed to be focusing on individual traits and processes".

<sup>11</sup>This has been observed historically (Sawyer, 2006).

- The creative worth evaluators attribute to variations resembles a reinforcement mechanism, implying those considered uncreative are less likely to subsist in the domain (Runco, 2007).

#### Evaluations, "Products"

- It is assumed evaluators judge a variation's phenotype (i.e. overall appearance; Chattoe, 1998, paragraph 4.7), even if they recognize its parts or genotype (e.g. the cheese in the casserole or the pirouette in the dance).
- There is no standardized definition of creativity used by all members of a specific field<sup>12</sup>.
- The domain of creativity research has yet to devise a formulation to denote things as creative or not, although the constituting dimensions *novelty* and *appropriateness* consistently reoccur in the literature.
- Even if the dimensions novelty and appropriateness are considered to be sufficient to evaluate a variation's creativity, there is no guarantee that different evaluators judging the same product use the scales in the same way.
- To this date, there is a lack of empirical evidence on how to validly combine these two dimensions to one overall judgement of creativity. Commonly, they are treated equally in aggregations<sup>13</sup>.
- The creativity of a particular variation is *indicated* or *validated* when relevant evaluators reliably agree so (Amabile, 1996; Moran, 2010).

All of the above implies that variations do not possess common features whose quantity or quality necessarily lead to overall consistent or reliable judgements by the field. The same variation can be rated based on different definitions of creativity even by members of the same field. This means that what is considered creative at a point in time is the result of collective evaluations. Knowledge of what is creative is socially differential and distributed. Creativity assessed by evaluators is therefore, and quite commonly, a highly subjective matter.

#### 3.6.4. Domain (Retention)

To some degree, the following appears to hold for the domain:

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<sup>12</sup>Although some fields do develop objective criteria for assessing constructs similar or equated to creativity, such as patents (Couger et al., 1989) or number of scientific publications (Simonton, 2003).

<sup>13</sup>Although the following notion is beyond the scope of this dissertation, the author would like to acknowledge that novelty and appropriateness may require differential weighing depending on the variation to be evaluated. Novelty may be, for instance, less important when judging toothbrushes than when rating haiku.

### Contents

- The domain refers to a (symbolic) system of more or less interrelated elements (Csikszentmihalyi, 1988, 1999), which constitute its *contents*.
- The elements, collectively termed *information* in this dissertation, refer to things such as products, ideas, conceptions, beliefs, standards, customs, conventions, notations, rules, procedures, morals, values, etc. (Csikszentmihalyi, 1988; Runco, 2007; Sawyer, 2006). They are, therefore, anything a member of the domain can acquire and disseminate.
- The domain is defined by a boundary, indicating there are elements which belong to it and some that do not (Dasgupta, 2004; Sawyer, 2006).
- The above does not imply that all elements in a domain are considered creative. The selection processes<sup>14</sup> prevalent in cultural evolution also retain elements which are less creative or adaptive (Baldus, 2002; Gabora & Kaufman, 2010). Moreover, as Moran (2010) notes, "...an idea does not remain creative indefinitely because it eventually becomes the standard for later ideas or products" (p. 79).
- The information in a domain is constituted by creators *and* evaluators (Cropley & Cropley, 2010). Given this, it changes over time depending on what creators and evaluators contribute to it (Kozbelt et al., 2010). As Sawyer (2006) describes, "members of a younger generation select from the traditions they inherit, but then they elaborate and transform those traditions" (p. 139).
- Although exceptions to this rule may exist, creators and evaluators usually do not have full access to all elements of a domain.
- The elements in a domain enable communication between creators and evaluators. They represent the means by which these entities do so.
- Dasgupta (2004) emphasizes the importance of retention, for without it "a successfully selected variation cannot make a lasting contribution to the relevant creative tradition" (p. 405).

### 3.6.5. Model specifics

It is important to note that in reality, creators and evaluators can be the same people. Someone who produces music, for instance, can also write album or concert reviews. In the model presented here, however, they are treated as separate entities. This coincides with the way creativity research is conducted in psychology (see for instance

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<sup>14</sup>These processes include those conducted by creators in the variation stage.



Runco, 1997). It also emphasizes the notion that even if creators and evaluators are the same people, they adopt different *roles* in taking their actions<sup>15</sup>.

Moreover, creators and evaluators may know each other personally. In a small research domain, a reviewer may know journal authors due to joint projects or conferences, therewith attributing more to their submitted work than just the perceived value of its mere contents. Again, the fundamental purpose of this dissertation is to model an abstract systems perspective of creativity enriched with normative ideas and practices commonly circulated in psychological research on the construct. As many studies implement anonymous evaluators and either individual creators or one-time groups with no obvious previous history, the model presented here does without such social complexity. This serves to justify why interpersonal factors such as leadership-follower dynamics, sympathy, reciprocity, bias, etc. are not addressed by it.

#### 3.6.6. Locating creativity in the model

As Kozbelt et al. (2010, p. 38) portrayed, "some of the broadest and most ambitious theories of creativity take the view that [it] is best conceptualized not as a single entity, but as emerging from a complex system with interacting subcomponents - all of which must be taken into account for a rich, meaningful and valid understanding of creativity". This contemporary perspective poses a substantial challenge if the research requires that creativity be concretely defined. From systems and VSR views, creativity is difficult to define in terms of one specific dependent variable - something experimental researchers would nevertheless rightfully demand. This notion exposes a fundamental difference in the scientific questions diverse creativity researchers ask. The systems approach to creativity ponders *where* creativity is opposed to *what* it is (Csikszentmihalyi, 1988; Kozbelt et al., 2010; Runco, 1997), a conundrum the majority of psychologists researching the construct admirably attempt to answer. There are to this day accepted and albeit abundant measures of creativity when it comes to investigating it in single systems, such as individuals or teams. If creativity is studied as an emergent property of such systems *and* their relations, however, it becomes difficult to locate it. In evolutionary terms, *diversity* of some sort should be the consequence of subsystem interactions (Baldus, 2002; Buss, 2004; Runco & Albert, 2010). Other consequences could be complexity, differentiation, fragmentation, drift (Baldus, 2002; Csikszentmihalyi, 1999; Gabora & Kaufman, 2010; Sawyer, 2006). Nevertheless, the question remains, what exactly do these attributes refer to? Which system or relation do they describe? In the model of creativity illustrated here, the domain is the higher-order system emerging from creator-evaluator relations, and it does not exist without their actions. As noted earlier, it does co-evolve with creators and evaluators, therewith affecting and changing them, too. However, creators and evaluators initiate it, and it in turn reflects their behaviour.

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<sup>15</sup>The author does acknowledge that even if these distinct entities refer to disparate roles in one single individual, they may influence each other (perhaps even dramatically). Yet however noteworthy this idea may be, it is beyond the scope this work's objectives.

## CHAPTER 3. MODELING A SOCIAL ENVIRONMENT TO INVESTIGATE CREATIVITY

In an attempt to locate and therewith establish the possibility to concretely measure creativity in the systems / VSR model presented thus far, the domain will be designated the focal system in which to do so. This by no means implies creativity does not play a role in the other subsystems. Pinpointing a locus to measure creativity, however, makes the systems / VSR model accessible to experimental investigation. It designates a dependent variable. The subsystems creators and evaluators, or rather parameters describing them, will be treated as independent variables. Figure 3.2 illustrates these points. At this stage, the intention is not to assign specific variables to the subsystems, but to designate which role they will play in experimental settings<sup>16</sup>. These specifications are an attempt to build a bridge between a spiral, systemic model of creativity and a linear, causal approach predominant in experimental methodology.

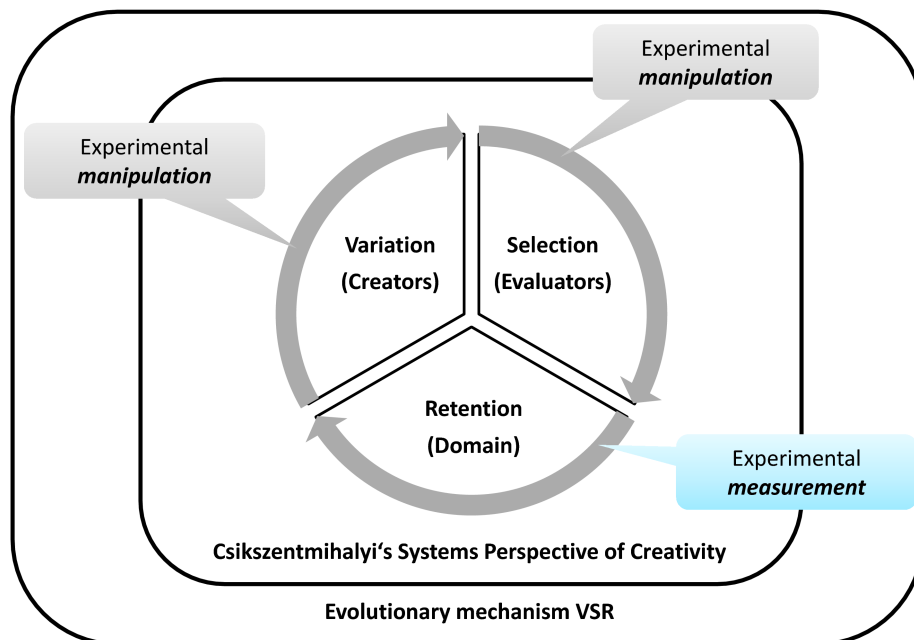


Figure 3.2.: *This model of creativity is based on the evolutionary mechanism of variation, selection and retention (VSR) as well as Csikszentmihalyi's (1999) systems view of creativity. It is spiral in nature, and creativity plays a part everywhere in it. For experimentation in this thesis, however, it will be **measured** in the domain. The other subsystems (creators and evaluators) will be **manipulated**.*

<sup>16</sup>The precise variables describing each system are developed in Chapters 6 - 9.

### 3.6.7. Concluding remarks

Although caution needs to be taken when using biological evolutionary terms to describe cultural and creative evolution (Baldus, 2002; Chattoe, 1998; Gabora, 2004; Kronfeldner, 2007, 2010), analogical thinking in the latter realm does facilitate comprehension among advocates of very diverse concepts of creativity. VSR theorizing also lends itself as an intermediary language to translate qualitative systemic concepts of creativity into a more precise form for systematic scientific exploration. Kronfeldner (2009) suggested using evolutionary analogies as a "Wittgenstein'sche Leiter", to aid thinking and communication *between fields*, and to leave the details to the *specific fields*. In this sense, the evolutionary mechanism of variation, selection and retention is used in this work to reclassify and isolate the processes assumed significant to creativity according to Csikszentmihalyi's (1999) model. VSR theorizing also facilitates the pinpointing of creativity in it, i.e. designating a spot in the cycle to measure and others to manipulate. The model is, at this stage, too general to offer a precise measure of creativity or other manipulation variables for that matter. The general assumptions made this section (3.6) as well as the distinction made between systems to be manipulated and those to be measured (Figure 3.2) serve as preparations for the designation of explicit variables in Part III. The latter is preceded by Part II, in which this work's objectives (Chapter 4) and research methodology (Chapter 5) are presented.



# **Part II.**

## **Method**



## Research style and objectives

### 4.1 Exploration: Creative and systematic science

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According to the Oxford Dictionaries Online<sup>1</sup>, the noun *exploration* is defined as: a) *the action of exploring an unfamiliar area*, and b) *thorough examination of a subject*. In the same resource, the verb *to explore* is defined as: a) *travel through (an unfamiliar area) in order to learn about it*, b) *inquire into or discuss (a subject) in detail*, c) *examine by touch*, and d) *surgically examine (a wound or part of the body) in detail*. Merriam-Webster's Dictionary<sup>2</sup> describes *exploration* in its thesaurus as a *systematic search for the truth or facts about something* and lists the synonyms *delving*, *disquisition*, *examen*, *examination*, *inquest*, *inquisition*, *investigation*, *probation*, *probe*, *probing*, *research* and *study*. Additionally, this dictionary defines the verb *to explore* as: a) *to investigate, study, or analyze; look into*, b) *to become familiar with by testing or experimenting*, c) *to travel over (new territory) for adventure or discovery*, d) *to examine especially for diagnostic purposes*, and e) *to make or conduct a systematic search*.

Apart from travel and medical connotations, all definitions and synonyms listed above coincide with those published in commonly used references for psychological methodology and statistics (Backhaus et al., 2000; Bortz & Döring, 2002; Field, 2005; Kleining, 1994; Lamnek, 2005). Bortz & Döring (2002) describe exploration as the more or less systematic collection of information about a specific topic and as an action which prepares the formulation of hypotheses and theories. They emphasize that exploration is a necessary step in basic as well as applied research. In defining the goal of qualitative social research, Kleining (1994) notes that extracting and systematizing exploration techniques from everyday perception and thinking constitutes and validates this discipline's research methodology. Lamnek (2005), another expert on qualitative social research, defines exploration as the *examination of something unknown with flexible and reflexive methods*. He notes that during exploration, the collection and testing of data requires continuous evaluation. As they are acquiring initial knowledge about a topic, scientists need to remain flexible while conducting research and adjust their actions to current findings. By exploring an issue, scientists know not beforehand but discover "along the way" which methods

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<sup>1</sup>All definitions retrieved on December 31, 2010, from <http://oxforddictionaries.com/>.

<sup>2</sup>All expressions retrieved on December 31, 2010, from <http://www.merriam-webster.com/>.

and data are most suitable for investigating a topic. Hellhammer (1989) stresses that exploration is a *research method* which is necessary to systematically generate hypotheses.

Referring to exploratory<sup>3</sup> multivariate analyses, Backhaus et al. (2000) describe this methodology as the scientific act of *discovering relations between variables or objects*. In the beginning of such analyses, the scientist may not have any assumptions about underlying structures in the data. In his one of chapter summaries, Field (2005) points out that exploring data has to do with *examining it properly* before conducting main statistical analyses. Also referring to exploratory data analysis, Leech et al. (2005) note that this method helps the scientist to better *examine, get to know and understand* data.

There are (at least) a few common denominators in all these definitions. Firstly, the target of exploration is something new, unfamiliar, still unknown or unexplained. Secondly, the act of exploration has to do with heuristic procedures or "trying things out", i.e. searching, learning, testing, experimenting and discovering. However, the example definitions and synonyms also emphasize that exploration is conducted in a thorough, detailed and systematic manner. Exploration, therefore, is defined a heuristic procedure, but the way it is carried out is characterized by a precise and rigorous manner.

This notion is not prevalent in psychology research. Sometimes synonymous with act of theory-building (Bortz & Döring, 2002; Dörner, 1994; Esser & Troitzsch, 1991; Lamnek, 2005; Witte, 1991), scientific exploration in psychology is a method which often is either not reported or is done so in an anecdotal manner more or less attributed to common myths of creative work (Bortz & Döring, 2002; Sawyer, 2006). Popper (1969), for instance, referred to the development of theories as an amorphous and irrational cognitive act which belongs to the realm of intuition. Dörner (1994) comments that theories emerge from the dark and chaotic parts of the human mind, from dreams and fantasies, making their development more difficult to formalize than processes of theory testing. The *context of discovery* warranted by scientific exploration may essentially be more creative and heuristic than the *context of justification* (Reichenbach, 1938, in Bortz & Döring, 2002), and therefore, as Dörner (1994) reviews, more difficult to standardize.

This does not mean, however, that exploration cannot be systematically carried out and documented. In fact, the latter attributes are, according to the definitions stated in the beginning of this section, part of what exploration consists of. Bortz & Döring (2002) make a similar observation when they note that exploration can very well be integrated into scientific research without establishing normative heuristics used to do so. Moreover, they see no contradiction between creativity and working systematically. Integration of a method – however heuristic or algorithmic it may be – into the process of science occurs via transparent communication, i.e. documentation, reflection and evaluation (Lamnek, 2005). As holds for other forms of

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<sup>3</sup>"Struktur-entdeckende Verfahren" in German.



creative work, systematization and documentation of heuristic procedures increases the probability of finding useful questions *and* answers.

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## **4.2 Research style**

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This thesis represents a type of research described by Bortz & Döring (2002) as "theory-based exploration" (p. 363). Broadly, it is defined as the generation of new hypotheses by systematically reviewing and analysing existing scientific and everyday theories of a particular construct. Working systematically is essential in defining this research style and in distinguishing it from unscientific forms of hypothesis generation. At a superficial glance, theory-based exploration may not appear to differ from concepts such as "common-sense psychology" or "implicit, lay, naive or intuitive theories" (Heider, 1958; Hong et al., 2001; Witte, 1989). However, it does fulfil research objectivity by requiring traceable, reproducible steps and precise documentation. The main steps of theory-based exploration are (see also Bortz & Döring, 2002, p. 369):

1. Systematically review and document the relevant scientific and, where appropriate, everyday models and theories of the topic under investigation.
2. Generate ideas and proposals on how to integrate the above.
3. Verbally and graphically formulate a tentative model or theory.
4. Examine the tentative model via computer simulation.
5. Develop recommendations and generate hypotheses for empirical research. Where appropriate, classify them in higher-order theories or approaches.

Figure 4.1 illustrates these research steps in terms of input, actions and output. In the rest of this section, they will be elaborated.

### **Input**

Theory-based exploration begins with a review and selection of scientific and, if appropriate, everyday sources of the topic under investigation. The resources chosen form the substantial basis from which research actions are taken. They can be revised, amended, synthesized or integrated in order to create the output intended by theory-based exploration: innovative new ways of thinking about a topic and more concretely, hypotheses and eventually preliminary theories (Bortz & Döring, 2002; Esser & Troitzsch, 1991; Ueckert, 1983; Witte, 1991). There are scientifically sound reasons for using other models and theories as "data" in this form of exploration. Firstly, many psychological constructs are described by "mini theories" (Ostrom, 1988, p. 384), meaning only one or very few particular aspects or latent variables are focused on. This can also imply just one specific social system is investigated

although the construct may, according to implicitly or explicitly made assumptions, emerge due to activities in more than one level of society (Esser & Troitzsch, 1991; Ostrom, 1988; Witte, 1989). These notions especially hold for creativity. Time and again creativity researchers have emphasized the lack of social complexity in studies (Amabile & Mueller, 2007; Csikszentmihalyi, 1999; Sternberg, 1999b; Westmeyer, 2001, 2008, 2009), although many models of creativity do account for it (Amabile, 1996; Csikszentmihalyi, 1999; Hennessey & Amabile, 2010; Zhou & Shalley, 2007). Understandably, one study can hardly take all factors presumed to influence a construct into account. This demonstrates, however, the value theory-based exploration has for a research domain. By surveying and pooling the ideas, concepts, models and theories already achieved by others, a different level of abstraction and therewith observation is reached. Theory-based exploration facilitates a perspective which looks beyond one focal study or theory in order to generate ideas about *what else* there could be to a specific construct.

### Actions

**Building a tentative model** Integrating the systematic review of existing models and theories (Steps 1 & 2) to a tentative model (Step 3) has several advantages (see also Dörner, 1994). Firstly, it helps the researcher to make the various and complex ideas presented in previously gathered sources transparent, which can facilitate comprehension of this scientific abundance<sup>4</sup>. Secondly, a tentative model can uncover logical or substantive gaps in what has been found as well as visualize new relationships between conceptual elements. Thirdly, a tentative model creates a frame in which particular research foci and subsequently experiments can be designated. All of these advantages enhance the scientific nature of exploratory research, which does not need to lack objectivity (i.e. transparency, salience) and focus despite its creative, heuristic character.

There are various ways to represent the tentative model. Bortz & Döring (2002) suggest creating a graphical representation in addition to verbal descriptions. Dörner (1994) recommends using analogies to generate ideas about how particular structures of the tentative model function. Additionally, analogies can facilitate communication of the model to other researchers and target groups. Esser & Troitzsch (1991, p. 21) note that models can also be represented formally and that this leads to fewer misunderstandings about its contents.

**Building a computer model** "The computer itself...plays no role other than providing a speedy way of discovering the implications of one's theoretical ideas" (Ostrom, 1988, p. 384). Building and conducting experiments with a computer model is one widely accepted heuristic method of exploring a tentative model (Bortz & Döring, 2002; Dörner, 1994; Esser & Troitzsch, 1991; Ostrom, 1988; Schnell, 1990; Ueckert, 1983; Witte, 1991). A computer model is a program which simulates the processes

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<sup>4</sup>This definitely holds for research work on creativity.

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### 4.3. RESEARCH HYPOTHESES VS. RESEARCH QUESTIONS

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formulated in the tentative model. In theory-based exploration, the simulation is not used to estimate parameters, but rather to investigate whether phenomena or effects postulated in the tentative model can be qualitatively produced and differentiated (Bortz & Döring, 2002). The goal in conducting exploratory simulations, therefore, is not to make quantitative prognoses (Schnell, 1990), but to make qualitative distinctions<sup>5</sup>. The computer model is, therefore, a heuristic *and* formal aid to generating hypotheses and constructing theories (Esser & Troitzsch, 1991; Ueckert, 1983). In being a formal medium (Ostrom, 1988), its assumptions and implications are easier to check, test, criticize and revise, which enhances transparency and thereby research objectivity. Dörner (1994) argued it is *the* choice method to construct theories, as it can be viewed as a "theoretical toolkit" (p. 386) to assist the human mind in processing 20 or more variables. Holding a similar stance, Bryson (2008) refers to the experiments she conducted with a computer simulation as "intuition pumps" (p. 1; see also Dennett, 1995).

#### Output

Examples of results obtained with theory-based exploration are listed in Figure 4.1. The main goal in terms of research output is to generate a "network of hypotheses" (Bortz & Döring, 2002, p. 359). Dörner (1994) argued that the multiple and variable interdependencies prevalent in psychological phenomena makes developing new hypotheses a *necessity*. Hypotheses generated in theory-based exploration should differ verbally from the assumptions or conclusions usually stated in the discussions of scientific articles. Particularly, they should be stated and recognized as scientifically testable hypotheses, but their operationalization is not the focus of this exploratory method (Bortz & Döring, 2002). Moreover, they should be interconnected by a higher-order framework of concepts or ideas. Based on this classification or network of hypotheses, more general assumptions or recommendations for theory development can be abstracted.

One potential confusing or paradox characteristic of theory-based exploration is that it generates results usually considered *input* the much more commonly published theory-testing research, namely *hypotheses and more theory*. This is the intended and consequential last step of the method. Although generating hypotheses is not as exact and formal a scientific activity as testing them is, the steps taken to do so are significant to create new material. In addition, the new hypotheses are developed with the purpose to overcome a common obstacle in science: fragmentary approaches to a phenomenon (Dörner, 1994).

### 4.3 Research hypotheses vs. research questions

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Given the previously defined, exploratory style of research (Section 4.2), the purpose of this thesis is not to confirm hypotheses, but to generate them. The overall steps of

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<sup>5</sup>Creativity researchers have come a long way, but they are far from *predicting* this phenomenon!

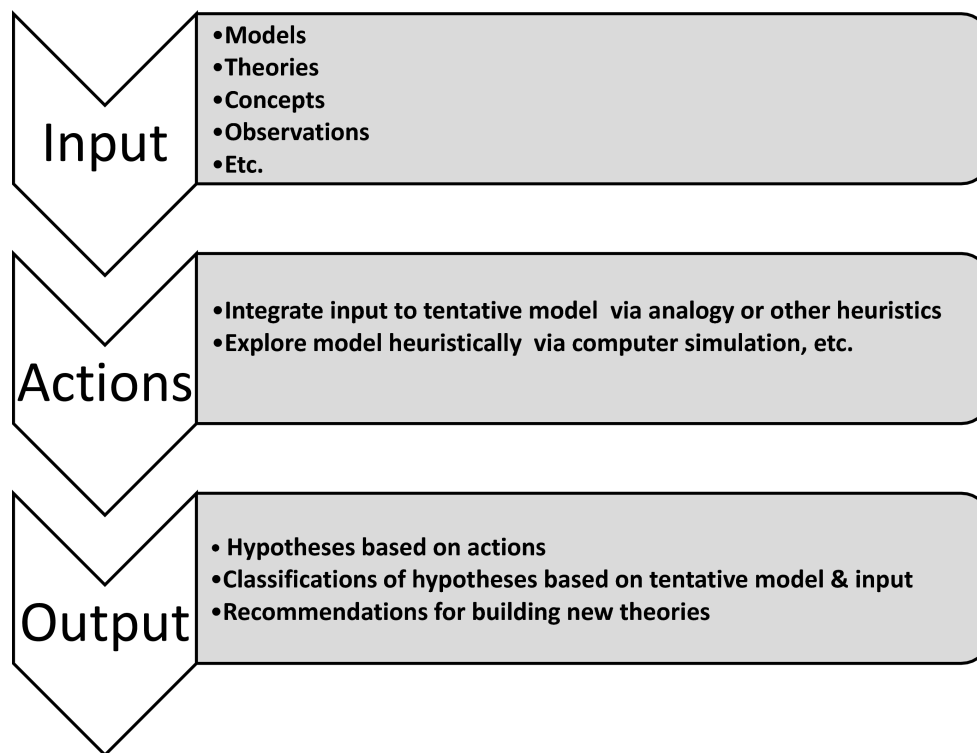


Figure 4.1.: A summary of steps taken in theory-based exploration in terms of input, actions and output.

theory-based exploration (Bortz & Döring, 2002) do require rigorous, systematic and reproducible implementation, but the main challenge is to investigate how a newly constructed model works. At this stage, it is futile to formulate specific, statistical hypotheses about a model whose behaviour has never been explored. Theory-based exploration, therefore, is not meaningfully guided by research hypotheses. This does not imply, however, that the researcher has no ideas or assumptions about which structures or processes could play a key role in describing a construct. Bortz & Döring (2002, p. 360) argued that exploratory studies are by no means "theoryless": The selection of constructs and variables to explore, as well as their chosen operationalizations, are ultimately guided by explicit or implicit assumptions. Therefore, the act of reviewing theories and developing a tentative model suggests distinctions are drawn between what could be relevant and not (Kriz, 1999; Simon, 2008; Wilke, 2000; Witte, 1990). However, the model to be explored is in an unrefined, preliminary state, which renders ideal for hypothesis generation but not for testing. Another way of describing this kind of procedure is to think of the model (or theory) as being in a construction and not in a testing phase.

Consequently, posing questions about a model to be explored for the first time

is feasible and meaningful in the sense that the questions can guide the researcher, firstly, in systematically investigating the model and, secondly, in fulfilling the criterion of objectivity in the research process. On the basis of this reasoning, the experiments in this thesis are designed according to predefined *research questions* and the experimental results should include the generation of *research hypotheses*. As Lamnek (2005) notes, exploration intentionally frees data interpretation from the necessity of a previous framework of statistical hypotheses. This dissertation's overall research questions are presented as objectives in Section 4.4. The specific research questions for each experiment conducted in this thesis are presented in the sections reserved for each respective study.

### 4.4 Research objectives

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This section describes the dissertation's overall objectives. They are based on the ideas, models and theories presented in Part I.

Csikszentmihalyi (1999) discerned that "...variables external to the individual must be taken into account if one wishes to explain why, when, and where new ideas or products arise from and become established in a culture..." (p. 313). The VSR approach to creativity incorporates a multilevel perspective on this construct by including the dynamics between systems assumed to be relevant. By multilevel, the inclusion of more than one social unit of analysis and particularly the units' interaction, i.e. the generation of higher-order system levels, is implied. The VSR approach is multilevel because it encompasses individuals creating, others evaluating and their interaction via artefact perception and assessment. In other words, the approach comprises the interaction between subsystems of a larger social system over time. As Amabile & Mueller (2007) noted, "all of this...complicates the researcher's task immensely" (p. 53), but widening the individualist or trait perspective of creativity to a systems / VSR approach is a challenge many creativity researchers have recommended (Amabile & Mueller, 2007; Csikszentmihalyi, 1999; Sternberg, 1999b; Westmeyer, 2001, 2008, 2009). In conclusion, the research objectives of this thesis are:

1. Describe and operationalize a systems / VSR model of creativity.
  - Model description will be achieved by applying scientifically accepted psychological models of creativity to the evolutionary metaphor of variation, selection and retention.
  - Model operationalization will be achieved by building computer simulations (agent-based models) based on the above.
2. Explore the systems / VSR model by conducting experiments with the agent-based models
  - Model exploration will be guided by predefined research questions.

Examples of such questions are: How does a technical independent variable such as "density" (number of agents in a specifically sized world) affect the development of dependent variables? How does the variance of dependent variables behave depending on sample size, whereas a *sample* constitutes the number of simulation *runs*? Does a predefined, theoretically-derived substantial independent variable, such as "imagination" (the probability of creating something never encountered before), affect dependent variables whatsoever?

3. Based on objectives 1 & 2 and due to the exploratory nature of this research project, generate hypotheses for future research on creativity as this dissertation's results. Examples of such hypotheses could be:
  - The less restrictions there are to a non-algorithmic task, the greater the overall creative output in terms of information diversity there will be. This would imply testing different types of creative tasks which vary in the number of their instructional constraints or guidelines.
  - Individual creative performance does not depend solely on individual traits, but on the interaction between individual traits and environmental information diversity. This could be investigated by testing the performance of extreme individuals, previously assessed according to their general creative aptitude, in different task situations which vary in the availability of informational resources to solve the task.
  - Uncreative evaluators do not recognize creative work. This could be tested by experimentally manipulating the informational focus (e.g. narrow vs. wide) of raters of brainstorming task performance and comparing their evaluations to control group raters' evaluations of the same task output.

# 5

## Research method

This chapter begins with an introduction to *agent-based modelling*, a type of computer simulation (Section 5.1.1), and its tricky methodological issues (Sections 5.1.2 – 5.1). It continues with examples of computer models used in social psychology (Section 5.1.4) as well as in general creativity research (Section 5.1.5). The second part of this chapter is dedicated to describing the simulation software used (Section 5.2.1) and the specific models built in this thesis (Sections 5.2.2 - 5.2.3).

### 5.1 Agent-based modelling

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#### 5.1.1. A primer on agent-based modelling

In this section, the terms *model*, *simulation* and *agent-based model* are defined<sup>1</sup>.

##### **Model**

A model is a simplification of a particular real-world phenomenon or target (Edmonds, 2005; Gilbert & Troitzsch, 1999; Saam, 2005), which may not be directly observable or too complex to validly assess. Generally, it is less detailed as well as less complex than its target. Models are unique, but not exclusive, meaning they serve as examples of their targets and resemble them in structure and/or function. Therefore, they typically refer to only some aspects of their targets, and two models of the same target can be completely different.

Models can be distinguished in terms of *what* is modelled and *how* it is modelled (Valentine, 1992), implying that they include a set of elements (e.g. objects, variables) and defined communication between them (e.g. relations, formulas). By constructing a model, relationships between the elements of a target can be expressed concisely and they may be tested by investigating the model rather than its more intricate target (Gilbert, 2008). Moreover, models in the social sciences are usually dynamic, because real world targets change over time and react to their environments (Gilbert & Troitzsch, 1999).

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<sup>1</sup>A shorter version of this section (5.1.1) appeared in: Kahl, C. (2009). Modeling a social environment to investigate creativity: An agent-based model. In E. Witte & Kahl, C. (Eds.), *Sozialpsychologie der Kreativität und Innovation* [Social psychology of creativity and innovation] (pp.27-52). Lengerich, Germany: Pabst Science Publishers.

### Simulation

A simulation is a representation of the functioning of one process or system by the means of another. A simulation therefore encompasses a model and the reproduction of its characteristics and/or functions over time, and it allows the researcher to experiment with the model in place of the target (Gilbert, 2008). Taber & Timpone (1996) described the method of simulation as "developing a process theory, expressing this theory as a computer program, and simulating the theory by running the program" (p. 3). Simulation therefore begins with the designation of a target, and the researcher using this method must not only translate the target into a conceptual model, but also into a programming language (a very precise model) which carries out the simulation. Just as there are countless models to describe a target, there are numerous ways to depict the model with program code. Although both the conceptual as well as the programmed model represent abstractions of the target, it is the program which allows the researcher to study the dynamics of a target in a manner more precise than with the natural language used to describe the conceptual model (Ostrom, 1988).

A social simulation is a method comprised of building a computer program to model the behaviour of some social target (Gilbert, 2008). The computer program is one "medium through which theoretical concepts can be represented and communicated" (Ostrom, 1988, p. 383). Similar to natural language or mathematics, the program represents a system containing symbols and rules for manipulating them. Ostrom (1988) argued that "...any verbal theory can be expressed in the form of a computer simulation" (p. 384), but the method requires precise definitions of theoretical ideas otherwise expressed in natural language. In using the method of computer simulation, researchers often become aware of too general, obscure, inconsistent or unstated assumptions in their conceptual models. On a general level, a social simulation requires some input, similar to independent variables, and produces via algorithms output, similar to dependent variables.

### Agent-based model

An agent-based model (ABM) is a computational model for simulating the behaviour of and interactions between autonomous individual entities, or *agents*, embedded in an environment (Gilbert & Troitzsch, 1999; Gilbert, 2008). Single agent behaviour (micro-level) represents the basis for the emergence of a collective's behaviour as a whole (macro-level; Macy & Willer, 2002). Agent-based models can therefore be used to show how simple rules of micro-level interaction can lead to macro-level phenomena (Janssen & Ostrom, 2006). From a methodological perspective, agent-based models simulate a system over time instead of statically assessing a system's features at a given point in time (Smith & Conrey, 2007). This method is especially instrumental when a researcher would like to study processes and their consequences. Moreover, it has been deemed a new experimental *tool* (Gilbert, 2008; Macy & Willer, 2002; Smith & Conrey, 2007) with which "research at the relational level" (Macy &



Waller, 2002, p. 161) can be conducted.

Agents are either self-contained computer programs or distinct parts of one computer program designed to represent social entities (Gilbert & Troitzsch, 1999; Gilbert, 2008). As Jennings et al. (1998) noted, there is a lack of universally accepted definitions as to what exactly agents are (see also Gilbert & Troitzsch, 1999; Smith & Conrey, 2007). However, researchers do agree on some features agents exhibit:

- **Ontological correspondence** There is a straightforward correspondence between agents and social actors in the target social system (Gilbert, 2008). This makes the agent-based model easier to program and to convey to others. Moreover, its output is therewith easier to interpret compared with that of equation-based models.
- **Autonomy** Agents are not controlled by a higher or global program. They act according to what they are programmed to do in a specific situation (Gilbert & Troitzsch, 1999; Macy & Waller, 2002; Smith & Conrey, 2007).
- **Heterogeneity** All agents within a particular model need not be equal. They can be programmed with differing rules of action and therewith operate accordingly (Gilbert, 2008). They can also gain different amounts or kinds of information, experience, etc. as time passes (Gilbert & Troitzsch, 1999). In this sense, no two agents are the same.
- **Bounded rationality** Agents possess "practical reasoning", meaning their behavior is guided by the pragmatic or heuristic reasoning assumed to prevail in humans (Macy & Waller, 2002; Smith & Conrey, 2007). It is therefore common to speak of agents having attitudes, beliefs, desires, intentions, goals, etc. For example, beliefs correspond to information an agent has about its environment, desires to its set of behavioural options and decisions to the behaviours it has committed itself to at a certain point in time. Practical reasoning in agents is implemented by, for instance, repeatedly updating perceived information from the environment (beliefs), filtering behavioural options, reinitiating decisions about which behaviour to exhibit and behaving accordingly (Gilbert, 2008).
- **Social ability** Agents can interact, meaning they can pass information to each other by way of a shared language, e.g. a specific programming language (Gilbert & Troitzsch, 1999; Gilbert, 2008; Macy & Waller, 2002; Smith & Conrey, 2007).
- **Situatedness** Agents exist within a larger environment which they can, to a specified degree, perceive, act and react to (Gilbert & Troitzsch, 1999; Gilbert, 2008). The environment is a virtual world, and it represents the target environment real actors interact with.

Agents can feature additional attributes besides the ones listed above, and depending on the application some characteristics may be more significant than others. Gilbert (2008) noted that it may be easier to understand what agents do by describing them as perceiving, performing, remembering information and abiding to policies. In terms of programming, agent perception is implemented by devising algorithms which allow agents to "see" what exists in a defined "neighbourhood". Performance is implemented by programming ways for agents act within their spatial and social environment, for instance movement in virtual space or communication with other agents. Agent memory is designed by programming variables which record specified information, and policies are implemented by equipping agents with rules or strategies for behaviour given their past and/or present states. Implementing these agent features may require algorithms which either do not exist or are yet to be understood for a specific target. Concluding, in justifying their less complex structure, agents only represent a model of their target, namely personal and/or social systems.

### 5.1.2. Verifying agent-based models

After constructing an agent-based model, there are a few significant and meticulous methodological steps a researcher should take to properly use this technology. One of them is called *verification*<sup>2</sup>. This refers to "the task of ensuring that a model satisfies the specification of what it is intended to do" (Gilbert, 2008, p. 31) or to the lengthy process of "checking that a program does what it is planned to do" (Gilbert & Troitzsch, 1999, p. 21). From a technical perspective, this step encompasses debugging the program (Galan et al., 2009; Smith & Conrey, 2007). A modeller needs to carefully and iteratively check if the code properly works and implements the ideas contained in the theoretical model. From a substantial perspective, verification is about ensuring that all forms of model translations are accurate enough, i.e. from verbal to graphical, from graphical to programmed (Balci, 1994; Boero & Squazzoni, 2005). Davis & Eisenhardt (2007) noted that verification is an important measure to "increase confidence in [simulation] results" (p. 492), and Boero & Squazzoni (2005) argued that it facilitates the "standardization and the communicability of results" (paragraph 5.2).

Although this phase has been discussed by many experts in the field (Balci, 1994; Boero & Squazzoni, 2005; Davis & Eisenhardt, 2007; Galan et al., 2009; Gilbert, 2008; Gilbert & Troitzsch, 1999; Smith & Conrey, 2007), it admittedly lacks standardisation - if this is at all possible. There is, therefore, no ultimate checklist or step-by-step plan to ensure perfect verification. Furthermore and unfortunately quite realistically, it is impossible to find all bugs. Nevertheless, several things can be done to fulfil the task of verification as best as a modeller can. The following recommendations have been made by experts, and by selecting those strategies suitable to one's modelling purposes, ideal verification can be approximated:

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<sup>2</sup>To beginning agent-based modellers' confusion and dismay, verification also goes by other terms in the scientific community: *debugging* (Smith & Conrey, 2007), *internal verification* (Boero & Squazzoni, 2005), *internal* or *program validation* (Galan et al., 2009).

### Coding

- Use object-oriented language to make salient correspondences between the theoretical and the program models (Gilbert, 2008). This can help to detect if some entity or interaction in the theoretical model is missing in the program.
- Use variable names that are meaningful to facilitate the assessment of model-to-program completion (Balci, 1994; Gilbert, 2008).
- Take time and care in coding to help avoid programming bugs (Gilbert, 2008). This really means allocating more than enough time in a project management scheme to do so!
- If feasible, have a second programmer also code the model (Smith & Conrey, 2007) or at least proofread the single version ("desk-checking"; Balci, 1994).
- Automate as many things as possible to avoid having too many repetitive "do-it-yourself" steps in the model. They can be prone to random, uncontrollable errors.
- Add so-called *assertions* (Balci, 1994; Gilbert, 2008). These are warnings that appear when specific pieces of code do not produce what they are intended for.
- Add a so-called debugging switch to the program (Balci, 1994; Gilbert, 2008). A battery of debugging procedures can be built in the model and turned off when not needed.
- If the coding platform offers a syntax analysis, use it. This is a built-in "programming language compiler to assure the mechanics of the language are applied correctly" (Balci, 1994, p. 136).
- Add additional pieces of code to the model in order to collect information solely about its behaviour during execution. These "probes" (Balci, 1994, p. 136) should produce output variables which differ from the output to be collected based on the substantial model. They constitute information about how the coded model works.
- Produce a test "harness" (Gilbert, 2008, p. 39), i.e. extra code which tests units of a program. Use it to check individual code modules and their interaction.

### Documenting

- Add comments to the code describing what the lines are substantially supposed to achieve (Gilbert, 2008). Keep them updated!
- Document the model code in another verbal form to (also let others) check its completeness. This can be achieved by using, for instance, NetLogo's Information Tab (if coding in Logo; Wilensky, 1999) or the ODD protocol (Grimm et al., 2006).

### Observing

- Program an abundance of output diagnostics, even if they are later deleted in final model versions, to aid bug detection immensely (Balci, 1994; Gilbert, 2008). Program graphical displays of interim and output variables to track their behaviour (Balci, 1994; Davis & Eisenhardt, 2007; Gilbert, 2008).
- Observe the simulation code step by step by running lines or procedures individually and checking their output (Gilbert, 2008).
- Animate the model's behaviour to produce another medium for checking whether the model is working as intended (Balci, 1994; Sargent, 2005).

### Testing

- Test conditions for which output parameter values are known (Gilbert, 2008).
- Run the program with extreme conditions to see if model assumptions hold (Davis & Eisenhardt, 2007; Gilbert, 2008; Gilbert & Troitzsch, 1999).
- Build a set of test conditions to run every time a change in the code is made (Gilbert & Troitzsch, 1999).
- Test units of code with a "harness" (see above). The unit tests should supply algorithms with predefined input values and the output needs to be compared with pre-calculated values.
- Use statistical testing to check whether the simulation model replicates assumptions made in the theoretical model.

### Comparing

- Simulation results can be compared qualitatively and/or quantitatively with assumptions made in the theoretical model. If they match, "the theoretical logic and its computational representation are likely to be correct" (Davis & Eisenhardt, 2007, p. 491)
- Does the simulation model function similarly in different programming languages?

### 5.1.3. Validating agent-based models

Another methodological issue relevant to agent-based modelling is called *validation*. It refers to the degree of correspondence between simulation model and target system, i.e. whether the simulation model reflects the target's behaviour correctly (Gilbert & Troitzsch, 1999; Gilbert, 2008) or is "an accurate representation of the actual system being studied" (Law, 2007, p. 243). Validation is therefore conducted

in relation to a specific target, but also in relation to a particular objective or purpose (Law, 2007; Sargent, 2005). This means a given simulation model can be valid for one stated purpose, but perhaps not for another.

Balci (1994) argues there are different kinds of validation (and verification). Besides assuring the simulation model accurately represents its target, a modeller can, for instance, additionally validate a model's results by presenting them in a sufficient way. This includes their interpretation, documentation and communication. In making another distinction regarding validation, Gilbert (2008) notes that it is important to recognize if a modeller is interested in assessing the fit a) between a theory and a model of theory or b) between a real-world phenomenon and a model of it.

### How is validation conducted?

A few general, methodological prerequisites are necessary to validate a model:

**Target** A specific target or particular aspects of it need to be clearly defined as the reference for assessing a simulation model's correspondence. A modeller may not want to validate the simulation model for all aspects of the target at once.

**Purpose** A model is developed for a specific purpose or application. Validation should be based on that (Sargent, 2005).

**Validator(s)** Who is responsible for validating a model? This can range from the modeller herself to any number of people such as users, subject matter experts, decision makers, etc.

**Measure(s)** Which measures or criteria are used to assess the degree of correspondence between simulation model and target system?

**Decision criteria** Given the above measures, when is a particular simulation model considered valid (enough)? What quantitative value or qualitative observation does a specific measure need to have to "pass the threshold to validity"?

In approximating simulation model validation, an initial step is to assess whether the macro-level regularities which emerged are the ones the researcher intends to explain (Gilbert, 2008). Are they expected and interpretable? This is a preliminary indication that the model corresponds to the target. However, there could be alternative scenarios which also produce the regularities. To shift from this initial form of validation to a more comprehensive check, such alternatives need to be experimentally tested.

It is often the case that input and output parameters do not coincide with empirical data, as Troitzsch (2004) noted for long times series of individual and group data. How, for instance, could something like a person's imagination be validly assessed in practice<sup>3</sup> and correspondingly as well as correctly be translated into a computer

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<sup>3</sup>This task is difficult and controversial enough as it is.

program? The easiest and most affordable way to check such work is to use sensitivity analysis. This means varying the values of input parameters to check which ones are sensitive, i.e. produce significant differences in the model's output parameters. As (Law, 2007) notes, sensitivity analysis can determine which model aspects have a "significant impact on the desired measures of performance" (p. 258). Using experimental design techniques aids in investigating more than one aspect at once.

*Abstract* simulation models are designed to formalise, develop and test a theory (Gilbert, 2008; Troitzsch, 2004). Such models offer a new way to observe and contemplate key processes believed to play a part in social interaction. As they do not refer to particular empirical cases, it is futile to validate them with such information. The models developed in this dissertation are abstract models of Csikszentmihalyi's (1999) systems perspective of creativity. Gilbert (2008) claims abstract models need to be "capable of generating further, more specific or 'middle range' theories" (p. 41) which can be tested with empirical data. Troitzsch (2004) argues "validation of simulation models is...the same (or at least analogous) to validation of theories" (p. 5). An abstract simulation model should therefore produce observations (data) which correspond to the model's and the modelled theory's assumptions. They should produce "qualitative descriptions of possible scenarios" (Troitzsch, 2004, p. 6) which fit to the simulation model as well as to the theory it is based on.

Additionally, face validation is a commonly used measure to validate abstract models (Balci, 1994; Gilbert, 2008). It can include relevant decision makers, supervisors, target experts, users or even laypeople and their subjective judgements about the correctness of the simulation model (Troitzsch, 2004). Attempts to face validate a model should be accompanied by systematic testing such as sensitivity analysis, however, and not stand alone. It is even quite common to use more than one strategy to approximate validation (Sargent, 2005). Figure 5.1 lists several techniques suggested by Law (2007) and Sargent (2005).

As Gilbert (2008) notes, "both theory and practice of validation are more complicated, and more controversial, than one might at first expect" (p. 40). The active scientific community dealing with agent-based modelling and computer models in general<sup>4</sup> has yet devised the ultimate method to validate simulation models. Especially in the social sciences, it is often hard to gather (enough) empirical data to satisfactorily fulfil this methodological step. Additionally, as Sargent (2005) admits, it is "often too costly and time consuming to determine that a model is absolutely valid over the complete domain of its intended applicability" (p. 1). At present, there is no "right" way to validate (Law, 2007) and there are a number of aspects the researcher must recognize and address in approximating the validity of a simulation model. Again, Sargent (2005) notes validation as well as verification are "part of the (total) model development process" (p. 1). Moreover, validation is never ultimately complete, as the objectives, data or theories backing a model may change over time. The issues highlighted in this section complicate a modeller's methodological tasks, but they do not free her from addressing them.

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<sup>4</sup>See for instance [<http://www.openabm.org/>] or [<http://jasss.soc.surrey.ac.uk/JASSS.html>].

Validation techniques according to Law (2007)	Validation techniques according to Sargent (2005)
<ul style="list-style-type: none"> <li>• Animation</li> <li>• Discuss model with subject-matter experts</li> <li>• Observe the target system</li> <li>• Use existing theory</li> <li>• Use results from other simulation studies</li> <li>• Rely on experience and intuition</li> <li>• Interact with supervisors / decision makers regularly</li> <li>• Maintain written assumptions document &amp; perform structured walk-through</li> <li>• Validate model components with quantitative techniques</li> <li>• Compare overall model output with existing system, existing theory, expert opinions, similar simulation studies or other models</li> </ul>	<ul style="list-style-type: none"> <li>• Animation</li> <li>• Operational graphics</li> <li>• Traces</li> <li>• Degenerate tests</li> <li>• Extreme conditions tests</li> <li>• Parameter variability / sensitivity analysis</li> <li>• Internal validity</li> <li>• Event validity</li> <li>• Historical data validation</li> <li>• Predictive validity</li> <li>• Comparison with other models</li> <li>• Face validity</li> <li>• Turing tests</li> <li>• Multistage validation</li> <li>• Historical methods</li> </ul>

Figure 5.1.: An overview of validation techniques

### 5.1.4. Agent-based models: Nothing new to social psychology

Although scarcely distributed among choice research methods, the use of computer simulations in social psychology is more than just a current trend in the discipline. In the very second issue of the renowned *Journal of Personality and Social Psychology*, Roby & Budrose (1965) published an article about group performance, and they investigated it with the aid of an empirical experiment and a computer simulation.

In social psychology, computer simulations are sometimes used to integrate or develop models or theories (Mosler, 2000; Smith & DeCoster, 1998). For instance, Schelling (1971) demonstrated that observed segregation in neighbourhoods does not necessarily mean inhabitants desire that kind of living condition. The phenomenon can occur when individuals do not want to be in the minority in their own neighbourhoods. Kameda et al. (2003) provided another example of theory development with the aid of computer simulation. These researchers tested a model of the communal-sharing norm with simulation experiments.

Other social psychological researchers focus on testing established models or theories with computer simulations. For example, Mosler et al. (2001) built a computer simulation of the elaboration likelihood model, which describes attitude development

and change based on persuasive communication and individual information processing. Furthermore, cognitive dissonance was modelled and explored by van Overwalle & Jordens (2002), and cooperation in social dilemmas by de Heus (2000).

### **More examples...**

The behaviour of juries regarding turn-taking and performance in discussions was investigated by (Stasser & Taylor, 1991) in mock and computer-simulated juries. Queller & Smith (2002) examined the occurrence and development of stereotypes with a connectionist network model, in which the effects of varying forms of exposure to stereotype disconfirmers were tested. Shoda et al. (2002) studied personality by modelling it as a cognitive-affective, information-processing system and by investigating the development of its relational status to a partner in a dyad.

Other examples deal with explanatory coherence in social explanations (Read & Marcus-Newhall, 1993), personality ratings by oneself and others (Paunonen, 1991), differences in perception of ingroup and outgroup members (Linville et al., 1989), the effect extraversion has on cognitive performance (Matthews & Harley, 1993), heuristic decision processes in personnel selection (Smith, 1968), as well as recruitment and performance outcomes depending on organizational context (Kroeck et al., 1983).

### **Specific examples of agent-based models**

In social psychology, agent-based models can be used to investigate intrapersonal processes (e.g. personality, memory effects), interpersonal processes (e.g. reciprocity, emotional transference, sympathy), group processes (e.g. leadership-follower behaviour, emergence of norms), intergroup processes (e.g. bias, discrimination), social and cultural differences (e.g. diffusion of innovation, transmission of cultural values; Smith & Conrey, 2007). Specific examples of agent-based models used in social psychology have been published by Axelrod et al. (2002) regarding cooperation independent of geographical proximity, and by Kalick & Hamilton (1986) on the importance of physical attractiveness in couple formation. Furthermore, Stasser (1988), Stasser & Davis (1989) and Stasser & Vaughan (1996) studied the influence shared knowledge has in group discussions. Kenrick et al. (2003) used agent-based models to investigate aggressive behaviour and mating strategies.

Sometimes considered part of social psychology (Mosler, 2000; Nawratil & Rabaioli-Fischer, 2010; Witte, 1989), the discipline of environmental psychology has brought forth a number of studies in which agent-based models are used. Mosler & Brucks (2003) studied cooperation in situations of resource scarcity using empirical data and agent-based modelling. Hunt et al. (2010) did not only create an agent-based model of management strategies for leisure fishing, they also discussed the model's contents and results with relevant stakeholders to ensure its validity. Other examples can be found on the following topics: resource management (Antona et al., 2002; Mosler & Brucks, 2003), controlling ecological and economical systems (Hare



et al., 2002; Krywkow et al., 2002), interventions for developing changes in people's environmental behaviour (Doran, 2001; Mosler, 2000; Tucker & Smith, 1999) as well as research on the cognitive and affective processes of environmental behaviour (Bergius & Engemann, 1985; Jager, 2000; Nerb, 2000).

### 5.1.5. Computer models of creativity

Doubtlessly, computer models of creativity do exist. However, they are not easy to locate because they often simulate individual cognitive processes relevant for but not exclusively characteristic of creativity, such as analogy building, associative processes, combinatorial processes or structural transformation (Boden, 1999). This implies the term *creativity* is not used in their names, titles, keywords, abstracts, etc., rendering them easy for interested searchers to overlook. Moreover, psychologists may have difficulties searching for computer models of creativity because many of them stem from other scientific domains such as artificial intelligence, cognitive science or even art. In the domain of psychology there are two book chapters dedicated to this issue, "Computer Models of Creativity" by Boden (1999, in Sternberg, 1999a)<sup>5</sup> and "Computational Approaches" by Sawyer (2006).

Boden (1999) distinguishes between two types of artificial intelligence (AI) models of creativity: *combinatorial* and *exploratory / transformational* creativity models. Combinatorial creativity models describe individual cognitive processes of association and analogy building. An example is the Structural Mapping Engine (SME), a computer simulation of analogical processing (Falkenhainer et al., 1989). Individual associative processing is demonstrated in a model described by Paulus & Brown (2003). It simulates the active search process a brainstormer undertakes when generating new ideas. Although different types of brainstormers varying in their fluidity and flexibility can be modelled, there appears to be no communication between them. Paulus & Brown (2003, p. 123) describe their example as a "highly convergent" brainstormer, someone who produces the most ideas in very few categories.

Examples of exploratory / transformational models are, for instance, DENDRAL, BACON, AARON, TALESPIN / MINSTREL and AM / EURISKO. DENDRAL (Lindsay et al., 1993) simulates the exploration of task-specific knowledge space to discover new information, such as molecular structures in organic chemistry. BACON is a model developed by Simon (1985) and colleagues (Bradshaw et al., 1983, see also Boden, 1999). Its purpose is to simulate or reproduce basic principles of physics and chemistry already discovered by renowned scientists<sup>6</sup>. AARON is an artificial painter developed by artist and professor Harold Cohen (see Ch. 6 in Sawyer,

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<sup>5</sup>Apart from this chapter, Margaret A. Boden has made substantial contributions to creativity research, cognitive science and artificial intelligence. See for instance Boden (1991, 1996, 2004, 2011).

<sup>6</sup>Its siblings are called BLACK, GLAUBER, STAHL and DALTON (Boden, 1999; Bradshaw et al., 1983).

2006)<sup>7</sup>. It creates drawings by an iterative design process, but it cannot alter its "style" without Cohen's assistance. AARON's creator evaluates its images and subsequently modifies the program code to reflect his personal aesthetic judgements. A recent advancement in this area is described by DiPaola & Gabora (2009) who have developed an evolutionary art algorithm which evaluates "by itself". The models TALESPIN and its sequel MINSTREL generate story plots, i.e. they simulate creative writing (Turner, 1994). Similar to AARON, MISTREL can incorporate the user's preferences in generating new plots (see also Boden, 1999). AM (Automated Mathematician) and EURISKO are two AI models developed to simulate learning by discovery (Lenat & Brown, 1984). Both include heuristics which enable them to change their own heuristics, therewith demonstrating a form of transformational creativity (Boden, 1999). Whereas AM applies to the domain of mathematics, EURISKO is domain-unspecific.

All of these models are individualist approaches, meaning they depict one single "creator" working on a given task. They do not model social interaction among individuals, something considered crucial to understanding creativity (Amabile, 1996; Csikszentmihalyi, 1999; Hennessey & Amabile, 2010). A few recent computational models do incorporate social perception and influence. In the domain of distributed artificial intelligence (DAI), models simulating collaborative creative processes such as orchestra performance have emerged (see Ch. 6 in Sawyer, 2006). From the disciplines of computer science as well as evolution and cognition research, Bryson (2008) has developed an agent-based model of cultural evolution with which forms of stabilization and innovation can be produced. Quite recently, Antonelli & Ferraris (2011) have developed an agent-based model of innovation combining systems and evolutionary theorizing with a Schumpeterian view of creativity (Schumpeter, 1947). Active in the social sciences, Paolucci & Picascia (2010) and Picascia & Paolucci (2010) have developed a model called "Meme-to-Web" (MtW) in which they abstractly depict cultural production processes. Individuals (*peers*) interact via the artefacts they produce, i.e. by accessing and contributing to a knowledge base of so-called memes. One of the noteworthy goals of this work is to "...derive hints on the impact that every filtering technology can have on cultural dissemination..." (Picascia & Paolucci, 2010, p. 10). In this aspect, MtW appears to be one possible operationalization of Csikszentmihalyi's (1999) theoretical ideas on how evaluation processes filter what enters and is retained in a domain.

Remarkably active in recent years, Gabora (1995, 2008a,b) has developed two agent-based models of cultural evolution which incorporate neural networks in agents' architecture: Meme And Variations (MAV) and EVOLution of Culture (EVOC). A number of experiments have been conducted with them to investigate various aspects of cultural evolution on both a micro-level and a macro-level (Leijnen & Gabora, 2009a,b, 2010). Similar to terminology used by Paolucci & Picascia (2010) and Picascia & Paolucci (2010), Gabora (1995) uses the meme metaphor to illuminate the

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<sup>7</sup>Most information on AARON can be found on the web. For an introduction see [http://www.usask.ca/art/digital\\_culture/wiebe/index.html](http://www.usask.ca/art/digital_culture/wiebe/index.html) (retrieved Feb. 14, 2011).

artefacts produced in MAV. Additionally, evolutionary terminology is predominant in MAV and EVOC. Gabora (1995, 2008a,b) describes the agents as producing artefacts (movements) labelled variations and selecting them based on a global function which calculates the fitness of a movement depending on an agent's current needs. Retention is regulated by fitness values of learned movements.

## 5.2 Building agent-based models

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In this section, the simulation software used to build the agent-based models in this thesis is described (Section 5.2.1) and a brief overview of the creativity models' computational representation is given (Section 5.2.2-5.2.3).

### 5.2.1. Simulation tool

NetLogo is a modelling environment created by Wilensky (1999) and it is suitable for implementing various kinds of simulation methods for a large range of purposes. In general terms, it is used for simulating complex systems evolving over time. Basically, NetLogo offers two agent types: turtles (mobile agents) and patches (stationary agents). Any number of agents can be programmed to study how their individual behaviour leads to emergent phenomena on a macro-level.

NetLogo is based on the programming language Logo. This language is highly intuitive, which facilitates its mastery especially for those with little to no prior programming experience. At the same time, Logo uses Java's math library to enable highly sophisticated modelling. NetLogo's graphical user interface (GUI) relaxes the programmer's goals immensely: With three separate tabs in the GUI, programmers can watch and develop a model in the interface tab, document the model in the information tab and write the model code in the procedures tab (Wilensky, 1999).

### 5.2.2. Computational representation

The systems / VSR model of creativity (Chapter 3) encompasses three basic steps in time, although in reality they can overlap and do not necessarily occur in chronological order. These three steps are:

- **Variation** Creators produce artefacts.
- **Selection** Evaluators judge creators' output.
- **Retention** The domain is updated based on artefacts produced by creators and favoured by evaluators.

Refer to Figure 3.1 for a visualization of these processes. In using the model of creativity defined in Section 3.6 as a theoretical basis, the agent-based models to be programmed will encompass two classes of mobile agents ("turtles" in NetLogo):

creators and evaluators. Furthermore, the individual artefacts creators make and an evolving domain representing the artefact collective are required. The artefacts will be represented as stationary agents ("patches" in NetLogo), and the domain will be modelled as an invisible and immobile turtle which collects information about the simulation world at each time step.

### 5.2.3. The agent-based models: CRESY-I & CRESY-II

In the following Part III of this dissertation, the agent-based models constructed to explore the model of creativity defined in Section 3.6 will be extensively reported. In particular, two agent-based models were constructed to link the theoretical model to an exploration tool: CRESY-I and CRESY-II<sup>8</sup>. CRESY-I contains a programmed model of the variation process with a simple form of retention, whereas CRESY-II includes the process of selection and a more sophisticated form of retention. The reasons for starting out "small", i.e. chiefly with just the variation subprocess, are explained in the following paragraphs.

Firstly, the highest priority in designing an agent-based model of a starkly abstract model of creativity is to build it on a strong foundation of existing creativity models used in psychology. These are, as the nature of creativity suggests, diverse and abundant. Secondly, variation represents the most common research perspective in this domain (Abuhamdeh & Csikszentmihalyi, 2004; Csikszentmihalyi, 1999; Kahl et al., 2009). Initiating modelling with this subprocess allows the establishment of a connection to existing research practice as well as the opportunity to challenge effective assumptions with a research method less common in the domain.

Finally, the base model CRESY-I is intended as a building block, or  $M_0$  as Cioffi-Revilla (2010) calls it (see also David et al., 2010). In describing a methodology for complex social simulations, Cioffi-Revilla (2010) argues that starting with the full complexity of a target system is intractable. Instead, he suggests defining a sequence of models from simple ( $M_0$ ; initial model) to complex ( $M_F$ ; final model) in order to gradually incorporate the complexity of the target. From a psychological perspective, this procedure increases the chances that a modeller can "get into action" more quickly, i.e. getting on the path to a goal, and not "getting stuck" in the most complex form of a theoretical model which make translating it into the first agent-based model even more difficult.

The way a conceptual model can be coded is often experienced first by programming it, so starting with this activity at an early stage in the research process can give insight on how to translate later, more complex versions of the model. By sequentially building agent-based models, the final target can be more flexibly approximated. Cioffi-Revilla (2010) suggests identifying a minimal set of essential entities and environmental features to create an initial simple world. Then, an initial model can be built by defining a) a minimal set of agent characteristics, b) their relations among each other and to the environment, and c) a fundamental set of dynamics. This

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<sup>8</sup>CRESY stands for CREativity from a SYstems perspective.

is the methodology by which the agent-based models CRESY-I and CRESY-II were designed.



## **Part III.**

# **Agent-Based Models of Creativity**





# 6

## Roadmap to CRESY-I

CRESY-I stands for "CREativity from a SYstems perspective I", and it is the name of the first agent-based model conceived in this doctoral thesis<sup>1</sup>. The purpose of this chapter is to provide the reader with:

- A protocol of CRESY-I's architecture
- Information on the model's verification
- An overview of independent and dependent variables
- The design of experiments conducted with CRESY-I

The chapter starts with a detailed model protocol (Sections 6.1 - 6.3). The latter is designed according to contemporary guidelines for documenting simulation models ("ODD Protocol"; Grimm et al., 2006, 2010; Janssen et al., 2008; Polhill et al., 2008, 2010). It includes aspects considered crucial to understanding the detail of a simulation model without having to read its code. It continues with information on the model verification process (Section 6.4). Following, CRESY-I's independent and dependent variables are explained (Sections 6.5 - 6.6). The chapter concludes with an overview of experiments conducted with CRESY-I (6.7).

### 6.1 ODD Protocol: Overview

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Sections 6.1 - 6.3 contain a detailed account of CRESY-I's architecture. They follow the ODD (*Overview*, *Design concepts* and *Details*) protocol for describing individual-based and agent-based models (Grimm et al., 2006, 2010). The ODD format was designed to facilitate writing and reading model descriptions, and to support modellers in defending the scientific nature of their work against criticism made otherwise. One of the greatest challenges modellers have is conveying the details of their scientific work in a transparent manner. At present, the ODD protocol is the state-of-the-art tool for doing so.

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<sup>1</sup>CRESY-I has been uploaded to the OpenABM site (<http://www.openabm.org/>). Please contact the author for access to it.

### 6.1.1. Purpose

The general purpose of this model, CRESY-I, is to simulate the variation subprocess of creativity (Campbell, 1960; Ford & Kuenzi, 2007; Kahl, 2009; Simonton, 2004). The model demonstrates the effects, in terms of emerging product domains, of stable creator types acting on the basis of behavioural variability, i.e. a theoretical continuum describing how differently (variable) an individual behaves or creates from time to time (Stokes, 1999, 2007). An abstract model, CRESY-I was designed for theoretical exploration and hypotheses generation. It is the base model in a series of models designed to describe a systems approach to creativity in terms of variation, selection and retention subprocesses (Csikszentmihalyi, 1988, 1999; Ford & Kuenzi, 2007; Kahl, 2009; Rigney, 2001).

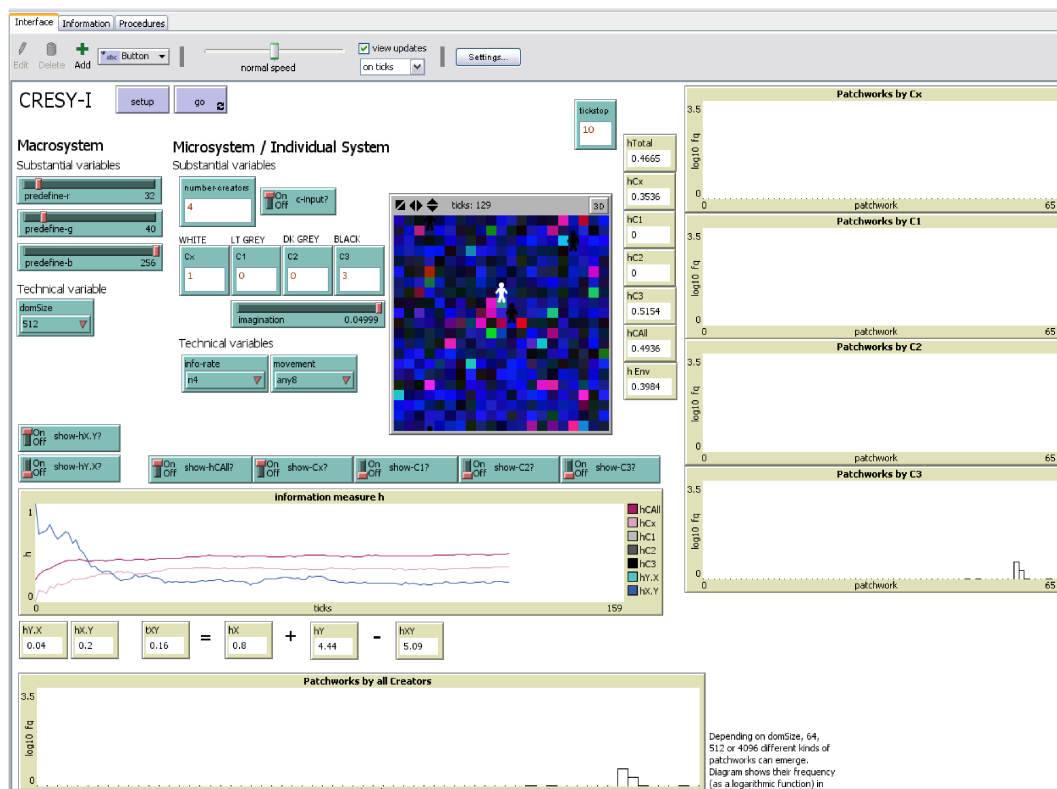


Figure 6.1.: Screenshot of CRESY-I

### 6.1.2. Entities, state variables, and scales

Programmed with NetLogo 4.1 (Wilensky, 1999), CRESY-I encompasses the following entities<sup>2</sup>: creators, patchworks, domain and global variables (see also Figure 6.1).

<sup>2</sup>Grimm et al. (2010) define *entity* as "a distinct or separate object or actor that behaves as a unit and may interact with other entities or be affected by external environmental factors. Its current

Creators are agents ("turtles" in NetLogo) characterized by the state variables<sup>3</sup> described in Table 6.1.

Table 6.1.: *CRESY-I Creator State Variables and Scales*<sup>1</sup>

Variable name	Brief description	Value
<i>label</i>	Describes (static) creator type.	{Cx,C1,C2,C3}
<i>cR, cG, cB</i>	Creator's 3 memory lists for red, green & blue values. Each a list of 256 nested lists; item 0 = <i>colour value</i> ( $c_j$ ), item 1 = <i>absolute frequency</i> ( $f_j$ ) of value $c_j$ .	[ [0 $f_1$ ] [1 $f_2$ ],..., [ $c_j$ $f_j$ ],..., [255 $f_{256}$ ] ]
<i>myPw</i>	List of patchworks creator has made, i.e. list of three-item nested lists. Each set of three items represents rgb values.	[ [r g b] [r g b],...]
<i>imagination</i>	How likely creators C1, C2 & C3 will generate an r, g or b value not in their memory. Same value for all three creator types <sup>2</sup>	[0.00, 0.25]
<i>info-rate</i>	How many neighbours (4 or 8) a creator obtains info from per time step. Same for all creators.	{n4,n8}
<i>movement</i>	How creators move in the world <sup>3</sup>	{straightFd1, ahead3, allButBehind7, any8}

<sup>1</sup> In CRESY-I, the creator variables *imagination*, *info-rate* and *movement* are defined globally for all creators.

<sup>2</sup> See Section 6.3.3 for more on how *imagination* works.

<sup>3</sup> The movement strategies are explained in Section 6.3.3.

Patchworks abstractly represent objects creators produce, such as ideas (Paulus & Brown, 2003), paintings (DiPaola & Gabora, 2009), movements (Leijnen & Gabora, 2010), or other cultural artefacts (Picascia & Paolucci, 2010). Technically, patchworks are considered agents or spatial units ("patches" in NetLogo). They appear as colours characterized by rgb values. The production of patchworks becomes visible to the observer, because creators do not only make an rgb colour by combining three separately selected values chosen from their memories, they "paint" the colour

state is characterized by its state variables or attributes" (p. 7).

<sup>3</sup>Grimm et al. (2010) describe a *state variable* as "a variable that distinguishes an entity from other entities of the same type or category, or traces how the entity changes over time" (p. 7). Further, state variables should be "low level or elementary in the sense that they cannot be calculated from other state variables" (p. 7).

on the patch they are currently standing on. Table 6.2 gives an overview of the patchworks' state variables.

The domain is a higher-level entity abstractly representing a symbolic, or informational, system (Csikszentmihalyi, 1988, 1999). It specifically constitutes the population of patchworks in the simulation at a current time step as well as over all time steps, and it is technically represented in NetLogo by a single, invisible agent (turtle) as well as a few global variables. Its purpose is to record information about the patchworks and calculate output variables at every time step. Theoretically, the domain is formed by variation and selection processes (Csikszentmihalyi, 1988, 1999; Kahl, 2009). Since the focus of CRESY-I is to face-validly model and explore the variation process, the selection process is only operationalized via the quantitative input variable *domSize*. The observer, in other words, can only perceive patchworks with a certain degree of differentiation, and this recognition is not as fine-tuned as that of creators. This feature corresponds to observers only perceiving products' phenotypes, whereas creators recognize their genotypes (Chattoe, 1998). Table 6.4 gives an overview of the domain's state variables.

Table 6.2.: *CRESY-I Patchwork State Variables and Scales*

Variable name	Brief description	Value
<i>pcolor, plabel</i>	Both a list of rgb values (24 bit).	[r g b]
<i>pDom</i>	List of rgb values reduced to domain variable <i>domSize</i> (6, 9 or 12 bit).	[r g b]
<i>pR, pG, pB</i>	Patch's current respective red, green and blue values.	Integer, [0,255]
<i>madeBy</i>	Who made patchwork? Environment <sup>1</sup> or creator type.	{Env,Cx,C1,C2,C3}
<i>pDomPos</i>	Position of <i>pDom</i> in global variable <i>rgbSpace</i> .	Integer, [0, <i>domSize</i> −1]
<i>whosNext</i>	Holds <i>who</i> value of creator potentially to next move on patch. Belongs to movement procedures of creators.	Integer, [1,number-creators] <sup>2</sup>

<sup>1</sup> "Environment" (Env) means a patch's colour has not been changed yet by any creator. It is still the colour it randomly received when the world was initiated.

<sup>2</sup> *number-creators* is a global variable (see Table 6.3) which defines the total number of creators in the world regardless of type.

A number of global or context variables are used in CRESY-I to define start-up configurations (see Table 6.3). Furthermore, the dependent variables as well as the interim variables used to calculate them are programmed as global variables in CRESY-I. They are listed separately in Table 6.5.

Table 6.3.: *CRESY-I Global Variables and Scales*

Variable name	Brief description	Value
<i>number-creators</i>	Observer defines number of creators in world.	$\geq 0$
<i>c-input?</i>	If true, ratio of creator types defined by observer. If false, defined randomly.	Boolean
<i>Cx, C1, C2, C3</i>	4 variables defining number of each creator type in world. Set by observer if <i>c-input?</i> true.	$\geq 0$
<i>predefine-r, predefine-g, predefine-b</i>	3 variables to set how many different red, green & blue values in world to start.	[1,256]
<i>max-pxcor, max-pycor</i>	Maximum x-coordinate and maximum y-coordinate for patches. Determines world size. Value used as default.	10
<i>tickstop</i>	If uncommented in code, simulation stops at length <i>steps &gt; tickstop</i> .	$\geq 1$

CRESY-I is based on theoretical ideas expressed in creativity research in psychology. Therefore, there are no explicit concepts of spatial and temporal scales. However, research in this domain is usually conducted as psychological experiments in which isolated, individual participants or groups are requested to generate ideas, products, etc. Therefore, one time *step* or *tick* in a simulation run can approximately equate to the time it takes to produce one idea or artefact. In CRESY-I, the duration of this time is the same for all creators, which is not necessarily the case in reality. Furthermore, total duration (temporal extent) can also vary depending on whether psychological investigations take place in a laboratory setting, in which time is more or less controlled, or in the field where, for example, the non-simulated creative production processes carried out by artists, scientists, students and the like can be of any duration.

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Table 6.4.: CRESY-I Domain State Variables and Scales<sup>1</sup>

Variable name	Brief description	Value
<i>domSize</i>	Size of product space, e.g. number of rgb colours (patchworks) discriminated by the observer (12, 9 or 6 bit).	{64,512,4096}
<i>rgbDomTotal</i>	List of nested lists with 4 items each. First 3 items represent patchwork (rgb), last item current rgb frequency ( $p_j$ ), and $N = \text{total number of patches in world.}$	$[[0\ 0\ 0\ p_1]$ $[0\ 0\ 1\ p_2], \dots,$ $[r_j\ g_j\ b_j\ p_j], \dots,$ $[domSize^{\frac{1}{3}} - 1$ $domSize^{\frac{1}{3}} - 1$ $domSize^{\frac{1}{3}} - 1$ $p_{domSize}]];$ $p_j \setminus \text{element}$ $[0, N]$
<i>rgbDomCx</i> , <i>rgbDomC1</i> , <i>rgbDomC2</i> , <i>rgbDomC3</i> , <i>rgbDomCAI</i> , <i>rgbDomEnv</i>	6 lists with structures just like <i>rgbDomTotal</i> , but separately assessed frequencies for each creator type, all creators (CAI) & the environment (Env).	See above, e.g. $p_{jCx} \setminus \text{element}$ $[0, N \mid$ $madeBy=Cx]$
<i>distTotal</i>	List of frequencies of each patchwork type.	$[p_1, \dots, p_j, \dots, p_{domSize}]$
<i>distCx</i> , <i>distC1</i> , <i>distC2</i> , <i>distC3</i> , <i>distCAI</i> , <i>distEnv</i>	Separate lists of frequencies of each patchwork type for each creator type, all creators (CAI) & the environment (Env).	See above, e.g. $p_{jCx} \setminus \text{element}$ $[0, Cx\text{-steps}]$

<sup>1</sup> In CRESY-I's code, *domSize* is a global variable. All other variables are attributes of the agent domain.

In CRESY-I, the term *space* refers to knowledge and not to geographical location. Obviously, where creators are located in the world will affect what knowledge (colour information) they acquire. However, as colours are randomly distributed on the grid when the world is initialized, geographical space has no systematic meaning in this model. By default, a 21x21 torus defines the knowledge-spatial extent of the world. Each patch on the torus represents one patchwork, i.e. a colour representing a creative product characterized by the three independent dimensions red, green and blue. The knowledge-spatial extent of the world is varied by altering the creator density in it.

Table 6.5.: *CRESY-I Dependent & Interim Variables<sup>1</sup> and Scales*

Variable name	Brief description	Value
$hY.X, hX.Y$	Mutual information with $X$ = creator type & $Y$ = patchwork type.	$[0,1]$
$hX$	Information measure (marginal entropy) for $X$ = creator type.	$\geq 0$
$hY$	Information measure (marginal entropy) for $Y$ = patchwork type.	$\geq 0$
$hXY$	Joint information (cell entropy)	$\geq 0$
$t_{XY}$	Transinformation for $X$ = creator type and $Y$ = patchwork type.	$0 \geq t_{XY} \geq \min(hX, hY)$
$hTotal$	Measure of relative information (absolute information divided by maximal information).	$[0,1]$
$hCx, hC1, hC2,$ $hC3, hCAll, hEnv$	6 measures of relative information calculated like $hTotal$ , but separately for each creator type, all creators and the environment.	$[0,1]$

<sup>1</sup> In CRESY-I,  $hCAll$  and  $hX.Y$  are used as dependent variables. All others are supplementary variables used for interim calculations or exploration. See also Sections 6.3.3 & 6.6.

### 6.1.3. Process overview and scheduling

CRESY-I consists of six subsequent processes ("procedures" in NetLogo): obtain-info, make-patchwork, move, forget-some-info, tick, update-domain. Their scheduling is linear, i.e. their order occurs in the exact order they are listed in the sequence diagram in Figure 6.2. The agentsets running the commands in each process do so serially, but in a random order on the basis of NetLogo's *ask* command. The state variables were updated asynchronously. Time was modelled discretely.

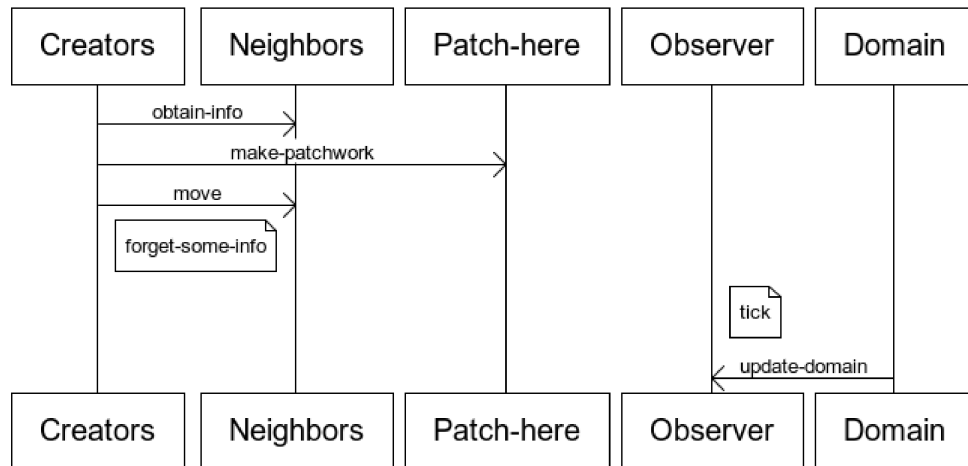


Figure 6.2.: Sequence diagram of CRESY-I.

## 6.2 ODD Protocol: Design concepts

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### 6.2.1. Basic principles

CRESY-I's overall architecture is based on a) the evolutionary mechanism of variation, selection and retention (VSR) as well as b) Csikszentmihalyi's (1999) systems perspective of creativity which encompasses individuals, a field and a domain. CRESY-I's focus is on the basal process of variation. In modelling the latter, different psychological models of the creative individual (see Chapter 7) and their products (see also Ch. 4 in Sawyer, 2006) are used to develop code. The domain, a higher-order entity representing the process of retention, is characterized by several measures of information (qualitative or nominal diversity) taken from Shannon's (1948) mathematical theory of communication (see also Section 6.6). Figure 6.3 summarises CRESY-I's basic principles graphically.

### 6.2.2. Emergence

The two key dependent variables  $hCAII$  and  $hX.Y$  are modelled as emerging, overall domain characteristics based on creators' behaviour in CRESY-I. Both variables are



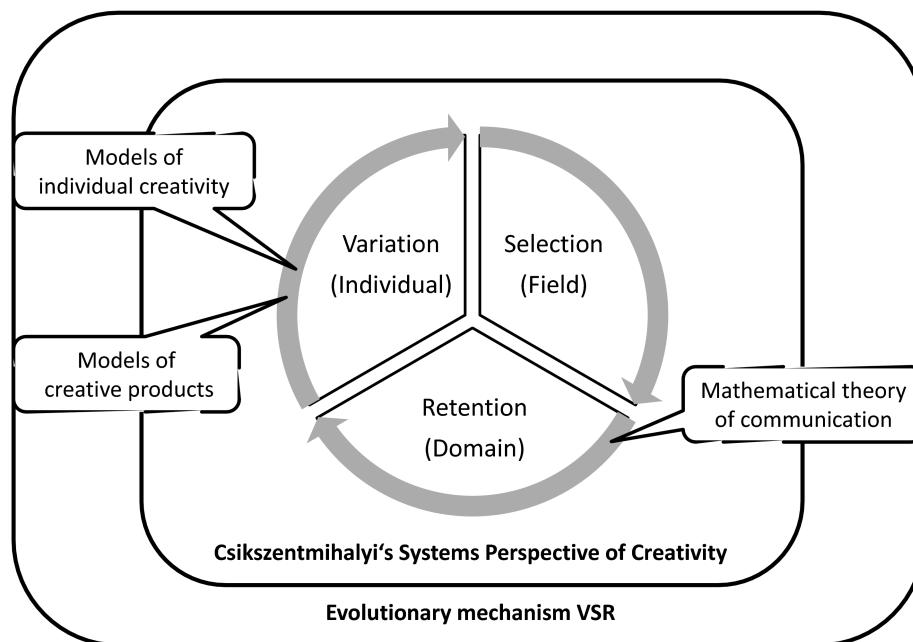


Figure 6.3.: The basic concepts and models used in CRESY-I are a) the evolutionary mechanism VSR, b) Csikszentmihalyi's (1999) systems perspective of creativity, c) psychological models of individual creativity, d) psychological models of creative products, and e) the mathematical theory of communication proposed by Shannon (1948).

expected to vary in magnitude and volatility depending on initial start-up conditions and creators' activity over time.  $hCAI$  measures the amount of diversity in the world, in terms of the distribution of patchwork types.  $hX.Y$  measures how well a creator type ( $X$ ) can be predicted given a randomly selected patchwork ( $Y$ ). It therefore indicates how easily creator types can be discriminated based on observing their artefacts.

### 6.2.3. Adaptation

Creators adapt to their environment by obtaining information from it every step (see submodel *obtain-information* in Section 6.3.3). This means they save the  $r$ ,  $g$  and  $b$  values of neighbouring patchworks in their memories, which influences the kinds of patchworks they produce in the future. Otherwise, creators act on the basis of constant behavioural rules and the independent variable *imagination* (see submodel *make-patchwork* in Section 6.3.3). Creators do not explicitly seek to increase their individual success, but their consistent behaviour based on their adapting memories is expected to contribute more or less successfully to the domains's overall "success"

in terms of diversity level ( $hCAI$ ) and creator type discrimination ( $hX.Y$ ).

### 6.2.4. Objectives

Creators have two implicit objectives: 1) They are supposed to produce diverse products, and 2) they are supposed to do so based on their individual behavioural type. Creators achieve the first objective by combining three elements (digits) from their memories to one patchwork (see Ch. 4 in Sawyer, 2006). Creators achieve the second objective by adhering to their behavioural rules. Creator type  $Cx$  "wants" to create what it "knows" best, whereas creator type  $C3$  "wants" to do things differently compared with what everybody else is creating (based on its memory, i.e. experience with patchworks). The creator types  $C1$  and  $C2$  are hybrids of  $Cx$  and  $C3$ . They "want" to deviate from the norm in certain aspects ( $r$ ,  $g$ ,  $b$  values) of their patchworks, and in others they do not<sup>4</sup>. How creators meet these objectives is measured collectively with the dependent variables  $hCAI$  (objective 1) and  $hX.Y$  (objective 2).

### 6.2.5. Learning

In CRESY-I, creators learn by "memorizing" or obtaining patchwork information from neighbouring patches. Their memories, i.e. adaptive traits, are also affected by their random forgetting of what they have encountered before (see also submodels *obtain-information* and *forget-some-info* in Section 6.3.3). Creators, however, do not learn to alter their behavioural rules.

### 6.2.6. Prediction

The concept of prediction does not appear to apply to CRESY-I.

### 6.2.7. Sensing

In CRESY-I, creators only sense parts of the environment locally by viewing different patchworks based on their movement strategy and by saving patchwork information (state variables  $pR$ ,  $pG$ ,  $pB$ ; Table 6.2) in their memory lists ( $cR$ ,  $cG$ ,  $cB$ ; Table 6.1). While creators can produce and view all possible red, green and blue values (0-255 per colour; 24-bit total colour space), the global observer cannot discriminate this detail with which creators produce patchworks. The domain, based on which the observer calculates the global dependent variables  $hCAI$  and  $hX.Y$ , encompasses only a reduced colour space according to  $domSize$  (Table 6.4; see also all submodels in Section 6.3.3).

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<sup>4</sup>Note that the aspects they do deviate in are selected randomly every step in the submodel *make-patchwork* (see also Section 6.3.3).

### 6.2.8. Interaction

Creators experience indirect interaction with other creators by locally viewing and obtaining information about their behaviour, i.e. patchworks. This feature is comparable to situations in which creators do not know each other personally, but know each other's works (Dennis & Williams, 2003; Müller, 2009; van den Besselaar & Leydesdorff, 2009).

### 6.2.9. Stochasticity

This design concept is used in the following areas. *Dispersion of creator types*: Creators are always randomly dispersed on the simulation grid when the world is initiated. *Dispersion of colours (patchworks)*: When the world is initialized, all patches (patchworks) are given predefined colours, which represents the world's start-up diversity. The colours are chosen randomly based on the numbers predefined by the modeller in the Interface Tab's sliders *predefine-r*, *predefine-g* and *predefine-b*. Say for example the *predefine-r* slider is set to 10. This means 10 different digits (red colour categories), namely 0 – 9, are used to sample the randomly selected digit for a patch's red colour. The same happens to select a patch's green and blue colours. In this way, each colour dimension value a patch has in the beginning is chosen randomly based on the sample size defined in the three respective sliders. *Making patchworks I*: When *C1* selects one colour dimension to vary originally and *C2* one to vary conventionally, their selection occurs randomly (see also submodel *make-patchwork* in Section 6.3.3). *Making patchworks II*: All creator types make use of a local random variable (based on cumulative distribution sampling) to select values for a patchwork. A new value for this random variable is generated for every selection process, i.e. separately for red, green and blue value selections. *Moving*: Depending on movement strategy, creators move to a randomly chosen patch within a defined neighbourhood. *Forgetting information*: For each memory list (*cR*, *cG*, *cB*; see Table 6.1) a creator has, one value from 0-255 with an absolute frequency  $> 0$  is randomly chosen to reduce its frequency by 1.

### 6.2.10. Collectives

The collectives in CRESY-I do not refer to emergent properties of individual agents, but to the kinds of entities the model encompasses. As collectives, there are creators, patchworks and a domain. Moreover, there are subtypes of creators (*Cx*, *C1*, *C2*, *C3*) which differ in the way they make patchworks (see submodel *make-patchwork* in Section 6.3.3). Perhaps the domain is the only entity or collective which can be considered to emerge from creator and patchwork interaction, i.e. based on creators' patchwork viewing and production. The domain technically consists of the state variables listed in Table 6.4, which are different types of patchwork frequency lists. However, the lists' actual values and the dependent variables calculated thereafter by the observer depend on creators' behaviour.

### 6.2.11. Observation

Data collection is conducted in two ways. Firstly, diverse monitors and plots are included in the NetLogo Interface Tab to allow graphical observation simultaneously while a simulation is running. There are plots for the following information: *hCAll*, *hCx*, *hC1*, *hC2*, *hC3*, *hY.X*, *hX.Y* as well as for the patchwork distributions of all creators and each creator type separately. There are monitors for the variables *hCAll*, *hCx*, *hC1*, *hC2*, *hC3*, *hEnv*, *hTotal*, *hX.Y*, *hY.X*, *tXY*, *hX*, *hY* and *hXY* (see Section 6.6 for more on these variables).

Secondly, numerical data collection was achieved by designing experiments with NetLogo's BehaviorSpace (Wilensky, 1999). Each experiment produced a .csv file containing values for all dependent variables (Table 6.5) at every time step of each simulation run. The data was used freely to analyse CRESY-I, although not all variables were selected for model analysis. All dependent variables are taken from the observer perspective.

## 6.3 ODD Protocol: Details

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### 6.3.1. Initialization

All variables used for initialization were derived from theoretical deliberations or empirical findings discussed in creativity research (see for example Ochse, 1990; Sawyer, 2006; Sternberg, 1999a; Sternberg et al., 2004; Zhou & Shalley, 2007). Their exact values were initially arbitrarily set and then explored in the experiments CI-1a, CI-1b, CI-2a, CI-2a-SupplExp and CI-2b. Please refer to each experiment's documentation for the exact initial settings (CI-1a, CI-1b, CI-2a, CI-2a-SupplExp: Sections A.1 - A.3 in the Appendix; CI-2b: Chapter 7; see also Figure 6.5).

### 6.3.2. Input data

CRESY-I does not use input data to represent time-varying processes. The model is an abstraction derived from normative ideas published in creativity research chiefly within the field of psychology (see Chapter 7 for more).

### 6.3.3. Submodels

This section describes CRESY-I's processes or *submodels* (see also Figure 6.2).

#### **obtain-info**

This submodel allows all creators to gather information every time step. Creators see neighbouring patches according to their state variable *info-rate* (Table 6.1). *info-rate* allows them to view either four (*n4*) or eight (*n8*) neighbouring patches, and creators save the patches' rgb values (*pR*, *pG*, *pB*; Table 6.2) in their memory lists

(*cR*, *cG*, *cB*; Table 6.1), thereby collecting either 12 or 24 pieces of information per time step. In this submodel, creators' state variables *cR*, *cG*, and *cB* (Table 6.1) are updated.

#### make-patchwork

In this submodel, creators' state variable *myPw* (Table 6.1) and patchworks' state variables *pcolor*, *plabel*, *madeBy*, *pR*, *pG*, *pB*, *pDomPos*, and *pDom* (Table 6.2) are updated. This is the time when patches change their colours in the world in NetLogo's Interface Tab. *make-patchwork* allows every creator to produce a patchwork (rgb colour) it "paints" on the patch it's currently standing on (called *patch-here* in NetLogo). It works differently for each creator type, but the underlying idea is the same for all: Creators combine three digits from 0-255, e.g. [141 141 141] for grey or [224 127 150] for pink. The way a creator selects these digits depends on its state variables *label* and *imagination* (Table 6.1).

**Conventional vs. original strategies** A creator's *label* (*Cx*, *C1*, *C2*, *C3*) indicates how it retrieves individual digits from its memory lists *cR*, *cG*, and *cB* (Table 6.1). *Cx* is highly likely to choose digits it has most often obtained before. In everyday terms, *Cx*'s behaviour is conventional, unoriginal or reliable, because it (re)produces what it "knows best". When *C3* makes a patchwork, it does so in an original or unreliable fashion<sup>5</sup>: All three digits it selects are highly likely to be ones it has rarely encountered before. *C1* and *C2* are hybrids of *Cx* and *C3*. *C1* selects one of the three digits in the highly original way *C3* does, and the other two in the conventional way *Cx* does. *C2* creates exactly in the opposite manner: It selects two digits in the highly original way *C3* does, and one in the conventional way *Cx* does. *C1* and *C2* can be considered intermediate categories on a theoretical continuum of behavioural variability (Stokes, 1999, 2007). See Figure 6.4 for a visual description.

**Imagination** Furthermore, the *original* digit selection strategies used by *C1*, *C2* and *C3* are affected by the state variable *imagination* (Table 6.1). This is a parameter describing how likely it is these creators will select a digit they have never encountered before during the submodel *obtain-info*, i.e. how likely a creator type will create a genuinely novel digit. Novelty in this sense refers to personal and not global novelty<sup>6</sup>, although the latter form can be a consequence of the former depending on the types of patchworks already in the world.

<sup>5</sup>The term *unreliable* refers to how an observer interprets *C3*'s behaviour. Technically, *C3* functions reliably based on a stable behavioural rule, i.e. *C3* will *always* select with high probability digits it has seldom encountered before. However, its behavioural outcomes (patchworks) are so diverse, that it appears to behave "unreliably", because an observer cannot predict its next patchwork as easily as one made by *Cx*. In other words, the observer is unreliable in foreseeing this creator's behaviour!

<sup>6</sup>Creativity researchers tend to refer to these situations as "little-c" (personal, everyday) and "Big-C" (global, historical, eminent) creativity (see for instance Beghetto & Kaufman, 2007; Boden, 1999).

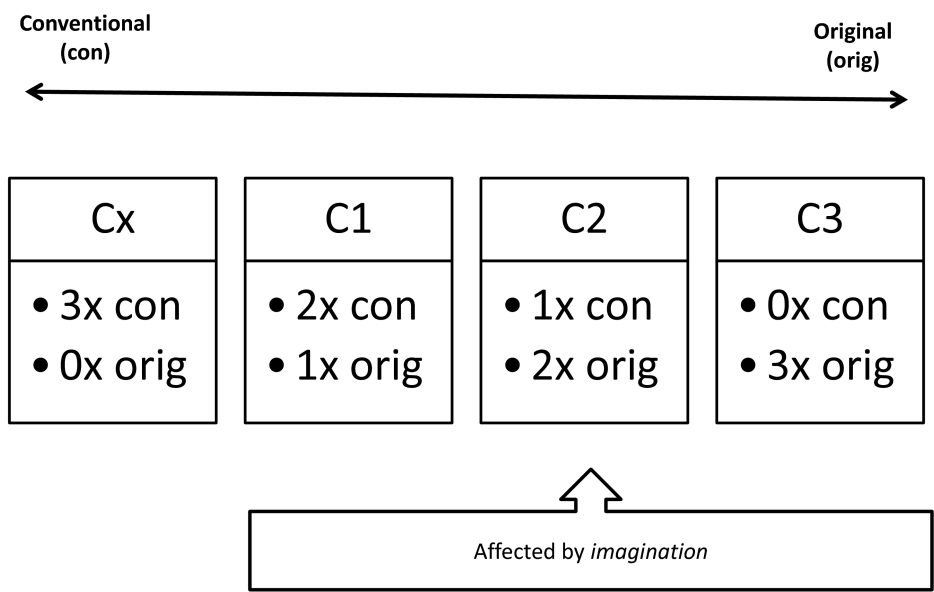


Figure 6.4.: Creators make patchworks by selecting three digits they combine to an *rgb* colour. The way a colour is selected depends on the creator (*Cx*, *C1*, *C2*, *C3*). A combination of conventional (*con*) and original (*orig*) selection strategies defines their respective types. Creators *C1*, *C2* and *C3* are additionally affected by the state variable *imagination* when they select values.

**An Example** Assume there are only three digits a creator can obtain: 0, 1, 2. As implemented in CRESY-I, a creator's memory list could look like this: `[[0 4][1 0][2 2]]`. This means the creator has obtained the information "0" four times, "1" zero times and "2" twice before. If the creator were to now produce a one-digit product using the *original* selection strategy implemented in *C3* for all three digits, in *C2* for two digits, and in *C1* for one digit, it would select either "1" or "2", because choosing "0" would be *conventional* (not *original*). This is where the *imagination* variable comes into effect: When "deciding" whether to select "1" or "2", the creator will always be less likely to choose "1", because it has never obtained "1" before. However, imagination regulates how less likely choosing "1" would be. Only one value for imagination is set for all creators affected by it. However, it comes into effect every time an original selection strategy is used (Figure 6.4), meaning *C3* is most affected by it, followed by *C2* and *C1*.

**How a colour value is selected** Each memory list (*cR*, *cG* and *cB*) and therefore colour dimension is treated independently when a patchwork is made. The first

step in selecting a digit (0-255) from a colour dimension (red, blue or green) is to calculate the relative frequencies of all digits in one dimension (memory list). Here is an example for *one* colour dimension. The relative frequency for each digit (0-255) of this colour dimension is calculated as

$$p_{i,con} := \frac{f_i}{N} \quad (6.1)$$

$f_i$  is the absolute frequency of digit  $i$ .

$N$  is the total number of digits a creator has in its memory list.

$p_{i,con}$  stands for the relative frequency of digit  $i$  for *conventional* selection.

Relative frequencies calculated as described in Equation 6.1 are the basis for selecting a digit with the *conventional* selection strategy. In implementing the *original* selection strategy, these frequencies are transformed twice. In the first transformation, they are inverted and normalized:

$$p_{i,con} \rightarrow p_{i,orig}^* = \begin{cases} \frac{1-p_{i,con}}{N-1} & \text{if } p_{i,con} > 0 \\ 0 & \text{if } p_{i,con} = 0 \end{cases} \quad (6.2)$$

Equation 6.2 qualitatively means that a creator using the *original\** ( $p_{i,orig}^*$ ) strategy will most likely "think of" those values it has seldom seen before compared with those it has. However, this first transformation does not ensure that a creator will produce a colour value it has never seen before. This is what the second transformation does. It incorporates the state variable *imagination* ( $IMG$ ):

$$p_{i,orig} = \begin{cases} (1 - IMG) * p_{i,orig}^* & \text{if } p_{i,orig}^* > 0 \\ \frac{IMG}{K} & \text{if } p_{i,orig}^* = 0 \end{cases} \quad (6.3)$$

$K$  is the number of  $p_{i,con}$  which are equal to zero.

$IMG$  (*imagination*) is the probability for a creator to choose a digit it has never seen before. This probability is assigned with equal weight to the digits which have zero frequencies in the respective memory list. Before a digit is chosen for a patchwork, the frequencies of all digits of the respective colour dimension (memory list) are either calculated as relative frequencies (Equation 6.1; *conventional* selection strategy) or calculated according to Equation 6.3 (*original* selection strategy). In both cases, digit selection is finally realized by cumulative distribution sampling: All  $p_{i,con}$  (respectively  $p_{i,orig}$ ) are added from the digit categories (0 - 255),  $p_{sum} = \sum_0^{255} p_{i,con}$ , which equals 1. Then, a value  $p_{crit}$  is chosen from 0 to 1 out of a uniform distribution. The first digit  $d$  for which  $\sum_0^d p_{i,con} > p_{crit}$  is selected as the digit to use to make a patchwork. Note that this entire process of calculating frequencies or probabilities *and* cumulative distribution sampling occurs three times every time a creator makes a patchwork, namely once for each colour dimension r, g and b.

### move

Different movement strategies are available for creators, and they can be set by the modeller with a so-called *chooser* in NetLogo's Interface Tab. Each turtle has a *heading*, i.e. a built-in variable indicating the direction it is facing. Movement strategies occur relative to this parameter. For example, if a turtle is supposed to move *ahead*, it does so relative to the direction it is already facing. If it is programmed to move *behind*, it moves backwards from the direction it is already facing.

- **any8** lets creators move to any empty, randomly chosen patch in their Moore neighbourhoods. This strategy is identical with turtle strategy #2 in "One Turtle Per Patch Example"<sup>7</sup>.
- **allButBehind7** lets creators move to any empty, randomly chosen patch in their Moore neighbourhoods except to the patch directly behind themselves.
- **ahead3** lets creators randomly move forward to any empty patch of the three patches ahead of them.
- **straightFd1** lets creators move only to the patch directly one step ahead of them.

Note only one creator per patch is allowed. If all patches assessed by a movement strategy are full, creators remain on the patches they are currently standing on. In this submodel, patchworks' state variable *whosNext* (Table 6.2) is updated.

### forget-some-info

A total of three pieces of information are deleted from creators' memory lists (*cR*, *cG*, *cB*; Table 6.1) every time step. In each list, one colour dimension value with a frequency larger than zero is randomly chosen, and then one is subtracted from this value's frequency counter. Note that colour values are randomly selected per creator memory list, not per creator or total group of creators. Therefore, the loss of information due to "forgetting" is not systematic. In this submodel, creators' state variables *cR*, *cG*, and *cB* (Table 6.1) are updated.

### tick

In this submodel, NetLogo's built-in time counter advances. Time is modelled in discrete steps, called *ticks* in NetLogo.

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<sup>7</sup>This example belongs to NetLogo's Models Library (Copyright 2004 Uri Wilensky) and may be freely copied, distributed, altered, or otherwise used by anyone for any legal purpose.



**update-domain**

During this process all dependent variables and the interim variables used for their calculation are updated (Table 6.5). For the exact equations, see Section 6.6. Additionally, all domain state variables except for *domSize* are updated (see Table 6.4) in this submodel.

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## 6.4 Model verification

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The following measures were taken to verify CRESY-I:

**Coding**

- An object-oriented language was used.
- Meaningful variable names were systematically used for all but local variables.
- Sufficient time was allocated for programming.
- A second programmer was asked to proofread parts of CRESY-I.
- Expert programmers on the NetLogo Users' List were asked for assistance with troublesome algorithms.
- Assertions were added to check whether input parameter values made sense.
- Additional pieces of code were added to each procedure to check input and output plausibility. This code was deleted in the final version.

**Documenting**

- Comments were added to the code to facilitate model-to-program translation.
- NetLogo's Information Tab (Wilensky, 1999) and the ODD protocol (Grimm et al., 2006) were used.

**Observing**

- An abundance of output diagnostics (histograms, monitors, plots of interim and final variables) were programmed in the NetLogo's Interface Tab (Wilensky, 1999).
- The model was animated using NetLogo's "View" (Wilensky, 1999).
- During model building, individual procedures were run singly and their output checked in NetLogo's Command Center (Wilensky, 1999).

### Testing

- Before experimentation, conditions for which output parameters are known were tested by observation. For instance, if there is only one creator type in the world,  $hX.Y$  is undefined. In this case, the model should produce a pseudo number for the measure, namely  $-1$ . Moreover, if the *predefine* sliders are low or high the relative information measure  $h$  for the environment ("*Env*") should reach respective values. This kind of observation testing was carried out for many conditions in which output variable values were known. CRESY-I was not used until the values were as expected.
- All experiments conducted with CRESY-I were run with (theoretically derived) extreme conditions. For example, the number of colours in the initial world was varied from the minimum (1) to the maximum ( $256^3$ ). Also, the creator types were sampled in a way to bring forth very conventional groups (mostly with creator type  $Cx$ ) and highly original ones (mostly with type  $C3$ ).
- In all experiments conducted with CRESY-I, graphical and statistical testing was used to back up modeller observations.

### Comparing

- After each experiment conducted with CRESY-I, data interpretations and discussions containing model-to-program comparisons were documented.

## 6.5 Independent variables

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Of all variables in CRESY-I (see Sections 6.1.2 & 6.3.3), the following were chosen as independent variables for experimentation. They are divided into *technical* and *substantial* variables (see Cioffi-Revilla, 2010)<sup>8</sup>.

### Technical independent variables

1. *density*: The number of creators in the 21x21 torus world.
2. *info-rate*: How many patches creators obtain information from per step.
3. *movement*: How the creators move in the world.
4. *domSize*: How many categories of colours are recognized by the domain and the observer.

### Substantial independent variables

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<sup>8</sup>Cioffi-Revilla (2010) uses the expressions "substantive", "core", "domain-specific" and "theoretically-driven" to describe research questions which differ from purely "technical" questions posed regarding a particular model. Here, this distinction is applied to independent variables.

1. *predefine-r, predefine-g, predefine-b*: How diverse is the world in a simulation's beginning in terms of the predefined amounts of r, g and b values?
2. *creator type ratio*: How many creators of each type make up the sample of creators in the world?
3. *imagination*: How likely is it that creator types *C1*, *C2* and *C3* will create colour values they have never encountered (saved in their memories) before?

## 6.6 Dependent variables

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This section provides descriptions of all dependent variables used in CRESY-I. They are called: *hCAI*, *hCx*, *hC1*, *hC2*, *hC3* and *hX.Y*

### 6.6.1. hCAI

The dependent variable labelled *hCAI* is an index of relative qualitative variation or, in other words, a measure of statistical dispersion in nominal distributions<sup>9</sup>. In CRESY-I it is used to assess the diversity of colours made by all creators at a particular step in the simulation. The formula for this measure is defined as (Attneave, 1959; Bischof, 1995; Mittenacker & Raab, 1973; Moles, 1968; Shannon, 1948)<sup>10</sup>:

$$hCAI = \frac{H}{H_{max}} \quad (6.4)$$

$H$  and  $H_{max}$  in Equation 6.4 are calculated as:

$$hCAI = \frac{-\sum_{j=1}^k rf_j \cdot \log_2 rf_j}{\log_2 k} \quad (6.5)$$

$rf_j$  is the relative frequency of observations in category  $j$ ,

$k$  = number of categories, and

by default  $k = domSize = \{64, 512\}$ .<sup>11</sup>

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<sup>9</sup>The variable name *hCAI* is composed of *h* (a letter used to denote information or entropy), *C* (for creator) and *AI* (symbolizing that colours made by all creators are assessed).

<sup>10</sup>Note the variable names used to refer to this formula may vary according to author.

<sup>11</sup>*domSize* is an independent variable (input measure) in CRESY-I. See Section 6.5 for a description of its substantial meaning.

**The numerator** The numerator of equation 6.5 describes the variability or diversity of a sample of categorical data. It increases with the difficulty to categorize a randomly selected observation from the given sample. This implies that the more categories  $k$  (adds in the numerator) there are, the larger the numerator will be. Moreover, the numerator depends on the distribution of observations in the categories. It reaches a maximum if the observations are equally distributed in the categories ( $rf_j = 1/k$ ), therewith making more "guesses" necessary when trying to categorize a randomly selected observation<sup>12</sup>. If the sample size  $n$  cannot be divided by  $k$ , the maximum cannot be reached. Finally, the numerator is always positive due to the minus sign and  $rf_j \leq 1$  (the logarithm is always negative, because  $\log 1/x = -\log x$ ).

The numerator of *hCall* is also known as "Shannon Index", entropy, information entropy, average information, uncertainty (Attneave, 1959; Bischof, 1995; Garner & Hake, 1951; McGill, 1954; Mittenecker & Raab, 1973; Moles, 1968; Pierce, 1980; Shannon, 1948; Young, 1971), and sometimes mistakenly as "Shannon-Weaver Index" or "Shannon-Wiener Index" (Spellerberg & Fedor, 2003). Furthermore, a common unit of measurement of information is the binary digit ("bit"; Attneave, 1959), which is why logarithms to the base 2 are used.

**The denominator** The denominator of Equation 6.5 contains the formula for maximum information (i.e. dispersion, variation) for  $k = domSize$  categories. This maximum can only occur when all categories have an equal number of observations. In CRESY-I, this would mean at a specific step in the simulation all possible colours ( $= domSize$ ) are equally frequent.

**What the fraction in Equation 6.5 means** Dividing the numerator in Equation 6.5 by its denominator describes the average information (numerator) of a particular event (step in simulation time) as a proportion of the maximum information (denominator) for that event. In other terms, the fraction describes the ratio of observed diversity (differences) to maximum diversity (differences). It is a standardized or relative measure of information (e.g. dispersion, variability, diversity, qualitative variation, etc.) which can vary between 0 – 1. *hCall* therefore describes the percentage of diversity in relation to maximum diversity produced by all creators. The higher this value, the greater the diversity of colours all creators produce at a given step in the simulation. If, for instance,  $domSize = 64$  and  $hCall = 1$ , all 64 colour categories would have exactly the same number of observations, i.e. the colours would be equally distributed among the categories.

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<sup>12</sup>Attneave (1959) illustrates the numerator's dependency on the number of categories ( $k$ ) and the data's distribution in the categories ( $rf_j$ ) in the following manner: "...the uncertainty of a question increases with the number of alternative answers it might have (provided the different answers are equally probable). Thus the result of throwing a die is more uncertain than that of tossing a coin, since a die may fall in six ways and a coin only in two..." (p. 2).

### hCx, hC1, hC2, hC3

The supplementary dependent variables labelled  $hCx$ ,  $hC1$ ,  $hC2$  and  $hC3$  are calculated in exactly the same manner as  $hCAII$  (see Equation 6.5), but each refers to a separate subsample of creators.  $hCx$  assesses the dispersion of colours produced by creator type  $Cx$  at a specific step in the simulation,  $hC1$  that of creator type  $hC1$ , etc. See Section 6.3.3 for substantial explanations of the creator types  $Cx$ ,  $C1$ ,  $C2$  and  $C3$ . In CRESY-I, these dependent variables are used for debugging and non-experimental exploration purposes.

### 6.6.2. hX.Y

The dependent variable labelled  $hX.Y$  refers to the mutual information<sup>13</sup> of two discrete variables  $X$  and  $Y$ , whereas in CRESY-I  $X$  refers to the four creator types ( $Cx$ ,  $C1$ ,  $C2$  and  $C3$ ) and  $Y$  to the  $c = k = domSize$  categories of colours. On a more general level,  $hX.Y$  is a directional measure of the association between two nominal variables:

$$hX.Y = \frac{\text{mutual information of } X \text{ and } Y}{\text{information measure for } X} \quad (6.6)$$

It is calculated as (Attneave, 1959; Bischof, 1995; Mittenecker & Raab, 1973; Rausche, 1999)<sup>14</sup>:

$$hX.Y = \frac{h_X + h_Y - h_{XY}}{h_X} \quad (6.7)$$

whereas  $0 \leq (h_X + h_Y - h_{XY}) \leq \min(h_X, h_Y)$ , and

$$h_X = - \sum_{i=1}^r rf_i \cdot \log_2 rf_i$$

$$h_Y = - \sum_{j=1}^c rf_j \cdot \log_2 rf_j$$

$$h_{XY} = - \sum_{i=1}^r \sum_{j=1}^c rf_{ij} \cdot \log_2 rf_{ij}$$

$r$  = number of discrete categories of variable  $X$

$c$  = number of discrete categories of variable  $Y$

$rf$  = relative frequency of observations in a particular category

<sup>13</sup>This measure often goes by "Transinformationsquotient" ("transinformation quotient") in German (Rausche, 1999; Mittenecker & Raab, 1973).

<sup>14</sup>Note the variable names used to refer to this formula may vary according to author.

**The numerator** Each addend in the numerator refers to a different way of categorizing the same set of observations, i.e. depending on the informational perspective, a different number of categories can be used to order the same set of data. Imagine a contingency table with rows  $r = 4$ , columns  $c = 64$  and therewith a total of cells  $r \cdot c = 4 \cdot 64 = 256$ . The addend  $h_X$  is the information measure for the variable  $X$  with categories  $r = 4$  (taking the marginal row totals into account), and the addend  $h_Y$  is the information measure for the variable  $Y$  with categories  $c = 64$  (taking the marginal column totals into account). The addend  $h_{XY}$  is the information measure for the set of data in the  $r \cdot c$  cells, which is a different way of categorizing the observations in the table. The numerator represents the overlap between  $h_X$  and  $h_Y$  within the confines of  $h_{XY}$  (Attneave, 1959, p. 49). It can also be described as the "information in the *joint occurrence*" (Attneave, 1959, p. 47) of  $X$  and  $Y$ . Together, the addends in the numerator are sometimes referred to as *transinformation*  $t_{XY}$  (Rausche, 1999) or *transmitted* or *shared information* (Attneave, 1959, p. 50).

**The denominator** The directionality of  $h_{X.Y}$  is determined by the denominator. In Equation 6.7, the denominator equals the information measure for  $X$  (creator types, categories  $c = 4$ ). If, for example, the denominator in Equation 6.7 were  $h_Y$ , this measure would be labelled  $h_{Y.X}$ .

**What the fraction in Equation 6.7 means** Dividing the mutual information (numerator) of  $X$  (creators types) and  $Y$  (colour categories) by the information measure (denominator) of  $X$  describes how much variability in the joint distribution  $XY$  can be "explained" by  $X$ . In CRESY-I, this means how well a creator type can be "predicted" or "guessed" by looking at a randomly selected colour. Such an interpretation is important for discriminating the creator types from each other, therewith assessing their validity as different behavioural types. In other words, do the creators behave as they are presumed to? Does  $C_x$  always produce a few particular colours and  $C_3$  a potpourri of colours?  $h_{X.Y}$  varies from 0 – 1.

## 6.7 Experimental design

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A total of five experiments were conducted with CRESY-I (see Figure 6.5). The first two experiments, CI-1a and CI-1b, were conceived to investigate the technical independent variables *density*, *info-rate*, *movement* and *domSize*. Experiment CI-1a explored how many runs and steps per run should be used in Experiment CI-1b's conditions, while the latter tested the effects the technical independent variables have on the dependent variables. See Sections A.1 - A.2 in the Appendix for a full documentation of these experiments. The results obtained in these first two experiments were used to design the last three. Experiments CI-2a, CI-2a-SupplExp and CI-2b were designed to investigate the substantial independent variables *creator ratio*, *imagina-*

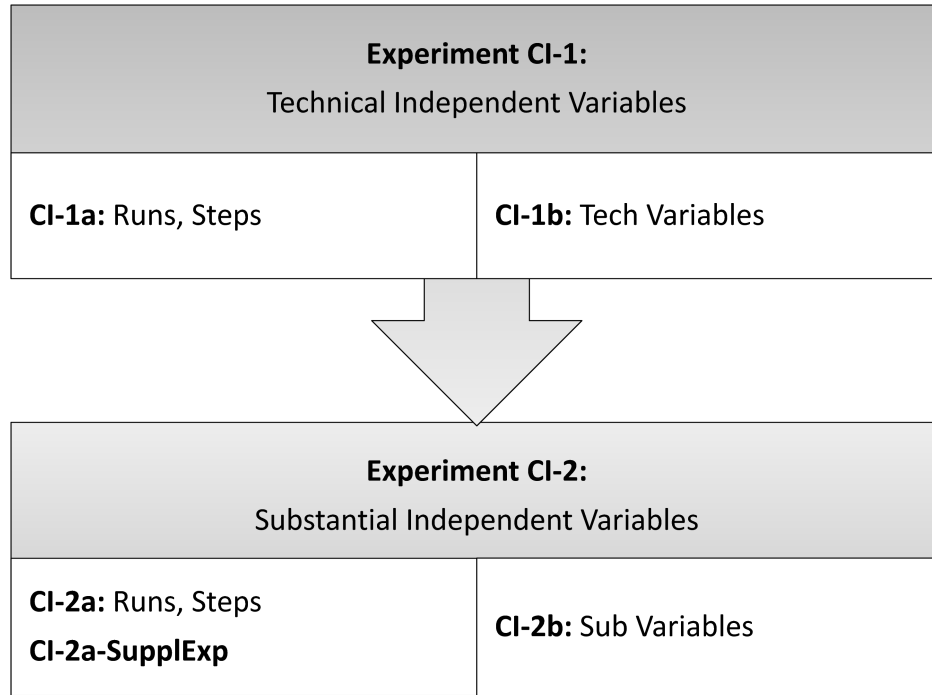


Figure 6.5.: Overview of experiments conducted with CRESY-I. Five experiments were conducted: CI-1a, CI-1b, CI-2a, CI-2a-SupplExp and CI-2b. Experiment CI-2a-SupplExp was conducted *ad hoc* after reviewing the results of Experiment CI-2a. See Section A.3 of the Appendix for full documentation.

tion, *predefine-r/-g/-b* and *domSize*<sup>15</sup>. Analogous to Experiment CI-1a, Experiment CI-2a explored how many runs and steps per run should be used in Experiment CI-2b, which systematically tested the effects the substantial independent variables have on the dependent variables. For a complete documentation of Experiments CI-2a and CI-2a-SupplExp, see Section A.3 in the Appendix. Experiment CI-2b is thoroughly described in Chapter 7.

<sup>15</sup>Due to the results in Experiment CI-1b (Section A.2 in the Appendix), the independent variable *domSize* was retested as a substantial independent variable in Experiments CI-2a and CI-2a-SupplExp (Section A.3 in the Appendix).





# 7

## CRESY-I

In the course of this dissertation, a total of five experiments were conducted with CRESY-I. The first four are documented in Sections A.1, A.2 and A.3 of the Appendix (see Section 6.7 and Figure 6.5 for a general overview). This chapter documents the last and main experiment conducted with CRESY-I, Experiment CI-2b. Its purpose is to explore how CRESY-I's substantial independent variables affect the dependent variables. Chapter 7 serves as the primary documentation of theoretical input behind CRESY-I, so it begins with a description of those models of individual creativity which served as the basis for the translation into CRESY-I's NetLogo code (Section 7.1). It continues with sections on Experiment CI-2b's methodology (7.2) and results (7.3), and it closes with a discussion (7.4).

### 7.1 Theory

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Psychological research on the creative individual offers a plethora of theories to irradiate this entity. Trait theories of creativity link the construct to particular personality or behavioural styles to describe the creative individual (Guilford, 1950; Sawyer, 2006). Accordingly, creative people consistently exhibit the following, partly overlapping characteristics (Feist, 1999; McCrae, 1987; Ochse, 1990; Schuler & Görlich, 2006): openness (e.g. curiosity, broad interests, tolerance of ambiguity, sensation seeking, boredom susceptibility), motivation to perform (e.g. drive, ambition, perseverance, delay of gratification), non-conformity (e.g. impulsiveness, autonomy, independence of judgement, social deviance), self-confidence (e.g. independence, risk-taking, creative self-image) and experience (e.g. knowledge, metacognitive skills, preference for complexity).

Some creativity researchers have derived cognitive styles to describe creative behaviour, such as Kirton's (1976) personality continuum of "adaptors" to "innovators". Accordingly, "...everyone can be located on a continuum ranging from the ability to 'do things better' to an ability to 'do things differently'..." (Kirton, 1976, p. 622). In other words, adaptors maintain existing paradigms, whereas innovators deviate from established ones (see also Dewett & Williams, 2007; Kwang et al., 2005). Kirton (1976) viewed this cognitive style as a basic dimension of personality which becomes observable in "any situation where creativity, problem solving, and decision making are applicable" (p. 629). His ideas reflect a common perspective

in personality psychological research on creativity: Creative people differ from their less creative peers in stable attributes<sup>1</sup>.

Cognitive theories of creativity connect individuals' measured variations in this construct to differences in the way they perceive and process information. So-called stage models depict creativity as a mental process containing the following, cyclical phases: preparation, incubation, insight and verification<sup>2</sup>. Other cognitive models of creativity offer descriptions of the mental operations assumed responsible for the human capacity to form ideas or solutions, i.e. they are models of what kind of information processing occurs between preparation and insight phases (Mumford, 2003; Simonton, 2002; Ward et al., 1999; Welling, 2007). Often based on introspective reports by famous creators (Brower, 2003; Campbell, 1960; Mednick, 1962; Simonton, 2003), in such models mental operations are interpreted as acts of combining or recombining elements (e.g. units of knowledge, memes, concepts) to form something novel (Sawyer, 2006; Sternberg & Lubart, 1999; Ward et al., 1999). A famous example for recombination including previous as well as novel ideas is the discovery of the chemical structure of DNA (Watson & Crick, 1953). Moreover, Sawyer (2006) describes a newly formed combination metaphorically as a data structure:

...with variables or slots that can be set to different values ... we can explain conceptual combination as a process of slot filling. Values of the slots of one schema filling in the values of the other, as the two schemas merge to form a single new one (p. 66).

In other terms, people transform or reorganize information they perceive based on their individual prerequisites (Beghetto & Kaufman, 2007), and this "processing" occurs on the basis of personal knowledge and experiential history (Gruber, 1988; Sawyer, 2006; Smith, 2008; Stokes, 2007; Welling, 2007). As Brower (2003) noted, "Creative individuals ... engage in an across-time, persistent series of transformations that begin with a knowledge base and result in the emergence of a valued product" (p. 63).

Campbell's (1960) model of blind variation and selective retention (BVSR) in creative thought illustrates how new knowledge emerges (see also Cziko, 1998; Richards, 1977; Simonton, 1998). Focusing on individuals in this theoretical model, he assumes they dispose of a mechanism for creating variations, a coherent process for selection as well as a mechanism for storing and reproducing previously selected variations. In

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<sup>1</sup>This notion has been challenged by some creativity researchers who claim creative people do not exhibit particular, stable attributes. They rather consistently exhibit great flexibility on personality assessment scales. This means their behaviour can move from one pole of a scale to the other, depending on their needs, the context, etc. (Abuhamdeh & Csikszentmihalyi, 2004). There is a lack of longitudinal studies on the creative personality to support this noteworthy idea. However, the general assumption that creative people are not as reliable and predictable as their less creative peers is quite common (Kirton, 1976; Stokes, 1999, 2007).

<sup>2</sup>Note the names and number of phases vary slightly from author to author. See for example Gruber (1988) or Sawyer (2006).

using the term "blind", Campbell (1960) means it is impossible to know beforehand if a generated variation will be selected, i.e. what impact newly generated knowledge will have on a relevant environment. Moreover, he left room in BSVR theorizing for individual differences he assumed to potentially exist in degree of information, intelligence, number and range of variations produced, as well as selection criteria.

Basing his perspective largely on extensive historiometric studies of scientific creativity, Simonton (2003, 2004) defines the construct as a constrained stochastic process. He postulates individuals possess an ever-evolving sample of ideas stemming from an idea population, e.g. a particular scientific discipline or domain (Csikszentmihalyi, 1999). The stochasticity of the creative process comes in when individuals use their idea samples in free recombination to discover novel and appropriate permutations, that is they process their ideas in a "combinatorial hopper" (Simonton, 2003, p. 478). Constraints arise thereafter when the creating individuals or other relevant gatekeepers filter the permutations in evaluative processes (Abuhamdeh & Csikszentmihalyi, 2004; Csikszentmihalyi, 1999). Individuals share parts of their idea subsets with others, but they also have ideas specific to their own subsets. They result from discrepancies in personal history, e.g. experience, training, knowledge. Moreover, Simonton (2003) admits scientists vary in their idea sample sizes as well as in other individual-difference variables which "must have direct effects on cognitive processes involved in creative problem solving" (p. 488).

Another classic example of a cognitive model of individual creativity is Mednick's (1962) associative basis of the creative process, which defines creative thinking as the forming of new and useful associations by connecting separate elements embedded in a (knowledge) network. Accordingly, associations are organized into hierarchies and are characterized by their strength. The strength of an association refers to the likelihood that a person will think of a particular element if another element is given as a cue. For instance, if the word "dog" is presented as a stimulus and participants are asked to respond it by stating all other words coming to their minds, they may say "leash", "pet", "bark", "wood" or "days". What and how many words they say depends on the organization of their individual associative hierarchies. Mednick (1962) conceived a dichotomous typology of individuals who possess either steep or flat associative hierarchies. A person with a steep, stereotyped associative hierarchy would, for instance, easily respond to "dog" with words relating to a dog as a pet or an animal. Compared with other possible associations, these associations would be characterized by high or dominant strengths. On the other hand, people with flat associative hierarchies would respond to "dog" with other words besides those commonly stated by people with steep hierarchies. That is, even if they stated stereotypical responses to "dog", they would also state other uncommon responses, meaning a) their dominant responses are less strong compared with the steep associations of their counterparts, and b) they potentially have more associations at their disposal. Mednick (1962) argued that people with flat associative hierarchies are more likely to produce original and potentially creative associations<sup>3</sup>. In sum, the

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<sup>3</sup>In his original article, Mednick (1962) also conceived a person with a steep, yet non-stereotypical

mental models outlined here describe a common denominator in cognitive psychological research on creativity: New ideas or solutions emerge via mental (re)combination of elements (Sawyer, 2006; Sternberg & Lubart, 1999) and creative people are assumed to process information in manners which differ from normative, established ways of thinking (Fink, 2008; Meyer, 2008).

Recently, Stokes (1999, 2001, 2007) has reintroduced behaviouristic ideas to creativity research (see also Skinner, 1972). Basing her work on learned variability theory, she describes creativity in terms of behavioural variability. Representing a measure of how differently a person behaves, Stokes (1999, 2007) construes variability as a continuum with two extremes. Accordingly, it ranges from stereotype/predictable to unreliable/novel. People, therefore, behave more or less predictable or more or less variable. Similar to the cognitive approaches described above, Stokes (2007) assumes elements are (re)combined when people behave creatively (see also Stokes & Fisher, 2005).

Summarizing, the majority of psychological approaches to individual creativity – the variation subprocess in VSR models – coincide in the assumption that observable behaviour is necessary to determine individual differences in creativity. Moreover, the behaviour exhibited emerges from individual information processing, i.e. (re)combination of units of knowledge or experience specific to the individual creating. Depending on creative type or style, information processing occurs differently. Whatever exactly happens in a creator's mind when conjuring, its outcome is described by observing scientists as combinations of elements representing what in everyday language are called ideas, products, concepts, artefacts, etc. Lastly, many psychological approaches tend to view individual creativity as dichotomous, i.e. people are creative or not, although the same approaches assume a continuum to relate these extremes. Agents (creators) designed to produce variations should, based on the models of individual creativity outlined above, therefore feature the following (see also Section 3.6):

- perceive and exchange information in their environment
- have specific, individual knowledge based on their past and present experience in their environment
- exhibit observable behaviour by producing a distinct variation
- create a variation by means of (re)combination of knowledge elements
- differ from peers by having a particular, consistent variation style located somewhere on a (theoretical) continuum from less to more predictable

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associative hierarchy. In his opinion, such a person would have dominant associative strengths between elements uncommonly connected. This would make the person quite original when compared with people with steep, stereotypical hierarchies, but at the same time more predictable than people with flat associative hierarchies.

### 7.1.1. Research questions

CI-2b is the last experiment in an extensive experimental exploration conducted with CRESY-I. Its purpose is to investigate the effects substantial independent variables have on the dependent variables. The variables are explained in detail below (Section 7.2). The main research questions are:

- How do three selected substantial independent variables affect the development of the dependent variables?
- Which hypotheses about the variation process of creativity can be generated from the simulated data?

## 7.2 Method

This section describes the experimental design chosen for Experiment CI-2b. It was derived based on results obtained in previous experiments<sup>4</sup>. The ODD protocol for CRESY-I is part of Chapter 6, the "roadmap" to the model. Experiment CI-2b has a total of 45 conditions. Three substantial input parameters were varied (see also Figure 7.1):

**predefine (p):** The interface sliders *predefine-r*, *predefine-g* and *predefine-b* were collectively set to one of three different numbers representing low, medium and high values (1, 128, 256). The substantial independent variable *predefine* refers to how colourful (diverse) the environment is at the begin of a simulation run. It represents the **macrosystem** in this simulated world.

**cRatio (c):** The ratio of creators (Cx:C1:C2:C3) was varied to reflect different levels of a sample's potential to produce diversity: low (3:0:0:1), medium (1:1:1:1) and high (1:0:0:3)<sup>5</sup>. This variable reflects the **microsystem** in the simulated world.

**imagination (i):** As previous, non-experimental exploration with CRESY-I indicated that *imagination* values above 0.05 lead to consistently low values of the dependent variable *hX.Y*, this variable was varied linearly in a range from 0.001–0.05. Five values were selected for experimentation (Figure 7.1). *Imagination* refers to the **individual systems** in this simulated world.

The technical independent variables were set to values tested and used in previous experiments<sup>6</sup>. A total of 30 runs with 6,000 steps each were conducted per experimental condition (see Section A.3.4 for a discussion on this issue). The dependent variables *hCall* and *hX.Y* were collected at each step of each run.

<sup>4</sup>They are not reiterated here. Please refer to Section 6.7 in Chapter 6 and Sections A.1, A.2 and A.3 of the Appendix.

<sup>5</sup>The variable's values appear without colons in this chapter's figures.

<sup>6</sup>The world was a 21x21 torus. *number-creators* was set to 4. Creators' *info-rate* was *n4*, their movement strategy *any8*. *domSize* was set to 512 (see Sections A.1, A.2 and A.3 of the Appendix).

predefine-r & predefine-g & predefine-b															
1				128				256							
creator type ratio (Cx:C1:C2:C3)															
3:0:0:1				1:1:1:1		1:0:0:3		3:0:0:1		1:1:1:1		1:0:0:3			
imagination															
0.00100	0.01325	0.02250	0.03775	0.05000	0.00100	0.01325	0.02250	0.03775	0.05000	0.00100	0.01325	0.02250	0.03775	0.05000	0.00100
0.05000	0.00100	0.01325	0.02250	0.03775	0.00100	0.01325	0.02250	0.03775	0.05000	0.00100	0.01325	0.02250	0.03775	0.05000	0.00100
0.00100	0.05000	0.00100	0.01325	0.02250	0.00100	0.01325	0.02250	0.03775	0.05000	0.00100	0.01325	0.02250	0.03775	0.05000	0.00100
0.05000	0.00100	0.00100	0.05000	0.00100	0.00100	0.05000	0.00100	0.00100	0.05000	0.00100	0.00100	0.05000	0.00100	0.00100	0.05000
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## 7.3 Data analyses and results

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Each experimental condition produced an output file which was subsequently analysed with R (Version 2.11.1). The following steps were taken:

1. Graphical analyses were conducted to gain a visual overview of *hCall* and *hX.Y* per experimental condition.
2. Quantitative descriptors were chosen to aggregate the abundance of simulation runs (time series of *hCall* and *hX.Y*) in a simple way.
3. Analyses of variances were conducted with the quantitative descriptors to gain insight into how *predefine*, *cRatio* and *imagination* affect *hCall* as well as *hX.Y*.

### 7.3.1. Graphical data analyses

#### Violin plots

A graphical method to display numerical data, violin plots are vertical boxplots with rotated kernel density plots at both left and right sides. There is no difference in the density plots other than the direction in which they extend. "The information that violin plots add to box plots increases the potential of these tools when used in data exploration" (Hintze & Nelson, 1998, pp. 181+). Note that the symbols in violin plots differ from those in boxplots: The white dot represents the median, and the thick black line the interquartile range (IQR). The thin black lines extend to the lowest datum still within 1.5 IQR of the lower quartile and to the highest datum still within 1.5 IQR of the upper quartile. Outliers of any kind are not depicted with extra symbols in violin plots. The density plots indicate them, however, because the entire data range is depicted. See Figures 7.4 – 7.5 for the results of this step.

### 7.3.2. Aggregating dependent variables

Each experimental condition produced 30 time series for each dependent variable (*hCall* & *hX.Y*). Two measures, the mode and the coefficient of variation, were chosen to describe them. They were selected based on principles of pragmatism and comprehension: The descriptors should be easy to calculate and to understand. By aggregating every time series of every dependent variable to one mode and one coefficient of variation, the simulation data were reduced to 30 single observations per experimental condition, dependent variable and quantitative descriptor (see Figure 7.2).

#### The mode: A quantitative descriptor of average location

The mode was chosen to describe the most characteristic level of each simulation run. It is "closer to the intuitive understanding of an 'average' than are the mean

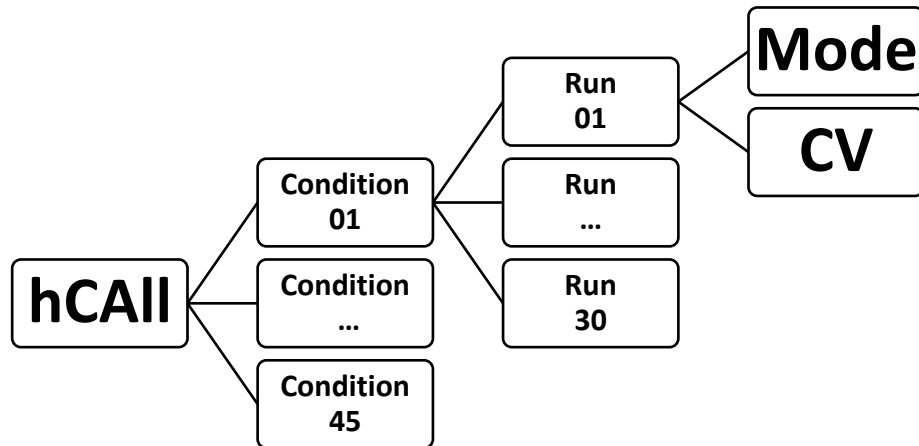


Figure 7.2.: Simplified example of aggregating time series data: The dependent variable *hCAII* was measured in 45 conditions of Experiment CI-2b. Each condition consisted of 30 simulation runs with 6,000 steps. Each run was condensed to one mode and one coefficient of variation (CV). The latter measures were used as dependent variables in ANOVAs. The same aggregation process was conducted for the dependent variable *hX.Y*.

and the median since it is the value with the maximum probability (Bickel, 2002, p. 154). As both dependent variables (*hCAII* & *hX.Y*) are continuous, the mode mathematically represents the value with the highest frequency density. Using the mode as an indicator of average location is most applicable when the data is unimodal, highly skewed, and has a large number of outliers. A brief visual analysis of Figures 7.4 and 7.5 show that all time series are unimodal and skewed. The presence of outliers in each experimental condition is visible in the "tails" of the violin plots. All modes were calculated with the half range mode estimation method described by Bickel (2002) using R's mode estimation package "modeest".

### The coefficient of variation: A quantitative descriptor of variability

The coefficient of variation (CV) is a measure of variability which scales the standard deviation ( $s_x$ ) of a particular variable ( $x$ ) by the magnitude of the variable's mean ( $\bar{x}$ ). The fraction is multiplied by 100 to express the result as a percentage:

$$CV = \frac{s_x}{\bar{x}} \cdot 100 \quad (7.1)$$

This statistic is useful for comparing the degree of variation from one data series



to another. The lower it is, the less volatility or risk in a data series<sup>7</sup>. The CV of the dependent variable  $hCAII$  describes how (un)stable creators' patchwork diversity is over  $t$  simulation ticks. The CV of the dependent variable  $hX.Y$  describes how volatile the average ability to recognize creator types based on their products is.

#### Correlation diagrams

The modes and CVs for  $hCAII$  and  $hX.Y$  were correlated in this step to gain an overview of their association. See Figure 7.3 for the results.

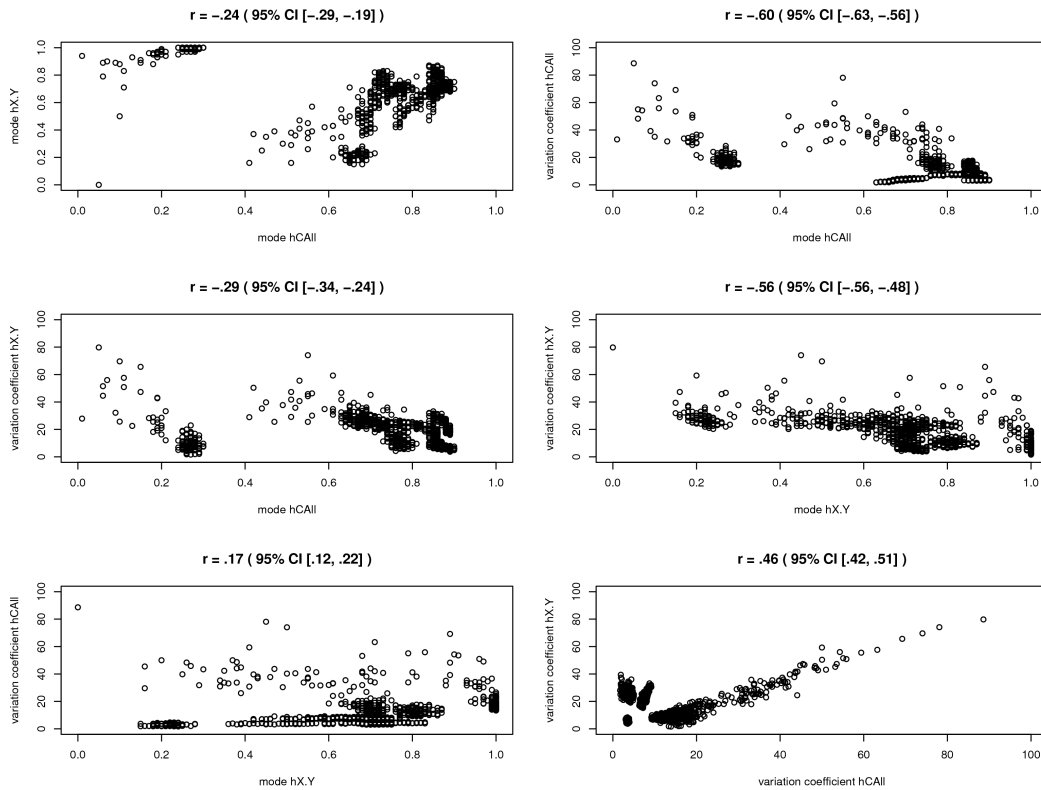


Figure 7.3.: Experiment CI-2b: Correlations between dependent variables  $hCAII$  and  $hX.Y$  (modes and CVs). All correlations were significant ( $p < 0.01$ ).

<sup>7</sup>High volatility of a variable expressed as a high coefficient of variation indicates movement or fluctuation in a system. On a general level, this could be a creative characteristic of a system, as movement indicates things are not remaining in one state, but are changing and perhaps evolving. Specifically, it is a matter of interpretation based on the particular variable  $x$  which CV refers to and on how creativity is defined for a particular system.

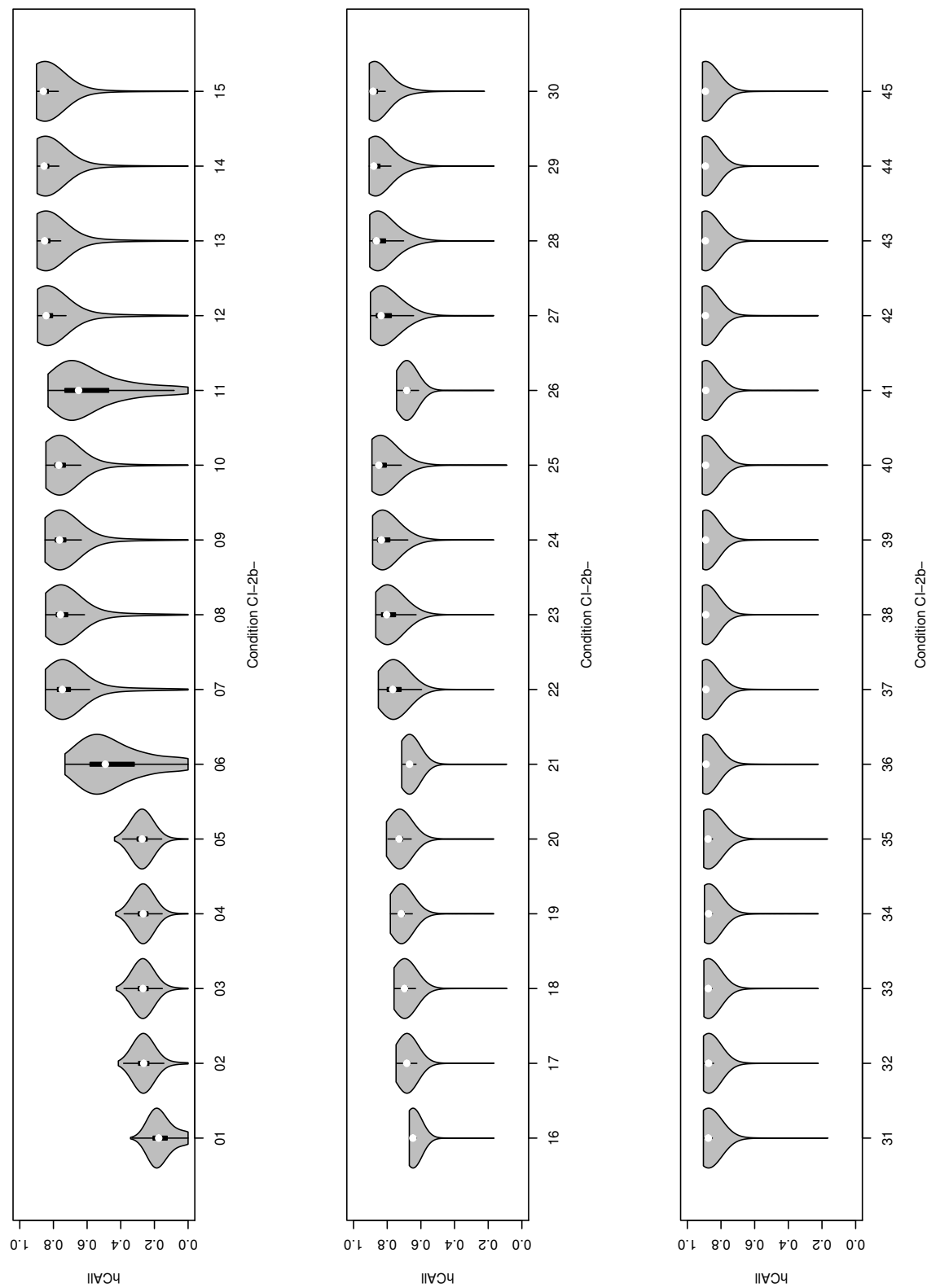


Figure 7.4.: Experiment CI-2b: Violin plots for hCAII

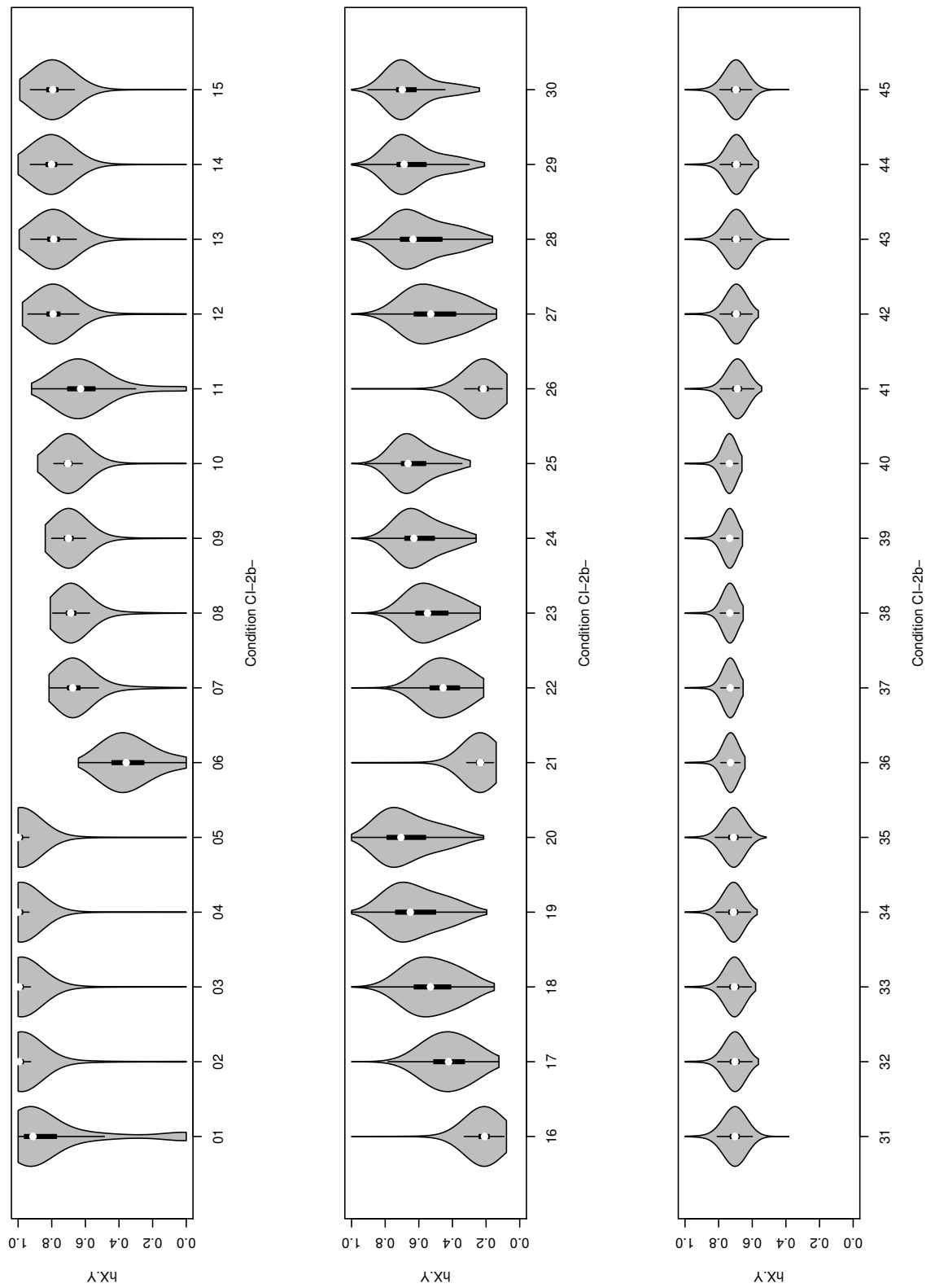


Figure 7.5.: Experiment CI-2b: Violin plots for  $hX.Y$

### 7.3.3. Analyses of variances

Three-way independent analyses of variances were conducted with the independent variables *predefine* (p), *cRatio* (c) and *imagination* (i) to test their effects on the average level (mode) and volatility (CV) of *hCAII* and *hX.Y*. The effect size  $\hat{\omega}_G^2$  (generalized omega squared; Olejnik & Algina, 2003) was additionally calculated for each effect. The results are summarised in Tables 7.1 – 7.4. Figure 7.6 summarises the modes and coefficients of variation of *hCAII* and *hX.Y* graphically.

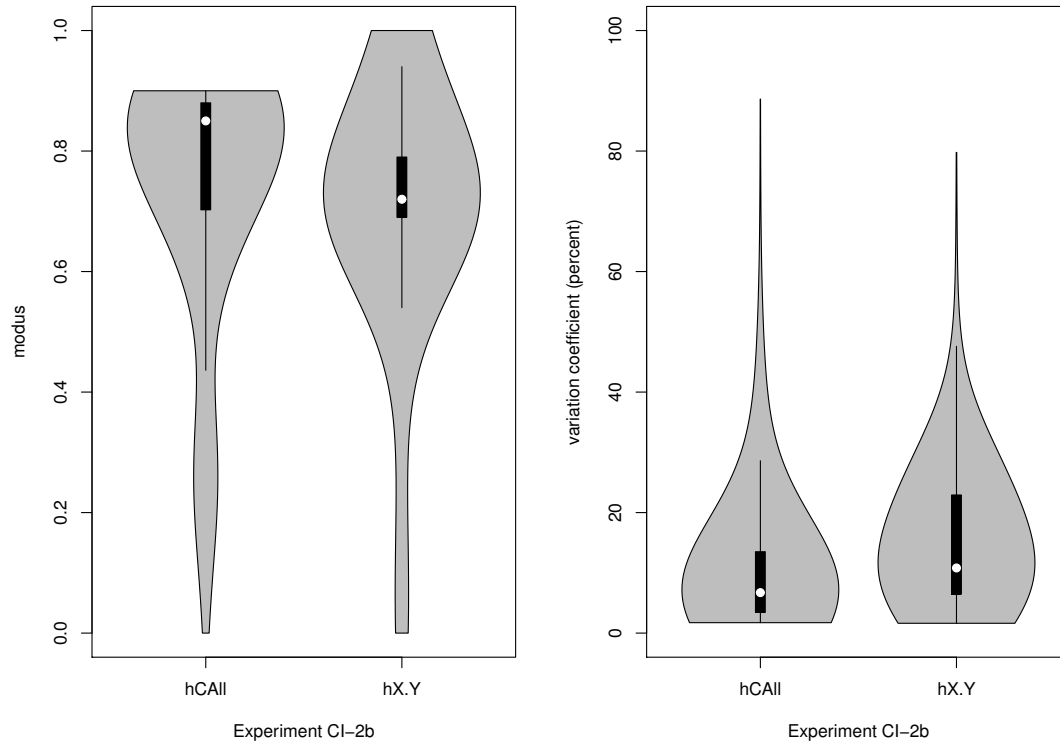


Figure 7.6.: Violin plots of the modes and coefficients of variation of *hCAII* and *hX.Y*. Each violin plot contains 1350 simulation runs from 45 experimental conditions.

**hCAII Modes** All effects except for the second-order interaction are significant. The first-order interactions are ordinal (Bortz & Döring, 2002, p. 534; Figure 7.7). The results are described in the following and in Table 7.1:

- **First-order interaction p x c ( $\hat{\omega}_G^2 = 0.75$ ):** The level of environmental diversity (*predefine*; p) differently affects the performance of samples (*cRatio*; c) in terms of the most common patchwork diversity level (*hCAII* mode). In a highly diverse initial world (p = 256), samples do not differ in performance. Slight differences are noticeable when the world is moderately diverse (p = 128). An

an obvious spread in diversity levels occurs when the initial world is minimally diverse ( $p = 1$ ). The least original sample ( $c = 3:0:0:1$ ) performs worst in this case. The most original sample ( $c = 1:0:0:3$ ) reaches a comparably high diversity level independent of the environment, while sample  $c = 3:0:0:1$  requires a larger amount of information to reach the diversity levels of the other samples (see top diagrams in Figure 7.7).

- **First-order interaction  $p \times i$  ( $\hat{\omega}_G^2 = 0.09$ ):** All levels of *predefine* ( $p$ ) have approximately the same effect on *hCAII* modes for each value of *imagination* ( $i$ ). The exceptions are conditions in which  $i = 0.001$  and  $p = 1$  or  $p = 128$ . In these cases, lower diversity levels are obtained (see middle diagrams in Figure 7.7).
- **First-order interaction  $c \times i$  ( $\hat{\omega}_G^2 = 0.01$ ):** All levels of *imagination* ( $i$ ) have approximately the same effect on patchwork diversity levels (*hCAII* modes) for each kind of sample (*cRatio*;  $c$ ). The exceptions are conditions in which  $i = 0.001$ . In these cases, noticeably lower diversity levels are reached (see bottom diagrams in Figure 7.7).
- **Main effect *predefine*  $p$  ( $\hat{\omega}_G^2 = 0.80$ ):** The common level of patchwork diversity achieved by creators after 6,000 steps slightly, yet significantly increases with the initial environmental diversity (*predefine*;  $p$ ).
- **Main effect *cRatio*  $c$  ( $\hat{\omega}_G^2 = 0.77$ ):** The common level of patchwork diversity achieved by creators after 6,000 steps slightly, yet significantly increases with the proportion of original creators in the sample (*cRatio*,  $c$ ).
- **Main effect *imagination*  $i$  ( $\hat{\omega}_G^2 = 0.23$ ):** The common level of patchwork diversity achieved by creators after 6,000 steps is significantly smaller when *imagination* is lowest ( $i = 0.001$ ).

**hCAII CVs** The first-order effects *predefine*  $\times$  *cRatio* ( $p \times c$ ) and *predefine*  $\times$  *imagination* ( $p \times i$ ) are significant, as well as the main effects *predefine* ( $p$ ) and *imagination* ( $i$ ). The first-order interaction  $p \times c$  is ordinal, whereas the first-order interaction  $p \times i$  is hybrid (Bortz & Döring, 2002, p. 534; see Figure 7.8). The results are reported in the following and Table 7.2:

- **First-order interaction  $p \times i$  ( $\hat{\omega}_G^2 = 0.21$ ):** In moderately ( $p = 128$ ) and highly ( $p = 256$ ) diverse initial worlds, creators' patchwork diversity is comparably stable over 6,000 steps for each *imagination* ( $i$ ) value. In a minimally ( $p = 1$ ) diverse world *hCAII* is less stable, especially when *imagination* is the lowest ( $i = 0.001$ ; see middle diagrams in Figure 7.8).
- **First-order interaction  $p \times c$  ( $\hat{\omega}_G^2 = 0.02$ ):** When the initial world is minimally diverse ( $p = 1$ ), patchwork diversity is less stable for all samples (*cRatio*;  $c$ ). In all other conditions, diversity fluctuation is comparably minimal (see top diagrams in Figure 7.8).

- **main effect p** ( $\hat{\omega}_G^2 = 0.55$ ): The level of diversity fluctuation (*hCAII* CV) depends on the set level for *predefine* (p). The differences between this measure's stability in conditions with p = 128 and p = 256 are negligible. Diversity fluctuates comparably more in minimally (p = 1) diverse initial worlds.

**hX.Y Modes** All effects are significant except for the first-order interaction between *cRatio* (c) and *imagination* (i) and the second-order interaction. The interaction p x c is disordinal, whereas the interaction p x i is hybrid (Bortz & Döring, 2002, p. 534; see Figure 7.9). The results are reported in the following and in Table 7.3:

- **First-order interaction predefine x cRatio (p x c;  $\hat{\omega}_G^2 = 0.11$ )**: The common levels of creator type differentiation (*hX.Y* modes) differ minimally in highly (p = 256) and moderately (p = 128) diverse environments for all sample types (*cRatio*; c). In these cases, creator types can be discriminated with approximately the same magnitude. In minimally (p = 1) diverse initial worlds, however, the case is different. The least original sample (c = 3:0:0:1) can be discriminated almost perfectly (see top diagrams in Figure 7.9).
- **First-order interaction predefine x imagination (p x i;  $\hat{\omega}_G^2 = 0.05$ )**: In highly diverse initial worlds (p = 256), creator types can be discriminated equally well independent of their *imagination* (i) values. In minimally diverse worlds (p = 1), this also applies except when *imagination* is lowest (i = 0.001). Creator type differentiation decreases then. In moderately diverse worlds (p = 128), creator type differentiation steadily drops as *imagination* (i) values decrease (see middle diagrams in Figure 7.9).

**hX.Y CVs** The first-order interaction *predefine* x *imagination* (p x i) is significant and hybrid (Bortz & Döring, 2002, p. 534; see Figure 7.10). The main effects *predefine* (p) and *imagination* (i) are also significant. The results are reported in the following list and in Table 7.4. The results of all analyses of variances are summarized in Table 7.5.

- **First-order interaction p x i ( $\hat{\omega}_G^2 = 0.12$ )**: In highly (p = 256) and moderately (p = 128) diverse initial worlds, creator type differentiation (*hX.Y*) is similarly stable for all *imagination* (i) values. In a minimally (p = 1) diverse initial world, creator type differentiation is more volatile when *imagination* is lowest (i = 0.001; see middle diagrams in Figure 7.10).
- **Main effect p ( $\hat{\omega}_G^2 = 0.16$ )**: The instability of creator type differentiation is comparably low in minimally (p = 1) and maximally (p = 256) diverse worlds. It is slightly, yet significantly higher in moderately (p = 128) diverse worlds.

Table 7.1.: Three-Way Independent Analysis of Variance for hCAII Modes

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	5344.66***	0.80(1) <sup>2</sup>	<2.2e-16
cRatio (c)	1	4405.85***	0.77(2)	<2.2e-16
imagination (i)	1	405.65***	0.23(4)	<2.2e-16
p x c	1	3995.26***	0.75(3)	<2.2e-16
p x i	1	135.38***	0.09(5)	<2.2e-16
c x i	1	21.99***	0.01(6)	3.02e-06
p x c x i	1	3.61	0.00(7)	0.06
Residuals	1342	(0.003) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

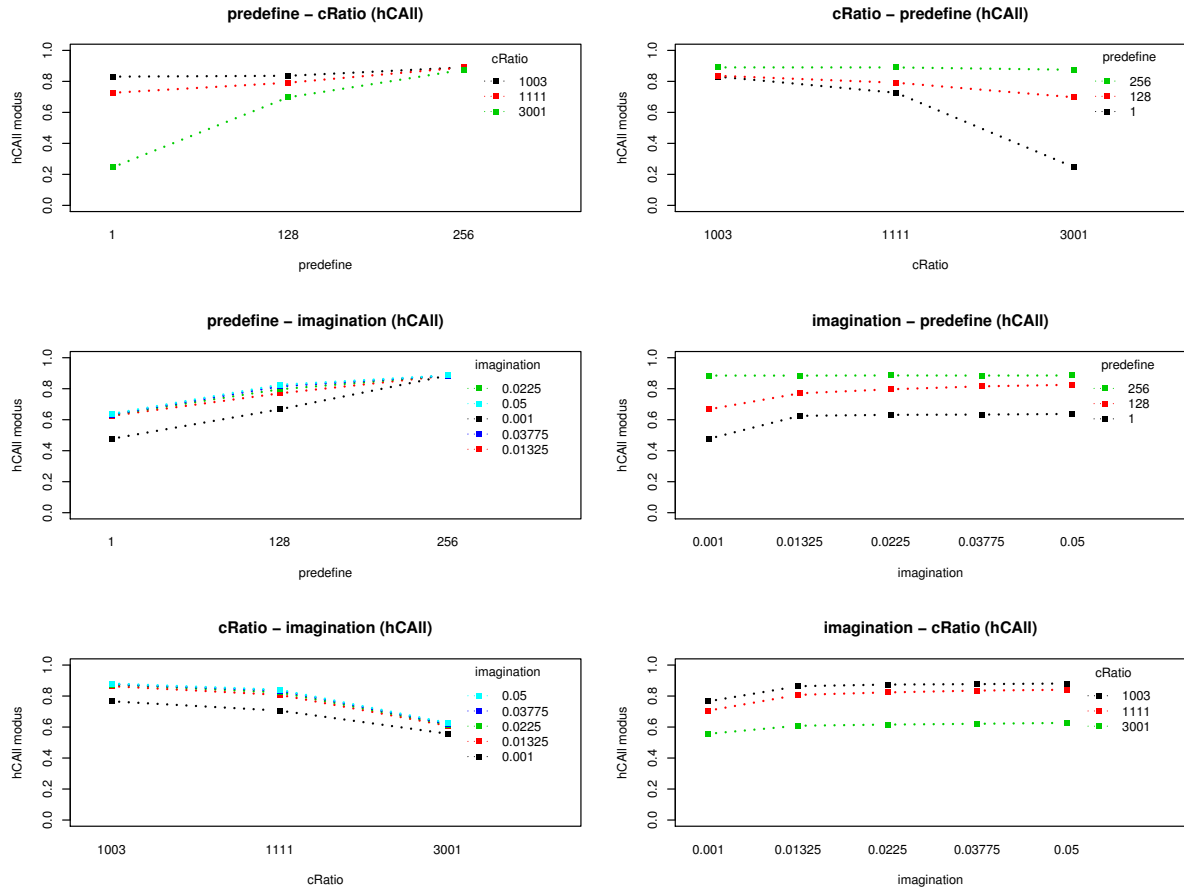


Figure 7.7.: Interaction plots for hCAII modes

Table 7.2.: Three-Way Independent Analysis of Variance for hCAII Coefficients of Variance (CV)

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	1688.91***	0.55(1) <sup>2</sup>	<2.2e-16
cRatio (c)	1	1.07	0.00(5)	0.30
imagination (i)	1	189.49***	0.12(3)	<2.2e-16
p x c	1	25.11***	0.02(4)	6.14e-07
p x i	1	359.54***	0.21(2)	<2.2e-16
c x i	1	0.09	0.00(5)	0.76
p x c x i	1	0.30	0.00(5)	0.59
Residuals	1342	(38) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

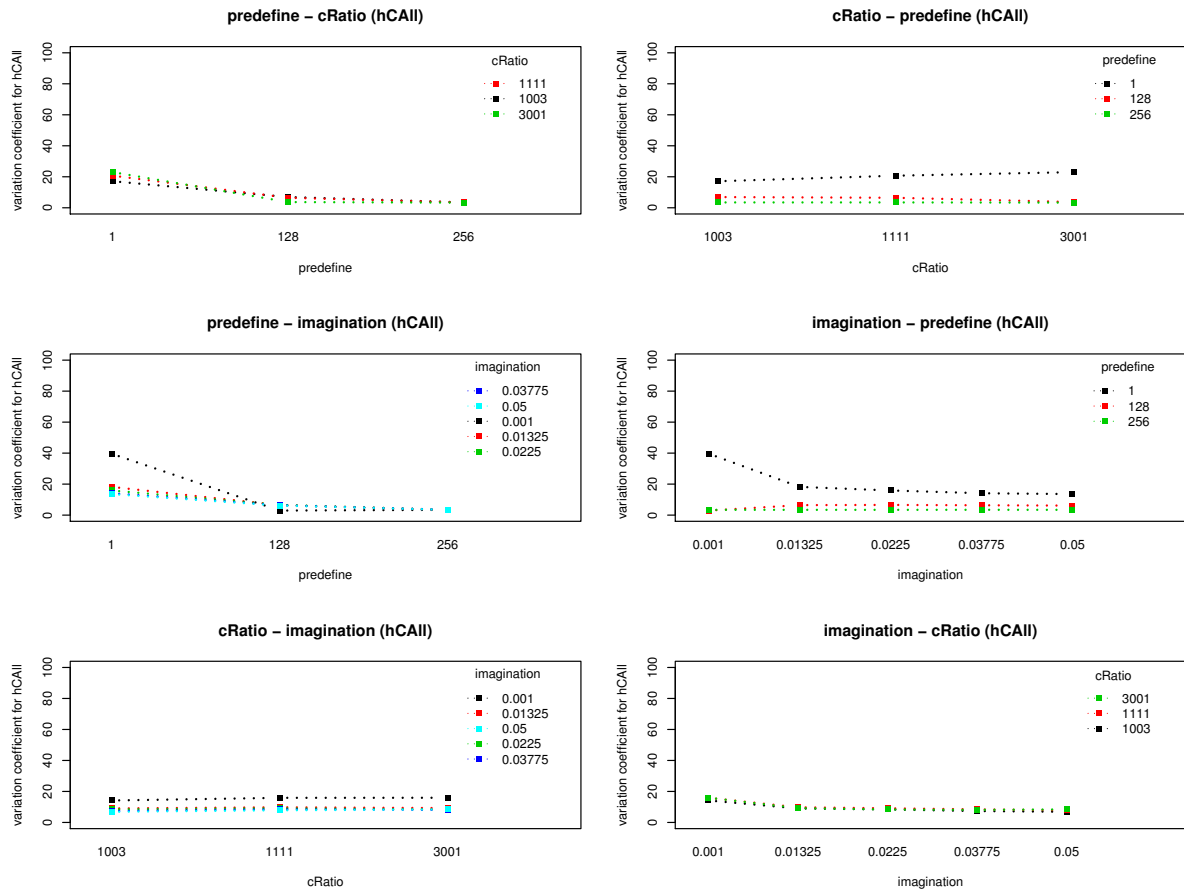


Figure 7.8.: Interaction plots for hCAII coefficients of variance



Table 7.3.: Three-Way Independent Analysis of Variance for  $hX.Y$  Modes

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	63.13***	0.05(4) <sup>2</sup>	4.07e-15
cRatio (c)	1	82.85***	0.06(3)	<2.2e-16
imagination (i)	1	366.10***	0.22(1)	<2.2e-16
p x c	1	163.89***	0.11(2)	<2.2e-16
p x i	1	32.58***	0.02(5)	1.41e-08
c x i	1	0.22	0.00(6)	0.67
p x c x i	1	2.79	0.00(6)	0.10
Residuals	1342	(0.03) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

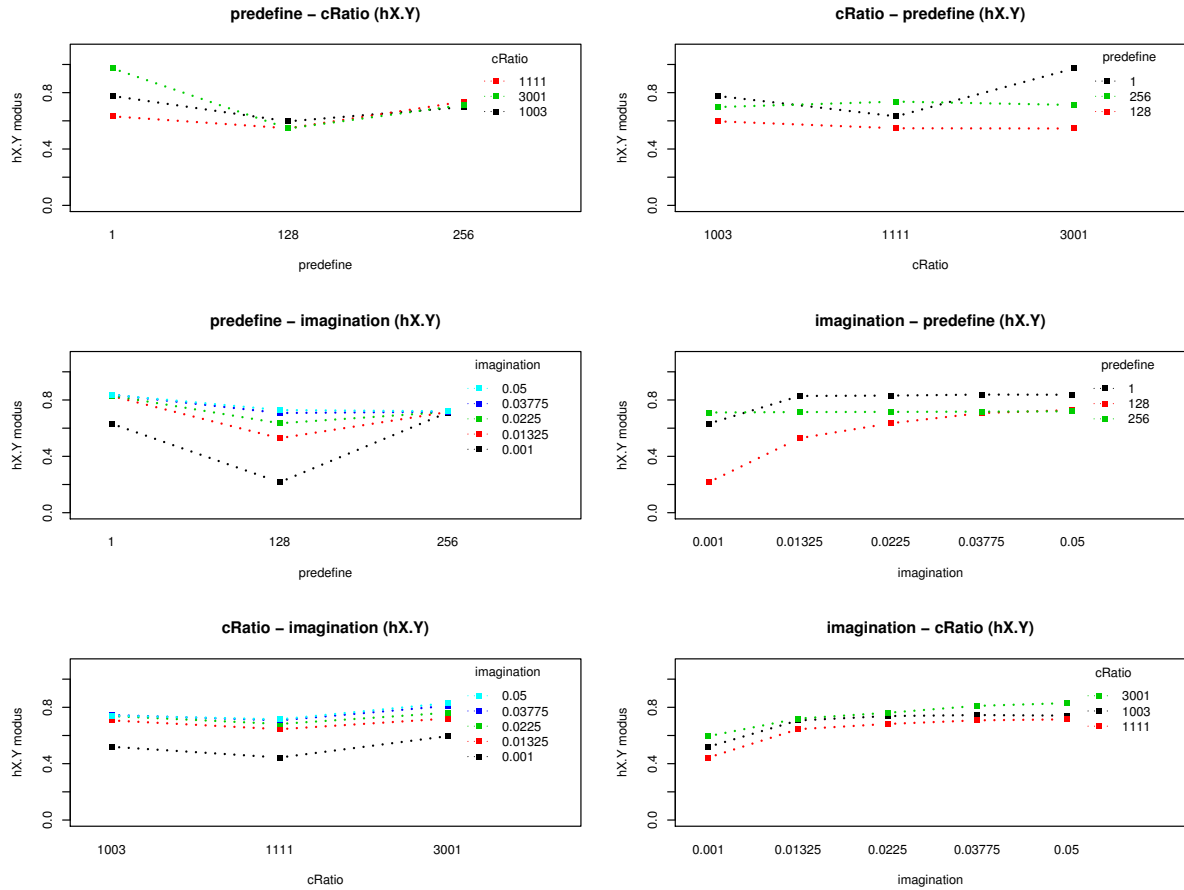


Figure 7.9.: Interaction plots for  $hX.Y$  modes

Table 7.4.: Three-Way Independent Analysis of Variance for  $hX.Y$  Coefficients of Variance (CV)

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	266.88***	0.16(1) <sup>2</sup>	<2.2e-16
cRatio (c)	1	3.31	0.00(4)	0.07
imagination (i)	1	245.56***	0.15(2)	<2.2e-16
p x c	1	1.95	0.00(4)	0.16
p x i	1	187.81***	0.12(3)	<2.2e-16
c x i	1	<0.00	0.00(4)	0.97
p x c x i	1	0.63	0.00(4)	0.43
Residuals	1342	(70.3) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

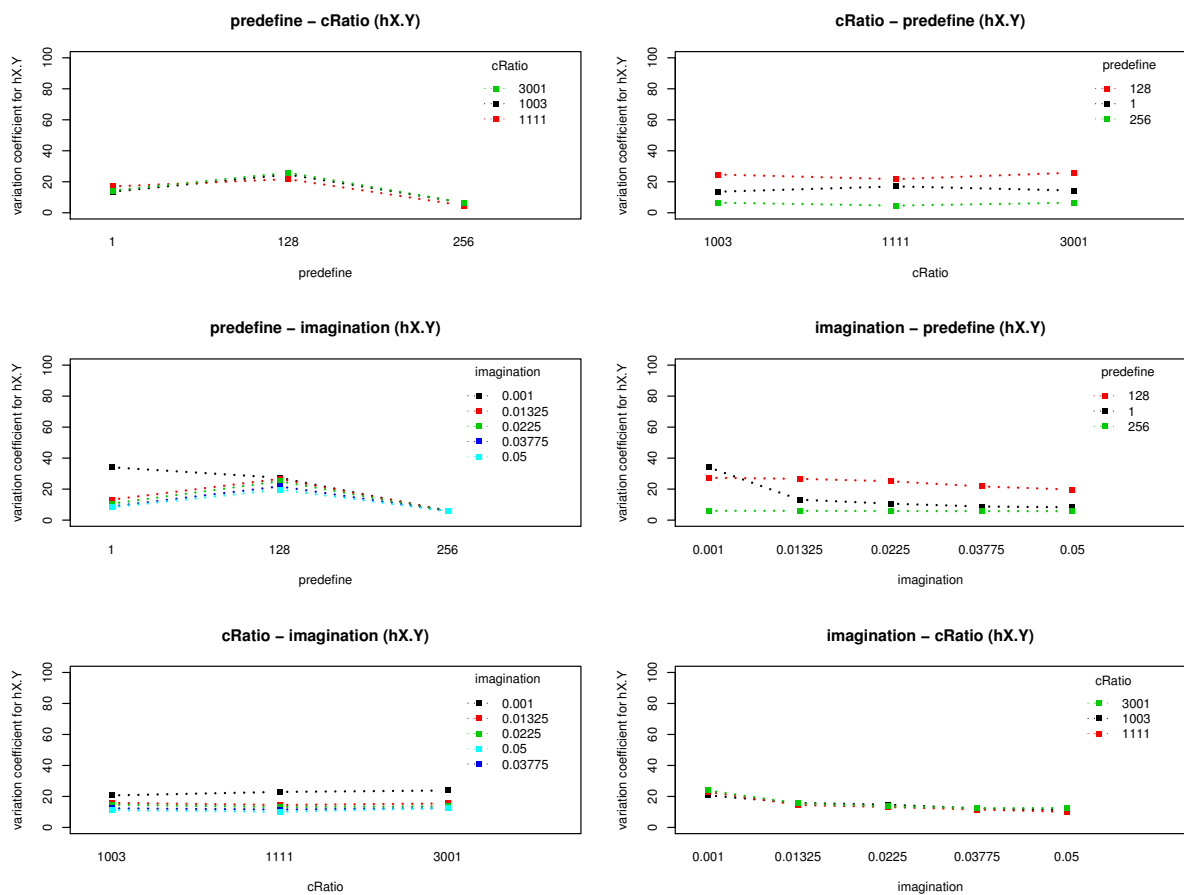


Figure 7.10.: Interaction plots for  $hX.Y$  coefficients of variance

Table 7.5.: *Experiment CI-2b Summary of Results*<sup>1</sup>.

Effect	hCAII mode	hCAII CV	hX.Y mode	hX.Y CV
p	.80	.55		.16
c	.77			
i	.23			
p x c	.75	.02	.11	
p x i	.09	.21	.05	.12
c x i	.01			
p x c x i				

<sup>1</sup> Cells contain the effect size values ( $\hat{\omega}_G^2$ ) for each interpreted effect per dependent variable. They are empty if the effect was not interpreted.

## 7.4 Discussion

CI-2b is the main experiment in a series of five designed to explore the variation sub-process of creativity as modelled in CRESY-I. A total of 45 conditions were produced to investigate three substantial independent variables *predefine* (p; macrosystem), *cRatio* (c; microsystem) and *imagination* (i; individual system). Their effects on the common level (mode) and stability (coefficient of variance, CV) of the dependent variables *hCAII* and *hX.Y* were explored graphically and with analyses of variances. *hCAII* refers to the relative diversity of patchworks produced by all creators, while *hX.Y* relays how correctly creator types (X) can be guessed by knowing patchwork colours (Y). In the analyses of variances no second-order interactions were significant, while first-order interactions were mainly responsible for the explained variance. The macrosystem variable *predefine* (p) appears to have the largest influence on the dependent variables, given it is part of the significant first-order interactions in each ANOVA and a consistent main effect.

As illustrated in Chapter 4, the purpose of this form of research is to generate scientific hypotheses based on theoretical explorations. Experiment CI-2b represents a systematic exploration of CRESY-I, and after thoroughly reviewing the most fruitful results the following hypotheses are conceived for potential future research.

### Product diversity (hCAII):

- 1a** High macrosystem diversity (p) equalizes product diversity levels (*hCAII* mode) reached by qualitatively unequal microsystems (c).
- 1b** Low macrosystem diversity (p) *and* low individual potential (i) to create novelty lead to lower levels of product diversity (*hCAII* mode).
- 1c** Macrosystem diversity (p) can compensate differences in microsystem and individual potential (c and i) to produce diversity (*hCAII* mode).

**1d** High macrosystem diversity (p) stabilizes product diversity levels over time (*hCAII* CV).

Product diversity is a latent variable of the manifest variable *hCAII*<sup>8</sup>, and it could be measured with other variables depending on the specifics of the scientific context. In brainstorming research for instance (Paulus & Nijstad, 2003), the amount of *fluidity* or *flexibility* a person or group has produced could indicate idea diversity. The abstract expression "macrosystem diversity" is derived from the macrosystem variable *predefine* (p), and it refers to the amount or diversity of contextual information available to fulfil a task. "Macrosystem potential" refers to what kind of creators a sample consists of (*cRatio*, c), while "individual potential" to create novelty is a construct derived from the individual system variable *imagination* (i).

At first glance, Hypotheses 1a - 1d may appear simple or trivial. Their contents acquire notable significance, however, when related to this chapter's theoretical introduction and Csikszentmihalyi's (1999) systems perspective of creativity. When the macrosystem variable *predefine* is low (= 1), the results adequately reflect diversity levels a researcher could expect given the models of individual creativity described in the beginning of this chapter (e.g. Kirton, 1976; Mednick, 1962; Stokes, 1999). More convergent, traditional, reliable and conforming individuals or samples would be expected to have lower product diversity levels than their more divergent, original, unpredictable and non-conforming counterparts. The results obtained in experimental conditions with low macrosystem diversity reproduce ideas expressed in these models, and they could be indicative of CRESY-I's face validity regarding the translation of verbal models of individual creativity into the creator types (Cx, C1, C2, C3).

When the macrosystem variable *predefine* is high (= 256), however, the results reflect diversity levels a researcher would not expect if the aforementioned models of individual creativity hold. In these experimental conditions, there are no noticeable differences between samples (*cRatio* levels) or individuals (*imagination* levels). Given this is not a sign of CRESY-I's lack of face validity, these results do not necessarily imply the assumptions underlying models of individual creativity are incorrect. The macrosystem's (p) significant interaction with microsystem (c) and individual (i) system factors instead offers a more complex and differential view of creativity modelled currently as the variation subprocess. Generating ideas, one could say the individual models do hold *under certain environmental circumstances*. Csikszentmihalyi (1999, pp. 318-319) hypothesised that creativity is facilitated by the accessibility and availability of information. High differentiation (diversity of domains) as well as high exposure to information are two other aspects he considers crucial to enhancing creators' potential. These ideas coincide with results obtained with the dependent variable *hCAII* as well as hypotheses 1a-1d. In relating individuals and samples to their environment, the new meaning created does not disqualify the assumptions made in models of individual creativity, but it does differentiate them.

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<sup>8</sup>The term "level of product diversity" is a construct derived from examining *hCAII*'s mode, while hypotheses about the (in)stability of product diversity are derived from analyses with its coefficient of variation (CV). This also applies to the hypotheses generated based on measurements of *hX.Y*

Csikszentmihalyi (1999) emphasises the necessity of communication between different subsystems to produce what he calls creativity. The existence of an individual or a group alone does not suffice to produce novel and appropriate things. The creating entity relies upon information –acquired knowledge and experience – from the domain to do so. Individuals as well as collectives also shape the domain by contributing their own creations. The results of this experiment as well as Hypotheses 1a – 1d mirror the relevance of creator-domain interaction in producing diversity<sup>9</sup>.

#### **Creator type differentiation ( $hX.Y$ ):**

- 2a** It is easiest to discriminate creator types ( $hX.Y$  mode) when macrosystem diversity ( $p$ ) *and* microsystem composition ( $c$ ) are low. Otherwise, creator types are discriminated with similar, mediocre ease.
- 2b** It is hardest to discriminate creator types ( $hX.Y$  modes) when macrosystem diversity ( $p$ ) is moderate *and* individual potential ( $i$ ) is low. Otherwise, creator types are discriminated with similar ease.
- 2c** Moderate macrosystem diversity ( $p$ ) concurs with slightly less stable levels of creator type differentiation ( $hX.Y$  CV).

Creator type differentiation is a latent variable of the manifest variable  $hX.Y$ . There are various ways to operationalize it, for example by assessing individual differences relevant for creative expression with personality scales (Schuler & Görlich, 2006) or similar questionnaires (Kirton, 1976). Other possibilities are observing differences in behavioural strategies (Stokes, 1999, 2007) or measuring associative production (Mednick, 1962). In CRESY-I,  $hX.Y$  is an exploratory dependent variable with psychological and technical relevance. The ability to discriminate people ("types") based on their behaviour ("products") is not specific to creativity research, but to the domain of psychology in general. Measuring it in CRESY-I has an ambivalent meaning: If for instance creator type differentiation is high, does it mean that the assumptions underlying models of individual creativity hold and/or that the agent types modelled in CRESY-I are face valid?

The results do indicate creator types are easier to discriminate in some conditions compared with others. Almost perfect differentiation is reached when informational diversity is low ( $p = 1$ ) and the sample most convergent ( $c = 3:0:0:1$ ). When the domain encompasses minimal diversity, because the number of initial colours is extremely low and the majority of creators are reproducing this minimum, it is comparably easy to detect the single creator deviating from the norm. As the number of diverging creators increases, more "noise" in terms of patchworks is produced. It becomes harder to trace which creator type created which patchwork. As the

<sup>9</sup>Note that in CRESY-I, the dependent variable  $hCAII$  only reflects *diversity*. To measure *creativity* as commonly defined in psychology (Amabile, 1996; Sawyer, 2006; Schuler & Görlich, 2006; Zhou & Shalley, 2007), the model requires some form of evaluation.

initially monochrome domain becomes more colourful, less divergent creators obtain and become affected by this new and diverse information. Their patchworks gradually start to resemble those of more divergent counterparts.

Interestingly, creator type discrimination does not differ between samples when macrosystem diversity is at least medium ( $p = 128$ ): Sample composition ( $cRatio$ ,  $c$ ) does not make a difference in this case. Additionally, the same levels of differentiation are reached among individuals of different *imagination* ( $i$ ) levels when macrosystem diversity ( $p$ ) is high: Individual potential ( $i$ ) does not matter in this case. Although discrimination is not perfect in any of these conditions, an important point can nevertheless be made. Certain levels of macrosystem diversity ( $p$ ) appear to render differences in sample ( $c$ ) and individual ( $i$ ) potential irrelevant.

The weakest creator type discrimination ( $hX.Y$  mode) is found in conditions with medium macrosystem diversity ( $p = 128$ ) and low individual potential ( $i = 0.001$ ). A surprising result, it can be partially explained in the following way: The lower individual potential ( $i$ ) is, the more creator types resemble each other. In these instances, it follows that they are more difficult to discriminate because they create similar things. Why is differentiation worst in environments with medium diversity levels, however? Why do creator types resemble each other the most in these conditions? In macrosystems with low diversity ( $p = 1$ ), similar yet different creator types (i.e. when  $i = 0.001$ ) appear moderately discriminable because minute deviations from the more or less monochrome norm are detectable enough. In macrosystems with high diversity ( $p = 256$ ), they perhaps have enough behavioural influences and consequently possibilities to differentially distinguish themselves with. They obtain more qualitatively different information, allowing more "room" for distinctions to be made. Maybe this is not the case in macrosystems with medium diversity ( $p = 128$ ). It could be that, given the creators are quite similar in their inherent potential ( $i = 0.001$ ), their environment is not extreme enough to bring out their potential differences.

In sum, creator type discrimination levels ( $hX.Y$  mode) are not perfect, but mediocre at worst. Moreover, in most cases they are stable over 6,000 steps. Conditions in which macrosystem diversity is medium ( $p = 128$ ) are a slight exception. In such instances, creator type discrimination levels (mode) are somewhat lower and their instability (CV) comparably but not alarmingly higher. The interpretation of results is still open and debatable for these conditions. They appear to induce slight restrictions in creator type discrimination level ( $hX.Y$  mode) and stability ( $hX.Y$  CV).

### Model validation

The target system CRESY-I models is the variation subprocess of a systems / evolutionary model of creativity described by Csikszentmihalyi (1999) and derived in Chapter 3. As variation is described only very generically according to this perspective, the models of individual creativity described in Section 7.1 were chosen to substantiate the phase. The target is therefore an abstract model, and a few middle-range models were used to facilitate its transition into a computer language.

Any validation strategies used should describe the fit between theory and simulation model. The purpose of the simulation model CRESY-I is to explore the theory and generate hypotheses. To date the following measures were taken to validate CRESY-I:

**Use existing theory** Where Csikszentmihalyi's (1999) perspective was too abstract middle-range theories / models of creativity were chosen to fill gaps.

**Modeller experience and intuition** The modeller has broad knowledge of the domain of creativity research. It guided model development and experimentation.

**Conversations with subject-matter experts during development / Face validity** CRESY-I was built with qualified advisers. Four scientists knowledgeable in social psychology, sociology, computer modelling and the mathematics of system processing regularly commented its development. During the same phase, CRESY-I was presented eight times to a group of scientists also working in the computer modelling field to gain feedback.

**Animation and operational graphics** The processes were animated to track the model's behaviour in real time. Operational graphics were used to check if output parameters behaved as expected.

**Extreme conditions tests** Values thought to be extreme were chosen for the input parameters to test how they affect the output parameter space.

**Internal validity** Many runs of one experimental condition were conducted to check if the condition was stable enough.

**Observing macro-level regularities** Simulation data was collected via experimentation to observe whether theory assumptions hold on the macro-level. At present, this appears to be the case for the data collected in Experiment CI-2b *except* for conditions in which *predefine* = 128. Whether CRESY-I is invalid for such conditions or an alternative explanation is available is still pending.

**Discuss model output with subject-matter experts and users / Face validity** The simulation results were discussed with the aforementioned scientists to dispute their validity. Moreover, CRESY-I was presented to approximately 40 psychology students with a semester's background in creativity research. They were requested to "play" with the model for one hour and develop hypotheses about the relationships between the variables they observe. Very realistic observations were confirmed, such as "the lower imagination is, the less colours appear in the world" or "the more C3 in the world, the faster and more diverse it changes".

These were the initial steps taken to validate CRESY-I. As indicated in Section 5.1.3, "true" validation can only be approximated. Especially the final step (asking students to generate hypotheses with the model) indicates that CRESY-I's purpose can be fulfilled by the current work: It is possible to explore the theory and generate hypotheses about it.

### Potential limitations

Despite the abundance of results and ideas gained by experimenting with CRESY-I, the model does have conceptual limitations worth noting here. It focuses on one particular form of variation, namely combinatorial creativity. In defending this choice, combinatorial creativity is not only the easiest kind to model (Boden, 1999), it is also the most widely and commonly defined kind in creativity research (see for instance Amabile, 1996; Sawyer, 2006; Sternberg, 1999a; Sternberg et al., 2004; Zhou & Shalley, 2007). It therefore lends itself as a good starting point for modelling. Furthermore, CRESY-I does not yet measure creativity but diversity. As thoroughly described in Chapter 6, this model's purpose is to recreate in abstract form the variation subprocess of creativity, the latter defined as the interplay of variation, selection and retention processes. It is therefore too early to speak of creativity, because the evaluation stage is still missing. This does not imply, as the results hopefully indicate, CRESY-I's scientific insignificance. The simulation model offers a translation of assumptions underlying verbal models of individual creativity, and it interestingly demonstrates in this abstract realm the limitations these translated assumptions have if the availability of information is varied.

Moreover, at this initial stage CRESY-I operates with simple forms of agent interaction. Creators do not communicate directly, but solely via their artefacts. There are no group dynamics; the agents simply represent a sample of individually creating entities. This circumstance is not a by-product of the technicalities of modelling, but a previously set decision. Research on creative group processes nowadays favours experimental settings in which group members actually work alone (see for instance Paulus & Nijstad, 2003; Unger & Witte, 2007), sometimes without viewing other members' work during the task fulfilment process. Beyond the reality of research laboratories, creative production processes taking place in everyday life do emerge as modelled in CRESY-I. Whether it be in academic publishing, art museums, peer production online content systems such as *Flickr*<sup>10</sup> and *deviantART*<sup>11</sup>, or the film industry - there are creators almost everywhere anonymously viewing, consuming and acknowledging products of other creators they do not necessarily know or communicate with personally.

Apart from these conceptual issues, CRESY-I may have technical limitations which restrict the generalizability of its experimental results. Firstly, the technical indepen-

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<sup>10</sup>This is an online photo sharing system. See <http://www.flickr.com/> (retrieved Feb. 28, 2011).

<sup>11</sup>This is an online artwork sharing system. See <http://www.deviantart.com/> (retrieved Feb. 28, 2011).



dent variables were held constant in this experiment. It is therefore impossible to validly argue that similar results would have been obtained with other technical settings. At this point however, it should be reminded that previous experiments (CI-1a, CI-1b, CI-2a, CI-2a-SupplExp) were conducted to investigate this issue, and it was concluded that the tested values for technical independent variables hardly influenced the dependent variables. This provides enough legitimization for holding their values in this experiment constant. This constraint is not specific to CRESY-I, however, but to any operationalization conducted on the basis of a predefined theoretical model.

Additionally, the low, medium and high values chosen for independent variables were more or less selected in an arbitrary manner. Obviously, other values could have been used, but *some* values need to be defined to initiate exploration. This is a common limitation the experimentation with abstract simulation models has. Another noteworthy issue is the fact that the realm of variations (patchworks) was finite and therefore known to the experimenter. This artefact is common in comparable simulation models (Bryson, 2008; Gabora, 1995, 2008a). In proposing potential upgrades, it should be reminded that no interventions occurred while the simulation was running. The macrosystem variable *predefine* was set during initialization and apart from creators' input no other environmental events happened.

### Outlook

In viewing this simulation model as a point of scientific departure, there are many possible destinations continuing research could head for. CRESY-I demonstrates a specific form of variation and a simplistic form of retention. It would be possible to conceive other forms of variation processes based on different views of what constitutes creative production. Besides combinatorial creativity, types such as exploratory and transformational creativity have been discussed (Boden, 1999; Edmonds, 1999). Moreover, a variety of more complex products beyond three-dimensional colours could be modelled and explored (for concrete examples see Gabora, 1995; Picascia & Paolucci, 2010). A more sophisticated CRESY could be developed by incorporating a selection process to see how it, in combination with the variation process, affects the domain. This advancement could move the model's output from a quantitative diversity assessment to one of a more qualitative kind, and it could be a step closer to modelling creativity as an emergent property of social interaction.



# 8

## Roadmap to CRESY-II

CRESY-II stands for "CREativity from a SYstems perspective II", and it is the name of the second agent-based model conceived in this doctoral work<sup>1</sup>. Similar to Chapter 6, the purpose of this chapter is to provide the reader with:

- A protocol of CRESY-II's architecture
- Information on the model's verification
- An overview of independent and dependent variables
- The design of experiments conducted with CRESY-II

The chapter starts with a detailed model protocol (Sections 8.1 - 8.3). The latter is designed according to contemporary guidelines for documenting simulation models ("ODD Protocol"; Grimm et al., 2006, 2010; Janssen et al., 2008; Polhill et al., 2008, 2010). It continues with information on the model verification process (Section 8.4). Following, CRESY-II's independent and dependent variables are explained (Sections 8.5 - 8.6). The chapter concludes with an overview of experiments conducted with CRESY-II (8.7).

### 8.1 ODD Protocol: Overview

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Sections 8.1 - 8.3 contain a detailed account of CRESY-II's architecture. They follow the ODD (*Overview*, *Design concepts* and *Details*) protocol for describing individual-based and agent-based models (Grimm et al., 2006, 2010).

#### 8.1.1. Purpose

The general purpose of this model, CRESY-II, is to simulate creativity as an emergent phenomenon resulting from creative production and evaluation processes exhibited by autonomous agents. The model demonstrates the effects, in terms of emerging product domains, of *creators* and *evaluators*. The former act on the basis of behavioural variability, i.e. a theoretical continuum describing how differently (variable)

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<sup>1</sup>CRESY-II has been uploaded to the OpenABM site (<http://www.openabm.org/>). Please contact the author for access to it.

an individual behaves or creates from time to time (Stokes, 1999, 2007). The latter act on the basis of varying levels of stringency regarding conventional evaluation criteria for creativity - novelty and appropriateness (Amabile & Mueller, 2007; Lubart, 1999; Metzger, 1986; Schuler & Görlich, 2006; Styhre, 2006; Preiser, 2006; Ward et al., 1999; Zysno & Bosse, 2009). An abstract model, CRESY-II was designed for theoretical exploration and hypotheses generation. It is the second model in a series designed to describe a systems approach to creativity in terms of variation, selection and retention subprocesses (Csikszentmihalyi, 1988, 1999; Ford & Kuenzi, 2007; Kahl, 2009; Rigney, 2001).

### 8.1.2. Entities, state variables, and scales

Programmed with NetLogo 4.1.2 (Wilensky, 1999), CRESY-II encompasses the following entities: creators, patchworks, evaluators, domain and global variables (see also Figure 8.1). The creators were carried over from CRESY-I. They are agents ("turtles" in NetLogo) characterized by the state variables described in Table 6.1 of CRESY-I's ODD Protocol (Chapter 6). The only difference is that CRESY-II creators lack the variable *myPw*, which was originally programmed just for debugging purposes.

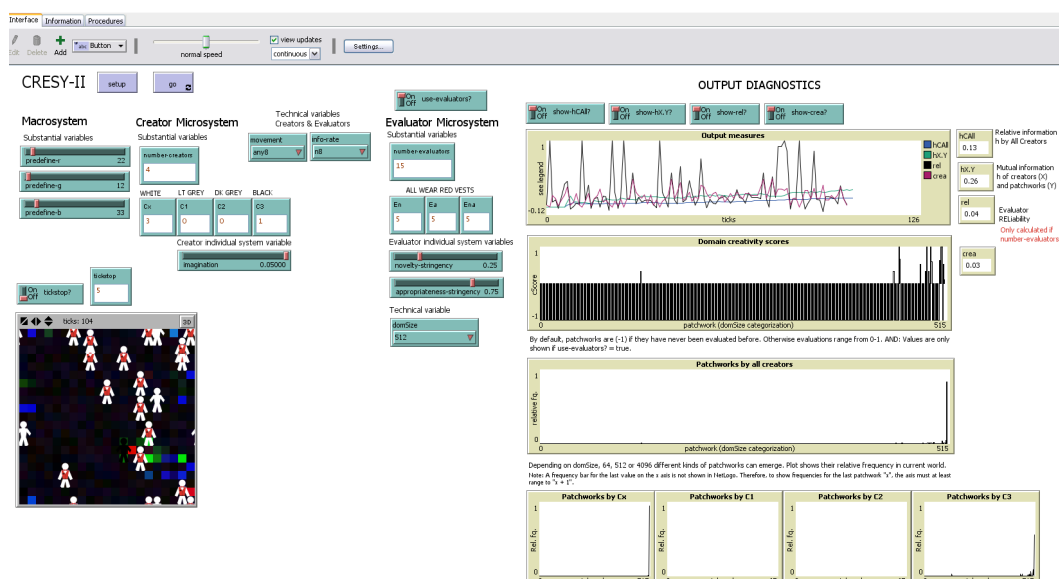


Figure 8.1.: Screenshot of CRESY-II

Patchworks have the basically same function as in CRESY-I. They abstractly represent artefacts creators produce and they are technically represented by stationary

agents in NetLogo ("patches"). In CRESY-II, patchworks still appear as colours characterized by rgb values, so they are visible to the observer in NetLogo's View. Moreover, they are the means by which creators and evaluators communicate. Creators do not interact with their peers or evaluators directly. They gain knowledge of the domain by viewing displayed patchworks. The same holds for evaluators. As the addition of evaluators made new patchwork variables necessary, all state variables patchworks have are (re)listed in Table 8.1.

Table 8.1.: *CRESY-II Patchwork State Variables and Scales*

Variable name	Brief description	Value
<i>pcolor</i>	List of rgb values (24 bit).	[r g b]
<i>plabel</i>	<i>domSize</i> category for <i>pcolor</i>	Integer, [0, <i>domSize</i> −1]
<i>pDom</i>	List of rgb values reduced to domain variable <i>domSize</i> (6, 9 or 12 bit).	[r g b]
<i>pR</i> , <i>pG</i> , <i>pB</i>	Patch's current respective red, green and blue values.	Integer, [0,255]
<i>madeBy</i>	Who made patchwork? Environment <sup>1</sup> or creator type.	{Env,Cx,C1,C2,C3}
<i>whosNext</i>	Holds <i>who</i> value of creator or evaluator potentially to next move on patch. Belongs to movement and evaluation procedures.	Integer, [1,number-creators] <sup>2</sup> OR [1,number-evaluators] <sup>2</sup>
<i>justMade</i>	Indicates whether patchwork was made during current step.	Boolean
<i>toDo</i>	Indicates whether evaluator still needs to judge patchwork.	Boolean
<i>hue</i>	Indicates whether patchwork's rgb colour is warm or cool.	{warm,cool}
<i>currentEvals</i>	List of evaluators current scores for given patchwork.	List with {0,1}
<i>cScore</i>	Patchwork's cumulative creativity score	Integer, [0,1] <sup>3</sup>
<i>PcScoreList</i>	Current domain evaluation list of <i>cScores</i> .	List of length <i>domSize</i> values of [0,1] <sup>3</sup>

<sup>1</sup> "Environment" (Env) means a patch's colour has not been changed yet by any creator. It is still the colour it randomly received when the world was initiated.

<sup>2</sup> *number-creators* and *number-evaluators* are global variables which define the total number of creators (evaluators) in the world regardless of type.

<sup>3</sup> If a patchwork has never been rated before, its *cScore* is set to -1 by default.

Evaluators are mobile agents ("turtles" in NetLogo) characterized by the state variables described in Table 8.2, and their task is to judge the patchworks creators make. Note that in CRESY-II the variable *domSize* belongs these agents. Evaluators,

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therefore, can only perceive patchworks with a certain degree of differentiation, and this recognition is not as fine-tuned as that of creators. In evolutionary terms, they only perceive a patchwork's phenotype, whereas creators are aware of patchworks' genotypes (Chattoe, 1998).

Table 8.2.: *CRESY-II Evaluator State Variables and Scales*

Variable name	Brief description	Value
<i>label</i>	Describes (static) evaluator type.	{En,Ea,Ena}
<i>eMem</i>	Evaluator's memory list for patchworks seen. List of <i>domSize</i> nested lists. item 0 = <i>domSize</i> value ( $c_j$ ), item 1 = <i>absolute frequency</i> ( $f_j$ ) of value $c_j$ .	[ [0 $f_1$ ] [1 $f_2$ ],..., [ $c_j$ $f_j$ ],..., [ $n$ $f_n$ ] ]
<i>domSize</i> <sup>1</sup>	Size of patchwork space, evaluators can perceive, e.g. number of rgb colours (patchworks) they can discriminate (12, 9 or 6 bit)	{64,512,4096}
<i>novelty-stringency</i> <sup>1</sup>	Percentage; How unknown may a patchwork be to be considered novel?	Integer, [0,1]
<i>appropriateness-stringency</i> <sup>1</sup>	Percentage; At least how appropriate should patchwork be to be considered so?	Integer, [0,1]
<i>info-rate</i> <sup>2</sup>	How many neighbours (4 or 8) an evaluator obtains info from per time step. Same for all.	{n4,n8}
<i>movement</i> <sup>2</sup>	How evaluators move in the world <sup>3</sup>	{straightFd1, ahead3, allButBehind7, any8}

<sup>1</sup> This variable is set by the observer globally for all evaluators.

<sup>2</sup> In CRESY-II, the variables *info-rate* and *movement* are defined globally for all creators and evaluators.

<sup>3</sup> The movement strategies are explained in Section 6.3.3.

The domain is a higher-level entity abstractly representing a symbolic, or informational, system (Csikszentmihalyi, 1988, 1999). It is technically represented in NetLogo by a single, invisible agent (turtle), and its purpose is to record information about the patchworks. As some changes in code were made from CRESY-I to

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CRESY-II, the domain consists of different variables in the later model. Table 8.3 gives an overview of them.

Table 8.3.: *CRESY-II Domain State Variables and Scales*

Variable name	Brief description	Value
<i>evalList</i>	List of <i>domSize</i> nested lists containing all evaluations ever made for particular patchwork.	$\{0,1\}^1$
<i>cScoreList</i>	List of length <i>domSize</i> containing current creativity scores for patchworks.	Integer, $[0,1]^2$
<i>justRated</i>	List of <i>number-creators</i> nested lists containing the creativity evaluations evaluators made in current step.	Integer, $[0,1]$
<i>justRatedTable</i>	List of length <i>number-creators</i> * 2 containing summed and squared creativity scores from <i>just Rated</i> .	$\geq 0$

<sup>1</sup> Note 0 = not creative, 1 = creative.

<sup>2</sup> Note a patchwork's *cScore* is set to -1 by default if it has never been evaluated before.

A number of global variables are used in CRESY-II to define start-up configurations (see Table 6.3 for those carried over from CRESY-I and Table 8.4 for new ones). Furthermore, CRESY-II's interim and output variables are defined as globals (see Table 8.5).

Table 8.4.: *CRESY-II Global Variables and scales<sup>1</sup>*

Variable name	Brief description	Value
<i>use-evaluators?</i>	Observer decides this.	Boolean
<i>number-evaluators</i>	Observer defines number of evaluators in world	$\geq 0$
<i>En, Ea, Ena</i>	3 variables defining number of each evaluator type in world. Set by observer.	$\geq 0$
<i>tickstop?</i>	Observer decides if run should stop at <i>tickstop</i>	Boolean

<sup>1</sup> CRESY-II's globals consist of CRESY-I's *and* the ones listed here.



Table 8.5.: *CRESY-II Dependent & Interim Variables and Scales*

Variable name	Brief description	Value
$hX.Y$	Mutual information with $X$ = creator type & $Y$ = patchwork type.	$[0,1]$
$hX$	Information measure (marginal entropy) for $X$ = creator type.	$\geq 0$
$hY$	Information measure (marginal entropy) for $Y$ = patchwork type.	$\geq 0$
$hXY$	Joint information (cell entropy)	$\geq 0$
$hCx$ , $hC1$ , $hC2$ , $hC3$ , $hCAI$	5 measures of relative information for each creator type and call creators	$[0,1]$
<i>rel</i>	Reliability measure.	$[-1,1]$
<i>crea</i>	Patchworks' overall creativity as judged by evaluators.	$[0,1]$
<i>cond</i>	Name of experimental condition.	String
<i>rgbSpace</i>	List of <i>domSize</i> nested lists. Each list contains <i>rgb</i> values according to <i>domSize</i> reduction.	Nested integer lists of length 3
<i>rgbSpaceDom</i>	List of <i>domSize</i> nested lists of length 2. Item 0 = <i>domSize</i> category; item 1 = 0 (default frequency).	Nested integer lists of length 2

CRESY-II is based on theoretical ideas expressed in creativity research in psychology. Therefore, there are no explicit concepts of spatial and temporal scales. However, research in this domain is usually conducted as psychological experiments in which individual participants or groups are requested to generate artefacts and independent raters are subsequently asked to judge them. Therefore, one time step in a simulation run can approximately equate to the time it takes to produce an artefact and to judge it. In CRESY-II, the duration of this time is the same for all creators and evaluators, which is not necessarily the case in reality. Furthermore, total duration (temporal extent) can also vary depending on whether psychological investigations take place in a laboratory setting, in which time is more or less controlled, or in the field where, for example, the non-simulated creative production and

evaluation processes carried out by artists, scientists, peers and the like can be of any duration and continuous, e.g. online ratings such as Amazon reviews.

In CRESY-II, the term *space* refers to knowledge and not to geographical location. Obviously, where creators and evaluators are located in the world will affect what knowledge (colour information) they acquire. However, as colours are randomly distributed on the grid when the world is initialized, geographical space has no systematic meaning in this model. By default, a 21x21 torus defines the knowledge-spatial extent of the world. Each patch on the torus represents one patchwork, i.e. a colour representing a creative product characterized by the three independent dimensions red, green and blue and the corresponding *domSize* category. The knowledge-spatial extent of the world is varied by altering the density of creators and evaluators in it.

### 8.1.3. Process overview and scheduling

CRESY-II consists of seven subsequent processes ("procedures" in NetLogo): obtain-info, make-patchwork, rate-patchwork, move, forget-some-info, tick, update-domain. Their scheduling is linear, i.e. their order occurs in the exact order they are listed in the sequence diagram in Figure 8.2. The agentsets running the commands in each process do so serially, but in a random order on the basis of NetLogo's *ask* command. As indicated in Figure 8.2, creators and evaluators obtain information, move and forget-some-information during the same stages of a simulation step. The state variables were updated asynchronously. Time was modelled discretely.

## 8.2 ODD Protocol: Design concepts

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### 8.2.1. Basic principles

CRESY-II's overall architecture is based on a) the evolutionary mechanism of variation, selection and retention (VSR) as well as b) Csikszentmihalyi; Csikszentmihalyi's (1988; 1999) systems perspective of creativity which encompasses individuals, a field and a domain. CRESY-II's focus is on the interplay of variation and selection, including a simple form of retention. Various psychological models of the creative individual (see Section 7.1) and their products (see also Ch. 4 in Sawyer, 2006) are used to develop the variation subprocess. The selection subprocess is modelled based on standard criteria used for evaluating creative products (Amabile & Mueller, 2007; Lubart, 1999; Metzger, 1986; Schuler & Görlich, 2006; Styhre, 2006; Preiser, 2006; Zysno & Bosse, 2009) and Amabile's (1996) Consensual Assessment Technique (CAT). The domain, a higher-order entity representing the process of retention, is characterized by a measure of information (qualitative or nominal diversity) borrowed from Shannon's (1948) mathematical theory of communication (see also Section 6.6). The domain's implementation is additionally based on the notion that the more an artefact is valued, the longer it remains in the domain. Figure 8.3 summarises CRESY-II's basic principles graphically.

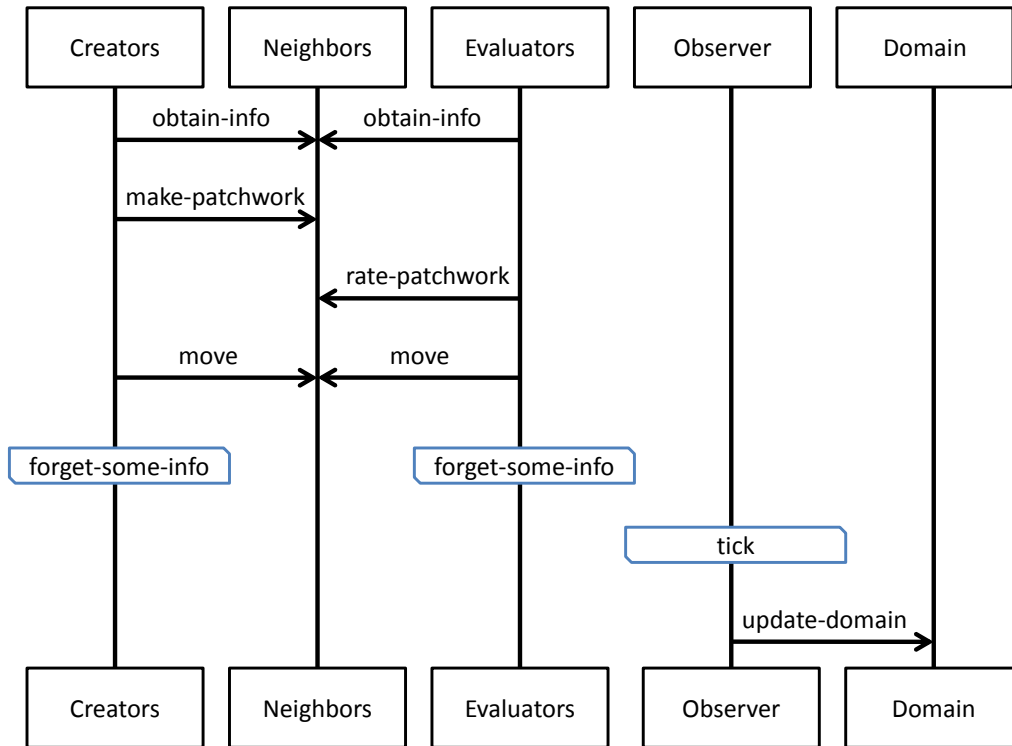


Figure 8.2.: Sequence diagram of CRESY-II.

### 8.2.2. Emergence

Review Section 6.2, as the notes on emergence in CRESY-I still hold in CRESY-II. Additionally, the two dependent variables *rel* and *crea* are modelled as emerging microsystem characteristics based on evaluators' behaviour. Both measures are expected to vary in magnitude and volatility depending on initial start-up conditions as well as activity exhibited by creators and evaluators. *rel* measures the reliability of evaluators' ratings. It is therefore an indicator of how similar these agents are in behaviour. Do they represent a homogeneous or heterogeneous microsystem? The measure allows the modeller to reflect their collective behaviour. *crea* measures how creative the evaluators find creators' patchworks in a given step. It therefore reflects the quality of artefacts, and in an aggregated form it gives way to diverse interpretations about the (sub)systems: If it is high, for instance, does it mean that creators are performing well or that evaluators are easy to please? Or could it mean the environment is just right for inducing high levels of creativity?

### 8.2.3. Adaptation

Review Section 6.2 to see how creators adapt. Additionally in CRESY-II, creators adapt to the constraints of the domain by having to paint their patchworks on neighbouring patches with the lowest creativity scores. In this way, they are subject to the most valued works for a longer time period. Evaluators adapt to their environ-

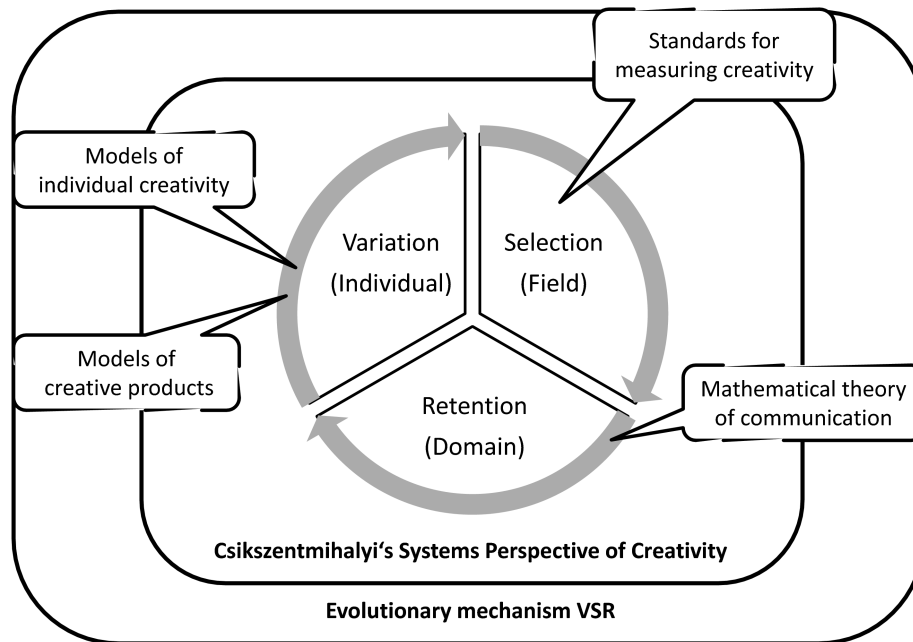


Figure 8.3.: *Basic concepts and models used in CRESY-II: Evolutionary mechanism VSR, Csikszentmihalyi's (1999) systems perspective of creativity, psychological models of individual creativity, psychological models of creative products, psychological standards for evaluating creativity and the mathematical theory of communication proposed by Shannon (1948).*

ment by obtaining information every step, which in turn affects the way they judge patchworks' novelty. They further adapt when rating appropriateness by viewing a part of the context a specific patchwork is embedded in. Evaluators do not explicitly seek to increase their individual success, but their consistent behaviour based on their adapting memories and the changing contexts surrounding patchworks is expected to contribute to the degree of creativity (*crea*) a domain is assessed to have.

### 8.2.4. Objectives

Creators' objectives were stated in CRESY-I's ODD Protocol (Section 6.2) and were not changed in the current model. Evaluators have two implicit objectives: 1) They are supposed to judge the creativity of patchworks, and 2) they are to do so based on their individual evaluator type, therewith incorporating the criteria novelty and appropriateness in their ratings. They achieve the first objective by giving a patchwork a zero if considered not creative, else a 1. The second objective is actually a prerequisite for the first, and the behavioural rules are set by the observer. Evaluator type *En* only uses perceived novelty as a basis for creativity ratings, *Ea* only appropriateness

and *Ena* both. How evaluators meet these objectives is measured collectively with the dependent variables *crea* (creativity; objective 1) and *rel* (reliability; objective 2). Note that both creators and evaluators do not adapt their behavioural rules (or types) to the environment, although their knowledge base does change over time. On a whole, however, the former act to increase diversity and the latter to qualify it in the domain.

### 8.2.5. Learning

In CRESY-II, creators and evaluators learn by "memorizing" or obtaining patchwork information from neighbouring patches. Their memories, i.e. adaptive traits, are also affected by their random forgetting of what they have encountered before (see also submodels *obtain-information* and *forget-some-info* in Section 6.3.3). Both entities, however, do not learn to alter their behavioural rules.

### 8.2.6. Prediction

The concept of prediction does not appear to apply to CRESY-II.

### 8.2.7. Sensing

In CRESY-II, creators and evaluators only sense parts of the environment locally by viewing different patchworks based on their movement strategy and by saving patchwork information in their memory lists. While creators can produce and view all possible red, green and blue values (0-255 per colour; 24-bit total colour space), evaluators cannot discriminate this detail with which creators produce patchworks. They only perceive a reduced colour space according to *domSize* (see Table 8.2 and the submodels in Section 8.3.3). This is comparable to consumers, users, etc. viewing end products without recognizing all their technical details. It is also a way of implementing the notion that evaluators only perceive the phenotypes of products, while creators are aware of their genotypes. Sensing also applies to the way creators place patchworks they currently make. A simple way to formalize retention, creators place their newly made patchworks on a neighbouring patch with the lowest creativity score (*cScore*). This ensures that the most valued patchworks remain in the domain longer. By sensing these scores, creators are influenced by evaluators' ratings.

### 8.2.8. Interaction

Creators and evaluators experience indirect interaction with other creators by locally viewing and obtaining information about their behaviour, i.e. patchworks. This feature is comparable to situations in which creators do not know each other personally, but know each other's works (Dennis & Williams, 2003; Müller, 2009; Runco et al., 1994; van den Besselaar & Leydesdorff, 2009), and this situation is common in creativity research (Kozbelt & Serafin, 2009). It is also comparable to the way products

are rated by judges in creativity research. Raters usually do not have contact with study participants. They judge the products independently and anonymously (Bechtoldt et al., 2010; Kaufman et al., 2008; Lonergan et al., 2004; Rietzschel et al., 2006; Silvia, 2008).

### 8.2.9. Stochasticity

The areas mentioned in CRESY-I's ODD Protocol still hold for CRESY-II (review Section 6.2). In addition to them, stochasticity also applies to the following areas. *Dispersion of evaluator types*: Evaluators are always randomly dispersed on the simulation grid when the world is initiated. *Making patchworks III* (continued from CRESY-I's ODD Protocol): When a creator places a patchwork on a neighbouring patch, it first determines all patches with the same lowest *cScore*. It then randomly chooses one of them to place the new patchwork on. Note in some cases there could be only one neighbouring patch to choose from. *Rating patchworks*: Stochasticity applies to the way appropriateness is assessed. In doing so, an evaluator looks at the hues of six of eight neighbouring patches. The six neighbours are chosen randomly, meaning not all evaluators use the same context as the basis for their appropriateness judgements. *Forgetting information*: Similar to the way creators forget, three *domSize* categories with absolute frequencies larger than zero are independently and randomly chosen from an evaluator's memory *eMem*. Each category's absolute frequency is then reduced by 1.

### 8.2.10. Collectives

The collectives in CRESY-II do not refer to emergent properties of individual agents, but to the kinds of entity groups the model encompasses. As collectives, there are creators, evaluators, patchworks and a domain. Moreover, there are creator subtypes (*Cx*, *C1*, *C2*, *C3*) which differ in the way they make patchworks (see submodel *make-patchwork* in Section 6.3.3). The evaluators form another entity group, and three types are available (*En*, *Ea*, *Ena*). Creators and evaluators are therefore separate kinds of entities with their own state variables and traits. Although they do not communicate directly with each other, they are affected by each other's behaviour. The information creators and evaluators obtain during the simulation (procedure *obtain-info*) is, especially as a run prolongs and with a large number of creators, produced by the collective of creators. Moreover, creators place their patchworks on patches with the lowest creativity scores (*cScores*), meaning they are affected by evaluators' work. So although both collectives are not characterized by direct intra- and interaction, they are influenced on a whole by what every agent is doing. This leads to the conclusion that they are affected by each others' work, i.e. patchworks and evaluations. These two things are what constitute the domain, a dynamic second-order entity whose characteristics are ultimately expressed in the dependent variables *hCAII* and *crea*.

### **8.2.11. Observation**

Data collection is conducted in two ways. Firstly, diverse monitors and plots are included in the NetLogo Interface Tab to allow graphical observation simultaneously while a simulation is running. There are plots for the following information: *hCAll*, *hX.Y*, *rel*, *crea*, domain creativity scores (*cScores*) as well as for the patchwork distributions of all creators and each creator type separately. There are monitors for the dependent variables *hCAll*, *hX.Y*, *rel*, *crea* and the interim variables *hX*, *hY* and *hXY* (see Sections 6.6 and 8.6 for more on these variables).

Secondly, numerical data collection was achieved by designing experiments with NetLogo's BehaviorSpace (Wilensky, 1999). Each experiment produced a .csv file containing values for all dependent variables (Table 8.5) at every time step of each simulation run. The data was used freely to analyse CRESY-II, although not all variables were selected for model analysis. All dependent variables are taken from the observer perspective.

## **8.3 ODD Protocol: Details**

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### **8.3.1. Initialization**

All variables used for initialization were derived from theoretical deliberations or empirical findings discussed in creativity research (see for example Ochse, 1990; Sawyer, 2006; Sternberg, 1999a; Sternberg et al., 2004; Zhou & Shalley, 2007). Their exact values were initially arbitrarily set and then explored in the experiments described in Section 8.7. Please refer to each experiment's documentation for the exact initial settings (see also Figure 8.6).

### **8.3.2. Input data**

CRESY-II does not use input data to represent time-varying processes. The model is an abstraction derived from normative ideas published in creativity research chiefly within the field of psychology (see Sections 7.1 in Chapter 7 and 9.1 in Chapter 9 for more).

### **8.3.3. Submodels**

This section describes CRESY-II's processes or *submodels* (see also Figure 8.2). If they function the in same way as in CRESY-I, they are not re-explained here but cross-referenced to CRESY-I's ODD protocol (Chapter 6).

#### **obtain-info**

Creators and evaluators obtain information in the same way as in CRESY-I (see Section 6.3.3). The only difference is that evaluators save patches' *plabel* variable, which

indicates their *domSize* category. This does mean creators have more (memory) variables than evaluators, and at face value they receive more information. However, each memory variable - be it that of creators or evaluators - is updated with the same amount of information according to *info-rate*<sup>2</sup>. Creators' state variables *cR*, *cG*, and *cB* (Table 6.1) and evaluators' state variable *eMem* (Table 8.2) are updated in this procedure.

### make-patchwork

Creators make patchworks in exactly the same manner as in CRESY-I (see Section 6.3.3). The only difference is that creators no longer place their patchworks on the patches they are currently standing on, but on one of the eight neighbouring patches with the lowest creativity score (*cScore*; Table 8.1). This simple form of retention ensures that more favoured patchworks remain longer in the domain ("survival of the fittest enough"). This is the time when patches' state variables *pR*, *pG*, *pB*, *pcolor*, *pDom*, *plabel*, *hue*, *madeBy* and *cScore* are updated.

### rate-patchwork

Evaluators rate patchworks according to their perceived novelty and/or appropriateness, and they can be one of three types: *En* (judges only novelty), *Ea* (judges only appropriateness) or *Ena* (judges both). An evaluator's judgement results in one dichotomous creativity score (*cScore*) for a particular patch: 0 = *not creative*, 1 = *creative*. Evaluators judging patchworks based on their perceived novelty do so according to the variable threshold *novelty-stringency*, and those judging appropriateness are influenced by the variable threshold *appropriateness-stringency*. Both thresholds are set by the observer in NetLogo's Interface Tab (see also Table 8.2), so they are the same for all evaluators affected by them. The pseudo code in Figure 8.4 describes how the different evaluator types make their judgements. Note that evaluator type *Ena* must judge a patchwork's novelty as given (1) *and* its appropriateness as given (1) in order to rate the entire patchwork as creative (1). The observer can set how many evaluators of each type are desired by using input boxes in NetLogo's Interface Tab.

**Assessing novelty** The variable *novelty-stringency* ranges from 0–1 and represents a threshold according to which an evaluator decides whether a patch under current evaluation is novel or not. The patchwork's (*p*) relative frequency (*rf<sub>pe</sub>*) is calculated from an evaluator's (*e*) memory, i.e. how often has evaluator *e* seen patchwork *p* before compared with all other patchworks it has also seen? If *rf<sub>pe</sub>* is less than or equal to *novelty-stringency*, the patchwork is considered novel (*n* = 1), otherwise it is not (*n* = 0; see also pseudo code in Figure 8.4). This way of operationalizing

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<sup>2</sup>So creators receive *info-rate* \* 3 pieces of information, whereas evaluators receive *info-rate* \* 1 pieces of information. Each memory variable (*cR*, *cG*, *cB* and *eMem*) receives *info-rate* pieces of information.



```

; How En and Ena assess a patchwork's novelty:
LET p = relative frequency of current patchwork in my memory
IF p <= novelty-stringency
  THEN SET novelty = 1 ; novel
  ELSE SET novelty = 0 ; not novel
; How Ea and Ena assess a patchwork's appropriateness:
LET h = patchwork's hue ; warm vs. cool
LET viewed = 6 randomly selected neighbors
LET c = number of viewed with hue = h
SET c = c / 6
IF c >= appropriateness-stringency
  THEN SET appropriateness = 1 ; appropriate
  ELSE SET appropriateness = 0 ; not appropriate
; How a patchwork's creativity score is set:
IF type = En THEN SET cScore = novelty
IF type = Ea THEN SET cScore = appropriateness
IF type = Ena THEN IF (novelty + appropriateness) = 2
  SET cScore = 1 ; creative
  ELSE SET cScore = 0 ; not creative

```

Figure 8.4.: The pseudo code explains how evaluators En, Ea and Ena judge novelty and appropriateness as well as turn these ratings into a creativity score.

novelty assessments may best be described by the following question: *How unfamiliar must a patchwork be to an evaluator to be considered novel?* Note that novelty assessment depends on an evaluator's memory; two evaluators may disagree about the same patchwork's novelty depending on what they have seen before.

**Assessing appropriateness** All patches have a variable called *hue*, which indicates whether their colour is warm or cool<sup>3</sup> (see Table 8.1). A patchwork is considered appropriate when its hue agrees with the hues of its neighbours, meaning it should have the same hue as the majority of surrounding patches. An evaluator about to judge a patchwork's appropriateness therefore first takes a look at the latter's surroundings. To simulate imperfection of humans' perception of their environment (see for instance Chattoe, 1998) and to enhance variability of judgements, an evaluator only

<sup>3</sup>Hues can be depicted with a colour circle of 360°. The rgb values of a patchwork are translated into their corresponding degrees on the circle. Values from 135° – 314° are categorised as cool, all others as warm.

checks the hues of six randomly selected neighbours<sup>4</sup>. It then assesses how many ( $c$ ) of the six have the same hue as the patchwork under current evaluation. By calculating the percentage of six neighbours with the same hue ( $\frac{c}{6}$ ), a number from 0 – 1 results. This number is finally compared with the variable *appropriateness-stringency*. The latter also ranges from 0 – 1 and represents a threshold according to which an evaluator decides whether a patchwork under current evaluation is appropriate or not. If  $\frac{c}{6}$  is greater than or equal to *appropriateness-stringency*, the patchwork is considered appropriate. This way of operationalizing appropriateness assessments may best be described by the following question: *At least how much does a patchwork need to fit to its surroundings in order to be considered appropriate by an evaluator?* See the pseudo code in Figure 8.4 for another description.

### **move**

Different movement strategies are available for creators and evaluators, and they can be set by the modeller with a so-called *chooser* in NetLogo's Interface Tab. The strategies were already explained in CRESY-I's ODD protocol (see Section 6.3.3).

### **forget-some-info**

Creators and evaluators forget according to the same-named submodel in CRESY-I's ODD protocol (see Section 6.3.3). Analogous to the way creators forget in CRESY-I, evaluators also forget three randomly selected pieces of information which are deleted from their memory *eMem*. Creators' state variables *cR*, *cG*, and *cB* (Table 6.1) and evaluators' state variable *eMem* (Table 8.2) are updated in this procedure.

### **tick**

In this submodel, NetLogo's built-in time counter advances. Time is modelled in discrete steps, called *ticks* in NetLogo.

### **update-domain**

During this procedure all dependent variables and the interim variables used for their calculation are updated (Table 8.5). For the exact equations, see Sections 6.6 and 8.6. Additionally, patches' *cScores* are updated to reflect the evaluation status of the domain. This is also the time when Interface plots are updated.

## 8.4 Model verification

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The following measures were taken to verify CRESY-II:

---

<sup>4</sup>Without this stochasticity appropriateness judgements would always be the same, as all evaluators would view the same eight neighbours and come to the same judgement according to the algorithm to follow.

### Coding

- An object-oriented language was used.
- Meaningful variable names were systematically used for all but local variables.
- Sufficient time was allocated for programming.
- A second programmer was asked to proofread parts of CRESY-II.
- Assertions were added to check whether input parameter values made sense.
- NetLogo's syntax analysis button ("check" in the Procedures Tab; Wilensky, 1999) was regularly used.
- Additional pieces of code were added to each procedure to check input and output plausibility. This code was deleted in the final version.

### Documenting

- Comments were added to the code to facilitate model-to-program translation.
- NetLogo's Information Tab (Wilensky, 1999) and the ODD protocol (Grimm et al., 2006) were used.

### Observing

- An abundance of output diagnostics (histograms, monitors, plots of interim and final variables) were programmed in the NetLogo's Interface Tab (Wilensky, 1999).
- The model was animated using NetLogo's "View" (Wilensky, 1999).
- During model building, individual procedures were run singly and their output checked in NetLogo's Command (Wilensky, 1999).
- During model building, an abundance of brief experiments were carried out to check if CRESY-II functions just as CRESY-I does in the procedures carried over from the latter model.

### Testing

- Before experimentation, conditions for which output parameters are known were tested by observation. CRESY-II was not used until the values were as expected.
- All experiments conducted with CRESY-II were run with (theoretically derived) extreme conditions.
- In all experiments conducted with CRESY-II, graphical and statistical testing was used to back up modeller observations.

### Comparing

- After each experiment conducted with CRESY-II, data interpretations and discussions containing model-to-program comparisons were documented.

## 8.5 Independent variables

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Figure 8.5 depicts a chart containing all parameters an experimenter can vary in CRESY-II. They are classified according to the system they belong to. Method-specific variables result due to the peculiarities of simulation modelling. The modeller can influence the size and shape of the programmed world. Furthermore, the number of runs and steps per run require setting for experimentation. The macrosystem and creator microsystem variables are the same as used in CRESY-I (Chapters 6 - 7). Technical variables in the evaluator microsystem correspond to those in the creator microsystem: The number of evaluators can be altered, and their movement strategies and information uptake rate may be varied. Substantial variables in this system are the ratio of evaluator types (*eRatio*), their novelty and appropriateness thresholds (*novelty-stringency*, *appropriateness-stringency*) and the number of categories they have to perceive patchworks (*domSize*). Note that *domSize* was a global variable in CRESY-I. In CRESY-II evaluation takes place in evaluators as autonomous agents and not in one global observer. Therefore, *domSize* now belongs to the former. It is set to one value for all evaluators.

In the experiments conducted with CRESY-II, not all parameters in Figure 8.5 are varied due to reasons of feasibility. Note that if each variable was varied in two ways, resulting in "simple" a  $2^k$  design, a total of 524,288 experimental conditions would be necessary. In the documentation of each experiment conducted with CRESY-II, the independent variables chosen for experimentation are explicitly stated.

## 8.6 Dependent variables

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### 8.6.1. hCAII

This dependent variable was used in CRESY-I and is reused in CRESY-II. It's formula is thoroughly explained in Section 6.6.1.

### 8.6.2. hX.Y

This dependent variable was used in CRESY-I and is reused in CRESY-II. It's formula is thoroughly explained in Section 6.6.2.

### 8.6.3. Creativity

After rating a patchwork's novelty and/or appropriateness, evaluators ultimately judge its creativity by giving it a binary score (*cScore*) of 0 (not creative) or 1 (cre-

Method-specific Variables	
Substantial	Technical
	number of runs number of steps (ticks) world size world shape (e.g. borders)
Macrosystem Variables	
Substantial	Technical
predefine-r predefine-b predefine-g	
Creator Microsystem Variables	
Substantial	Technical
cRatio imagination	number-creators info-rate movement
Evaluator Microsystem Variables	
Substantial	Technical
eRatio domSize novelty-stringency appropriateness-stringency	number-evaluators info-rate number-evaluators

Figure 8.5.: The input parameters available in CRESY-II are divided into method-specific, macrosystem and microsystem variables. They are subdivided into technical and substantial variables.

ative). Each evaluator rates every patchwork made in the current step. So *number-creators* \* *number-evaluators* creativity scores result every tick, because each creator makes only one patchwork and each evaluator rates every one. Subsequently, a total creativity assessment for the current step is calculated and expressed in the variable *crea*. For each patchwork *j* currently evaluated, its number of corresponding creative evaluations (1s;  $N_{1j}$ ) is set in relation to its total number evaluations ( $N_{totalj}$ , equal to *number-evaluators*). That is the single patchworks's current creativity score ( $c_j$ ). These interim creativity scores are then averaged to obtain the patchworks' mean creativity in the current step.

$$crea = \frac{\sum_{i=1}^n c_j}{n} \quad (8.1)$$

whereas  $n$  = number of patchworks made in the current step (equal to *number-creators*),

and  $c_j = \frac{N_{1j}}{N_{total\ j}}$  for patchwork  $j$

*crea* is therefore a percentage indicating how creative evaluators find creators' current work on average. Note again that *crea* is calculated every step only with the patchworks currently made and thus evaluated.

### 8.6.4. Reliability

Regardless of output type, measuring the accuracy or reliability of judgements is an essential part of creativity assessment (Silvia, 2008). In CRESY-II, reliability is measured with Fleiss'  $\kappa$  (Fleiss, 1971) for binary data as derived in (Bortz et al., 2008, p. 454-458).

## 8.7 Experimental design

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Two experiments were conducted with CRESY-II (see Figure 8.6). The first, CII-1a, was conceived to investigate how many runs, steps per run and evaluators (*number-evaluators*) should be used for further explorations (see Section A.5.4 in the Appendix for a full documentation of this experiment). The results obtained were used to design the second experiment, CII-1b. It's purpose was to explore how macrosystem, creator microsystem and evaluator microsystem variables affect the dependent variables. This experiment was therefore designed to investigate substantial variables regarded as essential in Csikszentmihalyi's (1999) model of creativity. The results gathered were used to generate hypotheses about his perspective (see Chapter 9 for a full documentation of Experiment CII-1b). Note that fewer preparatory experiments were conducted with CRESY-II compared with CRESY-I. This is due to the fact that only parameters values already used in CRESY-I were reused in CRESY-II, i.e. input parameters available in both models are set in CRESY-II with values already tested in CRESY-I.

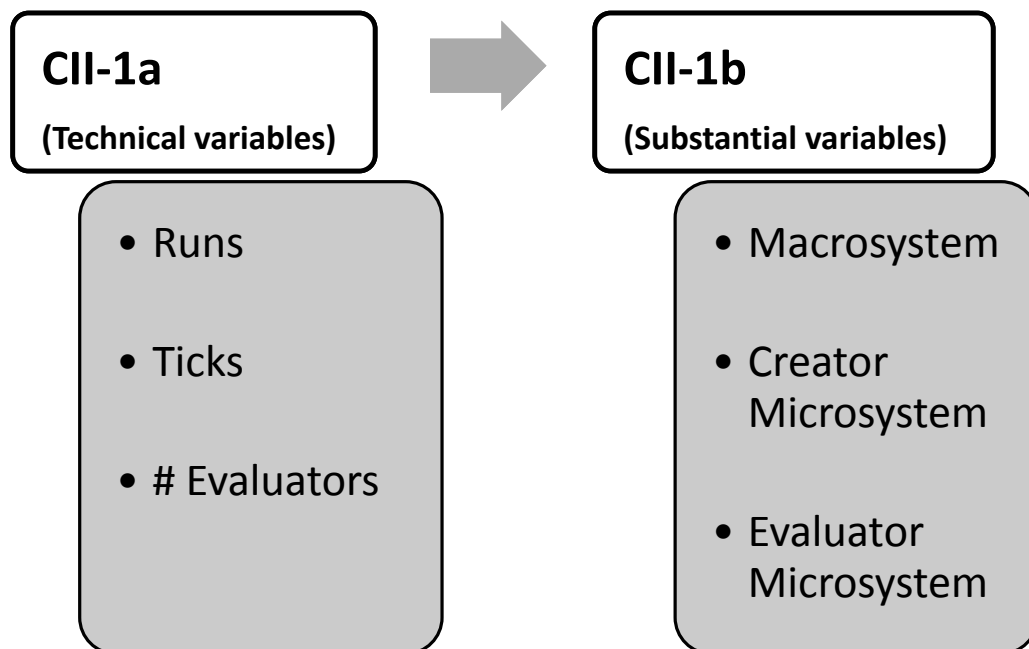


Figure 8.6.: Overview of experiments conducted with CRESY-II.





# 9

## CRESY-II

In the course of this dissertation, two experiments were conducted with CRESY-II (see Section 8.7 and Figure 8.6 for an overview). The first is documented in Section A.5 of the Appendix. This chapter documents the second and main experiment, Experiment CII-1b. Its purpose is to explore the influence key substantial input variables have on selected dependent variables.

Chapter 9 begins with a brief meditation on how evaluators are defined, differentiated and assessed in contemporary creativity research within the domain of psychology (Section 9.1). It continues with sections on Experiment CII-1b's methodology (9.2) and results (9.3), and it closes with a discussion (9.4). Note that theoretical and concrete ideas about creativity from a systems perspective and its relation to the evolutionary mechanism VSR are thoroughly described in Chapter 3. The technical details of CRESY-II can be found in Chapter 8.

### 9.1 Theory

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Creativity researchers have started to investigate the evaluation process inherent in their studies (Adarves-Yorno et al., 2006; Förster et al., 2010; Haller et al., 2011; Herman & Reiter-Palmon, 2011; Kaufman et al., 2008; Kozbelt & Serafini, 2009; Randel et al., 2011; Rietzschel et al., 2010; Silvia, 2011). Lonergan et al. (2004) even argue "the evaluative process itself may be a highly creative, or generative, undertaking" (p. 231). Silvia (2008) admits "...judges are a source of variability, so they are more appropriately understood as a facet in the research design" (p. 141). Although research on creative production massively outweighs that on creative evaluation, the work available sheds light on how evaluators are conceived and differentiated in contemporary creativity research.

Generally, the evaluators involved with creativity experiments are categorised as being a) selves or others and b) experts or non-experts (see Figure 9.1). Conventionally, creativity researchers administer creative tasks to (psychology) student samples and subsequently request students assistants recruited as evaluators to judge the answers. This trend still outweighs today (Adarves-Yorno et al., 2006; Bechtoldt et al., 2010; Lonergan et al., 2004; Rietzschel et al., 2006, 2010; Silvia, 2008). Such judges are best categorised as peers, i.e. "others" and their expert status depends on the creative task. To ensure reliability, the overseeing scientist may assist in evaluation

(Rietzschel et al., 2006, 2010). Another tradition in creativity research includes the study of art students' work, and the evaluators involved include the creators themselves, peer and professional artists (e.g. Runco et al., 1994). Sometimes, producers *and* consumers are studied such as Jaskyte et al.'s (2009) investigation of innovative teaching based on faculty and student perceptions. Some creativity researchers are particularly interested in the comparison of expert and non-expert judges, because expert judges are usually harder to recruit and more expensive (Kaufman et al., 2008; Kozbelt & Serafin, 2009). If non-expert ratings are similar enough to expert ones, so the idea, the former would be preferred for economical reasons.

Besides concrete experimental realisations, Förster et al. (2010) are developing ideas they call novelty categorization theory. It attempts to explain how novelty is perceived and processed based on an individual's existing mental categories. In their view, categorisation precludes the perception of something as novel or not, and it determines information processing styles. So-called *global* processing facilitates the inclusion and integration of novel events into existing knowledge structures, although it is not a guarantee that the event will ultimately be perceived as novel. Familiar events elicit *local* processing which make use of narrow, exclusive categories. Förster et al.'s (2010) ideas may prove valuable to creativity researchers investigating the evaluation process, as novelty is considered a key indicator in the recognition of creativity (Ward et al., 1999).

	Self	Other
Expert	Professional	Peer professionals Leading professionals Supervisors General public
Non-expert	Layperson	Peer laypeople General public Supervisors

Figure 9.1.: *Evaluators in creativity research can be classified as a) self or other and b) expert or non-expert. Note that status as an expert initially depends on the task at hand.*

There is more to the evaluation process than just the social categories describing the evaluators. Judges have a specific *task*, namely to rate creators' manifest behaviour with a predefined measuring instrument. Therefore, their generative behaviour is guided and influenced by a particular prompt. Although there are measures

of creativity which are more than less quantitative (e.g. fluidity and flexibility; Sternberg, 1999b), most evaluations rely on subjective judgements (Amabile, 1982). A common measure of creativity is implemented by asking judges "*How creative do you find...?*" (Kaufman et al., 2008; Runco et al., 1994; Silvia, 2008), even though they may give their answers on quantitative scales (e.g. 1-5, 0-6, 1-6). Other researchers ask recruited evaluators to select the *top* or *best*  $x$  artefacts, or those which are *good* or *creative enough* (Rietzschel et al., 2006, 2010; Silvia, 2008). Kozbelt & Serafin (2009) requested judges to rate artist drawings in progress on bipolar items using an 8-point scale. The items reflected the products' originality, technical skill and quality. Jaskyte et al. (2009) developed an instrument to measure innovative teaching with two groups of potential judges (faculty and students) and then administered it with new judges. Two instruments emerged, one for instructors and the other for students. Each encompasses over 20 items with a 5-point scale. One of the most complex operationalisations of the evaluation process is demonstrated in work by Lonergan et al. (2004). They make a distinction between a) the standard used to evaluate (*innovative* vs. *operative*) and b) the evaluation phase (product *appraisal* vs. *revision*). In doing so, they acknowledge that evaluation can encompass incongruent norms and different frames of reference, as well as take place more than once.

Despite the variability of creativity measures, most converge in their use of the criteria *novelty* and *appropriateness* as indicators of creativity (see also Chapter 3). A popular instrument which incorporates both is the *Consensual Assessment Technique* (CAT) by Amabile (1996, 1982). Designated creators are asked to produce something based on a given task, for example a collage or a poem. Afterwards, designated experts are asked to rate the work. The CAT's rating procedure has several specifics. First of all, it is based on the following *conceptual* definition (Amabile, 1996):

A product or response will be judged as creative to the extent that (a) it is both a novel and appropriate, useful, correct or valuable response to the task at hand, and (b) the task is heuristic rather than algorithmic (p. 35).

Secondly, it is implemented in the following manner:

- Judges make their ratings independently, and they are not previously trained by an experimenter or the like. They are prompted to use their personal, subjective definition of what is novel and appropriate.
- Interrater reliability must be sufficiently high, whereas decision criteria specific to the chosen reliability measure are used.
- Judges are to some degree experts, even if their domain-specific knowledge is not identical. They need not have created themselves, but require enough experience in the domain to have developed a personal sense for what is novel and appropriate.

In allowing raters to use their own subjective definitions of what is creative, Amabile (1982) acknowledges the fact that universally valid operationalisations of novelty and appropriateness are still lacking and most likely impossible to derive. Her consensual definition of creativity used as an explicitly operational one is as follows (Amabile, 1996):

A product or response is creative to the extent that appropriate observers independently agree it is creative. Appropriate observers are those familiar with the domain in which the product was created or the response articulated. Thus, creativity can be regarded as the quality of products or responses judged to be creative by appropriate observers, and it can also be regarded as the process by which something so judged is produced (p. 33).

The CAT has remained popular in creativity research because it is simple to administer and functions quite similarly to creative evaluations made in the real world, e.g. academic publishing, music charts, museum art collections. In everyday life, it is realistic to have designated experts decide on the creative value of artefacts from their domain. Moreover, it does not force a uniform definition of creativity upon evaluators, but decidedly leaves room for subjectivity regardless of what the latter ultimately reflects. Evaluators are prompted to use their own definitions and feelings of what is novel and appropriate. As Kaufman et al. (2008) note, the "judges' expertise provides a measure of face validity – it makes sense that experts in a domain could accurately assess performance in that domain" (p. 175). High interrater reliability alone only indicates people agree on something, i.e. the ratings share more variance than by chance.

This section is not intended to be exhaustive, but it hopefully illustrates methodological issues contemporary creativity researchers are increasingly paying more attention to. The study of the evaluation process involves debates on *who* evaluates and *how* they do so. Although some deviations exist (e.g. Boden, 1999), most creativity researchers agree that judgements of novelty and appropriateness suffice to assess creativity. An artefact is *novel* if it is considered unusual, original, statistically infrequent, unique or unexpected in reference to the observer judging it (DiPaola & Gabora, 2009; Sawyer, 2006). It is considered *appropriate* if it is useful, aesthetic, pleasing, valuable or fitting for an intended purpose or audience (ibid.). Judges either give one overall creativity rating on the basis of both dimensions, i.e. they are prompted to consider both when evaluating, or their separate, unweighed judgements on both dimensions are added to one creativity score.

### **Evaluators in computer models of creativity**

CRESY-2 resembles some of the computer models of creativity mentioned in Chapter 5 due to the incorporation of production, evaluation and evolutionary processes. In Bryson's (2008) model of conformity and innovation, the "evaluator" is the experimenter / modeller who sets a specific module (behaviour) agents are rewarded for

if they exhibit it. Rewards, a retention mechanism, ensure agents biologically reproduce. Edmonds (1999) published a model recreating visitor behaviour at a real-world bar. Although influenced by their peers, the "evaluators" in it are the same agents who create (attendance strategies).

In Gabora's (1995) model "Memes and Variations" (MAV), creating and evaluating entities are the same agents. They assess their own behaviour (body movements) with a predefined fitness function indicating how well their movements satisfy their need to attract mates. The function,  $F_1$ , is the same for all agents and does not change during the simulation<sup>1</sup>. Gabora's (2008a) computer model of cultural evolution (EVOC) is fundamentally similar to MAV (see also Gabora, 2008b; Leijnen & Gabora, 2009a, 2010). It includes an additional fitness function,  $F_2$ , to reward movements which satisfy the need to make tools<sup>2</sup>. In EVOC the fitness functions can be combined to simulate both needs<sup>3</sup>. It is noteworthy that a movement cannot satisfy both at once, so this feature deviates from the technically similar one in CRESY-2. In the latter model, a patchwork must be novel *and* appropriate to be creative (fit). A distinguishing characteristic of MAV and EVOC is that they attempt to reproduce biological phenomena such as genetic drift and epistasis as behavioural consequences of individual cognitive processes.

Picascia & Paolucci's (2010) "Meme-to-Web" (MtW) model incorporates evaluation as an information retrieval process exerted by creating agents. The artefacts MtW's agents produce can be accessed by them in different ways on the "web". Each retrieval strategy leads to differences in collective artefact and meme diversity in the long run. This model does not simulate conscious, qualitative appraisal, but it does realistically demonstrate that diversity is also navigated by technical filtering processes which influence variation and selection processes carried out by the respective entities.

### Specifics about CRESY-II

CRESY-II differs from the above computer models in several aspects. Firstly, creators and evaluators are modelled as separate entities. This increases the simulation's complexity, because the two agent types possess unequal experiential backgrounds on which they base their behaviour. In other terms, the "mind" creating a patchwork is not the same "mind" evaluating it, which is the case in Gabora's (1995, 2008) models. Furthermore, the evaluator is not the modeller herself, as is the case in work by Bryson (2008). Most importantly, the evaluation algorithm in CRESY-2 is a specific. It represents a way to formalise novelty and appropriateness assessments. Although technically similar in function, it is not directly comparable with the algorithms used by others (Bryson, 2008; Gabora, 2008a; Picascia & Paolucci, 2010). Moreover, the algorithm's frames of reference change every step in the simulation, because it is based on current individual (memory) and contextual (neighbourhood)

<sup>1</sup> $F_1 = m \cdot a_m + 2 \cdot m \cdot a_s + m \cdot i$ . See Gabora (1995) for further explanations.

<sup>2</sup> $F_2 = c \cdot (L + R + 2 \cdot H)$ . See Gabora (2008a) for further explanations.

<sup>3</sup> $F_{1+2} = 0.5 \cdot (y \cdot F_1 + z \cdot F_2)$  whereas  $y$  and  $z$  are user-defined variables (Gabora, 2008a).

factors. Finally, the intention is not to model different social categories of evaluators. The evaluators technically are *others* and they are assumed to be *experts*. As already emphasised, the focus is on a) formalising novelty and appropriateness judgements, and b) observing whether and how they affect the domain. Note the specific attributes and behaviour evaluators exhibit from a systems and evolutionary perspective are described in Section 3.6.3.

### 9.1.1. Research questions

CII-1b is the last experiment in a systematic exploration conducted with CRESY-II. Its purpose is to investigate how particular substantial independent variables affect selected dependent variables. The variables are explained in detail below (Section 9.2). The main research questions are:

- How do three selected substantial independent variables affect the dependent variables?
- Which hypotheses about creativity from a systems perspective can be generated from the simulated data?

## 9.2 Method

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This section describes the experimental design chosen for Experiment CII-1b. It was derived based on results obtained in previous experiments<sup>4</sup>. The ODD protocol for CRESY-II is part of Chapter 8, the "roadmap" to the model. Experiment CII-1b has a total of 20 conditions. Three input variables considered substantial were varied:

**predefine (p):** The interface sliders *predefine-r*, *predefine-g* and *predefine-b* were collectively set to one of two different numbers representing low and high values (1, 256). The substantial independent variable *predefine* refers to how colourful (diverse) the environment is at the start of a simulation run. It represents the **macrosystem** in this simulated world.

**cRatio (c):** The ratio of creators (Cx:C1:C2:C3) was varied to reflect different levels of a sample's potential to produce diversity: low (3:0:0:1) and high (1:0:0:3). This variable reflects the **creator microsystem** in the simulated world.

**evalStrategy (e)** This variable refers to the **evaluator microsystem** in the simulated world. Patchwork creativity ratings are based on the values for evaluators' variables *novelty-stringency* and *appropriateness-stringency* (see Chapter 8). They were varied together in five ways to reflect different evaluation strategies:

- **"nov"**: Ratings are only based on perceived novelty.

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<sup>4</sup>They are not reiterated here. Please refer to Section 6.7 in Chapter 6, Chapter 7, and Sections A.1, A.2, A.3 and A.5 of the Appendix.

- **"app"**: Ratings are only based on perceived appropriateness.
- **"cla"**: Ratings are classic, i.e. based on both novelty and appropriateness.
- **"equ"**: Novelty and appropriateness do not matter to evaluators. Patchworks have a 50% chance of being perceived as novel and appropriate.
- **"mix"**: Ratings are based on novelty only, appropriateness only or on both in the classic sense. This mixture of strategies is equally distributed among evaluators.

Figure 9.2 summarises the experimental design graphically. The rest of the experimental set-up resembles settings for CRESY-I as much as possible. The following variables were held constant: In each run, four creators and 15 evaluators were used in a 21x21 torus (*density*). The *info-rate* was set to *n8*, meaning creators and evaluators collected information about patchworks from eight neighbouring patches every step. Both agent types moved in the world based on the *any8* strategy, meaning they could move to any of the eight neighbouring patches as long as they were empty. Creators' *imagination* was set to *0.05*, which allowed for maximum differences in the dependent variables when creator sample compositions (*cRatio*) were compared in a previous experiment (CI-2b; Chapter 7). Evaluators' state variable *domSize* was set to *512*, as this value was used in CRESY-1 as well and is expected to lead to similar values for the dependent variable *hCAI*. *novelty-stringency* was set to *0.25* and *appropriateness-stringency* to *0.75*. These values are an operationalization of the demand that creative work must be sufficiently novel and appropriate. A total of 30 runs with 6000 steps each were collected per experimental condition. The following dependent variables were recorded at every step of every run: *hCAI* (diversity), *crea* (creativity), *rel* (reliability).

## 9.3 Data analyses and results

---

Each experimental condition produced an output file which was subsequently analysed with R (Version 2.13.0). The following steps were taken:

1. Graphical analyses
2. Aggregation of dependent variables
3. Correlation diagrams
4. Analyses of variances

### Step 1: Graphical analyses

Line and violin plots were made for the dependent variables *hCAI* (diversity), *crea* (creativity) and *rel* (reliability). See Figures 9.5 – 9.10 for the results. Line plots depict the average run per condition whereas violin plots display the entire data per

Macrosystem																			
predefine-r/-g/-b																			
1										256									
Creator Microsystem																			
cRatio																			
3:0:0:1					1:0:0:3					3:0:0:1					1:0:0:3				
Evaluator Microsystem																			
evalStrategy																			
nov	app	cla	equ	mix	nov	app	cla	equ	mix	nov	app	cla	equ	mix	nov	app	cla	equ	mix
novelty-stringency																			
.25	1.0	.25	.50	.25	.25	1.0	.25	.50	.25	.25	1.0	.25	.50	.25	.25	1.0	.25	.50	.25
appropriateness-stringency																			
.00	.75	.75	.50	.75	.00	.75	.75	.50	.75	.00	.75	.75	.50	.75	.00	.75	.75	.50	.75
Experimental Condition CII-1b-																			
lo	lo	lo	lo	lo	lo	lo	lo	lo	lo	hi	hi	hi	hi	hi	hi	hi	hi	hi	hi
lo	lo	lo	lo	lo	hi	hi	hi	hi	hi	lo	lo	lo	lo	lo	hi	hi	hi	hi	hi
nov	app	cla	equ	mix	nov	app	cla	equ	mix	nov	app	cla	equ	mix	nov	app	cla	equ	mix
01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20

Figure 9.2.: Experimental design for Experiment CII-1b. The bottom two rows include the names of conditions. Conditions CII-1b-lo-lo-cla-03 and CII-1b-hi-hi-cla-18 were also used in Experiment CII-1a (Section A.5).

condition. Additionally, line plots depicting the average run of each independent variable's level were made for the dependent variables *hCall* and *crea* (see Figures 9.11 – 9.13).

**Reliability.** Figures 9.9 – 9.10 show the reliability values characteristic for each condition. Almost perfect reliability was reached in nearly every condition ( $M = .94 - .99$ ). The only exceptions are Conditions 5, 10, 15 and 20 in which the mean reliability is moderate ( $M = .45 - .67$ ; Landis & Koch, 1977). These conditions share a common factor: They all have *evalStrategy* set to *mix*. This means the evaluators are not using the same strategy to judge patchworks. The other factors *predefine* and *cRatio* are completely varied among these four conditions. This result is not unusual, as it should be more difficult for evaluators to reach perfect agreement if they are using different selection criteria. In general, it is positive that evaluators agree so well in the other conditions. This indicates face and construct validity (Amabile, 1982; Kaufman et al., 2008) for the creativity criterion (*crea*).



**Average runs per factor level.** Figures 9.11 – 9.13 show the average run per level of independent variable for *hCAII* and *crea*. The diagrams indicate interesting and surprising tendencies in the data, even before multi-factorial statistical analyses are conducted: Figure 9.11 illustrates that patchwork creativity (*crea*) does not appear to depend on macrosystem diversity (*predefine*). Additionally, although patchwork diversity (*hCAII*) is initially larger in highly diverse macrosystems (*predefine* = 256), it drops somewhat below the levels in minimally diverse ones (*predefine* = 1) in the long run. Figure 9.12 indicates that the type of creator microsystem (*cRatio*) does not make a difference in the long run when patchwork diversity (*hCAII*) is measured, whereas microsystems assumed to produce more conventional patchworks (*c* = 3:0:0:1) coincide with higher levels of creativity compared with the work of their more original counterparts (*c* = 1:0:0:3). Figure 9.13 shows that evaluation strategies only incorporating novelty judgements (*e* = nov) concur with higher levels of diversity (*hCAII*) and creativity (*crea*) compared with other strategies.

#### Steps 2 & 3: Aggregation of dependent variables and correlation diagrams

Similarly as in CRESY-I, the dependent variables *hCAII* and *crea* were aggregated to their modes and coefficients of variation (CV) per run. The former is an indicator of a run's average location, the latter an indicator of a run's variability. This step allows the comparison of experimental conditions based on the dependent variables' centrality and stability. The modes and CVs for *hCAII* and *crea* were correlated in Step 3 to obtain a graphical overview of their association. See Figure 9.14 for the results.

#### Step 4: Analyses of variances

The modes and CVs calculated for *hCAII* and *crea* were separately tested in three-way independent analyses of variances with the factors *predefine* (*p*), *cRatio* (*c*) and *evalStrategy* (*e*). The effect size  $\hat{\omega}_G^2$  (generalized omega squared; Olejnik & Algina, 2003) was additionally calculated for each effect. The results are summarised in Tables 9.1 – 9.4. Figures 9.3 – 9.4 show the descriptive statistics and Figures 9.15 – 9.22 the interaction plots.

Descriptive statistics: hCAII Mode

p	c	e	Cond.	M	SD	n
predefine = 1	cRatio = 3:0:0:1	nov	01	0.76	0.02	30
		app	02	0.71	0.04	30
		cla	03	0.72	0.02	30
		equ	04	0.64	0.06	30
		mix	05	0.72	0.02	30
	cRatio = 1:0:0:3	nov	06	0.89	0.00	30
		app	07	0.79	0.01	30
		cla	08	0.74	0.03	30
		equ	09	0.81	0.03	30
		mix	10	0.71	0.03	30
predefine = 256	cRatio = 3:0:0:1	nov	11	0.88	0.00	30
		app	12	0.60	0.05	30
		cla	13	0.59	0.05	30
		equ	14	0.69	0.05	30
		mix	15	0.59	0.04	30
	cRatio = 1:0:0:3	nov	16	0.89	0.00	30
		app	17	0.62	0.02	30
		cla	18	0.61	0.02	30
		equ	19	0.74	0.05	30
		mix	20	0.61	0.02	30

Descriptive statistics: hCAII CV

p	c	e	Cond.	M	SD	n
predefine = 1	cRatio = 3:0:0:1	nov	01	14.39	1.34	30
		app	02	21.16	5.08	30
		cla	03	16.46	2.26	30
		equ	04	14.18	1.90	30
		mix	05	14.77	1.31	30
	cRatio = 1:0:0:3	nov	06	8.57	0.69	30
		app	07	9.84	1.11	30
		cla	08	7.97	1.14	30
		equ	09	8.00	1.08	30
		mix	10	8.60	1.79	30
predefine = 256	cRatio = 3:0:0:1	nov	11	2.93	0.03	30
		app	12	14.48	7.02	30
		cla	13	14.18	6.08	30
		equ	14	7.59	4.09	30
		mix	15	15.74	6.50	30
	cRatio = 1:0:0:3	nov	16	2.97	0.10	30
		app	17	13.92	2.32	30
		cla	18	14.88	2.45	30
		equ	19	5.06	3.36	30
		mix	20	15.22	2.47	30

Figure 9.3.: Descriptive statistics for hCAII (patchwork diversity).

Descriptive statistics: crea Mode

p	c	e	Cond.	M	SD	n
predefine = 1	cRatio = 3:0:0:1	nov	01	1.00	0.00	30
		app	02	0.82	0.10	30
		cla	03	0.75	0.02	30
		equ	04	0.83	0.12	30
		mix	05	0.83	0.00	30
	cRatio = 1:0:0:3	nov	06	1.00	0.00	30
		app	07	0.75	0.00	30
		cla	08	0.71	0.06	30
		equ	09	0.72	0.08	30
		mix	10	0.78	0.07	30
predefine = 256	cRatio = 3:0:0:1	nov	11	1.00	0.00	30
		app	12	0.75	0.00	30
		cla	13	0.75	0.00	30
		equ	14	0.75	0.00	30
		mix	15	0.83	0.00	30
	cRatio = 1:0:0:3	nov	16	1.00	0.00	30
		app	17	0.50	0.00	30
		cla	18	0.50	0.00	30
		equ	19	0.50	0.00	30
		mix	20	0.67	0.00	30

Descriptive statistics: crea CV

p	c	e	Cond.	M	SD	n
predefine = 1	cRatio = 3:0:0:1	nov	01	19.66	2.11	30
		app	02	20.78	1.49	30
		cla	03	34.72	5.29	30
		equ	04	29.35	3.83	30
		mix	05	20.88	2.65	30
	cRatio = 1:0:0:3	nov	06	5.99	0.59	30
		app	07	35.84	1.00	30
		cla	08	38.09	2.09	30
		equ	09	36.74	1.44	30
		mix	10	22.40	1.85	30
predefine = 256	cRatio = 3:0:0:1	nov	11	1.83	0.00	30
		app	12	31.22	6.18	30
		cla	13	30.54	4.36	30
		equ	14	24.99	3.02	30
		mix	15	19.32	3.48	30
	cRatio = 1:0:0:3	nov	16	1.83	0.00	30
		app	17	44.53	5.00	30
		cla	18	45.86	4.02	30
		equ	19	39.06	1.27	30
		mix	20	24.55	1.94	30

Figure 9.4.: Descriptive statistics for crea (patchwork creativity).

Selecting factors and interactions for meaningful interpretation is not an easy task given the current data. A significant value indicates a non-random effect, but it does not coincide with an obviously large difference between the factor levels (for descriptive statistics see Figures 9.1 – 9.4 and for interaction plots Figures 9.15 – 9.22). There are no thresholds (e.g. small, medium, large) available for the effect size  $\hat{\omega}_G^2$ ; its worth lies in its comparability across experiments (Olejnik & Algina, 2003). Moreover, such thresholds rarely apply to the subject-matter at hand; they were either subjectively set or derived from very different data. In spite of all of this, some kind of criterion is needed to decide which (significant) effects should be interpreted from the current data. The following was done to create an internal (i.e. for this experiment) frame of reference to select effects for interpretation: Firstly, all violin and interaction plots were compared and based on inspection certain effects were preselected for interpretation. Secondly, all effect sizes were ranked (see Tables 9.1 – 9.4). Thirdly, the effects preselected based on the plots were compared with the effect size ranks. In all but one case, the preselected effects indicated that only effects with a value  $\hat{\omega}_G^2 \geq 0.82$  would be considered meaningful enough to interpret as making a notable difference. These effects happen to be those ranked first in the ANOVAs. The only exception is the first-order interaction  $p \times c$  in the ANOVA for crea modes, although the effect sizes for the single factors  $p$  and  $c$  are comparably higher (see below and Table 9.4). This procedure allows for an overview of the kind of effect sizes reachable given the type of simulation data at hand, something which externally set thresholds do not account for. For the given data and besides the exception mentioned,  $\hat{\omega}_G^2 = 0.82$  is the lowest effect size of an effect the experimenter would interpret as meaningful after graphically inspecting the data. This could indicate an internal, pragmatic threshold ("meaningful", "large enough") for the given simulation data.

**hCAII Modes** The following effects are considered meaningful based on the interaction plots (Figures 9.15 – 9.16) and the effect size ranks (Table 9.1).

- **main effect e** ( $\hat{\omega}_G^2 = 0.82$ ): The common level of diversity (*hCAII* mode) is notably higher in conditions in which only patchwork novelty ( $e = \text{nov}$ ) is judged. It is notable that the other evaluation strategies *do not* appear to influence diversity levels (see also Figure 9.3 for descriptive statistics).
- **main effect p** ( $\hat{\omega}_G^2 = 0.49$ ): The main effect *predefine* does not have an effect size ranked first, but the interaction plots do indicate something interesting. The two types of macrosystems *do not* visibly differ in the common levels of patchwork diversity reached under their respective conditions (see also Figure 9.3 for descriptive statistics).
- **main effect c** ( $\hat{\omega}_G^2 = 0.34$ ): The main effect *cRatio* does not have an effect size ranked first, but the interaction plots do indicate something surprising. The two sample types *do not* visibly differ in their common levels of patchwork diversity (see also Figure 9.3 for descriptive statistics).

**hCAII CVs** No effects are considered meaningful based on the interaction plots (Figures 9.17 – 9.18) and the effect sizes (Table 9.2). In all 20 conditions, patchwork diversity is notably stable ( $CV < 20\%$ ).

**crea Modes** The following effects are considered meaningful based on the interaction plots (Figures 9.19 – 9.20) and the effect sizes (Table 9.3).

- **main effect e** ( $\hat{\omega}_G^2 = 0.88$ ): The common level of creativity (*crea* mode) is notably higher in conditions in which only patchwork novelty ( $e = \text{"nov"}$ ) is judged. It is actually perfect in those conditions. It is surprising that average creativity *does not* notably differ between conditions with the other evaluation strategies (see also Figure 9.4 for descriptive statistics).
- **second-order interaction p x c x e** ( $\hat{\omega}_G^2 = 0.14$ ); **main effect c** ( $\hat{\omega}_G^2 = 0.64$ ); **main effect p** ( $\hat{\omega}_G^2 = 0.53$ ): Average creativity is notably lower in conditions in which diversity is most expected ( $c = 1:0:0:3$  and  $p = 256$ ). Otherwise, it is striking that a) the two sample types *do not* noticeably differ and b) patchworks made by the least original sample type ( $c = 3:0:0:1$ ) are generally considered slightly more creative. It should also be noted that apart from the interaction between  $p = 256$  and  $c = 1:0:0:3$ , the different types of macrosystems *do not* appear to notably influence creativity levels.

**crea CVs** The following effect is considered meaningful based on the interaction plots (Figures 9.21 – 9.22) and the effect sizes (Table 9.4).

- **main effect e** ( $\hat{\omega}_G^2 = 0.92$ ): The instability of creativity judgements (*crea* CVs) is noticeably lower in conditions in which only patchwork novelty ( $e = \text{"nov"}$ ) is evaluated. Otherwise, the instability is similar across the remaining conditions and overall it is somewhat higher than the instability levels of patchwork diversity (*hCAII* CVs).

Table 9.1.: *Three-Way Independent Analysis of Variance for hCAII Modes*

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	572.03***	0.49(3) <sup>2</sup>	<2.2e-16
cRatio (c)	1	314.20***	0.34(4)	<2.2e-16
evalStrategy (e)	4	696.28***	0.82(1)	<2.2e-16
p x c	1	82.30***	0.12(7)	<2.2e-16
p x e	4	202.26***	0.57(2)	<2.2e-16
c x e	4	44.73***	0.23(5)	<2.2e-16
p x c x e	4	32.00***	0.17(6)	<2.2e-16
Residuals	580	(0.00117) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

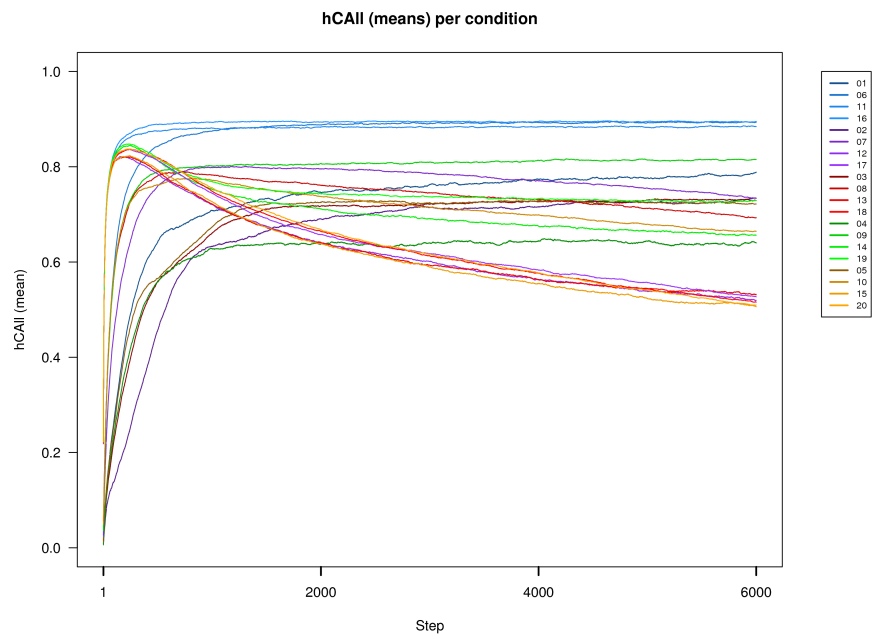


Figure 9.5.: Average run per condtion for hCAII.

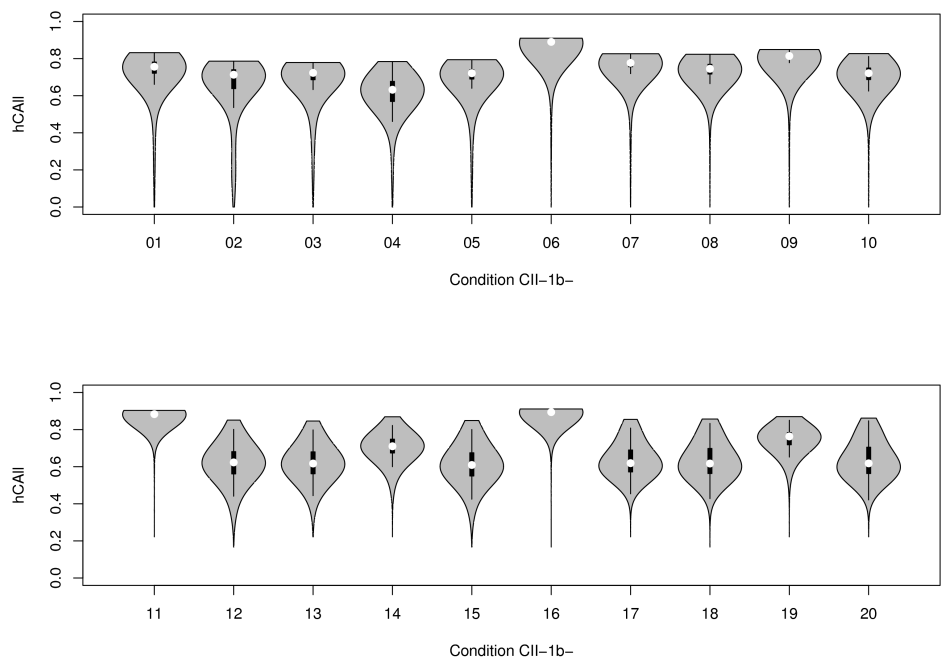


Figure 9.6.: Violin plots for hCAII (patchwork diversity).

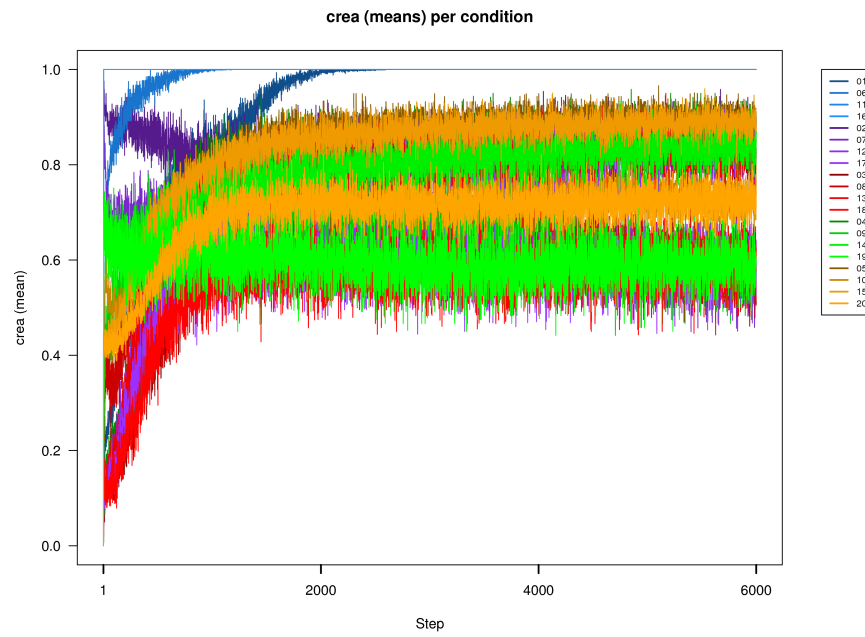


Figure 9.7.: Average run per condntion for crea.

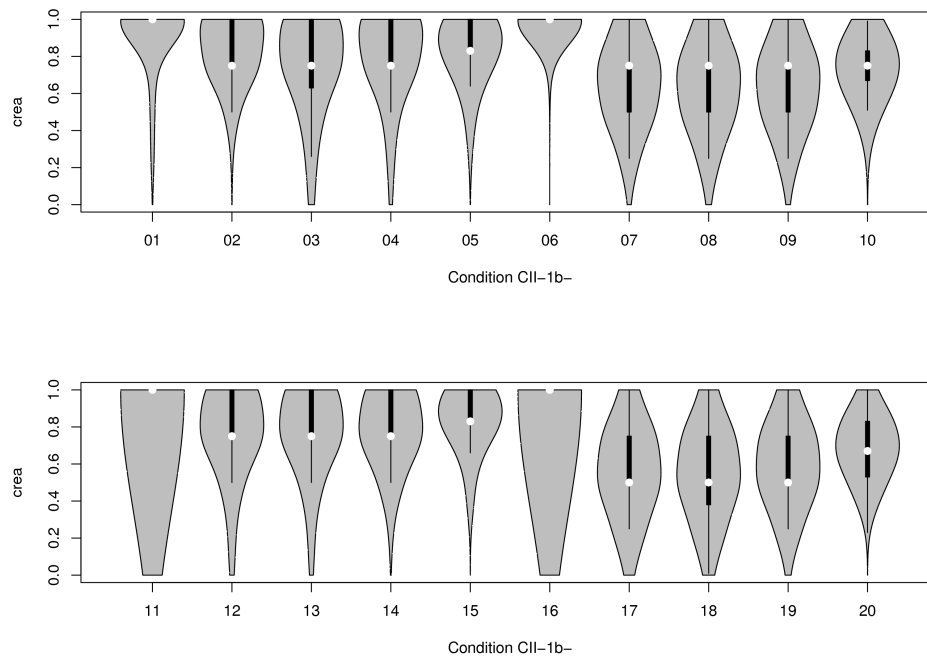


Figure 9.8.: Violin plots for crea (patchwork creativity).

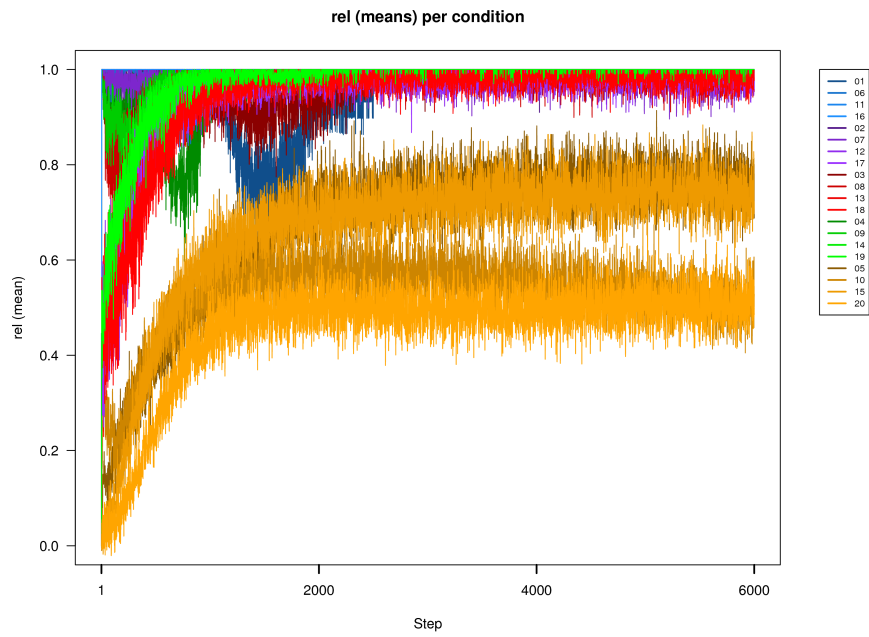


Figure 9.9.: Average run per condntion for rel.

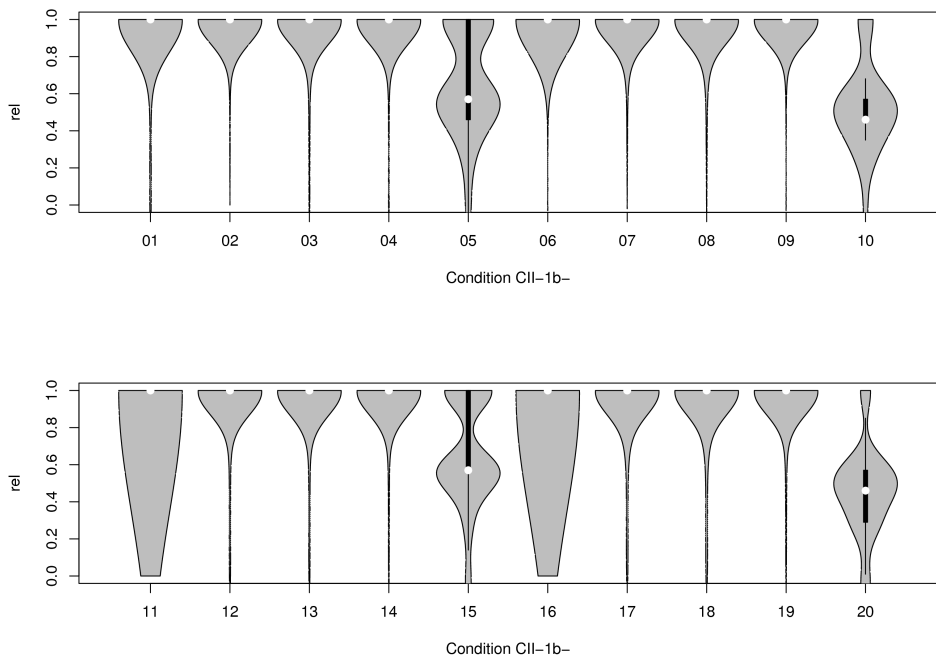


Figure 9.10.: Violin plots for rel (reliability).



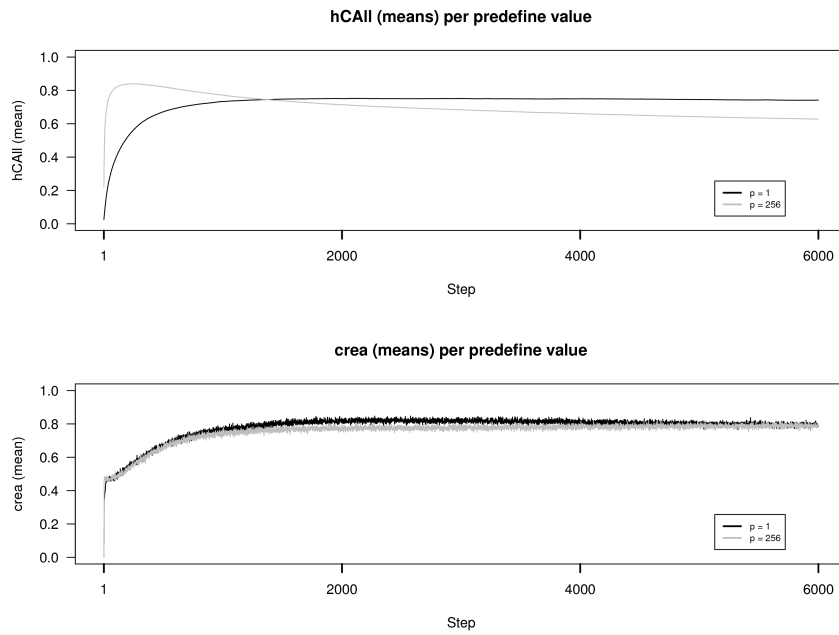


Figure 9.11.: Average run per predefined value for *hCAII* and *crea*.

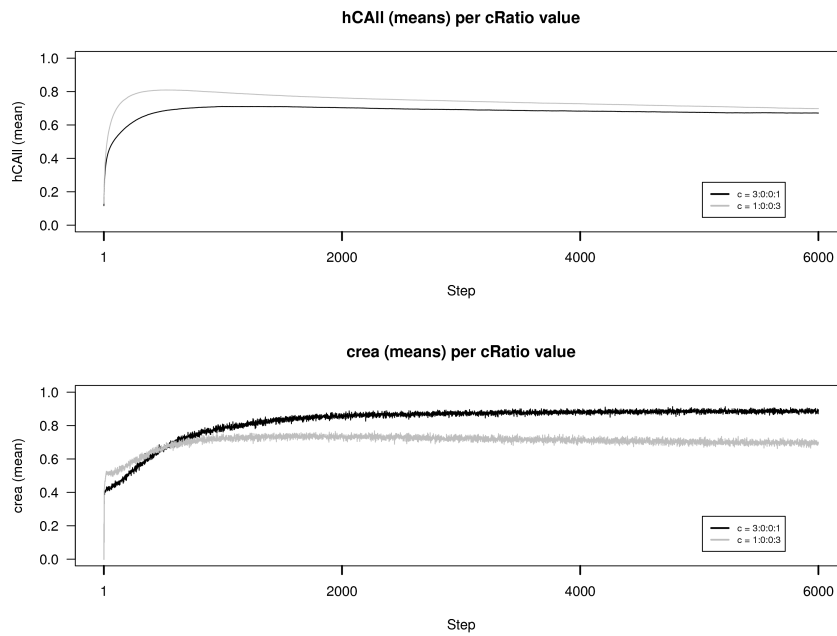


Figure 9.12.: Average run per *cRatio* value for *hCAII* and *crea*.

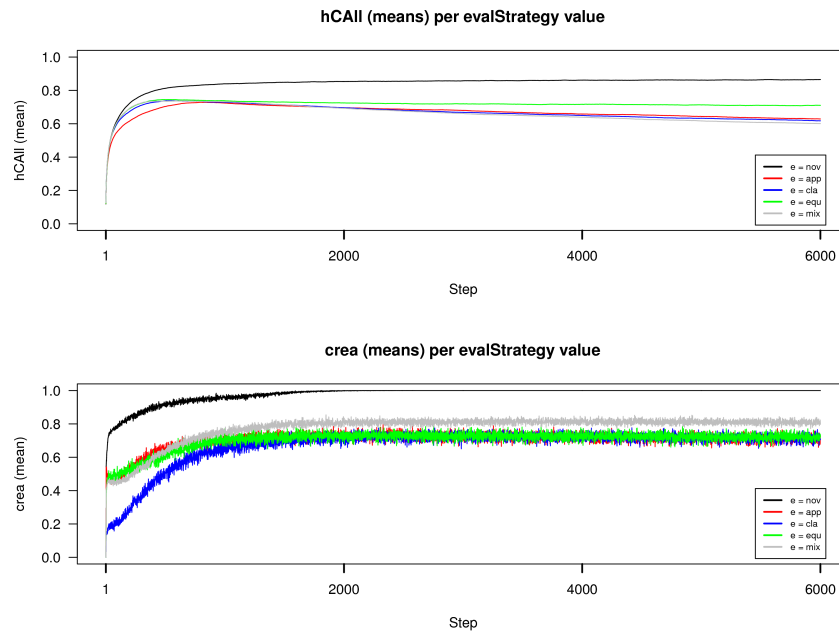


Figure 9.13.: Average run per evalStrategy value for hCAII and crea.

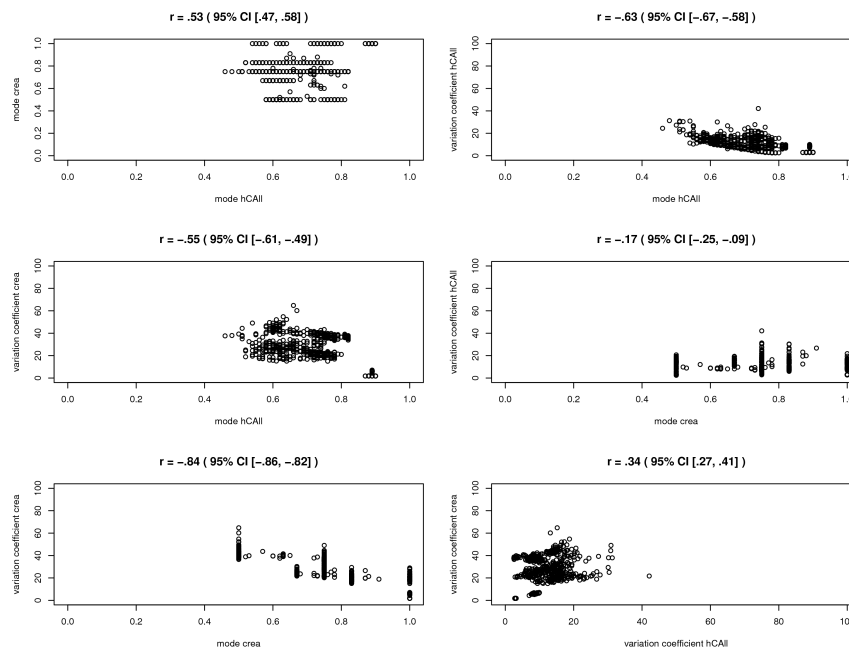


Figure 9.14.: Correlations between the modes and CVs of the dependent variables hCAII and crea. All correlations are significant ( $p < 0.01$ ).

### 9.3. DATA ANALYSES AND RESULTS

Table 9.2.: *Three-Way Independent Analysis of Variance for hCALL CVs*

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	39.56***	0.06(5) <sup>2</sup>	6.279e-10
cRatio (c)	1	227.72***	0.27(4)	<2.2e-16
evalStrategy (e)	4	123.67***	0.45(1)	<2.2e-16
p x c	1	167.91***	0.28(3)	<2.2e-16
p x e	4	70.04***	0.32(2)	<2.2e-16
c x e	4	3.75**	0.02(7)	0.005
p x c x e	4	5.65***	0.03(6)	0.0002
Residuals	580	(10.98) <sup>1</sup>		

\*\*  $p < .01$ .

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

Table 9.3.: *Three-Way Independent Analysis of Variance for crea Modes*

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	683.81***	0.53(3) <sup>2</sup>	<2.2e-16
cRatio (c)	1	1089.25***	0.64(2)	<2.2e-16
evalStrategy (e)	4	1101.27***	0.88(1)	<2.2e-16
p x c	1	317.04***	0.35(4)	<2.2e-16
p x e	4	69.57***	0.31(6)	<2.2e-16
c x e	4	78.87***	0.34(5)	<2.2e-16
p x c x e	4	25.33***	0.14(7)	<2.2e-16
Residuals	580	(0.00192) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

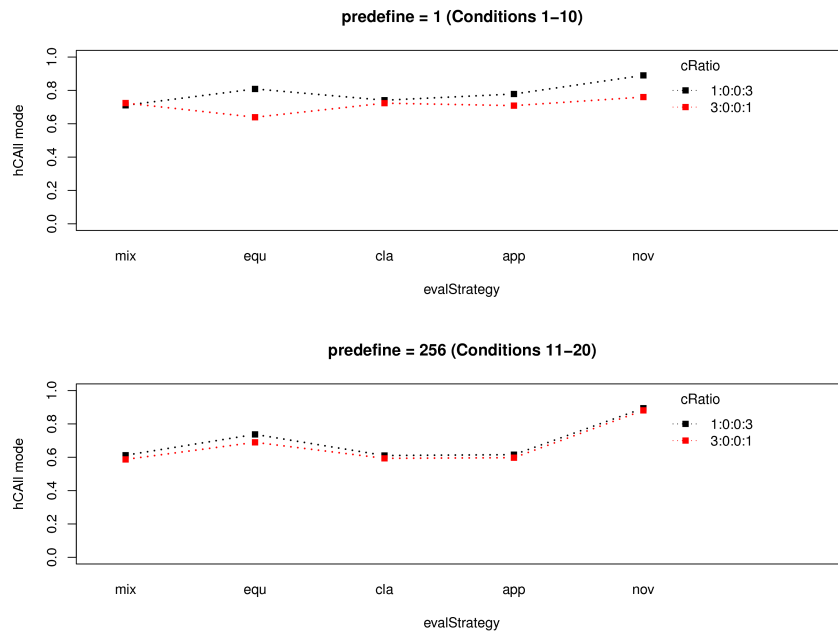


Figure 9.15.: Second-order interaction plots for *hCAII* modes.

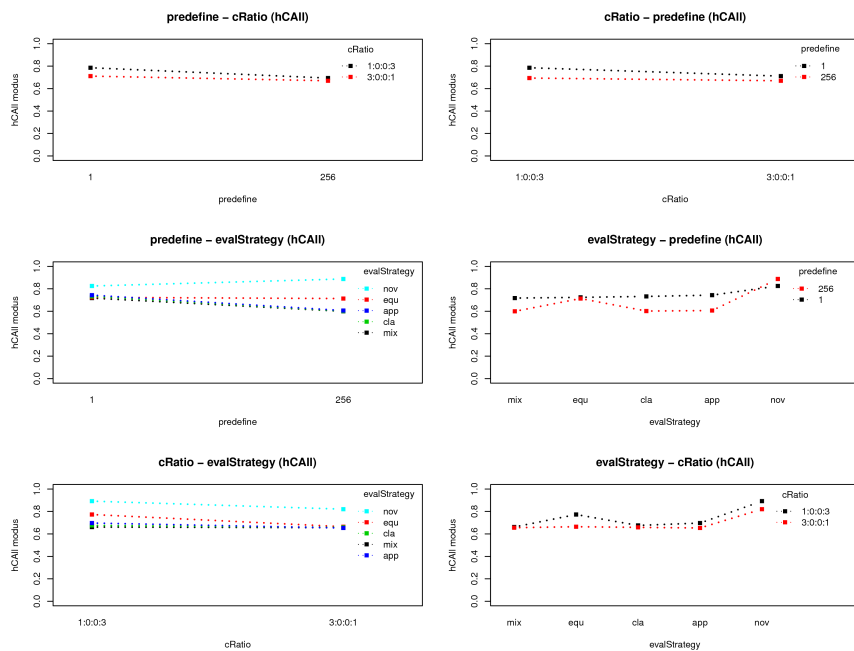


Figure 9.16.: First-order plots for *hCAII* modes.

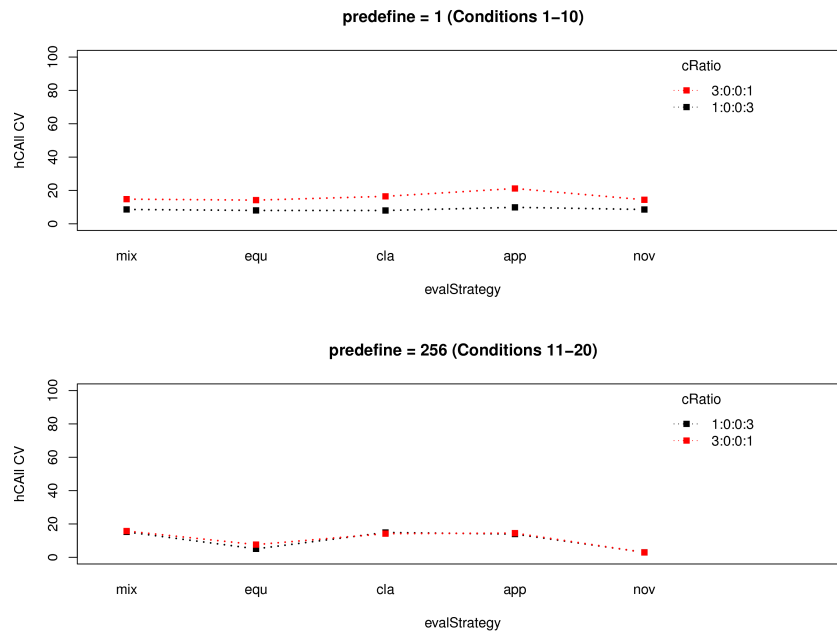


Figure 9.17.: Second-order interaction plots for hCAII CVs.

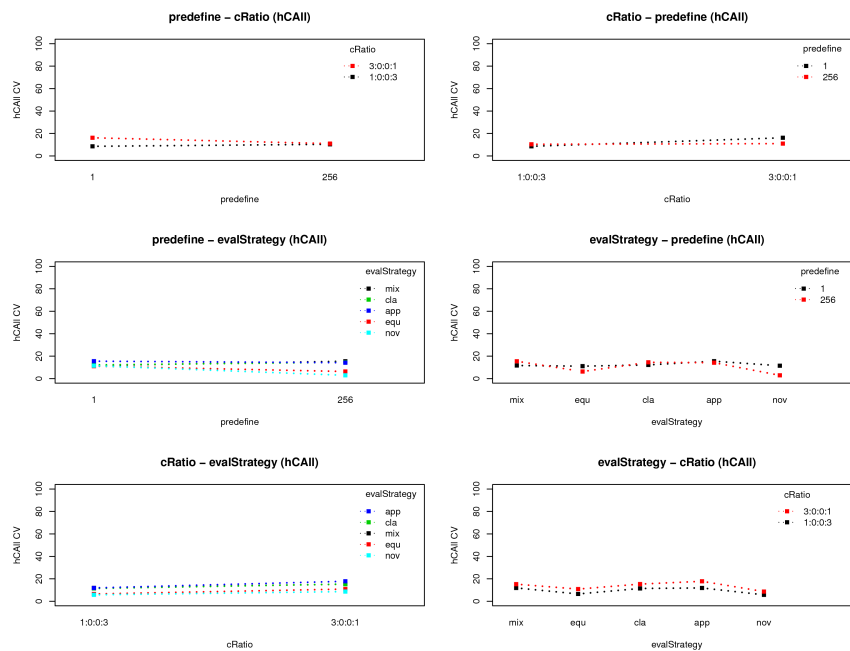


Figure 9.18.: First-order interaction plots for hCAII CVs.

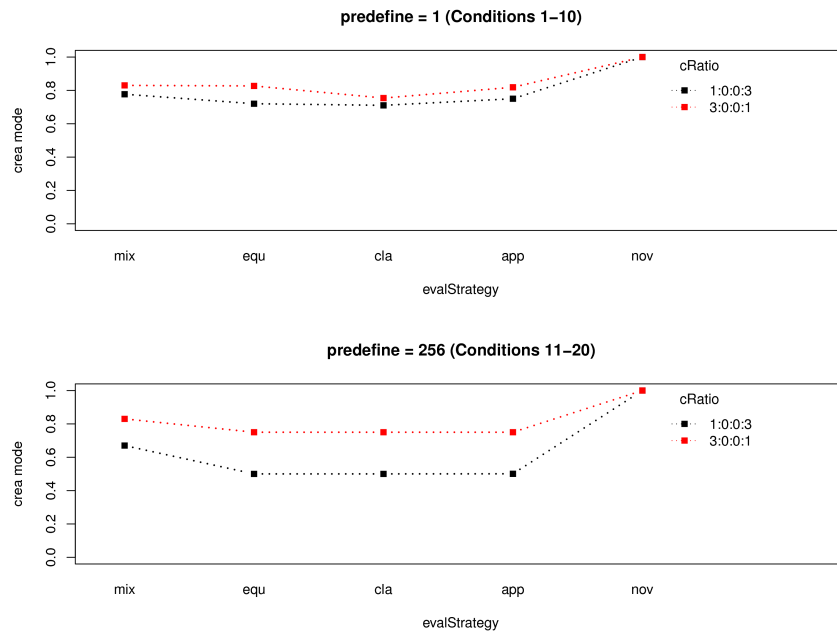


Figure 9.19.: Second-order interaction plots for crea modes.

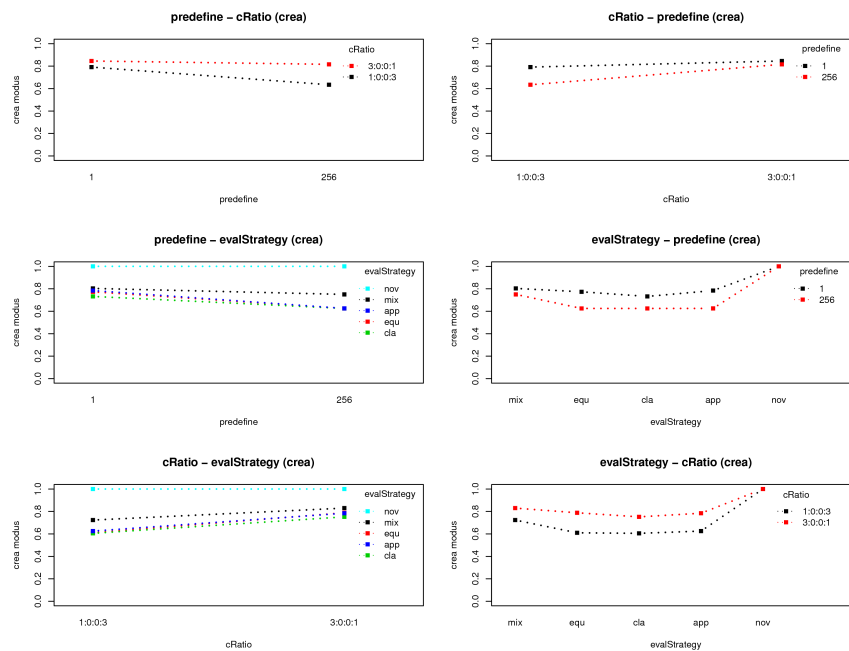


Figure 9.20.: First-order plots for crea modes.

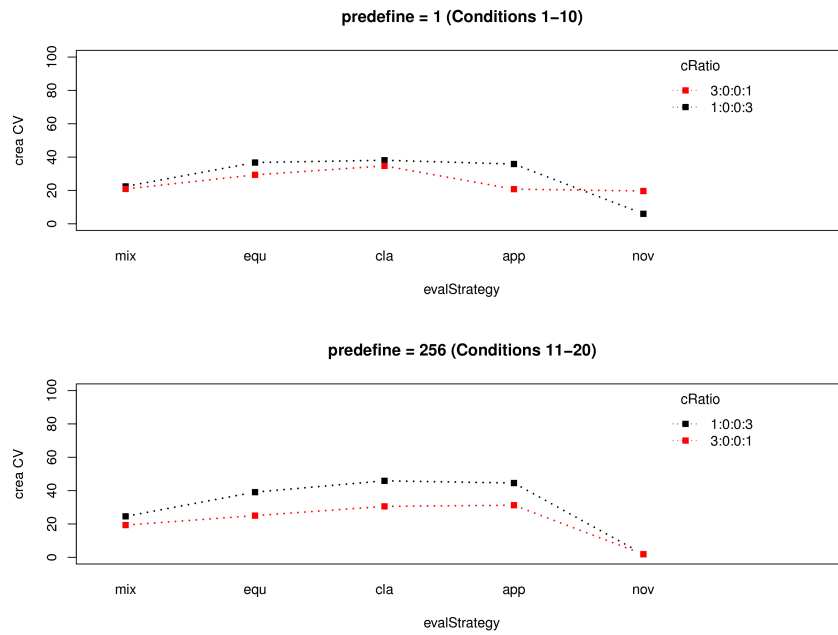


Figure 9.21.: Second-order interaction plots for crea CVs.

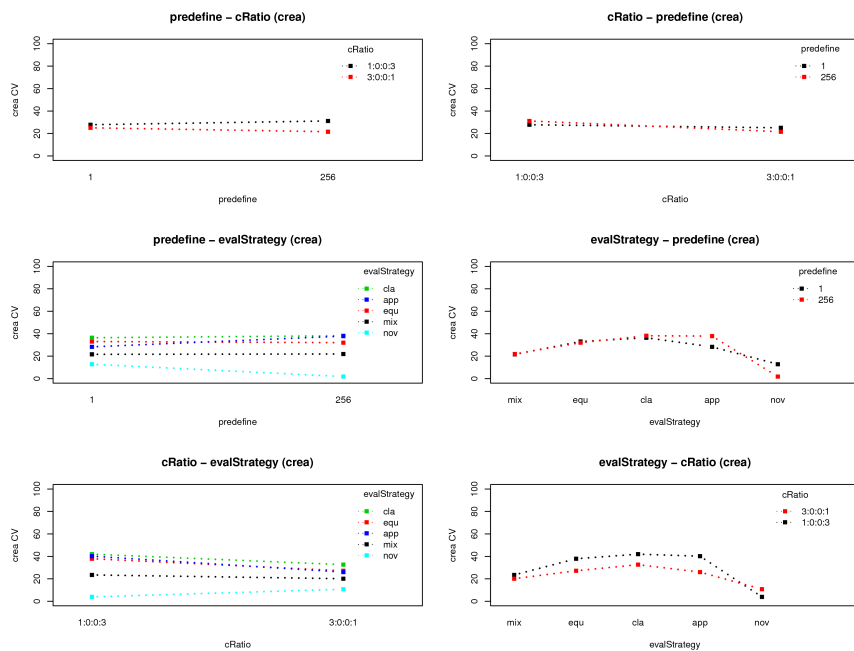


Figure 9.22.: First-order interaction plots for crea CVs.

Table 9.4.: *Three-Way Independent Analysis of Variance for crea CVs*

Source	df	F	$\hat{\omega}_G^2$	p
predefine (p)	1	0.70	0.00(7) <sup>2</sup>	0.79
cRatio (c)	1	591.60***	0.50(4)	<2.2e-16
evalStrategy (e)	4	1826.33***	0.92(1)	<2.2e-16
p x c	1	182.87***	0.23(5)	<2.2e-16
p x e	4	168.76***	0.53(3)	<2.2e-16
c x e	4	211.86***	0.56(2)	<2.2e-16
p x c x e	4	30.43***	0.16(6)	<2.2e-16
Residuals	580	(9.6) <sup>1</sup>		

\*\*\*  $p < .0001$ .<sup>1</sup> The value in parentheses is the mean square error.<sup>2</sup> The numbers in parentheses are the ranks of the effect sizes.

## 9.4 Discussion

CRESY-II is an extension of the base model CRESY-I in which five experiments were conducted to investigate the variation subprocess of creativity. In CRESY-II, CII-1b is the main experiment in a series of two designed to explore a systems / VSR perspective of creativity including the selection subprocess. A total of 20 conditions were used to investigate three substantial independent variables *predefine* (p; macrosystem), *cRatio* (c; creator microsystem) and *evalStrategy* (e; evaluator microsystem). Their effects on the common level (mode) and stability (coefficient of variance, CV) of the dependent variables *hCAII* and *crea* were explored graphically and with analyses of variances. *hCAII* refers to the relative diversity of patchworks produced by all creators, while *crea* refers to these patchworks' creativity as judged by evaluators. Although almost every effect (main, first-order, second-order) is significant in the analyses of variances, inspections of the graphical analyses (violin and interaction plots) and the descriptive statistics indicate few meaningful results in terms of the notable differences they produce in the dependent variables. The decision to interpret an effect *as producing a notable difference* was ultimately based on the graphs and on the size of an effect ( $\hat{\omega}_G^2 \geq 0.82$ ). Moreover, other effects are considered meaningful given the current data because they *do not appear to produce a notable difference* in the dependent variables despite their statistical significance.

As described in Chapter 4, the purpose of theory-based exploration is to generate scientific hypotheses based on systematic investigation, for instance with computer modelling. The hypotheses constructed in this discussion will incorporate two types of effects, i.e. those considered to have produced notable differences in dependent variables and those interpreted as not having done so. The latter are significant in understanding how CRESY-II works and how a systems / VSR perspective of creativity could function. As the CVs of both *hCAII* and *crea* are assumed to be low enough, the hypotheses to follow only refer to these variables' average levels



(modes).

**Product diversity (*hCAII*):**

- 1a** The evaluation of product novelty alone ( $e = \text{nov}$ ) leads to higher levels of product diversity (*hCAII* modes). The levels are lower when product appropriateness ( $e = \{\text{app}, \text{cla}, \text{equ}, \text{mix}\}$ ) is incorporated in evaluations.
- 1b** When evaluation takes place, macrosystem diversity (*predefine*) does not lead to noteworthy differences in product diversity (*hCAII* modes).
- 1c** When evaluation takes place, differences in creator microsystems (*cRatio*) do not lead to noteworthy differences in product diversity (*hCAII* modes).

Although creators do not produce ultimate diversity ( $hCAII = 1.00$ ) in any condition, their levels are moderately high ( $hCAII \text{ mode} = 0.59 - 0.89$ ). This is not a guarantee for creativity, but it does show variety emerges, which is a fundamental part of the phenomenon. Creators in CRESY-I produced patchworks uninhibitedly, and it is interesting that their diversity levels varied to a larger extent: The range for *hCAII* modes is approximately 0.20 – 0.90 (see Figure 7.7). This leads to the initial interpretation that selection (evaluation) and retention guide variation (production) in a way that condenses diversity. In the present case, these subprocesses even appear to prompt the increase of minimal diversity levels. In short, they may homogenize creators' productivity towards the maximal reachable levels under the given (and otherwise indeterminable or unobservable) circumstances.

Hypothesis 1a differentiates the effect evaluation has on production. Diversity levels are expected to be higher when a product's appropriateness is ignored. How can this be? Firstly, if selection processes assess both novelty and appropriateness, it is harder for a patchwork to be considered creative as it has to "pass two tests". This implies less patchworks are considered creative. As the retention process sorts out those with the lowest creativity scores, the current domain of patchworks decreases in variety. Creators and evaluators, however, continue to obtain information from this domain. Their knowledge, therefore, also decreases in variety. If that is the case, they will tend to produce less diversity. Conversely, if only novelty is assessed it is probable that more patchworks will be considered creative as only one assessment has to be passed. The more patchworks considered creative enough, the more diverse information creators obtain is. The reason why the same, i.e. higher levels of diversity, does not hold when only appropriateness is judged appears to be technical. Evaluators base their novelty judgements on their ever-growing memories. Appropriateness judgements are based on six neighbouring patches. Simply, there are more chances for a patchwork to be considered novel than appropriate. In transferring these ideas to a social system in real life, this could imply some evaluation criteria may impose more constraints on creative task solutions than others. This, in the long run, can affect the diversity of solutions produced. If a large variety of solutions are desired, less restrictive selection criteria may be advisable.

A striking result, patchwork diversity levels do not differ starkly depending on the type of macrosystem (*predefine*) or the type of creator microsystem (*cRatio*). In CRESY-I, a highly diverse macrosystem ( $p = 256$ ) did compensate for differences in creator type samples ( $c = 3:0:0:1$  vs.  $c = 1:0:0:3$ ). In everyday terms one could assume that when enough resources and stimulation are available, creative potential inherent in individuals does not matter. In CRESY-II, this is the case, too. However, it also holds for minimally diverse microsystems ( $p = 1$ )! In the latter, creator microsystems expected to have less creative potential ( $c = 3:0:0:1$ ) "keep up" with creator microsystems with more creative potential ( $c = 1:0:0:3$ ). All in all, neither macrosystem nor creator microsystem make a notable difference when diversity levels are assessed. This leads to the assumption that the selection and retention processes unique to CRESY-II compared with CRESY-I are influential enough to level the effects of the other system components. Moreover, the difference in CRESY-I was that in minimally diverse macrosystems ( $p = 1$ )  $c = 3:0:0:1$  performed much *worse* than  $c = 1:0:0:3$  in terms of patchwork diversity. In CRESY-II, both microsystems perform similarly well. In transferring these ideas to a social system in real life, this could imply evaluation criteria incorporated in a retention process convey guidelines creators orientate their behaviour towards. As creators with less deviating potential adhere more to given norms, their performance may flourish if these guidelines are geared to enhance diversity.

### Product creativity (*crea*):

- 2a** The evaluation of product novelty alone ( $e = \text{nov}$ ) leads to perfect levels of product creativity (*crea* modes). The levels are lower when product appropriateness ( $e = \{\text{app}, \text{cla}, \text{equ}, \text{mix}\}$ ) is incorporated in evaluations.
- 2b** If the macrosystem is highly diverse ( $p = 256$ ) *and* evaluations include appropriateness ( $e = \{\text{app}, \text{cla}, \text{equ}, \text{mix}\}$ ), conventional creator microsystems ( $c = 3:0:0:1$ ) produce more creative products (*crea* modes) than their less conventional counterparts ( $c = 1:0:0:3$ ).
- 2c** When evaluation takes place, macrosystem diversity (*predefine*) does not lead to notably large differences in product creativity (*crea* modes).
- 2d** When evaluation takes place, differences in creator microsystems (*cRatio*) do not lead to notably large differences in product creativity (*crea* modes).

Overall, evaluators find creators' patchworks moderately to highly creative (*crea* modes = 0.50 – 1.00). This is a sign that creators' and evaluators' indirect communication via patchwork viewing, or rather the retention phase, functions in a way which makes co-adaptation possible. In other words, creators gain a sense of what evaluators approve of and evaluators recognize creative value in their work. Interestingly, there are no modes below 0.50. It raises the question of which conditions would lead to very low creativity scores?

The strategy evaluators use (*evalStrategy*) influences creativity levels the most. This is a good sign for the model's internal validity, as the creativity scores are based on these agents' behaviour. Nevertheless, it is striking that strategies only incorporating novelty judgements lead to perfect creativity levels while those also assessing appropriateness do not (Hypothesis 2a). This differentiation is observable with diversity levels, too. In the evaluation strategy *nov*, a patchwork is deemed creative if it is considered novel. It has, therefore, only one "test to pass". Moreover, a patchwork has more chances of being considered novel than appropriate, because its novelty is compared with an evaluator's ever-growing memory. Creativity scores based on novelty and appropriateness ( $e = \{app, cla, equ, mix\}$ ) require that both assessments are passed, and the likelihood of passing the novelty test is greater than that of passing both novelty and appropriateness tests. In sum, it is comprehensible that evaluation strategies incorporating appropriateness lead to overall lower creativity levels. Transferring these results to a target product in real life, this indicates some evaluation criteria may be harder to fulfil than others. If this is the case, it may abate the product's overall perceived creativity.

Actually, the previous conclusion is expressed by Hypothesis 2b. When product appropriateness is evaluated *and* the remaining subsystems are designed to produce diversity, their work may lack perceived creativity as it is not adaptive enough. Comparing such situations with the same conditions ( $p = 256$ ,  $c = 1:0:0:3$ ) when only novelty counts reveals the contrary: A diverse macrosystem as well as a diversity-producing creator microsystem appear to have all the resources necessary to perfectly adapt to evaluation criteria. Transferring these ideas to real-life circumstances, this means highly original environments and people may need more guidance or feedback if their work is to satisfy more restrictive criteria. On the other hand, they may be exactly the right people for a generation phase (see CRESY-I), but less qualified for a selection phase if they are not guided.

Besides the above exception (Hypothesis 2b), both the macrosystem and the creator microsystem do not differ notably in the creativity levels they stimulate (Hypotheses 2c & 2d). On the one hand, this implies the evaluation strategy is the largest influence on creativity in the system modelled. That appears fitting, and Csikszentmihalyi (1999) does attribute great meaning to the judgement process. On the other hand, if environment and creators do not make a notable contribution, it emphasizes not just the evaluators' influence on the creative process, but rather their *power*. Their behaviour, according to the results of this experiment, seem to homogenize differences in the other subsystems. Transferring these notions to creativity research, the increasing attention scholars are paying to the evaluation process seems to be a wise and necessary step. It may just be the key factor generating creativity!

### Model validation

CRESY-II models a systems / VSR perspective of creativity as described by Csikszentmihalyi (1999) and derived in Chapter 3. The target is itself an abstract model and a few middle range models such as Amabile's (1996) Consensual Assessment

Technique were used to enable translation into a computer language. CRESY-II's purpose is to explore the target and generate hypotheses about it. Chosen validation techniques should therefore describe the fit between the theory and simulation model. To date, the following measures were taken to validate CRESY-II:

**Use existing theory** Where Csikszentmihalyi's (1999) perspective was too abstract middle-range theories / models of creativity were chosen to fill gaps (see Section 9.1).

**Modeller experience and intuition** The modeller has broad knowledge of the domain of creativity research. It guided model development and experimentation.

**Use results from other simulation studies** The parameter settings chosen for experiments with CRESY-II were selected based on results gained from experiments with CRESY-I.

**Animation and operational graphics** The processes were animated to track the model's behaviour in real time. Operational graphics were used to check if output parameters behaved as expected.

**Extreme conditions tests** Values thought to be extreme were chosen for the input parameters to test how they affect the output parameter space.

**Internal validity** Many runs of one experimental condition were conducted to check if the condition was stable enough. Furthermore, the fact that evaluator reliability is almost perfect except for conditions in which *e* = mix indicates a few methodological aspects: Near perfect reliability in almost all conditions emphasizes CRESY-II's internal validity in attempting to model a construct of creativity. A product is defined as creative if relevant judges reliably agree it is so (Amabile, 1982, 1996). According to this definition, the values for creativity (*crea*) can therefore be accepted as valid for the given way of measuring it, and this speaks for the computer model. Sufficient reliability in conditions with *e* = mix also indicate the model functions properly. In those conditions, evaluators use different strategies to judge patchworks. It is expectable that they disagree more than evaluators using the same algorithms.

Additionally, the stability (CV) of the dependent variables *hCall* and *crea* is not meaningfully disrupted by the substantial independent variables *predefine*, *cRatio* and *evalStrategy*. The diversity measure has a CV range of 2.93–21.16, whereas the creativity measure ranges from 1.83 – 45.86. This indicates creators behave somewhat more stably than evaluators, but both agent types function stably enough. None of the independent variables affect the CVs notably. This indicates the simulation model runs consistently.

**Observing macro-level regularities** Simulation data was collected via experimentation to observe whether theory assumptions hold on the macro-level.

The following steps still need to be taken to enhance face validity:

**Conversations with subject-matter experts** CRESY-II should be presented and discussed with subject-matter experts from the fields of computer modelling, sociology and psychology to debate its face validity.

**Discuss model output with users** To check whether people familiar with creativity research and Csikszentmihalyi's (1999) model are able to generate hypotheses with CRESY-II, a test session is planned with students in an upcoming university course on creativity research.

### Potential limitations

A simulation model is highly precise and self-contained. It requires the modeller to make distinctions about a target which may not be as discriminable in practice. Distinctions of this sort go along with omissions of some other. The decisions made in implementing CRESY-II may evoke limitations in model validity and generalizability, and they are noted here. Firstly, the conceptual and methodological limitations discussed for CRESY-I (see Section 7.4) still hold for CRESY-II: The form of variation modelled (task and product complexity), the indirect communication between creators and evaluators via patchwork-viewing, the settings for technical independent variables as well as the designation of low and high conditions have been debated and the value in modelling these aspects as they are was defended.

The way the selection and retention subprocesses were modelled may pose other limitations. The evaluation algorithm, for instance, is specific and constructed. There is no proof that evaluation truly functions as modelled CRESY-II in real life. On the other hand, there are no formalizations of this subprocess in real life! It was necessary to construct something to make modelling possible, and the algorithm's realization accounts for what creativity researchers implicitly agree upon: Novelty and appropriateness are to be considered when judging creativity, and they are aggregated with equal weighing. Moreover, novelty refers to the observer's history whereas appropriateness refers to the solution's fit to a given history. The evaluation algorithm was constructed in a way which reflects these ideas. Additionally, it was varied in this experiment to explore it in more than one, static way. A potential advancement of this algorithm would be to base appropriateness judgements on a larger sample than just six neighbouring patches. At present, it is harder for a patchwork to be considered appropriate than novel. Altering the algorithm to make both attributes equally easy (or hard) to assign to a patchwork may shed a new light on a domain's composition. Another development could be to weigh the criteria differentially.

Both the selection and the retention processes are new in CRESY-II. Retention was not varied across the experimental conditions, and it is therefore difficult to estimate

its influence on the dependent variables. Exploring the systems / VSR perspective of creativity with CRESY could be advanced by altering this process and testing its effects. Last but not least, the information creators and evaluators saved in the algorithm *make-patchwork* was not weighed, for instance according to patchworks' creativity scores. The weighing occurred by having creators place their patchworks on patches with the lowest creativity scores. A potential further development could be to make information retrieval more differential or complex.

### Outlook

CRESY-II is an innovative way to explore a holistic, relational perspective of creativity otherwise difficult to longitudinally investigate in practice. Presently, it also appears to stand alone as agent-based modelling (ABM) has yet entered the domain of creativity research in psychology. The lack of experimental research on Csikszentmihalyi's (1999) model as well as the unique standing ABM has in our domain poses a challenge in assessing CRESY-II's value in advancing creativity research. What the model needs next is a domain it can be perceived and evaluated in. Its interdisciplinary nature actually renders it interesting for several domains. A next step could include publishing or presenting it to experts from the domain of computer modelling as well as from creativity research. This would establish possibilities to critically reflect CRESY-II's technical architecture as well as its substance. Given feedback from domain experts, CRESY-II's further development could be initiated. Moreover, by making the model public others could be inspired to create their own variations. Besides locating and entering appropriate methodological (ABM) and substantial (creativity research) domains, it would be recommendable to continue assessing the model's value in fulfilling its purpose, namely to generate hypotheses or *denkweisen* about creativity. This can be initiated by offering it to those thinking about the issues: students, scientists, artists, etc.

# **Part IV.**

## **Discussion**





# 10

## Discussion

### 10.1 Summary

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This project began with an investigation of current doctoral work on creativity in order to assess how the construct is modernly defined and assessed in science (Chapter 1). Focal questions covered which social level, aspect and methodological approach the researchers used. Creativity research in the domain of psychology places the most emphasis on studying individuals and their traits. This also holds for neighbouring disciplines such as education and social sciences. Among all the disciplines examined, the individual was the social level most often studied, and empirical approaches outweighed theoretical ones. Moreover, even if individual disciplines do have a characteristic approach to studying creativity, they also exhibit diversity by using multiple approaches. This internal variety leads to overlapping approaches across disciplines, making it difficult to conclude one discipline is solely responsible for one particular research approach. Nevertheless, it became clear that the domain of psychology converges on studying individuals' traits in an empirical fashion.

This study of creativity research initiating the present work lead to the realisation that there is more to creativity than just the individual and her traits (Chapters 2 – 3). Raters of some sort were always part of the studies at hand. Creativity appears to be more than just a creating individual's behaviour, and in psychological studies people are recruited to assess the construct. Admittedly, creativity researchers have started to acknowledge this by now (cp. Haller et al., 2011; Herman & Reiter-Palmon, 2011; Randel et al., 2011; Silvia, 2011). However, there are hardly any models which account for this relation. Csikszentmihalyi's (1999) systems perspective does, and it illustrates which relations could play a key part in cultivating creativity. Its qualitative nature makes it difficult to systematically test, which is probably why there are few studies which do so to this date (cp. Abuhamdeh & Csikszentmihalyi, 2004; McIntyre, 2008). Redescribing it in evolutionary terms does not explain it in a better way, but it facilitates the transition from illustrative to formalisable (Kronfeldner, 2009, 2010).

Despite the transition from a qualitative, illustrative model to a somewhat more formalised, graphical one, questions about how such a model can be investigated and which kinds of questions could be answered with it remained (Chapters 4 – 5). Since the systems / VSR perspective of creativity lacks experimental studies to confirm it, exploratory research with the model appeared to be a meaningful approach. As

the model not only encompasses more than one social level but also more than one point in time, a form of longitudinal analysis is necessary to reproduce it. For reasons of feasibility, it became clear that a methodological alternative to a technique such as longitudinal field experiments would be required. The technique of agent-based modelling fulfils such prerequisites. The choice to investigate Csikszentmihalyi's (1999) model on the one hand, and to do so in an exploratory manner with agent-based modelling on the other, deviates from previous and current norms in the domain of psychology. This can be an advantage as it allows the modeller freedom to implement ideas otherwise devalued in normative science. However, it goes along with a lacking frame of reference to clearly assess the value and validity of such unique work.

The second half of this dissertation (Chapters 6 – 9) deals with implementing the above. The systems / VSR perspective was gradually translated into a form so precise to allow simulation modelling. To facilitate comprehension, the model's complexity was transformed gradually. CRESY-I emerged as the initial model covering the variation subprocess of creativity. CRESY-II followed and includes selection as well as a more sophisticated form of retention. Translating a qualitative, illustrative model into a programming language is a challenge. The methodological issues surrounding agent-based modelling are another. Aspects such as design of experiments, data analysis, verification, validation as well as what kind of conclusions one may draw from simulated data followed and revealed a realm of questions with no final scientific answers. The ambivalence in the domain of computer modelling adds to the difficulty of discovering a prevalent frame of reference to judge the present work.

The data gathered in experiments conducted with CRESY-I uncovered noteworthy relations between the postulated subsystems, i.e. the macrosystem (operationalised as *predefine*) and the creator microsystem (operationalised as *cRatio*), and the output variable product diversity (*hCall*). When the macrosystem (domain) is moderately to highly diverse, all kinds of creator microsystems produce the same, high amount of diversity. The individual capacities, or traits, they have do not make a difference. If the macrosystem is not diverse whatsoever, different kinds of creator microsystems do make a difference. The more original they are, the more product diversity can be expected (and vice versa). The relation between the macrosystem and the creator microsystem reveals that it is not always a creator's trait, in the broadest sense of the word, that counts. Product diversity can be stimulated by the environment, rendering individual differences meaningless.

This relation changes in CRESY-II. When the systems / VSR model of creativity encompasses selection and retention processes, the macrosystem (*predefine*) and the creator microsystem (*cRatio*) do not stimulate noteworthy differences in product diversity levels (*hCall*). Overall, product diversity is moderate to high in the scenarios investigated. However, it is notably boosted when evaluators only judge the products' novelty. The production of diversity is obviously stimulated by the encouragement to produce novelty, indirectly expressed via novelty evaluations and the retention of products so judged. At first thought, this may seem trivial. However, it

is powerful statement when related to the influence the macrosystem and the creator microsystem exhibited in CRESY-I. Moreover, product diversity is not enhanced and even lower when appropriateness is included in evaluations. It is harder for a product to be considered creative when two criteria are to be fulfilled. The task to produce something creative has more constraints, and the likelihood of respecting all of them decreases. In the case of CRESY-II, it was generally and technically harder for a product to be considered appropriate than novel. This does not necessarily mean this has to be the case in real life, although it is quite imaginable that originality has more degrees of freedom than appropriateness. What, nevertheless, is demonstrated by these results is that a particular criterion may be harder to fulfil, and this may lead to lower overall scores in creativity assessments.

When it comes to judging product creativity (*crea*), the strategy evaluators use (*evalStrategy*) has a similar effect as on product diversity (*hCAI*). Overall, the creativity levels are moderate to high. So the model does not, at this stage, reveal which system conditions would lead to low creativity. When only novelty is judged, creativity levels are perfect regardless of macrosystem (*predefine*) and creator microsystem (*cRatio*) qualities. In such cases, these two subsystems make absolutely no difference. When appropriateness is incorporated into evaluations, the macrosystem and the creator microsystem do play a role in establishing creativity levels. Specifically, a highly diverse macrosystem and a highly original creator microsystem lead to notably lower creativity levels than all other scenarios. A system designed to facilitate the most change ends up last when the suitability of its variations are assessed. These results demonstrate the power an evaluation strategy can have on constructing creativity. In CRESY-II, the evaluator microsystem has the largest effect on creativity levels while the macrosystem's and the creator microsystem's influences depend on the former.

## 10.2 Discovering relations

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Abuhamdeh & Csikszentmihalyi (2004, p. 33) asserted "variables external to the individual" must be explored to understand creativity. A systems / VSR perspective of this construct focuses on where creativity takes place rather on which indicator exactly measures it (Kozbelt et al., 2010; Runco, 2007). Its key postulate states "creativity can be observed only in the interrelations of a system made up of three main elements" (Abuhamdeh & Csikszentmihalyi, 2004, p. 33). The elements are the *domain* (information in a particular discipline at a particular time), the *field* (gatekeepers deciding which variations are to be preserved for next generations) and *individuals* (who produce variations of domain information). Consequently, creativity is constructed as occurring "when a person makes a change in the information contained in a domain, a change that will be selected by the field for inclusion in the domain" (Abuhamdeh & Csikszentmihalyi, 2004, p. 33). Sawyer (2006) labels this a contextualist, sociocultural approach and notes "the definition of creativity is fundamentally and unavoidably social...[it] is defined by social groups, and it's culturally

and historically determined" (p. 122).

CRESY-I and CRESY-II are implementations of the above. As experimental studies of the systems perspective are rare (Abuhamdeh & Csikszentmihalyi, 2004; Csikszentmihalyi, 1999; McIntyre, 2008), the simulation models offer a way to explore assumptions the model makes, albeit within a given, specific realisation. Figure 10.1 illustrates the connections between Csikszentmihalyi's (1999) model and CRESY. Both models consist of three subsystems, and the figure relates the key input variables operationalised to represent to each. The focal relations investigated in CRESY are expressed by the main output variables *hCall* and *crea*. *hCall* describes how much diversity the creator microsystem adds to the domain, while *crea* relays how this diversity is valued. In the CRESY models, creators and evaluators affect each other indirectly via their local perspectives on the domain, i.e. they obtain information in relation to where they are currently situated in the world. Creators affect evaluators' judgement (*crea*) with the diversity they produce (*hCall*) and evaluators influence creators' diversity (*hCall*) with their evaluations (*crea*).

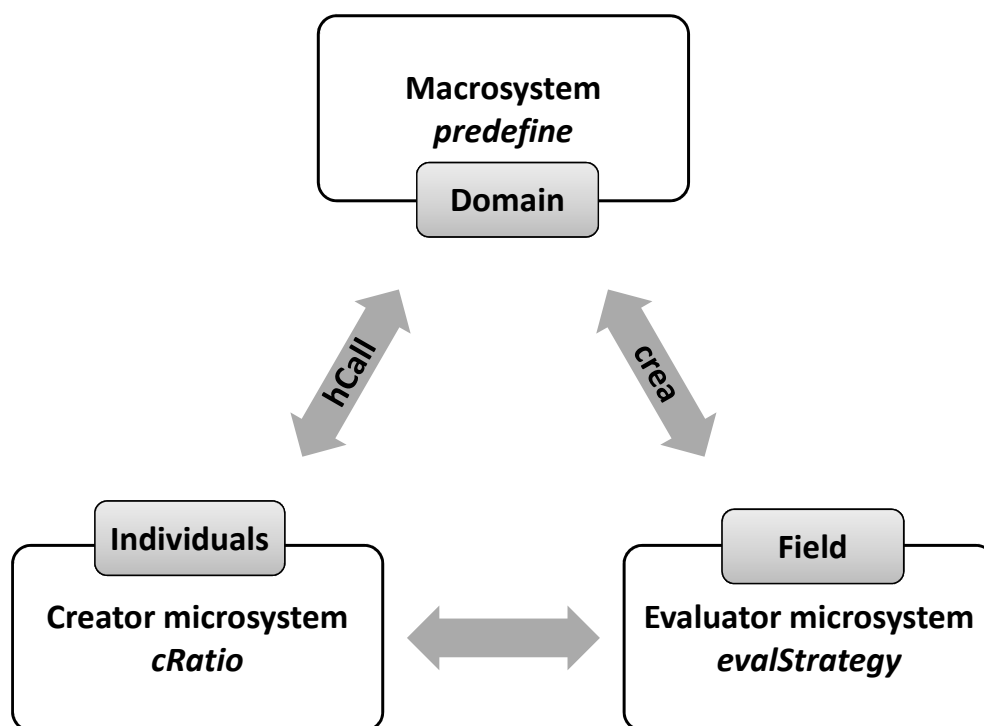


Figure 10.1.: Csikszentmihalyi's (1999) systems perspective (domain, field, individuals) and CRESY's subsystems (macrosystem, creator microsystem, evaluator microsystem) and three main input variables (predefine, *cRatio*, *evalStrategy*).

The effects the three subsystems have on diversity and creativity are reproduced

in Figure 10.2. In CRESY-I, the macrosystem and the creator microsystem exerted large effects on diversity. When the systems / VSR model was completed with the evaluator microsystem in CRESY-II, this changed. The field has a comparably larger influence on diversity than the domain or the creating individuals do. Moreover, creativity is chiefly shaped by evaluators' activity. What does this have to say about the fit between the systems / VSR model and CRESY? Quite apparently, it demonstrates CRESY is able to recreate ideas stated in Csikszentmihalyi's (1999) model. According to him, evaluators are the ones "who have the right to add memes to a domain" (p. 324), and "if one wishes to increase...creativity, it may be more advantageous to work at the level of the fields than at the level of individuals" (p. 327). In CRESY-II, the evaluator microsystem is the factor influencing creativity and diversity the most. The fact that the macrosystem and the creator microsystem play such a larger influential role on diversity in CRESY-I than in CRESY-II emphasises this. In spite of this difference, both models reveal how meaningful contextual factors such as the domain and the field are in generating and sustaining diversity and creativity. A variation is just as or even more dependent on the properties of its environment than on its creator (Cropley & Cropley, 2010). As Westwood & Low (2003) accurately state, creativity "takes place within, is constituted and influenced by, and has consequences for, a social context" (p. 236).

## 10.3 From current obstacles to future steps

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Studying creativity comes with a number of obstacles. To start, researchers do agree that there is disagreement about how to define and investigate the phenomenon (Westmeyer, 1998). Actually, even artists - classically considered creative in Western culture - do not always agree about what constitutes creativity or a creative person (Glück et al., 2002)! In the first line of their article, Westwood & Low (2003) admit creativity "is a complex and not fully understood process" (p. 235). Boden (1999) claims creativity "...is not purely a scientific concept, since...value is not found by science, but negotiated by social groups..." (p. 351). Runco (2004a) advises those who study creativity to "maintain a flexible approach and avoid relying too heavily on one perspective" (p. 677). Sternberg (2006) notes creativity research is currently advancing not via its answers, but via its questions. According to him, the "definition and criteria for creativity are a matter of ongoing debate" (Sternberg & Lubart, 1996, p. 681).

These condensed stances expressed by experts in the field of creativity research illustrate a major obstacle in conducting research on the phenomenon - there appear to be more exceptions than rules. This circumstance does enhance the degrees of research freedom. On the other hand the plethora of definitions and methods quickly indicate there will always be something missing in one's own approach and that there will be ample gatekeepers who disagree with one's work! Finding an adequate approach to creativity and viable, valid methods to study it remain challenges no

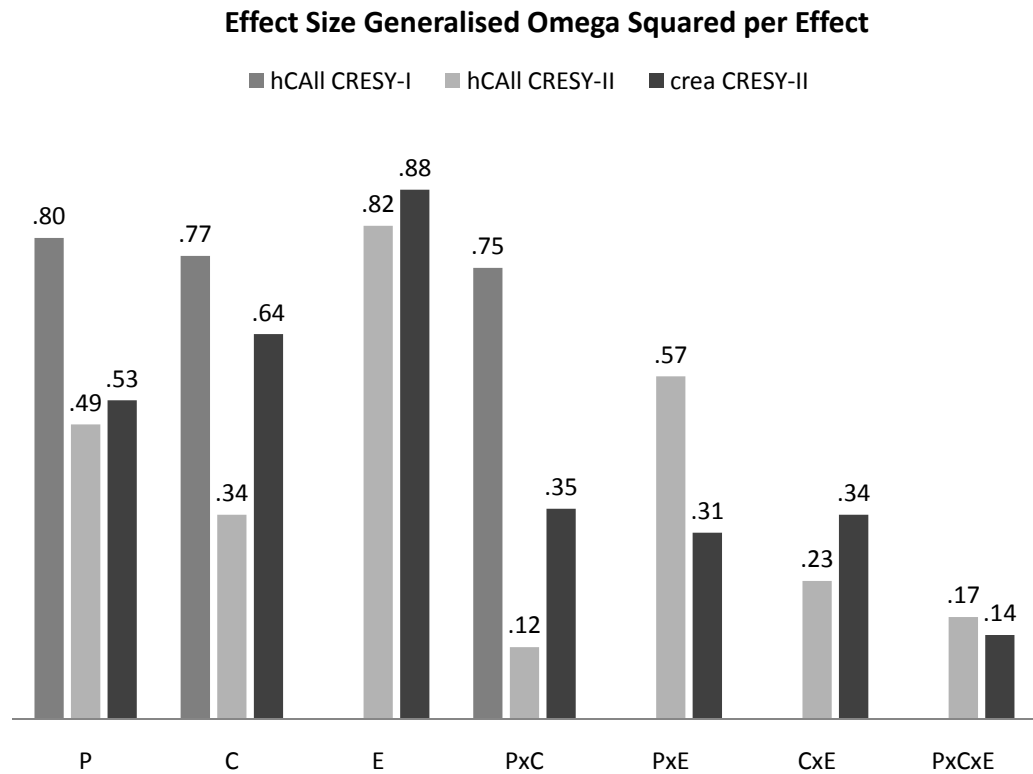


Figure 10.2.: *Subsystem effects on diversity and creativity. P stands for predefine (macrosystem), C for cRatio (creator microsystem), E for eval-Strategy (evaluator microsystem), the other abbreviations for their interaction. The effect size generalised omega squared ( $\hat{\omega}_G^2$ ) is shown per subsystem (macrosystem, creator microsystem, evaluator microsystem), measure (hCAII, crea) and model (CRESY-I, CRESY-II).  $\hat{\omega}_G^2$  ranges from 0 – 1.*

creativity researcher can work around. To make things more complicated, Csikszentmihalyi's (1999) model has apparently never been investigated experimentally. There is a lack of systematically manipulated data to test his noteworthy ideas, which has, by the way, not prevented others from conceptually developing his model further (Gangadharbatla, 2010). The broad scope of the systems model offers a richness many approaches to creativity lack, and so it appears appropriate and attractive for empirical research. Kozbelt et al. (2010) pinpoint, however, the obstacle in attempting the latter: "...the qualitative nature of many aspects of the model make it more difficult to test hypotheses unambiguously...particularly as his approach is less grounded in methodological particulars" (p. 40). Admittedly, systems approaches to creativity are commonly mentioned as last or "outlook perspectives" in collections and overviews (Hennessey & Amabile, 2010; Kozbelt et al., 2010).

Apart from the obstacles highlighted so far, i.e. the difficulty and freedom in selecting an approach, a stimulus, a reaction, an analysis method and a frame of

reference to conduct and judge creativity research, there are a few others worth mentioning. Firstly, scepticism exists about how the creativity of a product relates to the creativity of a person. Does a creative product automatically make its creator creative? Does every creative person produce creative artefacts? Is the degree of the one attribute exactly the same as the other? Creativity researchers in the domain of psychology commonly circumvent this debate as it does decelerate scientific flow. The discipline's insight into an individual is via her output. We only access what a person communicates, regardless of the medium. By observing, analysing and rating this behaviour, we infer from it to a person's inner qualities or traits. Indeed, most definitions of creativity contain the observation of a product or process (cp. Amabile, 1996; Kaufman & Sternberg, 2010; Sternberg, 1999a). Sometimes, creativity researchers really are only concerned with the creativity of products, so the debate does not matter (e.g. Cropley & Cropley, 2010). Yet others are interested in assessing and developing the creative individual, group, etc. and view their behaviour as indicators of their creativity (cp. Sternberg et al., 2004). This is basically how creativity research "works" in psychology, even though there is some dissent (Beghetto & Kaufman, 2007; Nicholls, 1972; Smith, 2008). Runco (2004b), for instance, makes a distinction between creative potential and creative performance. He argues the former is universal and generalised, while the latter depends on factors external to the individual. Beghetto & Kaufman (2007) argue for increased focus on "mini-c" creativity. This category differs from eminent ("Big-C") and everyday ("little-c") creativity by describing intrapersonal creativity, i.e. processes involved with an individual's "construction of personal knowledge and understanding" (Beghetto & Kaufman, 2007, p. 73). The construct shifts the focus from the product to the person, as individuals may not necessarily attract scientific attention based on their performance in conventional creativity assessments.

Another intriguing notion creativity researchers sidestep to date is whether evaluators really have to agree, as demanded via adequately high interrater reliabilities. High reliability only indicates raters agree, but as long as experts or other relevant gatekeepers are the ones agreeing creativity researchers consider it to be an appropriate indicator of face validity (Amabile, 1982; Kaufman et al., 2008). Some scientists even administer rater trainings to ensure their agreement is high enough (Rietzschel et al., 2006, 2010), something other experts discourage (Amabile, 1996). The absence of high interrater reliability means, according to the discipline, creativity was not measured. Yet is this the only interpretation of the number? Could the measure, for instance, indicate raters are being creative themselves? In contemplating the evaluation process inherent in every study of creativity, Lonergan et al. (2004) call it "a highly creative, or generative, undertaking" (p. 231). Presently, there is a lack of work reflecting this idea and its consequences for creativity research. Evaluators' potential to stimulate change, as for example remarked by Amabile (1996) and Csikszentmihalyi (1999), as well as demonstrated with CRESY-II, could encourage scholars to focus on rater dissent and its meaning in future research.

An obstacle, or rather a given, creativity researchers will seemingly never over-

come is the context dependency of their work. Any set of results depends on the approach, stimulus, reaction, analysis method and evaluation criteria chosen. Moreover, scientific trends, cultural aspects and the overall historical period play a part in constructing creativity. There is no "one-size-fits-all approach" (Mumford, 2003, p. 110). Results, their validity, generalisability and lifetime need to be viewed in this light. Lubart (1999, p. 339) urged to not "decontextualize" creativity. Adopting figurative words, Runco stated in an interview "to really understand creativity you have to throw a wide net" (see Henshon, 2010, p. 2)

How does the present research confront these obstacles? Scientific flexibility was demonstrated by selecting a model and a research technique quite alternative to the domain of creativity research. Csikszentmihalyi's (1999) model is known and cited, but experimentation with it does fill a gap. Kozbelt et al. (2010) even stated the use of his model is a "necessary risk" (p. 40). Moreover, connecting it to agent-based modelling facilitated the generation of new questions about the model as well as about creativity in general, something the field encourages as we are by far from agreeing on how to exactly define and study the phenomenon. The connection also allowed for a more complex view of the construct, which is a call often made at the latest in the discussion section of articles. Furthermore, CRESY-II is an opportunity to explore interrater reliability. It would be possible to search for conditions in which the measure is low and relate them to diversity and creativity. Nevertheless, the current work requires something the entire domain of creativity research is in need of: integration and differentiation. Future steps should include its incorporation into relevant domains, e.g. computer modelling, creativity research, organizational creativity, innovation research. The latter two domains could offer seminal comparisons between their research and the hypotheses constructed with CRESY, because they usually encompass longitudinal studies. The value of the current work lies in its interdisciplinary approach, its consideration of complexity (multiple system levels and variables), and its originality in combining a rarely investigated model with a progressive method. All of these are qualities future research on creativity would suit.

Last but not least, the CRESY models are representations of Csikszentmihalyi's (1999) systems perspective. They aid in clarifying and testing his model (Jaccard & Jacoby, 2010). As virtual experiments they offer fresh perspectives on this sociocultural approach, and they are a powerful tool for investigating this complex, dynamic system otherwise difficult to empirically study. CRESY is an inductive approach to a deductive model currently lacking unambiguous empirical validation. Its value does not stop at the level of theory construction, however. The agent-based models can be used to inform and stimulate empirical research, too. As noted, experimental research on the systems perspective is lacking and systematic, non-experimental research on it is hardly available (Abuhamdeh & Csikszentmihalyi, 2004; Csikszentmihalyi, 1988, 1999; McIntyre, 2008). This is quite understandable given the resources a research would need to operationalise his model. Yet the CRESY models can aid in preselecting hypotheses, variables and their relations for empirical testing. By using



the agent-based models to better understand the target, empirical studies can be more efficiently designed. This would save time and scientific personnel as well as spare study participants' nerves for the model does call for many repetitions over a long time period (Duffy, 2006). The models can be used to isolate promising effects before empirical investigations are carried out. Specifically, a researcher could check a priori what creator and evaluator sample sizes and compositions make a notable difference, or how much information the macrosystem would need to offer to boost creativity levels. Moreover, there is much discussion in the creativity research community about how to properly aggregate evaluations (e.g. Silvia, 2008, 2011). The evaluation strategies constructed in CRESY-II are a basis for testing assumptions and aggregations before laborious empirical rating data is collected. In addition, CRESY is not a final piece of work. Scientists interested in testing other kinds of evaluation strategies could program their own in the model. Presently, CRESY does not include any "interventions" which occur during a simulation run, such as a sudden change of macrosystem information or a switch in evaluation strategies (e.g paradigm shift, policy modification). Such occurrences are quite realistic in the real world and could be fruitful for understanding the systems model in empirical investigations. By programming and observing interventions in CRESY beforehand, empirical research on them could be designed to enhance their feasibility. Nevertheless, CRESY's value for empirical research is not unidirectional. Empirical research generated with CRESY not only aids in validating Csikszentmihalyi's (1999) ideas, but also in validating CRESY. Data gained in real-life settings can be used to qualify and improve the agent-based models and vice versa. Enhancing the fit between program and empiricism could also be a promising path to increasing the face and convergent validity of Csikszentmihalyi's (1999) theoretical model.

## 10.4 Concluding remarks

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The present research was conducted from late 2006 to mid 2011. In the beginning of this period three journals dedicated to creativity research were available (*Journal of Creative Behavior*; *Creativity Research Journal*; *Creativity and Innovation Management*). Since then three more have emerged (*Psychology of Creativity, Aesthetics and the Arts*; *International Journal of Creativity and Problem Solving*; *Thinking Skills and Creativity*). The construct is obviously attracting scientific interest rapidly, and the abundance of knowledge is fragmenting (Mumford, 2003; Runco, 2004a). There are numerous scientific handbooks of creativity. Many of them were recently updated with new editions or are in press (Cropley et al., 2010; Glover et al., 2010; Kaufman & Sternberg, 2006, 2010; Mumford, 2011; Piirto, 2004; Runco, 2007; Runco & Albert, 2011; Runco & Pritzker, 2011; Sawyer, 2006; Sternberg, 1999a; Sternberg et al., 2004; Zhou & Shalley, 2007). All of this given creativity research just turned 60 in 2010! Nevertheless, a quick retrieval of the above journals' articles published from January – July 2011 reveal that the psychological dissection of the creating individual still prevails. Moreover, Csikszentmihalyi's (1999) model may be

cited, but it is not systematically investigated. The current work approaches the task with a powerful yet controversial method. The next step is to offer this provocative research to appropriate gatekeepers in the hope that it will enter domains in which it stimulates others to vary, select and retain it.



# Appendix

## A.1 Experiment CI-1a

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This section contains the experimental design and results of Experiment CI-1a (see Chapter 6). The purpose of the experiment is to explore the behaviour of the dependent variables specifically in order to set the number of runs and steps in Experiment CI-1b, in which all technical parameters are to be tested.

### A.1.1. Research questions

The research questions to be answered in this experiment are:

- How many runs per experimental condition should be used in Experiment CI-1b?
- How many steps per run should be used in Experiment CI-1b?

### A.1.2. Experimental design

Experiment CI-1a has a total of six conditions (see Figure A.1). Two parameter sets were varied: a) number of runs (30, 60, 120) and b) values of the technical parameters (low, high). The exact values of the technical independent variables (*density*, *info-rate*, *movement*, *domSize*) in the low and high conditions are listed in Figure A.1.

The substantial independent variables were held constant in this experiment: The *ratio* of four creator types (Cx, C1, C2, C3) was equal. The *predefine-r*, *predefine-g* and *predefine-b* sliders were set to 128<sup>1</sup>. *Imagination* was set to 0.12<sup>2</sup>. Steps (ticks) were held constant at 1000. The following dependent variables were recorded at every step of every run: *hX.Y*, *hCall*, *hCx*, *hC1*, *hC2*, *hC3*.

---

<sup>1</sup>128 represents an arbitrarily designated intermediate value, because the number of r, g and b values in the world ranges from 1 – 256 for each colour dimension. The *actual* values of r, g and b colours range from 0 – 255.

<sup>2</sup>0.12 represents an arbitrarily designated intermediate value, because the imagination slider ranges from 0.00 – 0.25. An imagination value of 0.12 implies that a creator using an *original* strategy to select a colour dimension value (r, g or b) will have a 12% chance of selecting a value it has never encountered before, given there is still at least one value it has not encountered yet (see also Section 6.3.3).

number of runs					
30		60		120	
technical independent variables					
Low	High	Low	High	Low	High
density					
4	8	4	8	4	8
info-rate					
n4	n8	n4	n8	n4	n8
movement					
ahead3	any8	ahead3	any8	ahead3	any8
domSize					
64	512	64	512	64	512
Experimental Condition CI-1a					
30 Low	30 High	60 Low	60 High	120 Low	120 High

Figure A.1.: *Experimental design for Experiment CI-1a. The bottom two rows include the names of conditions (CI-1a 30 Low, ..., CI-1a 120 High).*

### A.1.3. Analyses

Each experimental condition produced an output file which was subsequently analysed with R (Version 2.11.1). The following steps were taken to analyse the simulation's output per experimental condition:

1. Correlations were calculated and tested between  $hCAI$  and all other relative information measures ( $hCx$ ,  $hC1$ ,  $hC2$ ,  $hC3$ ).
2. Scatterplots were produced separately for  $hX.Y$  and  $hCAI$  for each experimental condition.
3. Moving averages were calculated for the dependent variables  $hX.Y$  and  $hCAI$  for each condition.

#### Step 1: Correlations between $hCAI$ and other information measures

Pearson's correlations ( $r$ ) were calculated between  $hCAI$  and all other relative information measures ( $hCx$ ,  $hC1$ ,  $hC2$ ,  $hC3$ ) to decide whether the behaviour of  $hCAI$  is sufficiently representative of these measures. The reason for this procedure was to increase the efficiency of the analysis process. If the correlations between  $hCAI$

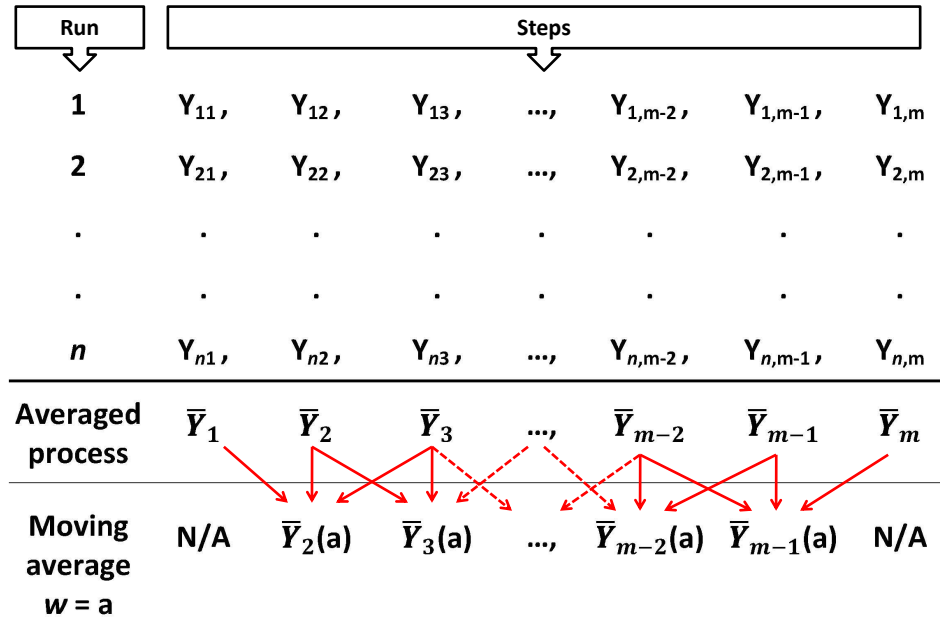


Figure A.2.: Averaged process of  $n$  runs with  $m$  steps and moving averages with  $w = a = 1$ . If a moving average did not have  $2w + 1$  observations, it was set to N/A by default.

and each of the other variables is positive and significantly different than zero, the effects the independent variables have on  $hCAII$  can be carefully generalized to the other measures. The chart in Figure A.3 depicts all correlations, their  $t$  values and confidence intervals. As all correlations are significant ( $p < 0.000$  in all cases), only the dependent variables  $hCAII$  and  $hX.Y$  were further analysed.

### Steps 2 & 3: Scatterplots and moving averages of $hX.Y$ & $hCAII$

The moving averages were calculated according to the procedure explained by Law (2007, pp. 509-510) and by using R's *decaverage* function, which decomposes a single regular time series (e.g. an averaged process) with a moving average filtering. The averages calculated are called moving, because the series of averages used to calculate them move through time. The advantage of depicting moving averages instead of the averaged process lies in the former's ability to display a long-term trend without the high-frequency oscillations integrated in the latter (Law, 2007, p. 509). After an averaged process is calculated, moving averages can be determined by first designating a window  $w$  around each observation (e.g. average; see Figure A.2). The window size chosen in this experiment was  $w = 1$  with sides  $s = 2$ . This means a window was centred around the current average and the averages directly before and after it were used to calculate the moving average for the current one. For each average  $\bar{Y}_i$  in the averaged process, a moving average was calculated if there were  $2w + 1$  observations for it. For the process depicted in Figure A.2 as well as for the

data collected in this experiment, this means no moving averages were calculated for the averages  $\bar{Y}_1$  and  $\bar{Y}_m$ . All averages used to calculate a moving average were not weighted and solely added (additive model). They are depicted as lines in the scatterplots A.4 – A.15 made for the dependent variables  $hX.Y$  and  $hCAll$  for all conditions of Experiment CI-1a.

### A.1.4. Discussion

#### Determining run length and number

As all correlations between  $hCAll$  and the other relative uncertainty measures ( $hCx$ ,  $hC1$ ,  $hC2$ ,  $hC3$ ) are positive and highly significant in all six conditions of Experiment CI-1a, only the dependent variables  $hCAll$  and  $hX.Y$  were observed to make a decision about the length and number of runs for Experiment CI-1b. After inspecting all graphs and correlations depicted in section A.1, the following parameters were consensually selected by three experienced scientists familiar with the processes modelled in CRESY-I. These values will be used in the subsequent Experiment CI-1b to investigate the effects of technical parameters on output measures: **run length** = 1000 steps (ticks); **number of runs** = 30.

Exp. Cond.	hCAI1 & hCx			hCAI1 & hC1			hCAI1 & hC2			hCAI1 & hC3		
	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>
CI-1a												
30 Low	.94	489.68*	> .94	.97	643.76*	> .97	.97	690.74*	> .97	.96	591.41*	> .96
30 High	.92	413.59*	> .92	.93	443.75*	> .93	.92	400.11*	> .92	.90	358.52*	> .90
60 Low	.94	673.08*	> .94	.96	870.77*	> .96	.96	885.45*	> .96	.96	797.41*	> .96
60 High	.93	615.24*	> .93	.93	596.78*	> .92	.91	543.80*	> .91	.88	462.83*	> .88
120 Low	.94	921.33*	> .94	.96	1230.83*	> .96	.97	1267.95*	> .96	.96	1172.27*	> .96
120 High	.92	827.49*	> .92	.93	872.28*	> .93	.92	818.03*	> .92	.90	699.95*	> .90

Figure A.3.: Pearson's correlations ( $r$ ) between hCAI1 and the relative information measures hCx, hC1, hC2, hC3. Bonferroni-corrected  $t$  values ( $\alpha = 0.05/k$ ;  $k = 4$ ) and 95% confidence intervals ( $CI$ ) are given for each  $r$  to demonstrate how much larger than zero they are. The correlations were rounded to two decimal places to adhere to standards of the American Psychological Association (APA). Only the rounded, lower boundaries of confidence intervals are shown. Significant  $t$  values ( $p < 0.000$ ) are indicated by \*.

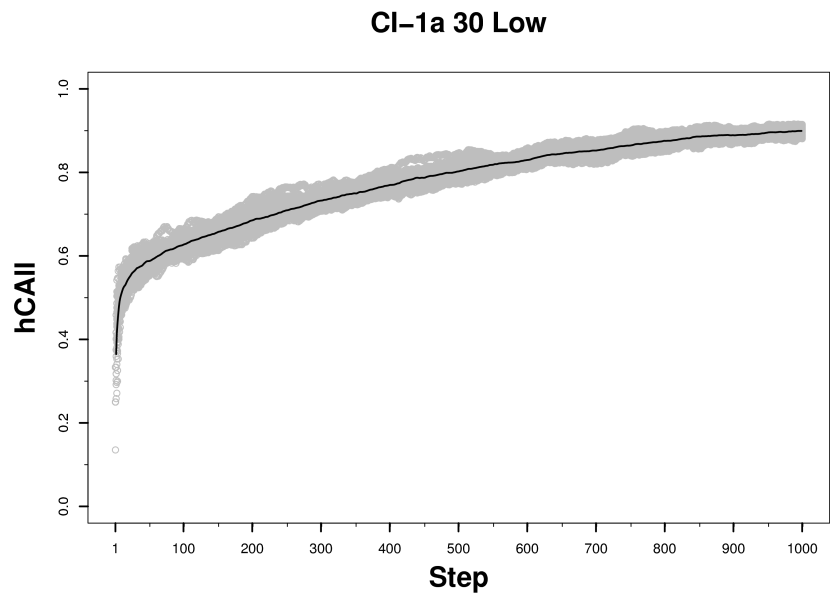


Figure A.4.: Scatterplot of  $hCAII$  including moving averages (Condition CI-1a 30 Low)

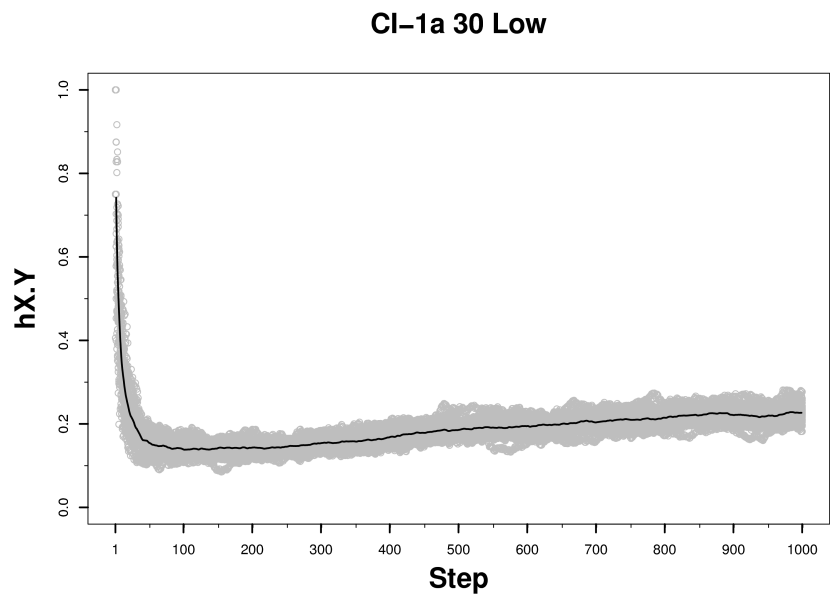


Figure A.5.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-1a 30 Low)



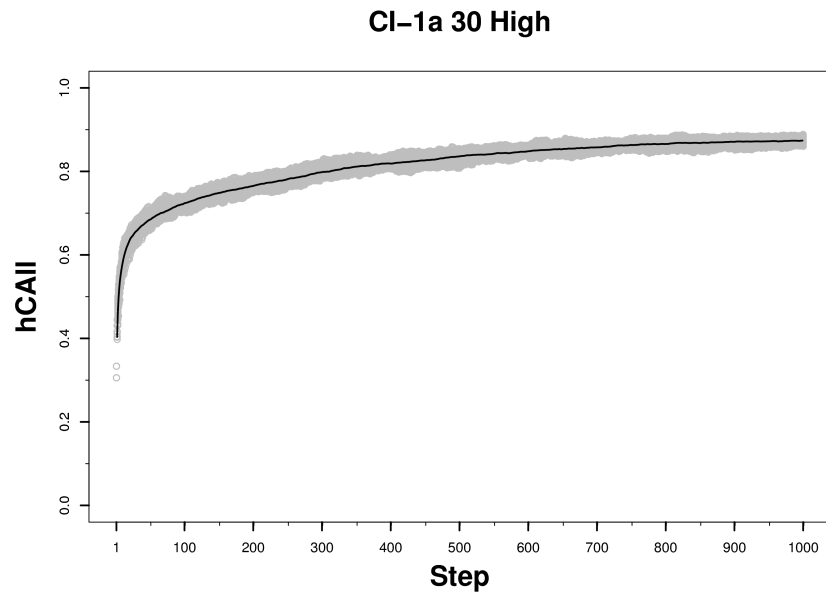


Figure A.6.: Scatterplot of  $hCAII$  including moving averages (Condition CI-1a 30 High)

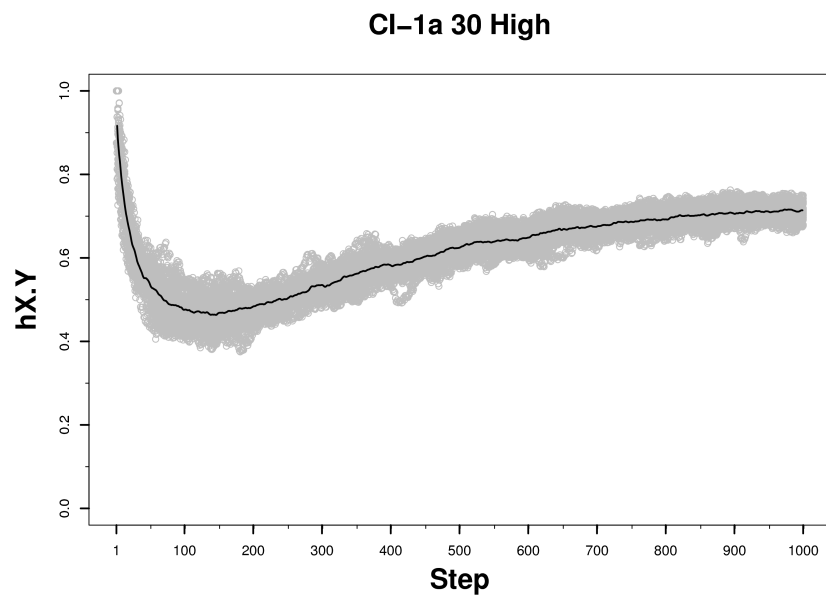


Figure A.7.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-1a 30 High)

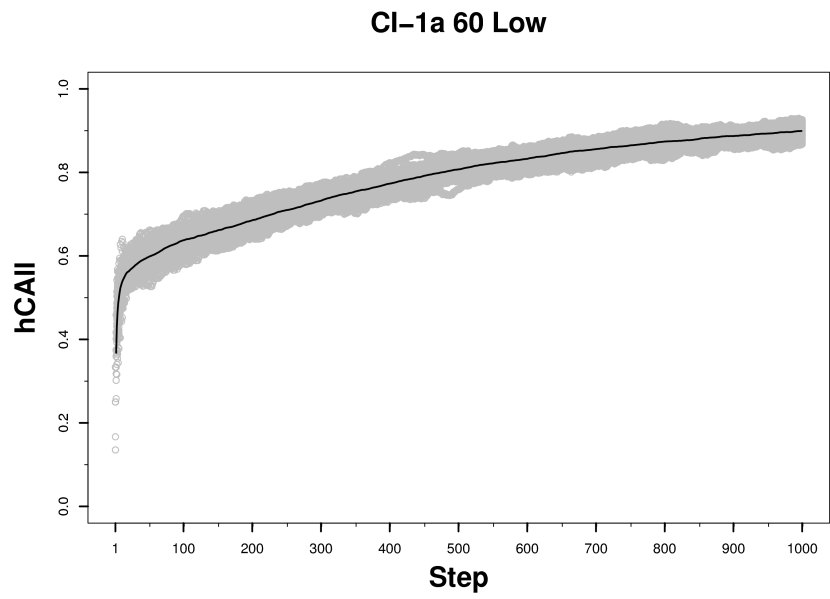


Figure A.8.: Scatterplot of  $hCAII$  including moving averages (Condition CI-1a 60 Low)

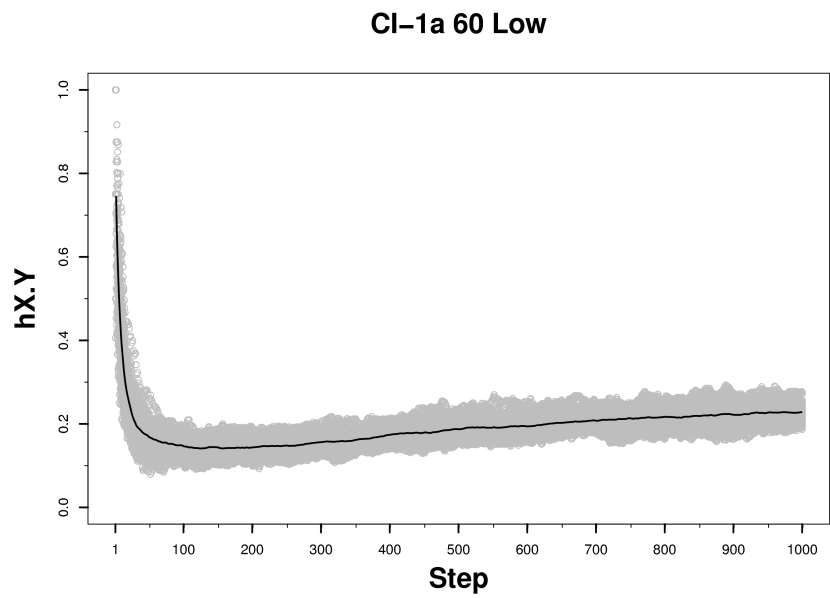


Figure A.9.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-1a 60 Low)

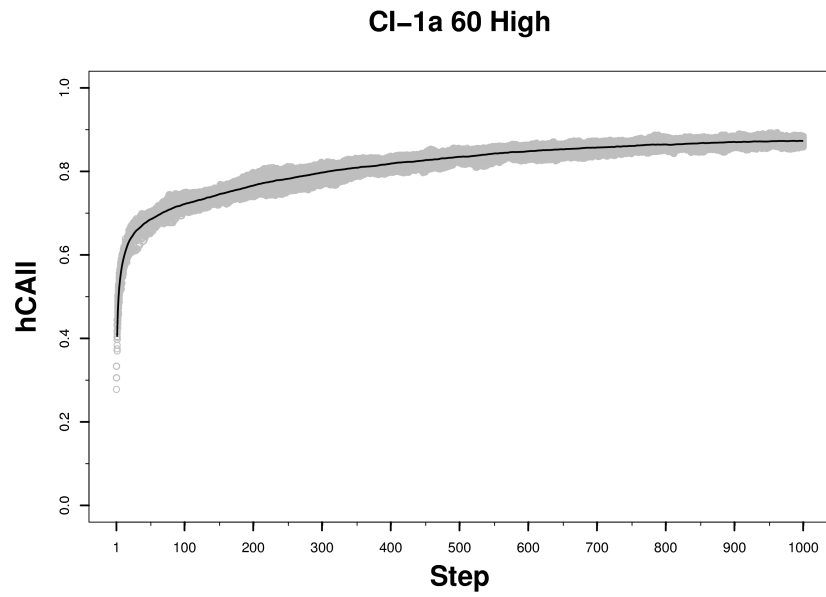


Figure A.10.: Scatterplot of  $hCAII$  including moving averages (Condition CI-1a 60 High)

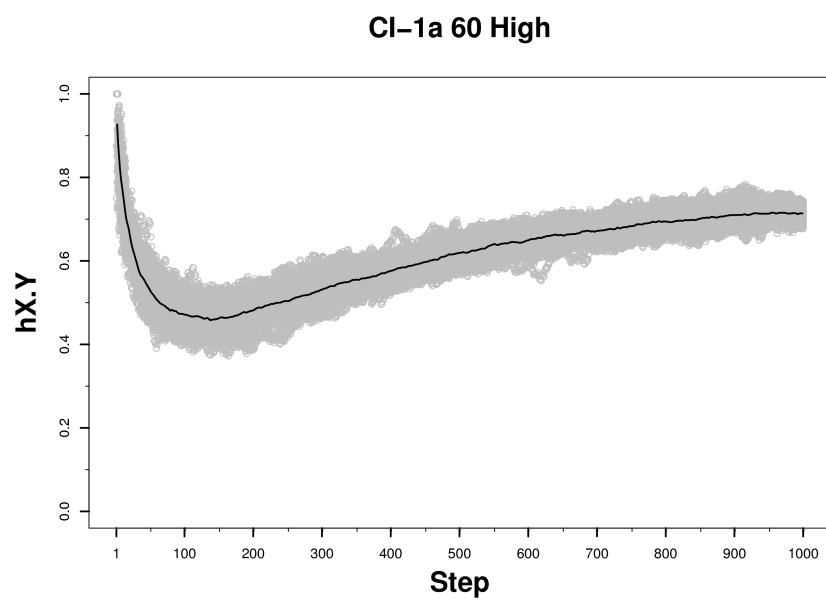


Figure A.11.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-1a 60 High)

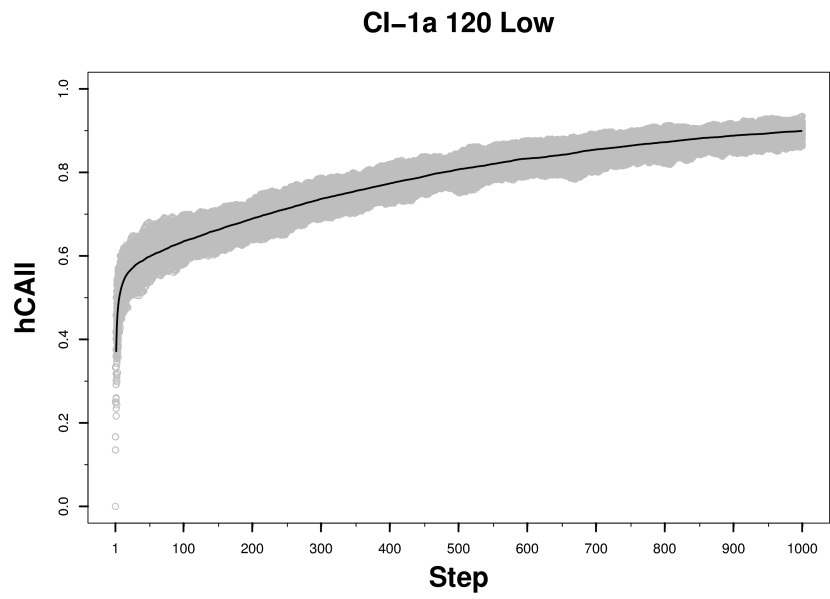


Figure A.12.: Scatterplot of  $hCAII$  including moving averages (Condition CI-1a 120 Low)

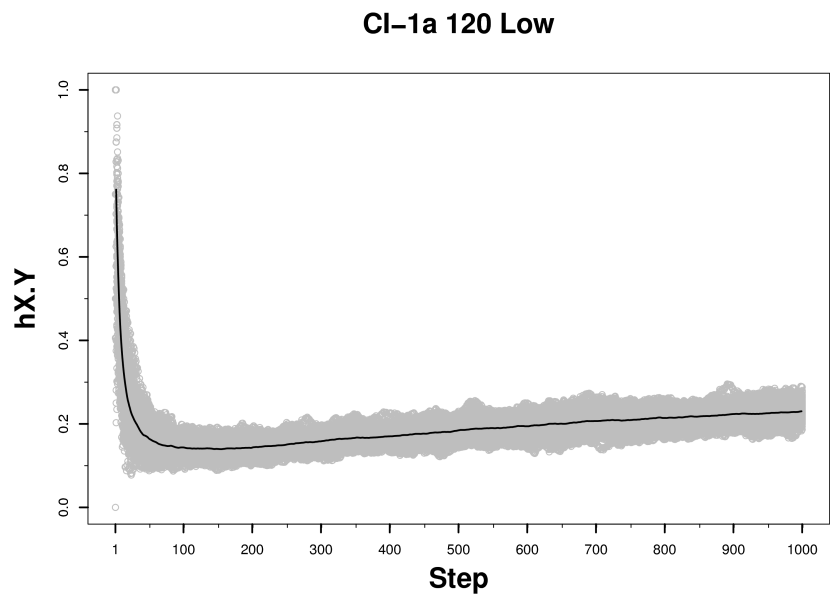


Figure A.13.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-1a 120 Low)

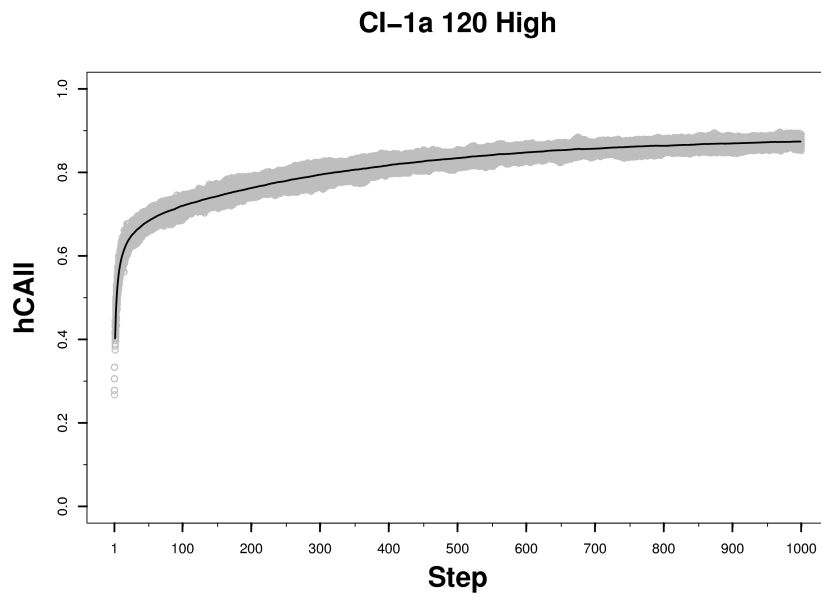


Figure A.14.: Scatterplot of  $hCAII$  including moving averages (Condition CI-1a 120 High)

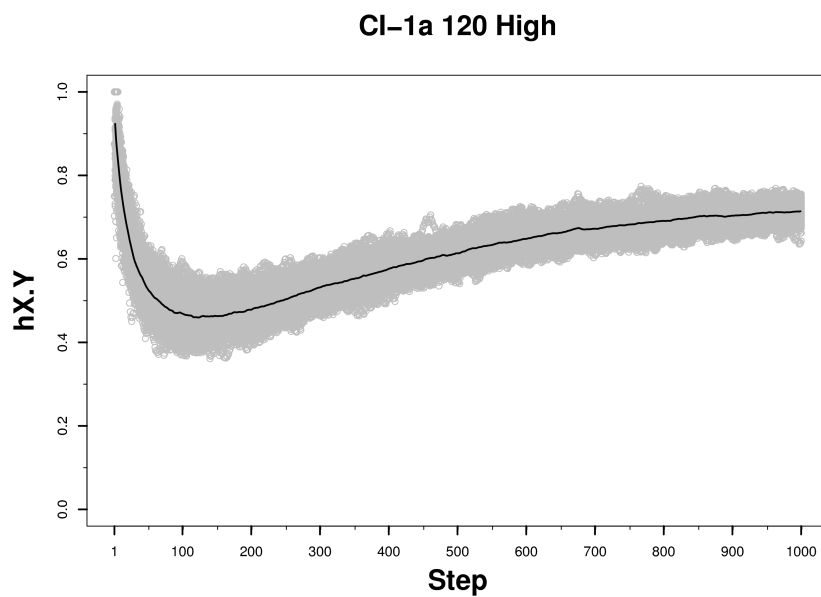


Figure A.15.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-1a 120 High)

## A.2 Experiment CI-1b

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This section contains the experimental design and results of Experiment CI-1b (see Chapter 6). The purpose of this experiment is to test the four technical independent variables CRESY-I features. At this stage, their influence on the dependent variables is still unknown. After exploring them in this experiment, particular values for each technical independent variable can be chosen for the subsequent experiments CI-2a & CI-2b, in which the substantial<sup>3</sup> independent variables are to be explored.

### A.2.1. Research questions

The research questions to be answered are:

- How do the four technical independent variables affect the development of the dependent variables?
- Which value(s) for each technical variable should be used in Experiment CI-2?

### A.2.2. Experimental design

Experiment CI-1b had a total of 16 conditions. The following four technical independent variables were varied in a  $2^k$  factorial model ( $k = 4$ ; Kleijnen et al., 2005; Law, 2007; Montgomery, 2005): *density*, *info-rate*, *movement*, *domSize*. Their exact values as well as the overall experimental design are depicted in Figure A.16.

All substantial independent variables were held constant: The *ratio* of four creator types (Cx, C1, C2, C3) was equal. The *predefine-r*, *predefine-g* and *predefine-b* sliders were set to 128<sup>4</sup>. *Imagination* was set to 0.12<sup>5</sup>. Steps (ticks) were held constant at 1000. A total of 30 simulation runs per condition were conducted (see Experiment CI-1a in Section A.1 for an explanation). The following output measures were recorded at every step of every run: *hCall*, *hCx*, *hC1*, *hC2*, *hC3*, *hX.Y*.

### A.2.3. Analyses

Each experimental condition is named after a number from 1 – 16 with a prefix indicating the experiment's label (CI-1b; see Figure A.16). One output file per condition was generated and subsequently analysed with R (version 2.10.1). The following steps were taken to analyse this data:

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<sup>3</sup>For a distinction between *technical* and *substantial* see Cioffi-Revilla (2010) and Chapter 6.

<sup>4</sup>128 represents an arbitrarily designated intermediate value, because the number of r, g and b values in the world ranges from 1 – 256 for each colour dimension. The *actual* values of r, g and b colours range from 0 – 255.

<sup>5</sup>0.12 represents an arbitrarily designated intermediate value, because the imagination slider ranges from 0.00 – 0.25. An imagination value of 0.12 implies that a creator using an *original* strategy to select a colour dimension value (r, g or b) will have a 12% chance of selecting a value it has never encountered before, given there is still at least one value it has not encountered yet.

density															
4								8							
info-rate															
n4				n8				n4				n8			
movement															
any8		ahead3		any8		ahead3		any8		ahead3		any8		ahead3	
domSize															
64	512	64	512	64	512	64	512	64	512	64	512	64	512	64	512
Experimental Condition CI-1b															
01	05	02	06	09	13	10	14	03	07	04	08	11	15	12	16

Figure A.16.: *Experimental design of Experiment CI-1b. The bottom two rows include the names of conditions (e.g. CI-1b 01, ..., CI-1b 16). Conditions 2 and 15 represent the low and high conditions (for technical independent variables) used in the previous Experiment CI-1a (see Section A.1).*

1. Correlations were calculated and tested between  $hCAI$  and all other relative information measures ( $hCx$ ,  $hC1$ ,  $hC2$ ,  $hC3$ ).
2. The overall behaviour of the dependent variables  $hCAI$  and  $hX.Y$  was analysed graphically per experimental condition to decide which steps should be used for further analyses.
3. All 30 runs per condition and dependent variable were correlated to decide whether the subsamples of runs are similar enough to be averaged per condition and dependent variable.
4. All 30 runs per condition and dependent variable were averaged to one process and then linearly regressed on *step* to identify each experimental condition's and dependent variable's characteristic intercept and gradient.
5. Forest plots of each dependent variable's intercepts and gradients were generated in order to interpret Experiment CI-1b's output.

### Step 1: Correlations between *hCAII* and *hCx*, *hC1*, *hC2*, *hC3*

Pearson's correlations ( $r$ ) were calculated between *hCAII* and all other relative information measures (*hCx*, *hC1*, *hC2*, *hC3*) to decide whether the behaviour of *hCAII* is sufficiently representative of all other measures. The rationale behind this procedure is to increase the efficiency of the analysis process. If the correlations between *hCAII* and each of the other variables is positive and significantly different than zero, the effects the independent variables have on *hCAII* can be carefully generalized to the other measures. The chart in Figure A.17 depicts all correlations, their  $t$  values and confidence intervals. As all correlations are significantly ( $p < 0.000$ ) larger than zero, only the dependent variables *hCAII* and *hX.Y* were further analysed.

### Step 2: Determining the start for further analyses

The purpose of Step 2 is to decide on a starting step from which simulation runs are further analysed. Originally, each simulation was run from 1 – 1000 steps. However, the initial steps of simulation runs often exhibit transient behaviour (Law, 2007, p. 488), which is visible in starkly fluctuating variances of dependent variables per step. Since the dependent variables will be aggregated per step (over all runs of one experimental condition) for further analyses, checking and assuring the relative homogeneity of their variances is important in order to allow comparisons between steps or processes of different conditions. Such comparisons are the basis for answering the research questions posed in this experiment (Section A.2.1).

The following was undertaken to determine a starting step for further analyses: Firstly, the starting step to be designated must be the same for each condition. In other words, all 480 runs ( $30 \text{ runs} \cdot 16 \text{ conditions}$ ) should have the same number of observations (steps). Secondly, there are two dependent variables to be analysed, *hX.Y* and *hCAII*, so the variances of both need to be considered. Thirdly, to gain a rough overview of the distributions of dependent variables per step, boxplots were made for each dependent variable per condition. Specifically, for every one of the 16 experimental conditions, two graphs were made, i.e. one for each dependent variable. Each graph contains boxplots from steps 1 – 1000. Since there are 30 runs in each experimental condition, every step (boxplot) contains 30 measurements. The boxplots' whiskers stretch to the outliers. Figures A.18-A.49 contain the results. Note the following: a) The dependent variables are depicted as differences from step medians to emphasize variance distributions. b) The 1000 boxplots are, obviously, so close to each other that only the development of these distributions is decipherable. This should suffice, however, to gain insight on dependent variable variances over time. Finally, after examining all graphs, quasi steady-state behaviour (Law, 2007, p. 488) appears to start at step 250 at the latest for *hX.Y* as well as for *hCAII*. Therefore, all further analyses will be conducted from **steps 250-1000**.



Exp. Cond.	hCAII & hCx			hCAII & hC1			hCAII & hC2			hCAII & hC3		
	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>
01	.85	284.44*	>.85	.92	414.26*	>.92	.95	523.79*	>.95	.95	549.38*	>.95
02	.93	451.84*	>.93	.96	598.15*	>.96	.96	620.48*	>.96	.96	580.66*	>.96
03	.92	406.54*	>.92	.96	570.98*	>.96	.96	594.93*	>.96	.95	520.00*	>.95
04	.96	568.88*	>.96	.98	754.19*	>.97	.97	736.42*	>.97	.96	589.09*	>.96
05	.91	371.00*	>.90	.93	427.35*	>.93	.95	527.30*	>.95	.94	497.63*	>.94
06	.93	456.81*	>.93	.95	534.11*	>.95	.95	523.59*	>.95	.94	490.40*	>.94
07	.91	373.13*	>.91	.91	386.78*	>.91	.90	350.15*	>.89	.90	355.79*	>.90
08	.93	424.43*	>.92	.93	430.34*	>.93	.91	385.99*	>.91	.90	359.66*	>.90
09	.90	354.54*	>.90	.95	525.03*	>.95	.96	621.50*	>.96	.95	535.07*	>.95
10	.95	527.73*	>.95	.97	702.68*	>.97	.97	676.41*	>.97	.94	489.91*	>.94
11	.92	411.10*	>.92	.97	659.17*	>.97	.97	655.00*	>.97	.93	441.04*	>.93
12	.95	548.41*	>.95	.98	829.63*	>.98	.98	767.18*	>.97	.93	439.49*	>.93
13	.92	417.73*	>.92	.95	508.25*	>.95	.94	494.59*	>.94	.95	507.83*	>.95
14	.95	531.15*	>.95	.96	574.21*	>.96	.95	508.09*	>.95	.93	430.42*	>.93
15	.91	384.72*	>.91	.92	404.11*	>.92	.90	359.33*	>.90	.90	349.95*	>.90
16	.94	496.32*	>.94	.95	500.05*	>.94	.92	419.75*	>.92	.88	316.51*	>.87

Figure A.17.: Pearson's correlations (*r*) between hCAII and the relative information measures hCx, hC1, hC2, hC3. Bonferroni-corrected *t* values ( $\alpha = 0.05/k$ ;  $k = 4$ ) and 95% confidence intervals (*CI*) are given for each *r* to demonstrate how much larger than zero they are. The correlations were rounded to two decimal places to adhere to standards of the American Psychological Association (APA). Only the rounded, lower boundaries of confidence intervals are shown. Significant *t* values ( $p < 0.000$ ) are indicated by \*.

**CI-1b 01**

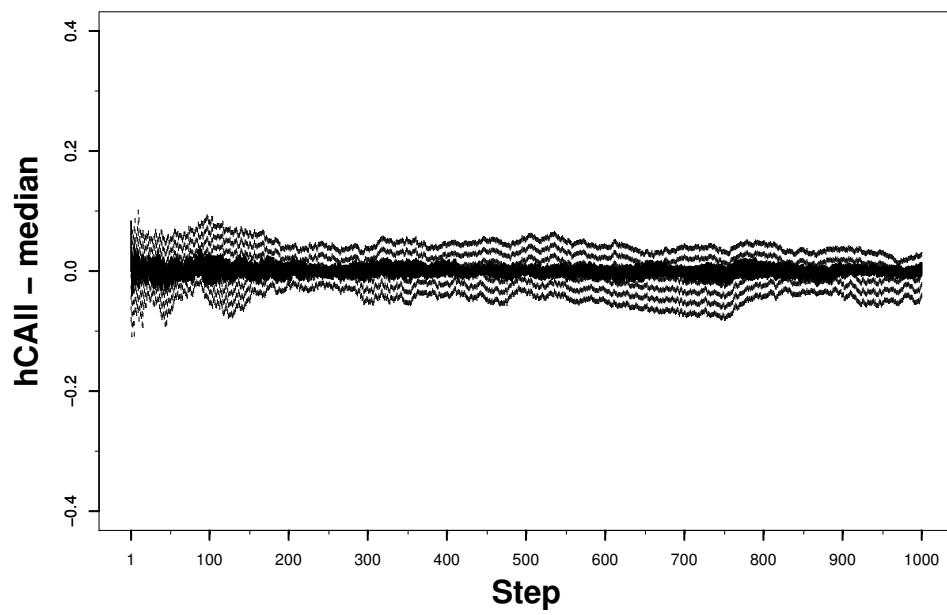


Figure A.18.: *hCAII boxplots (Condition CI-1b 01)*

**CI-1b 02**

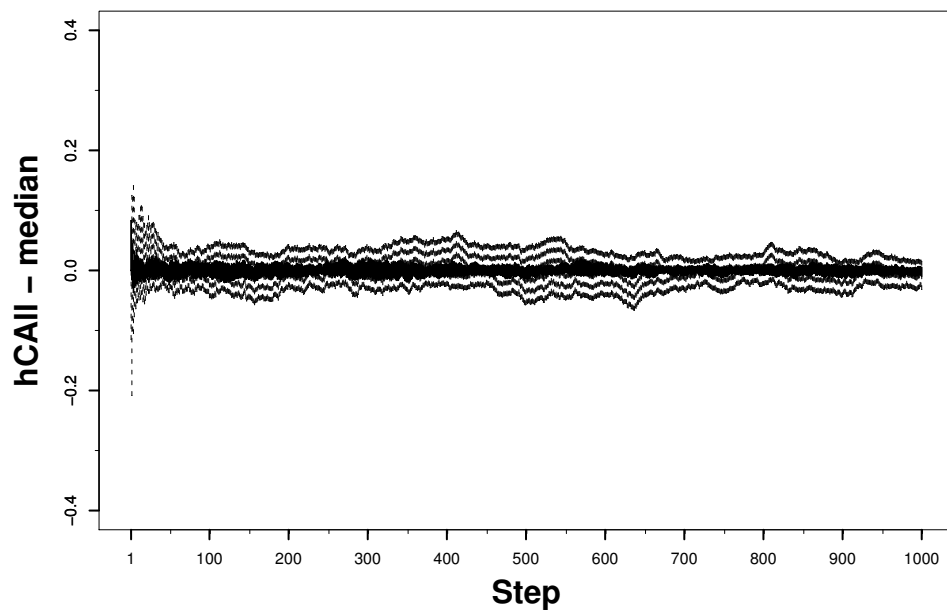
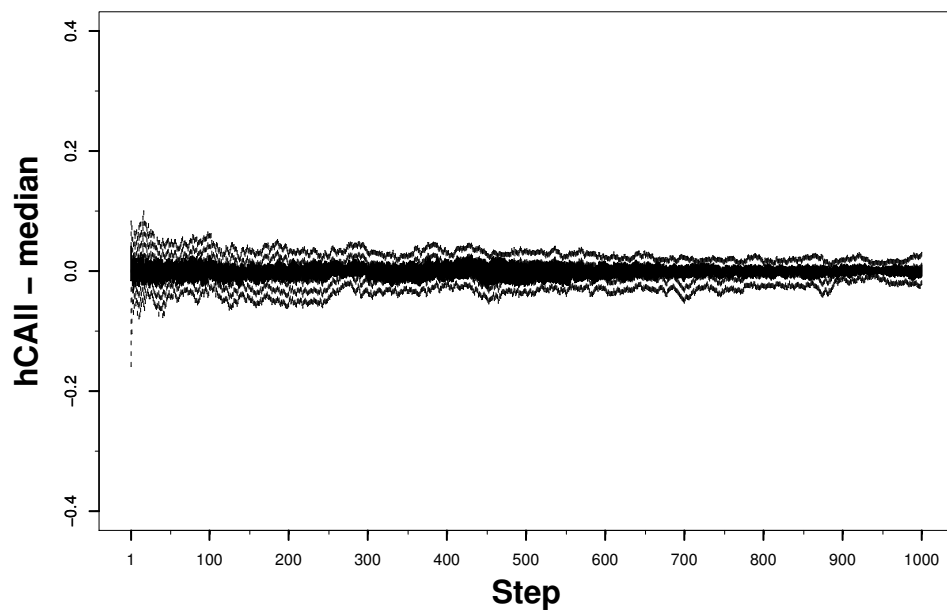
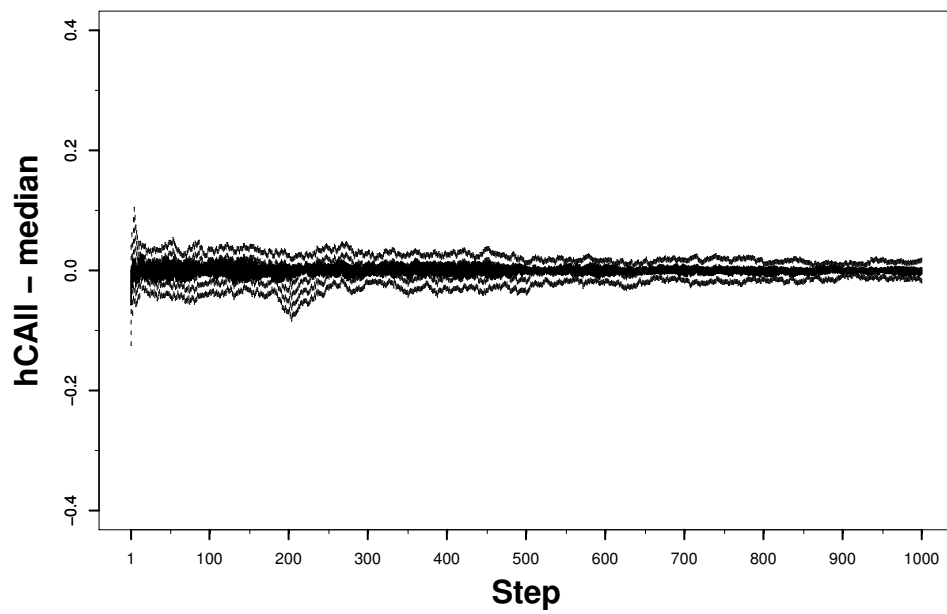


Figure A.19.: *hCAII boxplots (Condition CI-1b 02)*

## CI-1b 03

Figure A.20.: *hCALL boxplots (Condition CI-1b 03)*

## CI-1b 04

Figure A.21.: *hCALL boxplots (Condition CI-1b 04)*

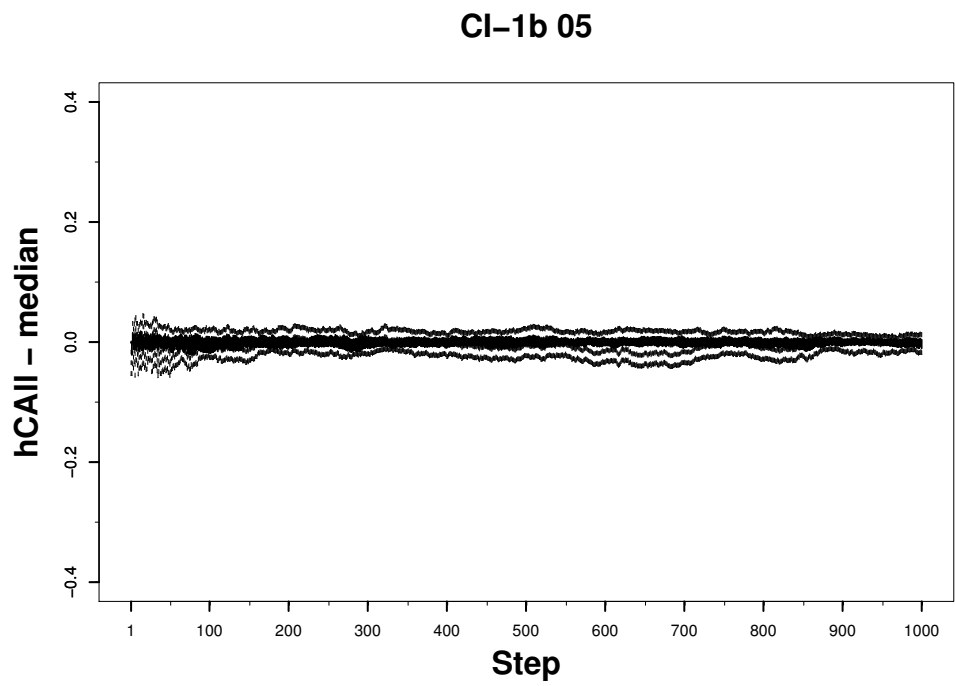


Figure A.22.: *hCALL boxplots (Condition CI-1b 05)*

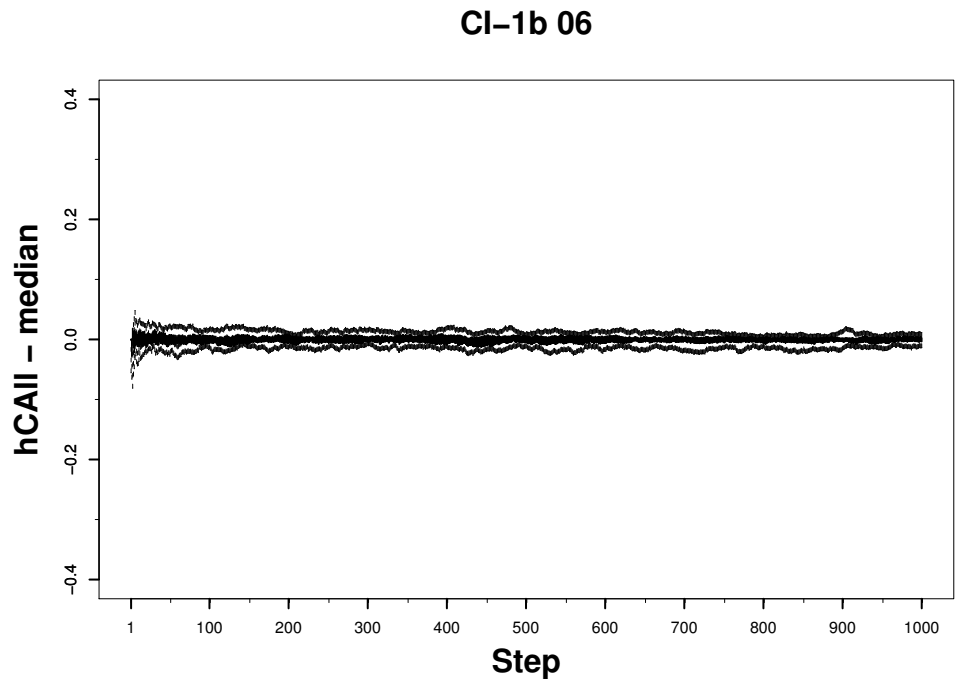
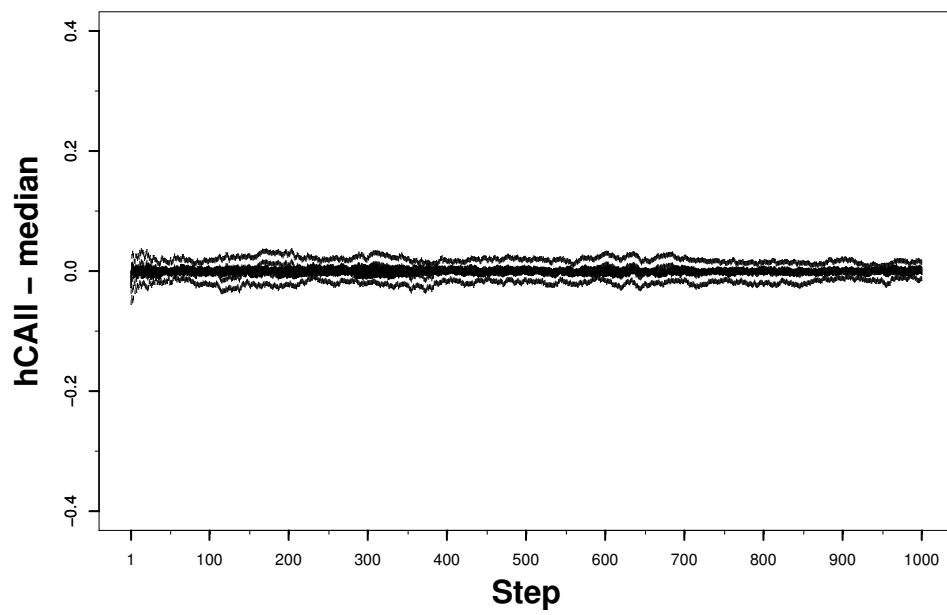
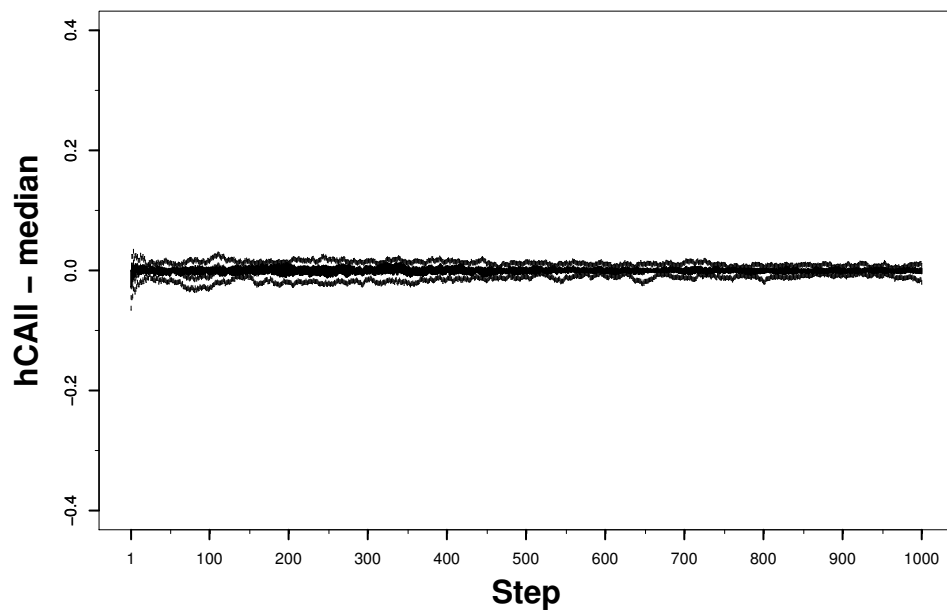


Figure A.23.: *hCALL boxplots (Condition CI-1b 06)*

CI-1b 07

Figure A.24.: *hCALL boxplots (Condition CI-1b 07)*

CI-1b 08

Figure A.25.: *hCALL boxplots (Condition CI-1b 08)*

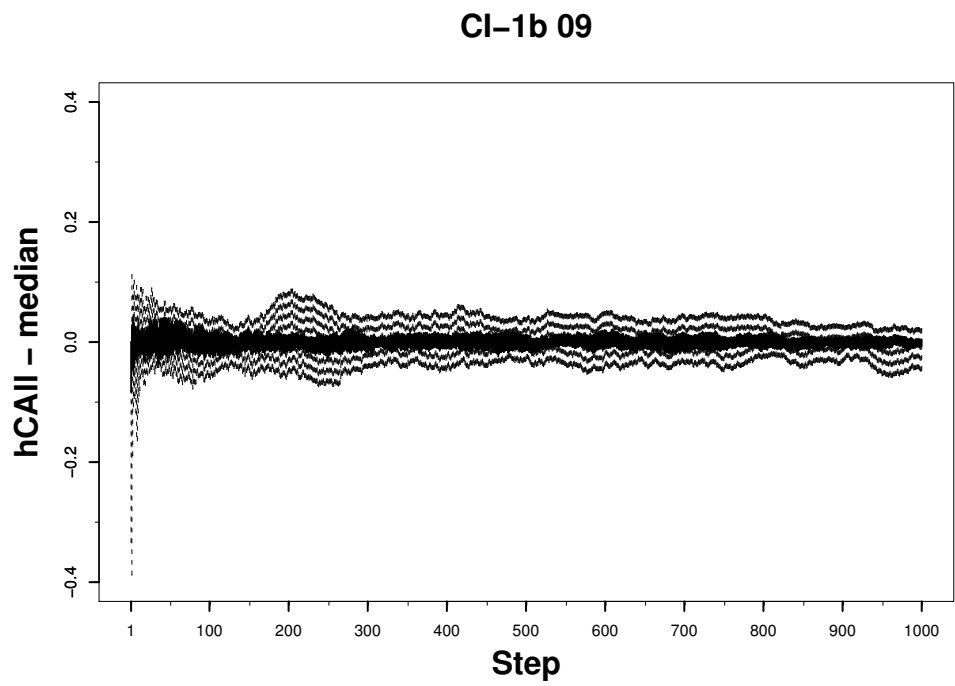


Figure A.26.: *hCALL boxplots (Condition CI-1b 09)*

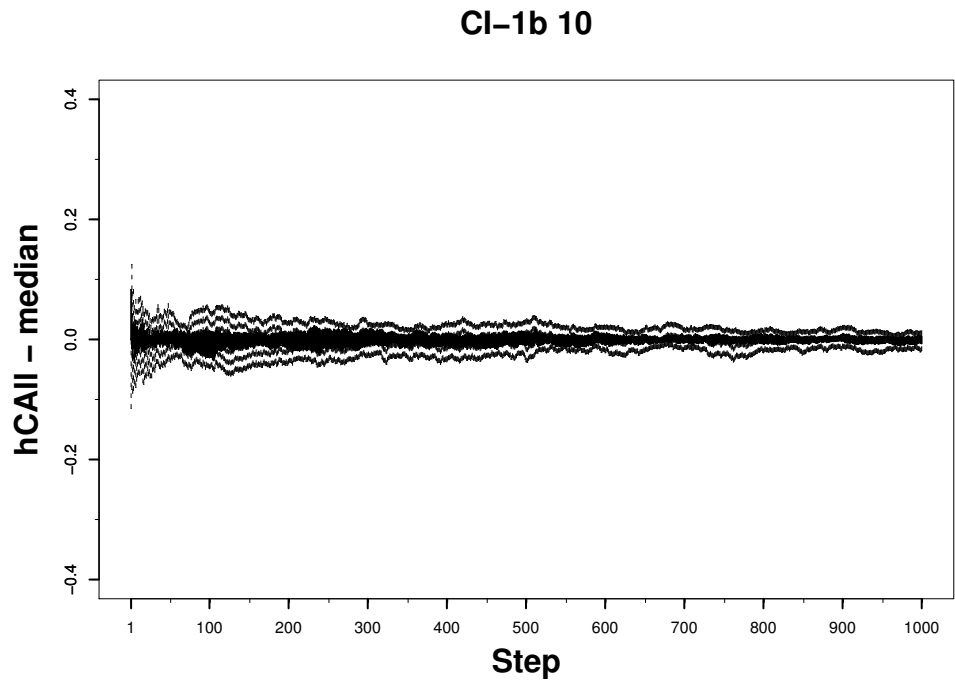
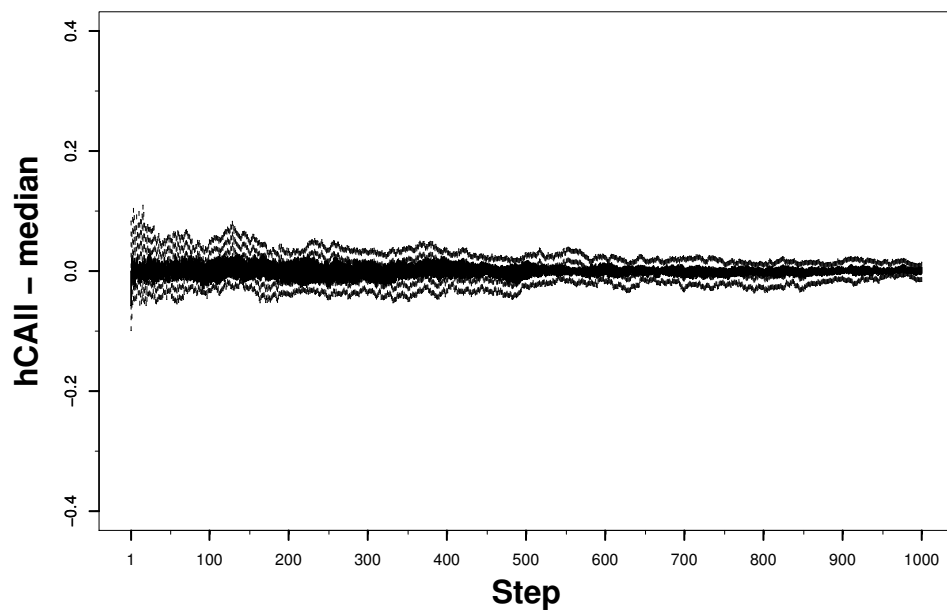
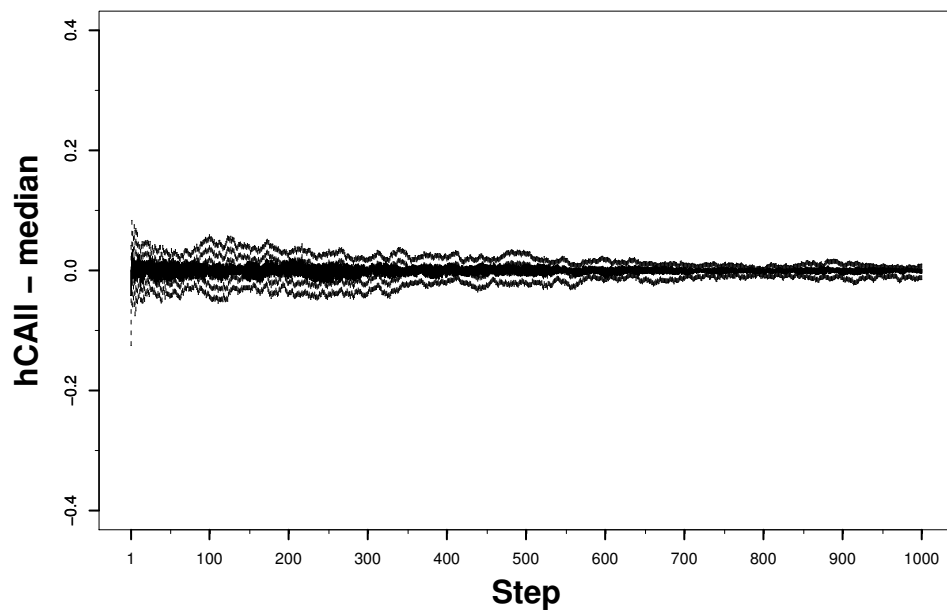


Figure A.27.: *hCALL boxplots (Condition CI-1b 10)*

## CI-1b 11

Figure A.28.: *hCALL boxplots (Condition CI-1b 11)*

## CI-1b 12

Figure A.29.: *hCALL boxplots (Condition CI-1b 12)*

**CI-1b 13**

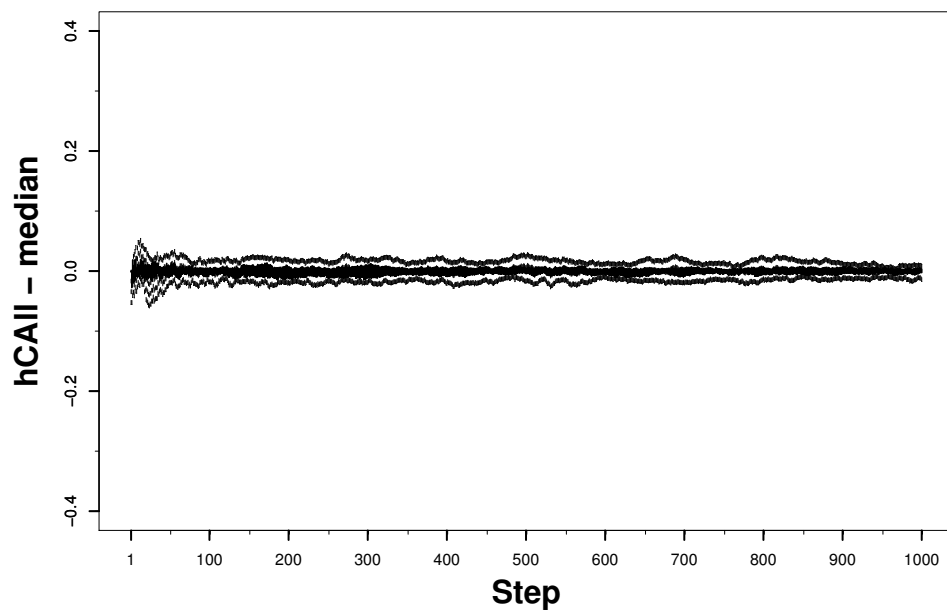


Figure A.30.: *hCALL boxplots (Condition CI-1b 13)*

**CI-1b 14**

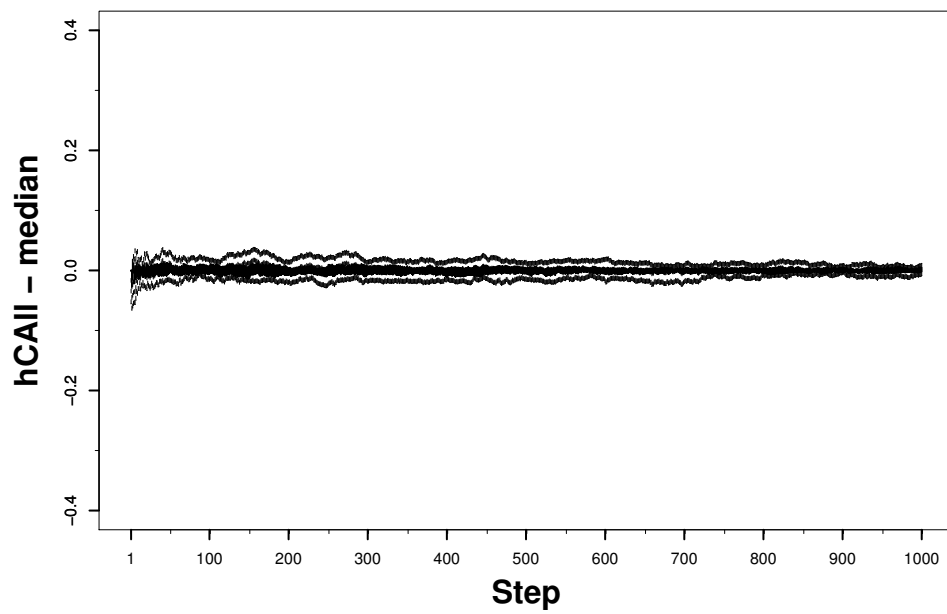
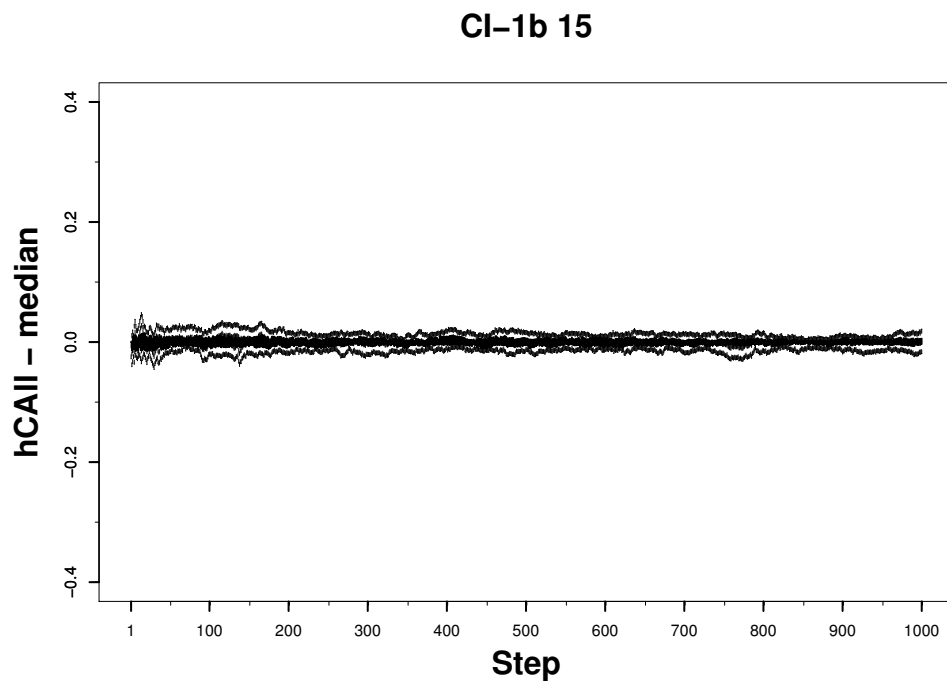
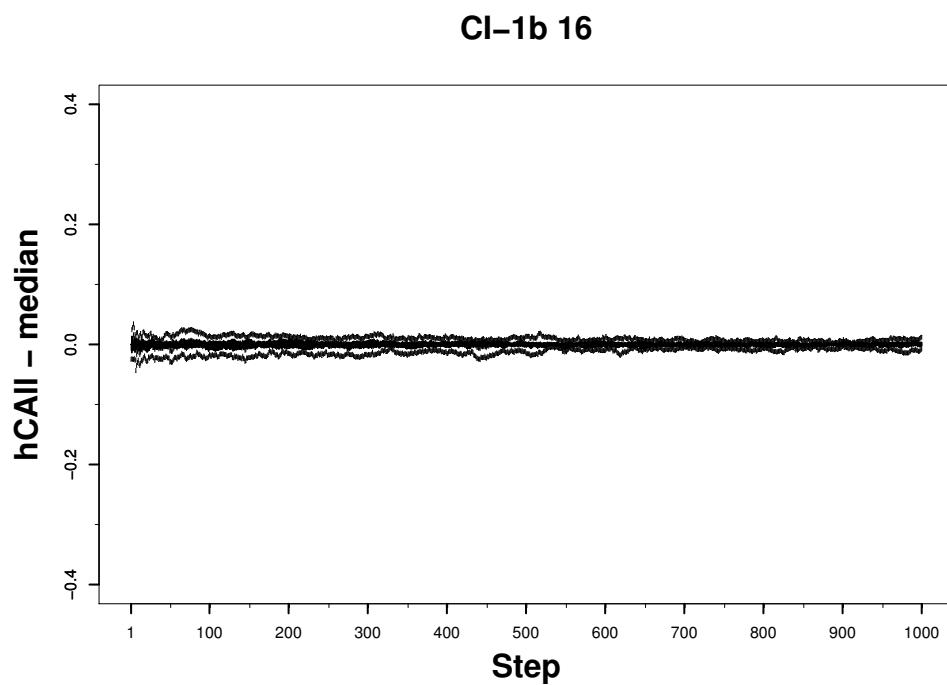


Figure A.31.: *hCALL boxplots (Condition CI-1b 14)*



Figure A.32.: *hCALL boxplots (Condition CI-1b 15)*Figure A.33.: *hCALL boxplots (Condition CI-1b 16)*

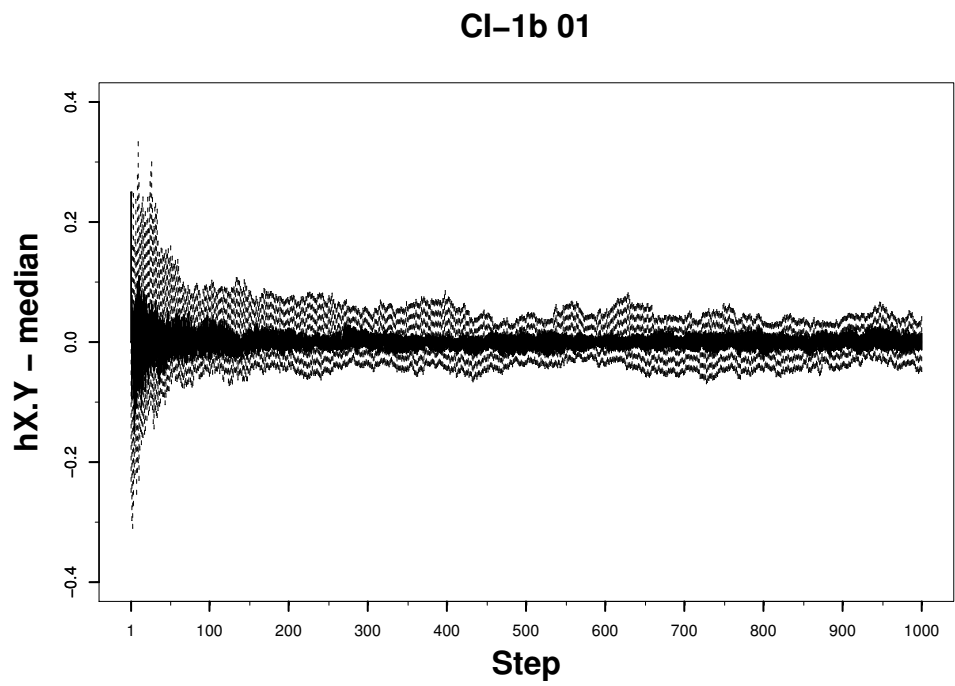


Figure A.34.:  $hX.Y$  boxplots (Condition CI-1b 01)

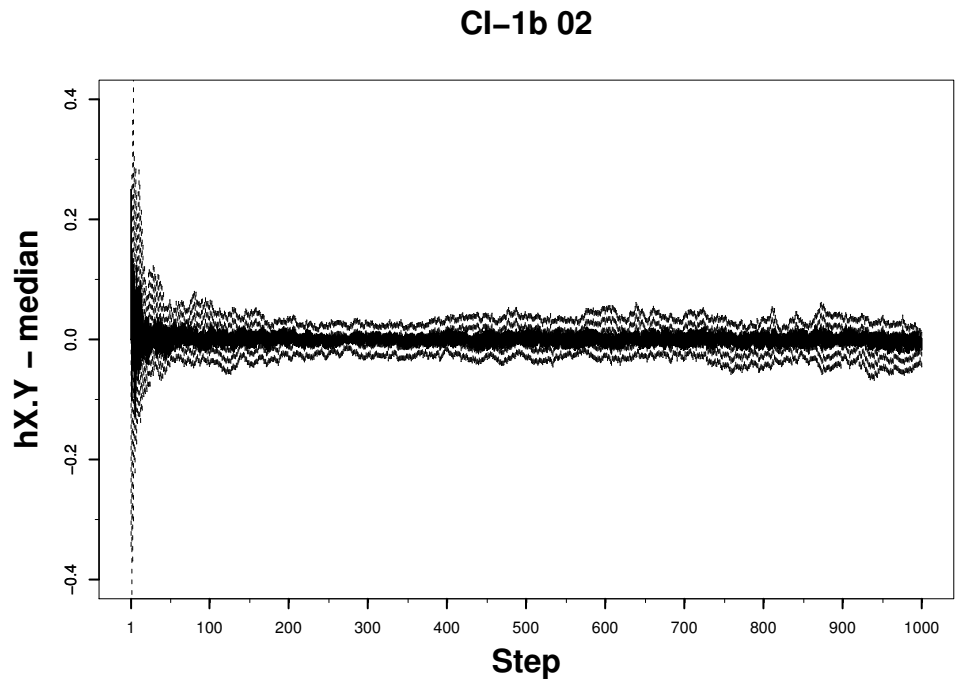
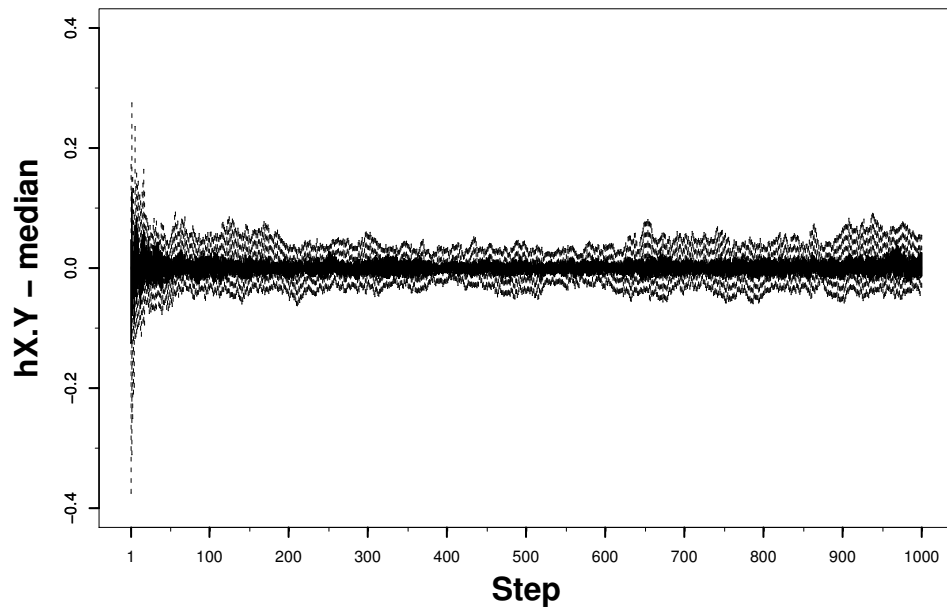
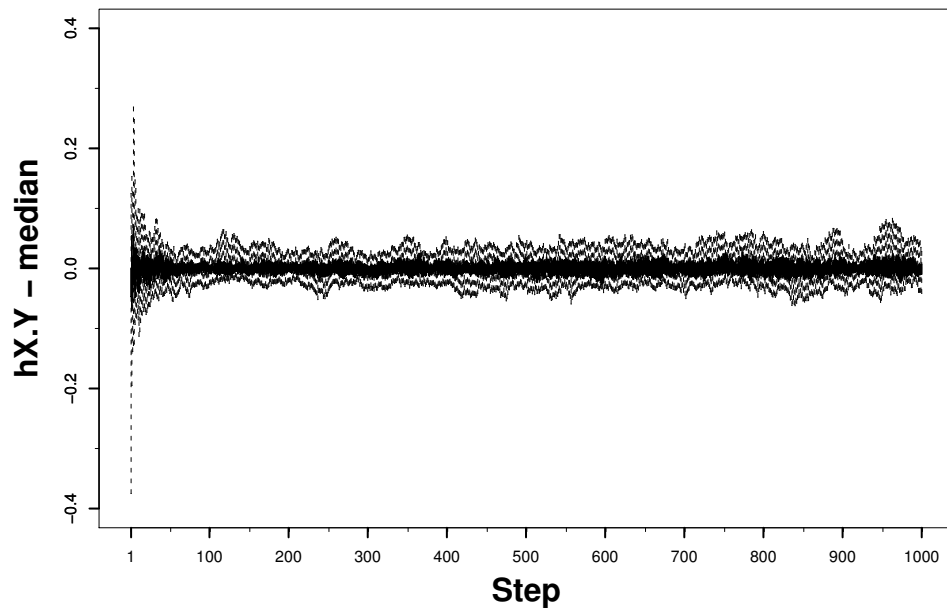


Figure A.35.:  $hX.Y$  boxplots (Condition CI-1b 02)

## CI-1b 03

Figure A.36.:  $hX.Y$  boxplots (Condition CI-1b 03)

## CI-1b 04

Figure A.37.:  $hX.Y$  boxplots (Condition CI-1b 04)

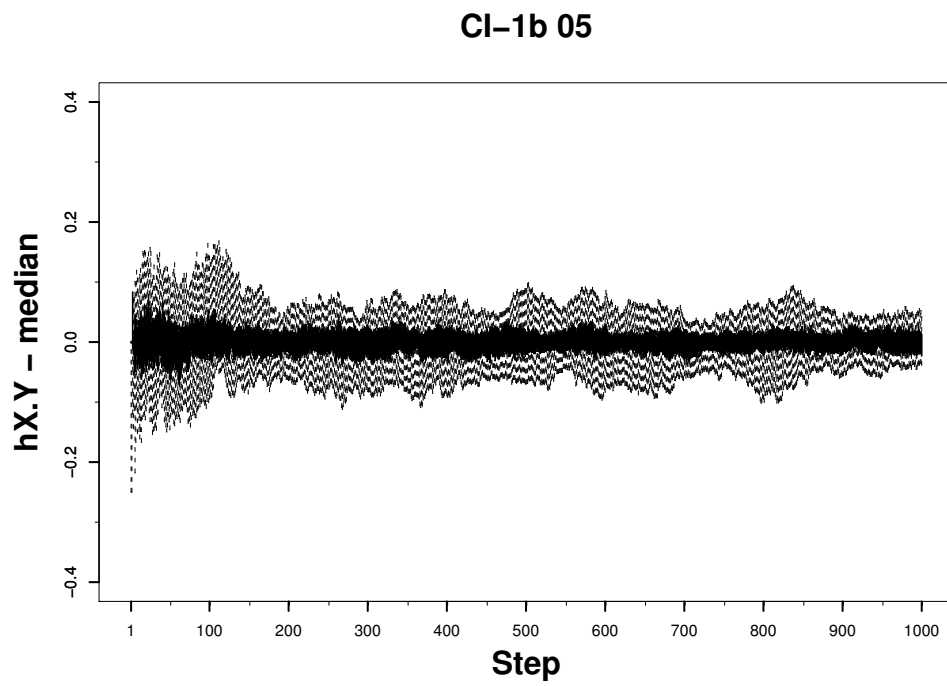


Figure A.38.:  $hX.Y$  boxplots (Condition CI-1b 05)

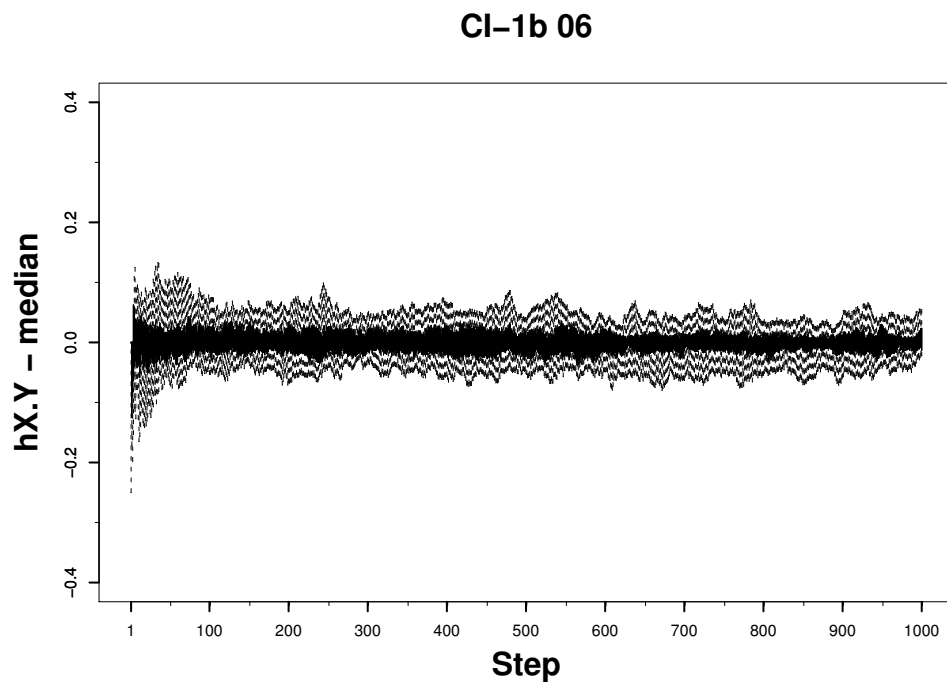
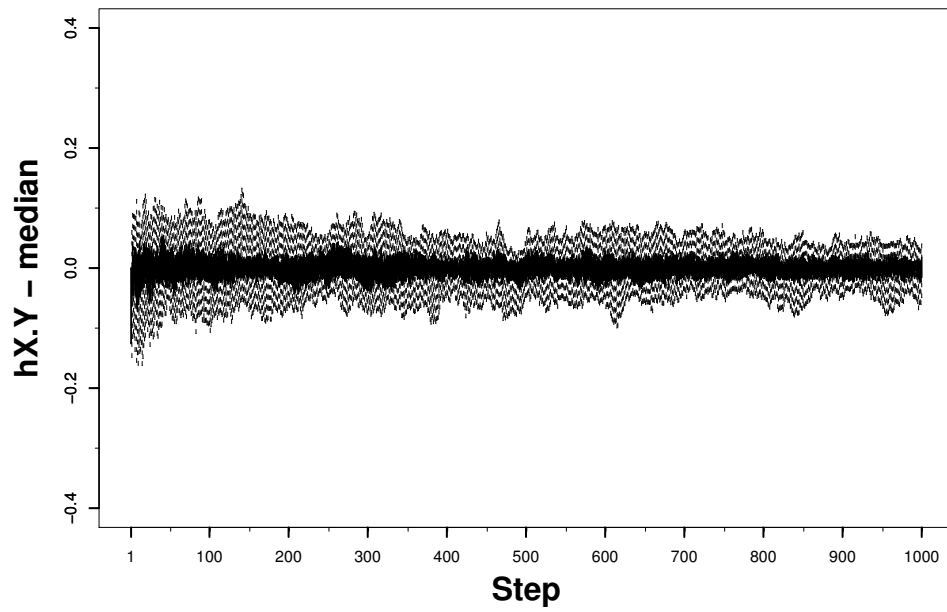
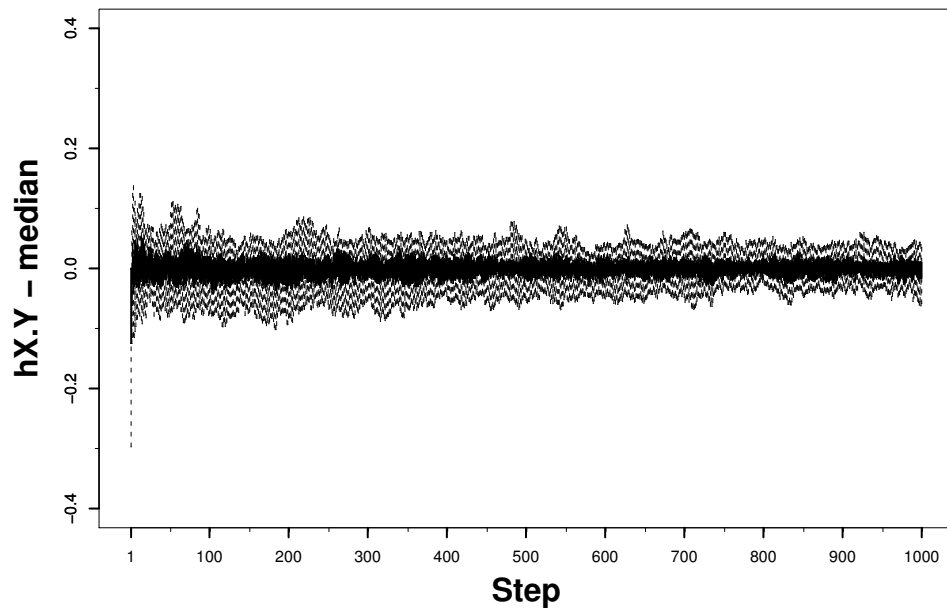


Figure A.39.:  $hX.Y$  boxplots (Condition CI-1b 06)

## CI-1b 07

Figure A.40.:  $hX.Y$  boxplots (Condition CI-1b 07)

## CI-1b 08

Figure A.41.:  $hX.Y$  boxplots (Condition CI-1b 08)

CI-1b 09

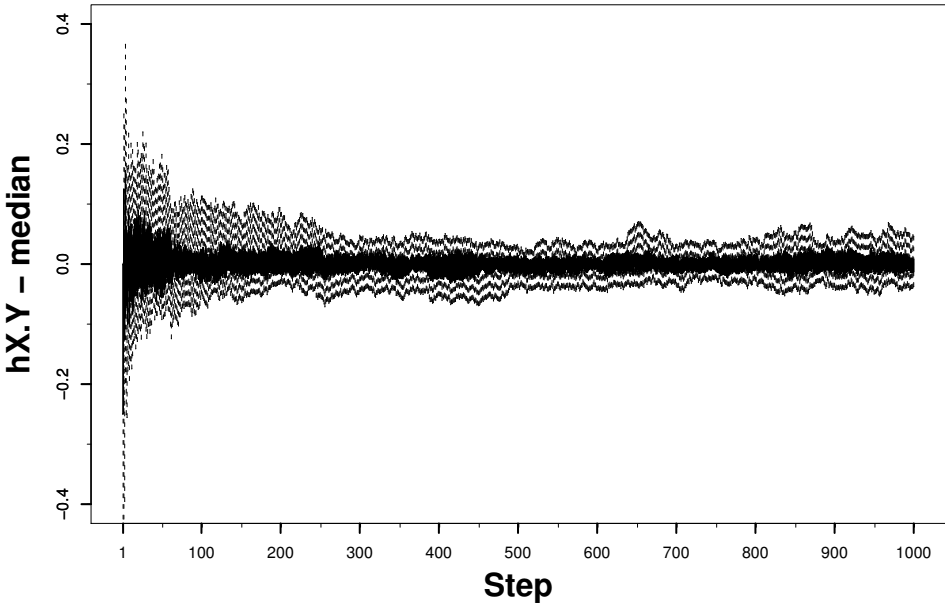


Figure A.42.:  $hX.Y$  boxplots (Condition CI-1b 09)

CI-1b 10

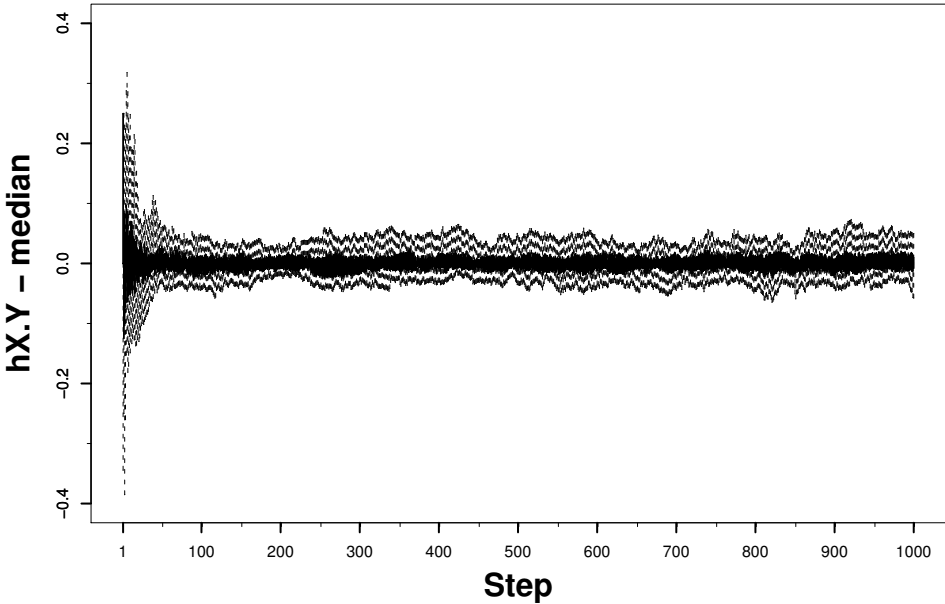
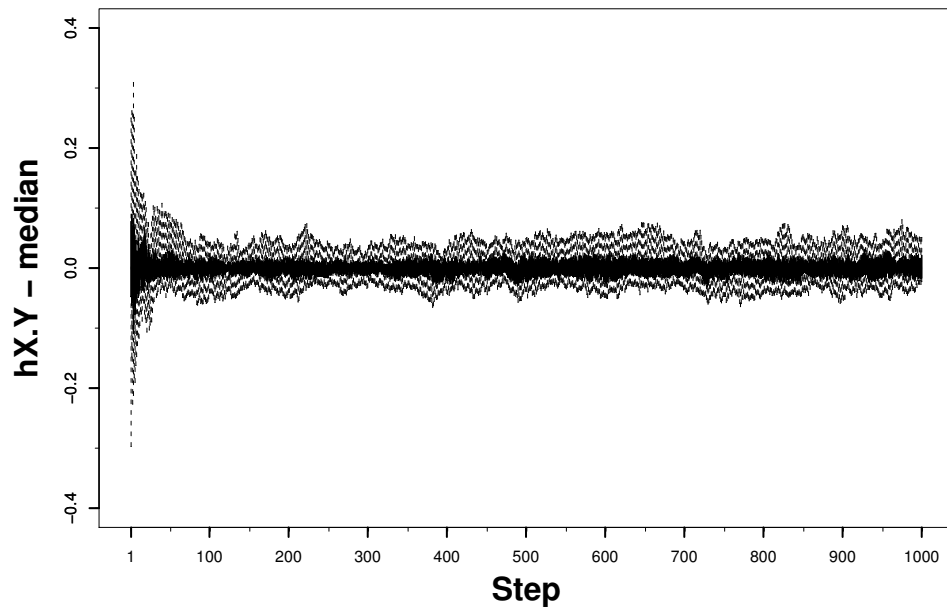
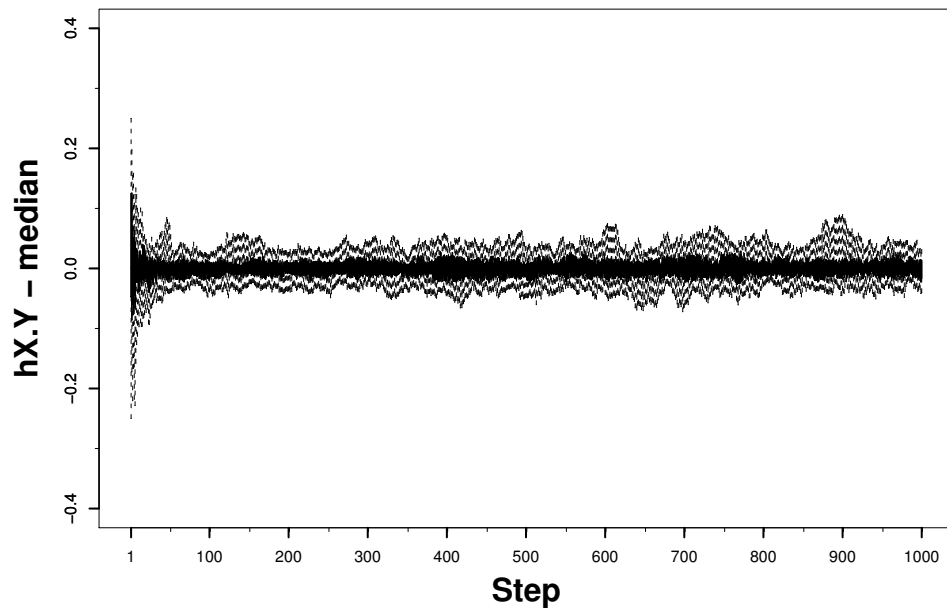


Figure A.43.:  $hX.Y$  boxplots (Condition CI-1b 10)

## CI-1b 11

Figure A.44.:  $hX.Y$  boxplots (Condition CI-1b 11)

## CI-1b 12

Figure A.45.:  $hX.Y$  boxplots (Condition CI-1b 12)

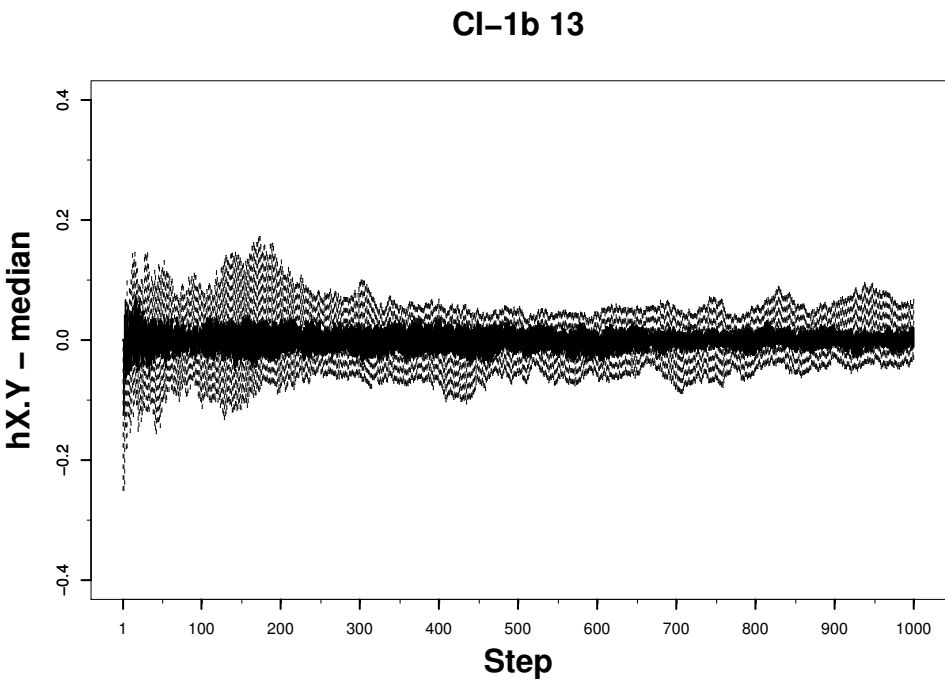


Figure A.46.:  $hX.Y$  boxplots (Condition CI-1b 13)

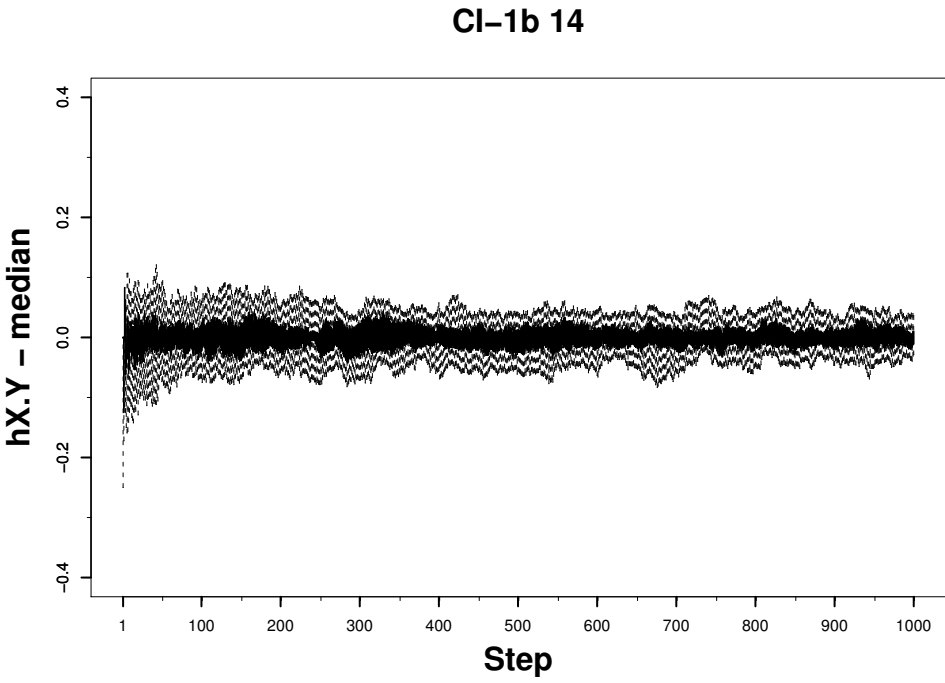
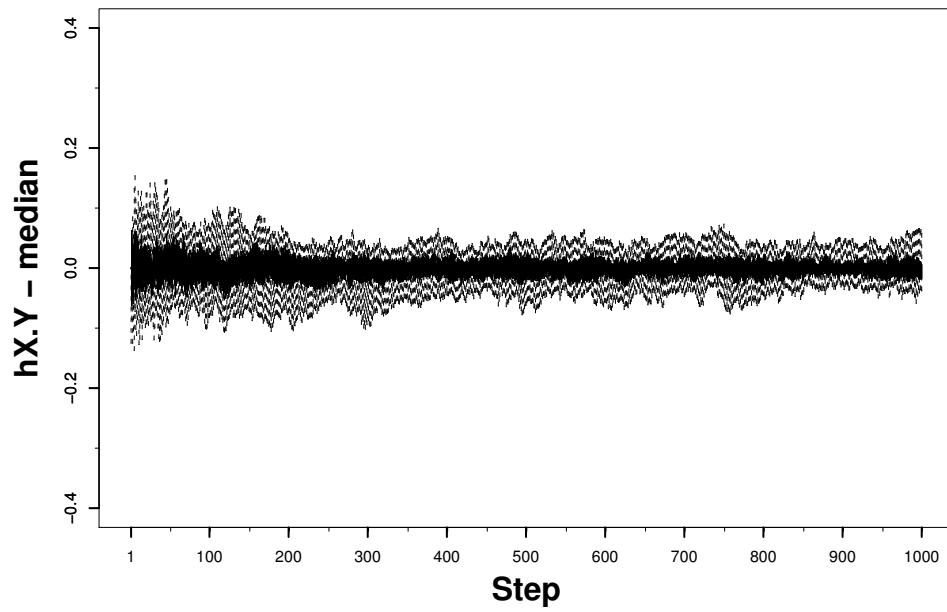


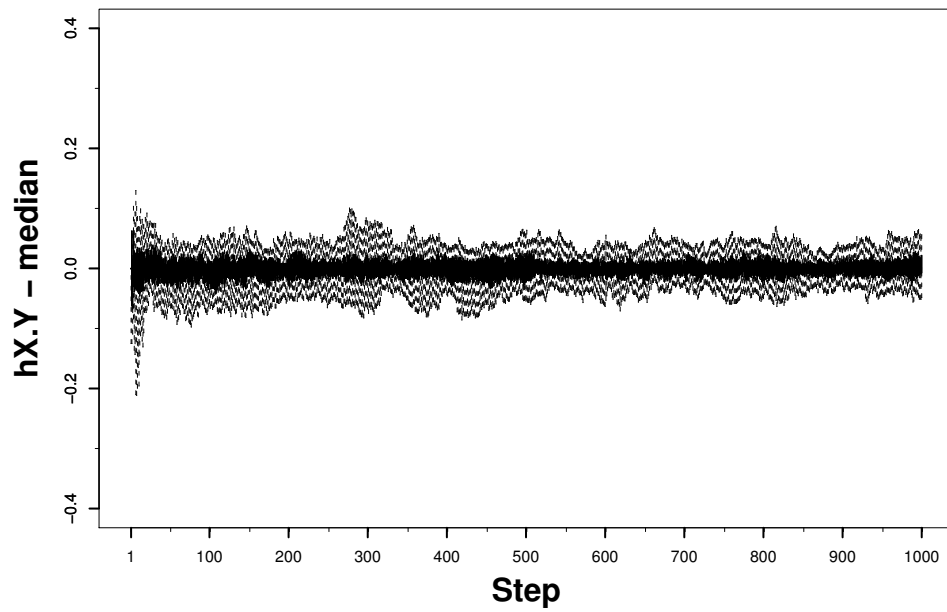
Figure A.47.:  $hX.Y$  boxplots (Condition CI-1b 14)



## CI-1b 15

Figure A.48.:  $hX.Y$  boxplots (Condition CI-1b 15)

## CI-1b 16

Figure A.49.:  $hX.Y$  boxplots (Condition CI-1b 16)

### Step 3: Correlating all runs per condition and dependent variable

All 30 runs per condition and dependent variable were correlated to decide whether the subsamples of runs are similar enough to be averaged per condition and dependent variable. This was achieved by correlating *hCall* and *step* as well as *hX.Y* and *step* per condition and testing these correlations. The results are summarized in the chart depicted in Figure A.50. As all correlations are positive and significantly larger than zero, the averaged process of each dependent variable per experimental condition will be used in subsequent analyses.

### Step 4: Linear modelling of averaged processes

For each dependent variable (*hCall*, *hX.Y*) in every condition (1 – 16), the 30 runs were averaged to one. The resulting 2 · 16 averaged processes were fit linearly, i.e. each outcome was regressed on the predictor *step*. The reason for this procedure is to obtain parameters which describe the development of each dependent variable over time. Simple linear models<sup>6</sup> contain two parameters, one describing the intercept and the other the gradient of the line (Field, 2005; Howell, 2007). Once they have been estimated, they can be used as secondary dependent variables to interpret the effects the independent variables have on the *development* of the original dependent variables. In other words, the level (intercept) and the inclination (gradient) of *hCall* and *hX.Y* are considered indicators of the these dependent variables' development. Their magnitude can be compared regarding the technical parameters *density*, *info-rate*, *movement*, and *domSize* (see Step 5 below). The charts in Figures A.51-A.52 summarize the results of Step 4.

---

<sup>6</sup> $y = ax + b$  whereas  $y = \text{outcome}$ ,  $a = \text{gradient}$ ,  $x = \text{predictor}$ ,  $b = \text{intercept}$ .

Exp. Cond	hCALL & Step			hX.Y & Step		
	<i>r</i>	<i>t</i>	<i>CI</i>	<i>r</i>	<i>t</i>	<i>CI</i>
01	.92	358.89*	>.92	.73	159.12*	>.72
02	.95	448.55*	>.95	.81	209.05*	>.81
03	.93	364.32*	>.92	.78	189.65*	>.78
04	.93	390.69*	>.93	.73	159.18*	>.72
05	.92	348.36*	>.92	.83	227.11*	>.83
06	.94	426.90*	>.94	.92	362.80*	>.92
07	.91	330.75*	>.91	.90	303.15*	>.89
08	.91	322.30*	>.93	.90	304.63*	>.89
09	.93	371.11*	>.94	.76	176.12*	>.76
10	.94	424.21*	>.92	.74	165.80*	>.74
11	.93	370.45*	>.86	.74	166.59*	>.74
12	.86	257.44*	>.94	.28	43.17*	>.26
13	.95	435.86*	>.92	.89	290.21*	>.89
14	.93	366.53*	>.92	.92	340.12*	>.91
15	.92	356.70*	>.92	.91	333.53*	>.91
16	.86	255.26*	>.86	.80	200.00*	>.80

Figure A.50.: Pearson's correlations (*r*) between hCALL & step and hX.Y & step. The *t* values and 95% confidence intervals (*CI*) are given for each *r* to demonstrate how much larger than zero they are. The correlations were rounded to two decimal places to adhere to standards of the American Psychological Association (APA). Only the rounded, lower boundaries of confidence intervals are shown. Significant *t* values ( $p < 0.000$ ) are indicated by \*. All  $df = 22528$ .

$$\widehat{hCALL} = a(step) + b$$

Exp. Cond.  CI-1b	Gradient $a$			Intercept $b$			Fit
	$a$	$SE$	$t$	$b$	$SE$	$t$	$R^2_{adj}$
01	<0.000	1.10e-06	215.0*	0.64	7.24e-04	889.2*	.98
02	<0.000	1.68e-06	149.5*	0.67	1.11e-03	600.9*	.97
03	<0.000	1.78e-06	122.2*	0.71	1.18e-03	604.7*	.95
04	<0.000	2.07e-06	98.9*	0.76	1.37e-03	554.1*	.93
05	<0.000	7.90e-07	158.9*	0.71	5.22e-04	1362.7*	.97
06	<0.000	9.80e-07	128.9*	0.74	6.48e-04	1137.2*	.96
07	<0.000	9.49e-07	123.1*	0.75	6.28e-04	1192.4*	.95
08	<0.000	1.22e-06	84.3*	0.78	8.07e-04	966.5*	.90
09	<0.000	1.60e-06	148.7*	0.68	1.06e-03	646.0*	.97
10	<0.000	2.28e-06	102.9*	0.73	1.51e-03	487.2*	.93
11	<0.000	2.16e-06	100.4*	0.75	1.43e-03	524.7*	.93
12	<0.000	2.68e-06	55.2*	0.84	1.77e-03	471.6*	.80
13	<0.000	9.48e-07	149.6*	0.73	6.27e-04	1158.4*	.97
14	<0.000	1.25e-06	100.4*	0.76	8.24e-04	927.2*	.93
15	<0.000	1.15e-06	100.1*	0.77	7.59e-04	1018.8*	.93
16	<0.000	1.37e-06	57.6*	0.82	9.02e-04	904.8*	.82

Figure A.51.: Results from linearly regressing  $hCALL$  on  $step$ . Note the differences between gradients are minimal. \* indicates all parameter values are significant ( $p < 0.000$ ).

$$\widehat{hX.Y} = a(step) + b$$

Exp. Cond.  CI-1b	Gradient a			Intercept b			Fit
	<i>a</i>	<i>SE</i>	<i>t</i>	<i>b</i>	<i>SE</i>	<i>t</i>	$R^2_{adj}$
01	<0.000	5.15e-07	200.7*	0.14	3.41e-04	421.9*	.98
02	<0.000	6.37e-07	180.2*	0.12	4.22e-04	289.0*	.98
03	<0.000	9.04e-07	129.6*	0.14	5.98e-04	235.0*	.96
04	<0.000	1.21e-06	77.1*	0.16	8.05e-04	192.82*	.89
05	<0.000	5.64e-07	360.8*	0.41	3.73e-04	1111.4*	.99
06	<0.000	1.35e-06	209.9*	0.39	8.93e-04	435.0*	.98
07	<0.000	1.82e-06	148.5*	0.42	1.20e-03	348.4*	.97
08	<0.000	2.72e-06	95.1*	0.47	1.80e-03	260.5*	.92
09	<0.000	4.88e-07	232.7*	0.15	3.23e-04	479.0*	.99
10	<0.000	1.15e-06	92.9*	0.16	7.38e-04	218.8*	.92
11	<0.000	1.45e-06	78.0*	0.17	9.60e-04	177.1*	.89
12	<0.000	2.26e-06	14.1*	0.21	1.50e-03	143.4*	.21
13	<0.000	8.08e-07	320.1*	0.43	5.35e-04	805.6*	.99
14	<0.000	2.29e-06	125.9*	0.45	1.52e-03	297.1*	.95
15	<0.000	2.51e-06	109.9*	0.47	1.66e-03	284.6*	.94
16	<0.000	3.65e-06	51.4*	0.57	2.42e-03	235.1*	.78

Figure A.52.: Results from linearly regressing  $hX.Y$  on  $step$ . Note a) the differences between gradients are minimal, and b) experimental condition 12 has a significant, yet comparably poor fit. \* indicates all parameter values are significant ( $p < 0.000$ ).

### Step 5: Forest plots of each dependent variable's linear parameters

Forest plots (Lewis & Clarke, 2001; McGill et al., 1978) were created to depict the amount of variation between experimental conditions for the estimated linear parameters. For each experimental condition, a square centred on the the point estimate is shown. A horizontal line runs through each square representing a 95% confidence interval. These plots allow the reader to view the results of the linear modelling of all experimental conditions (Step 4) at a glance.

Forest plots were not generated for the gradients estimated for  $hCAI$  and  $hX.Y$ , because they are negligibly small. For an overview of their values, refer to the charts in Figures A.51-A.52. In other words, the technical variables *density*, *info-rate*, *movement* and *domSize* do not appear to have an effect on the dependent variables' development over time.

The intercepts, however, do vary between experimental conditions for both dependent variables. See Figures A.53-A.54 for the results. For  $hCAI$ , there appears to be three trends the data. Firstly, there is a general positive linear trend in  $hCAI$ 's intercept as the values for the technical variables increase. That is, the higher these values are, the higher the estimated intercept. Secondly, within the positive linear trend there appears to be a "middle section" in which little variation between estimated intercepts occurs (see conditions 13, 10, 7, 4 and 15 in Figure A.53). Thirdly, apart from the middle section, the intercepts do seem to also vary according to the technical variable *domSize* (see conditions 1, 5, 2, 6, 9, 14, 3, 8 and 11 in the same figure). This effect is easy to explain given the structure of the equation used to calculate  $hCAI$  (see Equation 6.5 in Section 6.6.1). The larger the number of categories  $k$  is, the greater the value of  $hCAI$  will be. The number of categories in this experiment equals *domSize*, i.e. either  $k = 64$  or  $k = 512$ .

For  $hX.Y$ , the intercepts appear to differ according to the value of *domSize*. When *domSize* is set to 64, the intercept  $b$  varies from approximately 0.10 – 0.20. When it is set to 512, the intercept varies from approximately 0.38 – 0.56. The higher *domSize* is, the larger the intercept of  $hX.Y$  appears to be. This difference can be traced back to mathematical properties of the equation used to define and calculate  $hX.Y$  (see Equation 6.7 in Section 6.6.2). The size of  $h_Y$  and  $h_{XY}$  in that equation depends on the number of categories ( $c$ ) the variable  $Y$  has. The more categories there are, the larger both values will be. Due to the values used for *domSize*,  $c$  will either be 64 or 512. At the same time,  $h_X$  has a constant number of categories ( $r = 4$ ) in this experiment, because all four creator types were used in the simulations. Therefore, the maximal value for  $h_X$  (the denominator) will always be the same, no matter how many categories  $Y$  has. Consequentially in this experiment, the value for  $hX.Y$  increases with increasing values for the number of categories used to define  $Y$ . This explains the clear difference between the estimated intercepts displayed in Figure A.54.

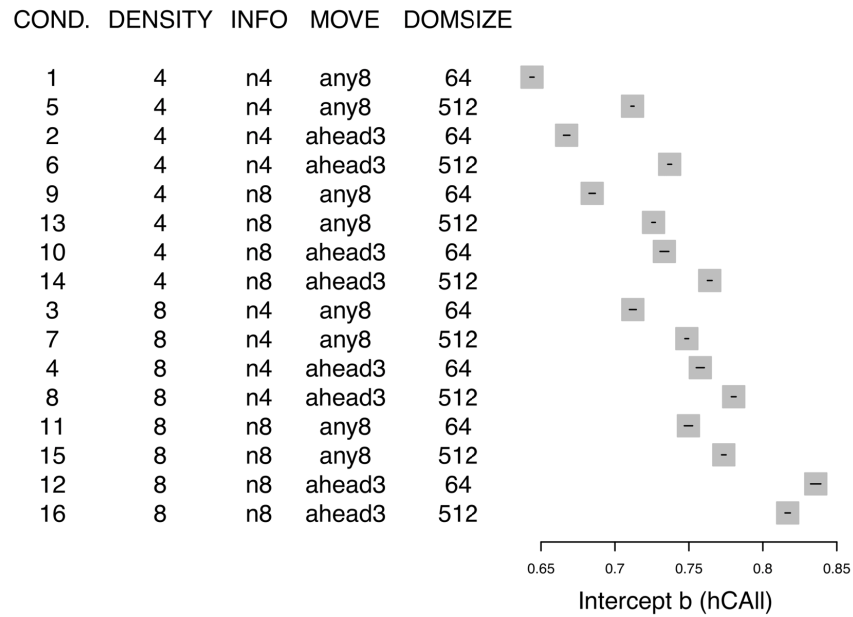


Figure A.53.: Forest plot of estimated intercepts for  $hCALL$ . Note: 95% confidence intervals are included as horizontal black lines, but they are tiny as their variation starts in the third decimal place.

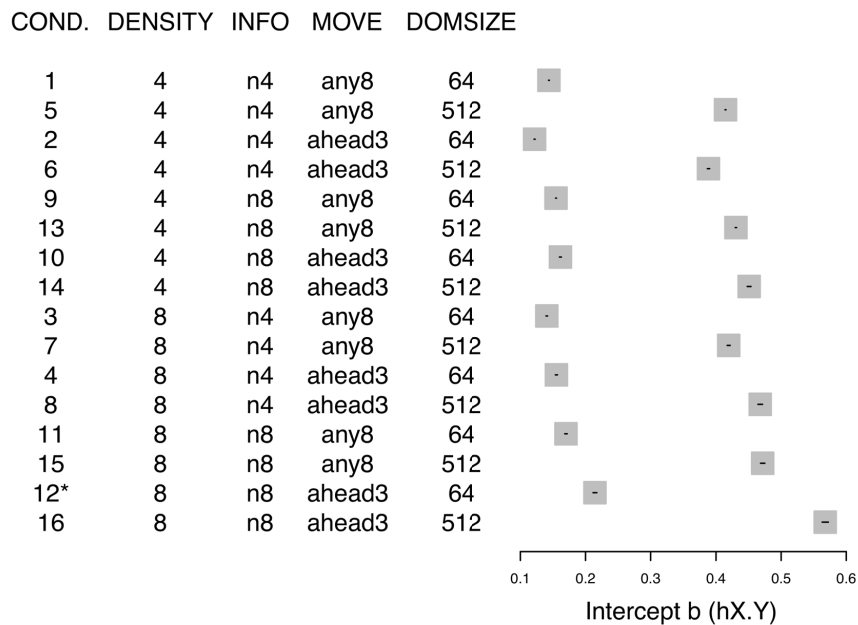


Figure A.54.: Forest plot of estimated intercepts for  $hX.Y$ . Note: 95% confidence intervals are included as horizontal black lines, but they are tiny as their variation starts in the third decimal place.

### A.2.4. Discussion

In returning to the research questions posed in Section A.2.1, the following answers are summarised:

- The technical independent variables *density*, *info-rate*, *movement* and *domSize* do not affect the development of the dependent variables *hCAI* and *hX.Y* for the tested, mid-range combination of substantial independent variables. This was distinguished by observing the gradients from estimated simple linear models of both dependent variables for all experimental conditions.
  - Simple linear modelling of the dependent variables *hCAI* and *hX.Y* for all experimental conditions did reveal differences in level (intercepts) depending on the values of the technical independent variables. Particularly, the values used for the independent variable *domSize* are associated with clear differences in intercepts for *hX.Y* and, for some conditions, with similarly distinct differences for *hCAI*.
  - It is noted that the aforementioned differences can be traced back to properties of the equations used to calculate *hCAI* and *hX.Y*.
  - For *hCAI*, it appears that lower values of the technical independent variables correspond to lower intercepts. In the long run (over many steps), this implies that lower values of these parameters offer more "room" for development over time, because the maximal value for *hCAI* is fixed (see Section 6.6.1 for an explanation).
- In choosing values for the technical independent variables for subsequent experiments, a twofold strategy is selected:
  - The technical independent variable *domSize* will be "carried over" and varied in upcoming experiments. This will be done to compare the magnitude of dependent variables based on *domSize*'s value.
  - All other technical independent variables will be set to levels which correspond to lower levels of the dependent variables in order to allow for a larger range in which the latter can vary over time.



## A.3 Experiment CI-2a

This section contains the experimental design and results of Experiment CI-2a. The experiment's purpose is to explore how stably CRESY-I's dependent variables behave given extreme values for substantial independent variables.

### A.3.1. Research questions

The research questions to be answered in this experiment are:

- How many runs per experimental condition should be used in Experiment CI-2b?
- How many steps per run should be used in Experiment CI-2b?

### A.3.2. Experimental design

Experiment CI-2a has a total of six conditions (see Figure A.55). Two parameter sets were varied: 1) number of runs (30, 60, 120) and 2) settings for the substantial independent variables (low, high). The exact values of the substantial variables (*predefine-r/g/b*, *creator ratio*, *imagination*, *domSize*) in the low and high conditions are listed in Figure A.55.

The low and high values of the substantial independent variable *imagination* were chosen based on the following reasoning: Originally, the low value was set to 0.00. After observing several test simulation runs, however, the dependent variables *hCall* and *hX.Y* did not increase or change if this value was set *and* the *predefine-r/-g/-b* sliders were set to low values such as 1, i.e. if the color environment possessed minimal informational diversity. At *imagination* = 0.00, therefore, not enough variance (information) in dependent variables was produced, rendering the value ineffective for experimental conditions<sup>7</sup>. The reason for the dependent variables' development when *imagination* = 0.00 can be inferred from Equations 6.5 and 6.7 in Section 6.6 and from CRESY-I's process *make-patchwork* (Section 6.3.3). If there is absolutely no chance (*imagination* = 0.00) that any new color value will be produced in an informationally homogeneous world (*predefine-r/-g/-b* = 1), no new information will emerge (detected in growth and changes in *hCall*) and following, potential behavioural differences between creator types will not occur (detected in growth and changes in *hX.Y*). For these reasons, the *low* value for *imagination* was set instead to 0.001. The value is > 0, so it allows the dependent variables to change. However, it is still small enough to be considered a "low" value in an experimental condition in which independent variables are set to reflect a minimum<sup>8</sup>. The "high" value for *imagination* was originally set to 0.12, a mid-range value on a scale from 0.00 – 0.25 (see

<sup>7</sup>Basically, the dependent variables did not change, so there was no need to simulate their behaviour.

<sup>8</sup>Note that in a simulation model in which independent variables have theoretical ranges, such exploration is necessary to derive qualitatively different variable ranges in terms of "high", "low", etc.

submodel *make-patchwork* in Section 6.3.3). It is the same value used in the previous Experiments CI-1a & CI-1b. During those investigations, however, the value's influence on creators' behaviour appeared to be too large, i.e. the chance of producing new color values was so great that creator types affected by this parameter (*CI*, *C2*, *C3*) could not be discriminated. In other words, they did not differ in their contributions to informational diversity (*hC1*, *hC2*, *hC3*; see Section 6.6.1), which lead to a barely noticeable increase in the dependent variable *hX.Y*. For this reason, a "lower" high value of *imagination* = 0.050 was chosen after observing test simulation runs.

All technical independent variables were held constant in this experiment: In each condition, there were four creators in a 21x21 torus (*density*). The *info-rate* was set to *n4*, meaning creators collected information about patchworks from four neighbouring patches (von Neumann neighbourhood) every step. Creators moved in the world based on the *any8* strategy, meaning they could move to any of the eight neighbouring patches (Moore neighbourhood), as long as they were empty. Refer to Experiments CI-1a and CI-1b for more on determining values of technical independent variables (Sections A.1 - A.2). The following dependent variables were recorded at every step of every run: *hX.Y*, *hCAll*, *hCx*, *hC1*, *hC2*, *hC3*.

number of runs					
30		60		120	
substantial independent variables					
Low	High	Low	High	Low	High
predefine-r/g/b					
1	256	1	256	1	256
creator ratio					
3:0:0:1	1:0:0:3	3:0:0:1	1:0:0:3	3:0:0:1	1:0:0:3
imagination					
0.001	0.050	0.001	0.050	0.001	0.050
domSize					
64	512	64	512	64	512
Experimental Condition CI-2a					
30 Low	30 High	60 Low	60 High	120 Low	120 High

Figure A.55.: Experimental design of Experiment CI-2a. The bottom two rows include the names of conditions (e.g. CI-2a 30 Low, ..., CI-2a 120 High).

### **A.3.3. Analyses**

Each experimental condition produced an output file which was subsequently analysed with R (Version 2.11.1). The following steps were taken to analyse the simulation's output per experimental condition:

1. Moving averages of the dependent variables ( $hX.Y$  and  $hCAII$ ) were calculated for each condition.
2. Scatterplots of  $hX.Y$  and  $hCAII$  were produced separately for each experimental condition. Each dependent variable's moving average line was added to its scatterplot.

#### **Steps 1 & 2: Moving averages and scatterplots of $hX.Y$ & $hCAII$**

The moving averages were calculated according to the procedure described in Section A.1.3. See Figures A.56 – A.67 for scatterplots and corresponding moving average lines of the dependent variables  $hX.Y$  and  $hCAII$  for all conditions of Experiment CI-2a.

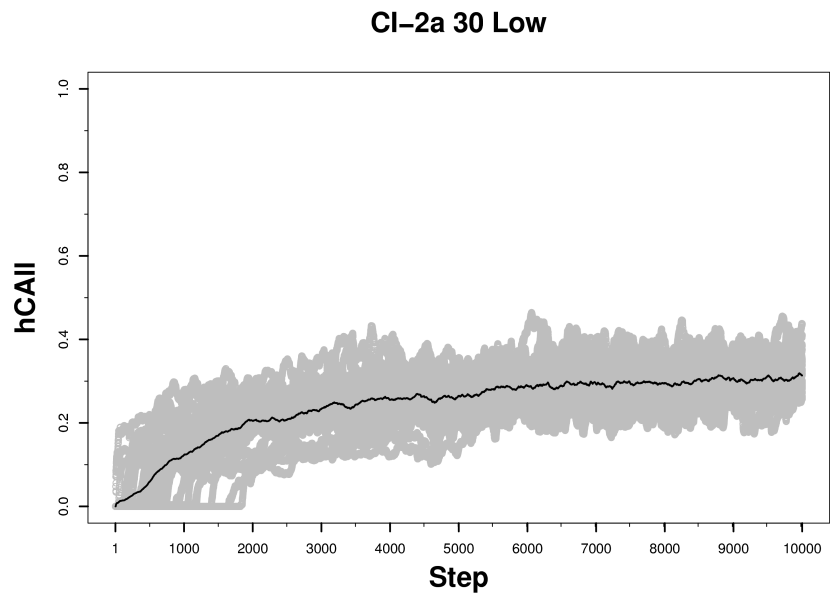


Figure A.56.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a 30 Low)

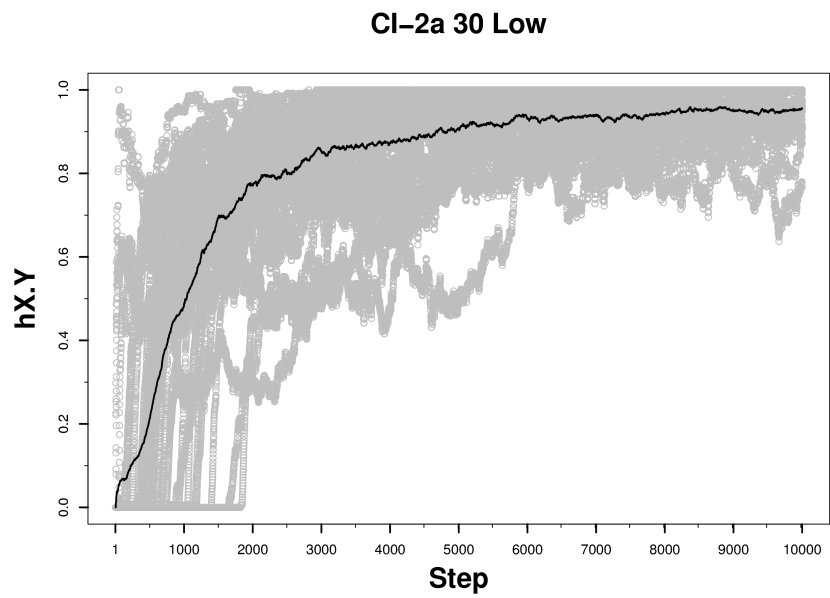


Figure A.57.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a 30 Low)

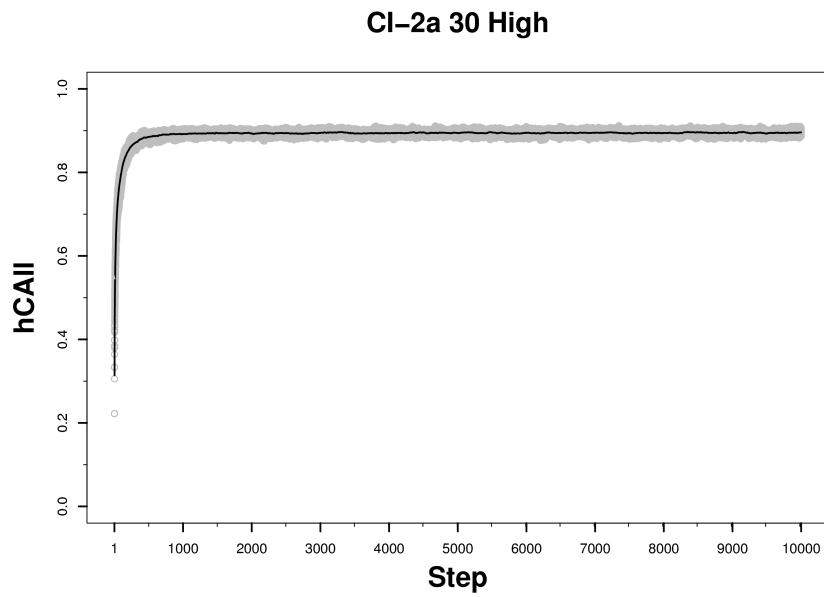


Figure A.58.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a 30 High)

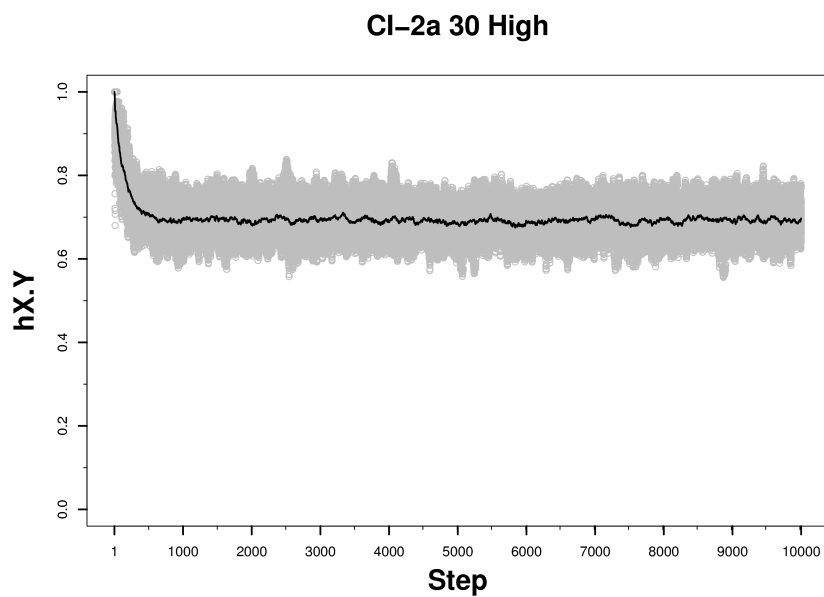


Figure A.59.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a 30 High)

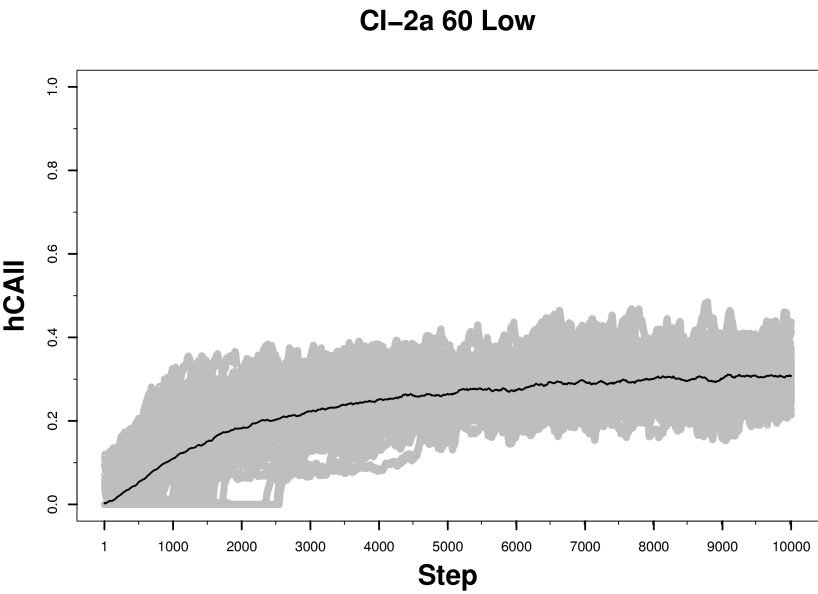


Figure A.60.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a 60 Low)

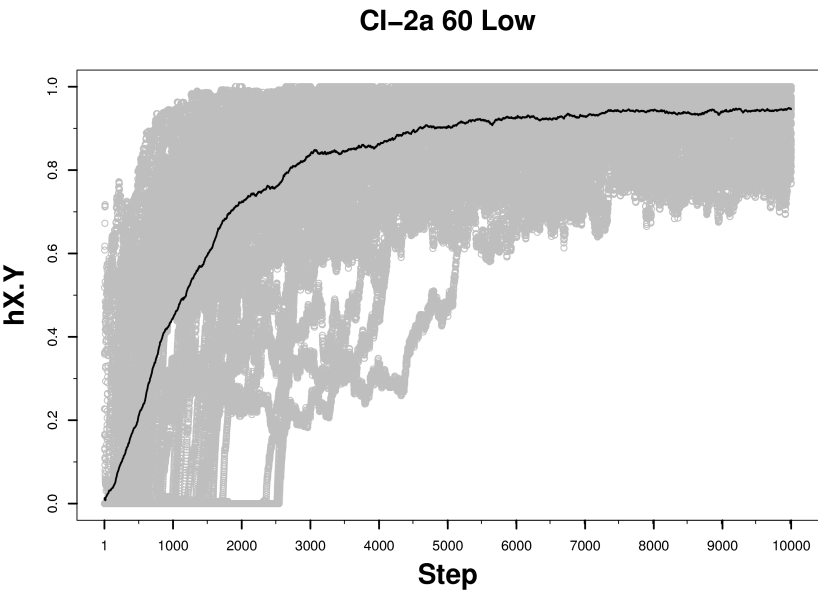


Figure A.61.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a 60 Low)

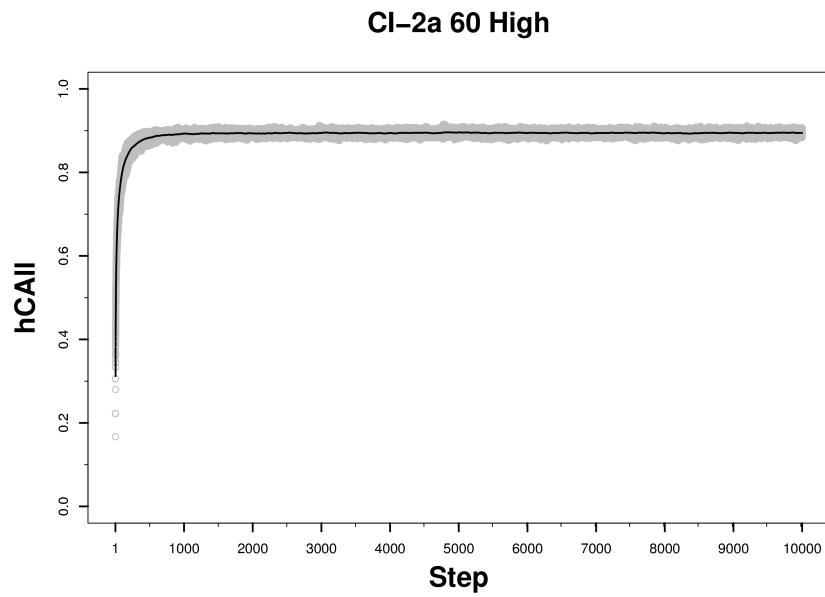


Figure A.62.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a 60 High)

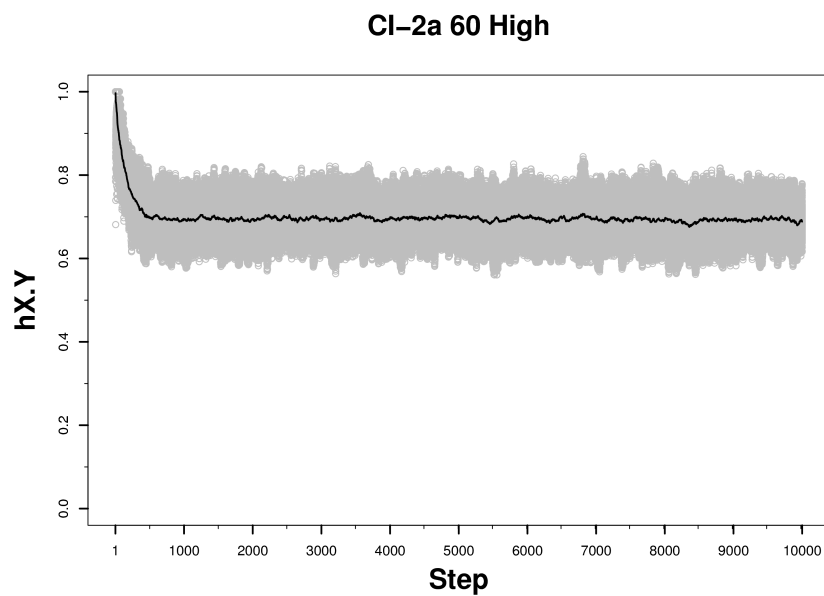


Figure A.63.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a 60 High)

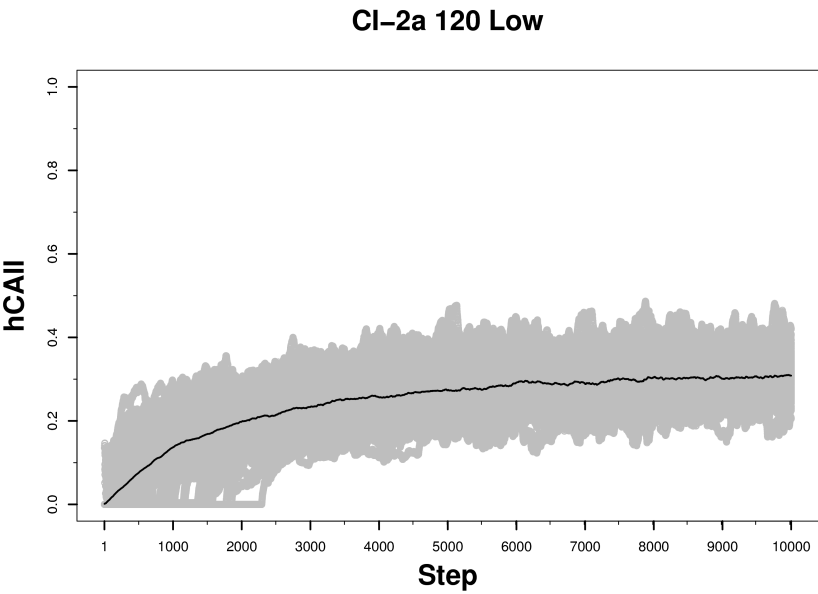


Figure A.64.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a 120 Low)

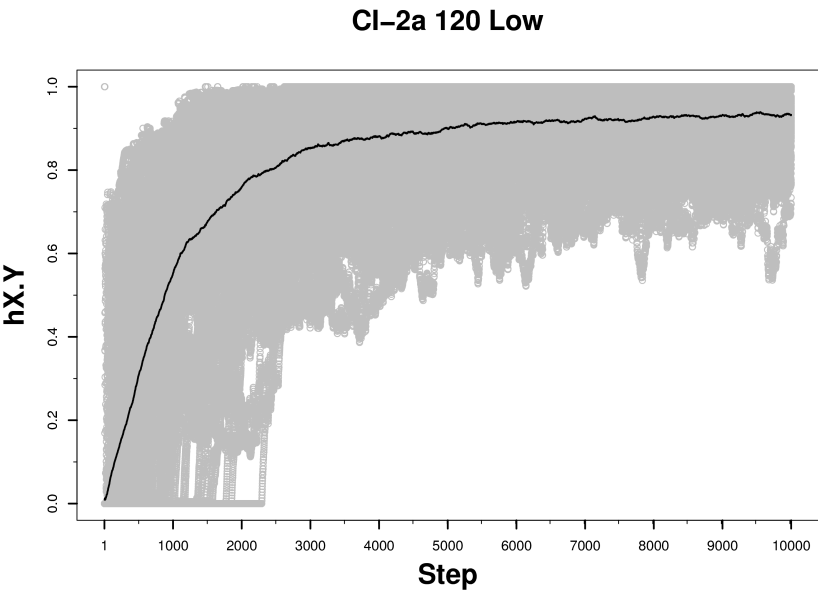


Figure A.65.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a 120 Low)



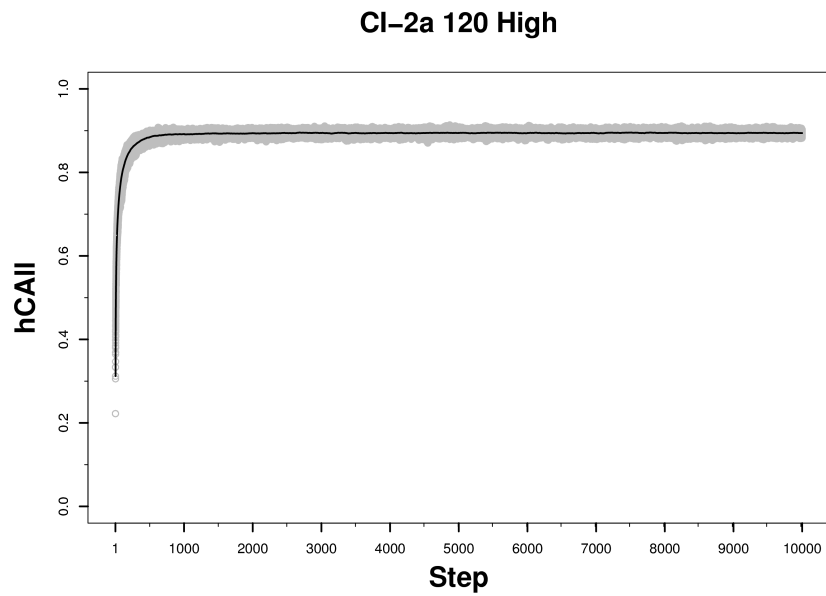


Figure A.66.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a 120 High)

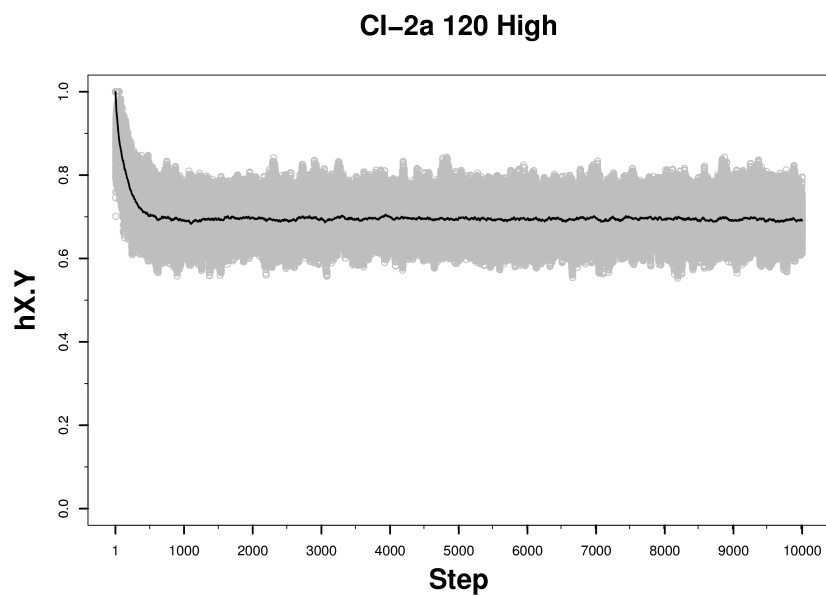


Figure A.67.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a 120 High)

### A.3.4. Discussion

The following observations were made after studying Figures A.56 – A.67:

- The distributions of both dependent variables ( $hCAI$  and  $hX.Y$ ) do not change with sample size, i.e. number of simulation runs. This implies 30 runs compared with 60 or 120 suffice to investigate them.
- Both dependent variables reach a steady state at 6000 steps at the latest. This implies more steps are not necessary to investigate them, at least on the basis of the present data.
- The level of steady dependent variables differs according to the high and low settings of substantial independent variables.
- The differences in level are not the same for both dependent variables. They are larger for  $hCAI$ .
- The dependent variables' variances are larger in the high conditions compared with the low conditions.
- Due to the experimental design, it is not possible to decipher how the independent variable *domSize* affects the dependent variables.

According to these observations, the next Experiment CI-2b will have **30 runs** with **6000 steps** each. The independent variable *domSize* was originally classified as a technical independent variable (see Section 6.5 in Chapter 6 and Experiments CI-1a & CI-1b in Sections A.1 - A.2 of the Appendix). After studying the results of Experiment CI-1b, *domSize* was reclassified as a (potential) substantial independent variable and varied in this experiment. Due to the experimental design (Figure A.55), however, it is not possible to decipher how *domSize* affects the dependent variables  $hCAI$  and  $hX.Y$ . Therefore, a supplementary experiment was designed to explore this circumstance.

## A.4 Supplementary Experiment CI-2a-SupplExp

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This section contains the experimental design and results of the supplementary experiment (CI-2a-SupplExp) conducted after studying the results of Experiment CI-2a (Section A.3). Its purpose is to explore how the independent variable *domSize* affects the dependent variables when all technical independent variables are held constant (see Experiments CI-1a & CI-1b in Sections A.1 and A.2) and the substantial independent variables are varied in high and low conditions (see Experiment CI-2a in Section A.3).

### A.4.1. Research question

The research question to be answered in this experiment is:

- Does *domSize* affect the dependent variables *hCall* and *hX.Y*?

### A.4.2. Experimental design

Experiment CI-2a-SupplExp has a total of four conditions (Figure A.68). Two parameter sets were varied: a) *domSize* (64, 512) and b) settings of the substantial independent variables (low, high). The exact values of the substantial variables (*predefine-r/g/b*, *creator ratio*, *imagination*) in the low and high conditions are listed in Figure A.68. The values of the technical independent variables are the same as in Experiment CI-2a (Section A.3). A total of 30 runs with 10,000 steps each were conducted per experimental condition (see Section A.3.4 for a discussion on this issue). The dependent variables *hCall* and *hX.Y* were collected at each step.

domSize			
64		512	
substantial independent variables			
Low	High	Low	High
predefine-r/g/b			
1	256	1	256
creator ratio			
3:0:0:1	1:0:0:3	3:0:0:1	1:0:0:3
imagination			
0.001	0.050	0.001	0.050
Experimental Condition CI-2a-SupplExp			
64 Low	64 High	512 Low	512 High

Figure A.68.: Experimental design for Supplementary Experiment CI-2a-SupplExp. The bottom two rows include the names of conditions (e.g. CI-2a-SupplExp 64 Low, ..., CI-2a-SupplExp 512 High). The conditions CI-2a-SupplExp 64 Low and CI-2a-SupplExp 512 High (highlighted in green) correspond to the high and low conditions used in Experiment CI-2a (see Figure A.55).

### A.4.3. Analyses

Each experimental condition produced an output file which was subsequently analysed with R (Version 2.11.1). The following steps were taken to analyse the simulation's output per experimental condition:

1. Moving averages of the dependent variables (*hCall*, *hX.Y*) were calculated separately for each condition.
2. Scatterplots of *hX.Y* and *hCall* were produced separately for each experimental condition. Each dependent variable's moving average line was added to its scatterplot. See Figures A.69 - A.76 for the scatterplots and moving averages mentioned in these first two steps.
3. Two-way independent ANOVAs were calculated with the factors *domSize* and *sub* (substantial independent variable settings) separately for each dependent variable (*hCall* and *hX.Y*).

#### Step 3: Two-way independent ANOVAs

The factors *domSize* (64, 512) and *sub* (substantial independent variables; high, low) were used in independent ANOVAs to test their individual and combined effects on the dependent variables *hCall* and *hX.Y*. Both dependent variables were altered for this step: Originally each experimental condition produced 30 runs with a total of 10,000 steps each. After studying the scatterplots and moving average lines in Figures A.69 - A.76, the last 5000 steps of each run were averaged to one value. This lead to a total of 30 single values, or averages, per experimental condition (cell) in the respective ANOVA. This kind of data reduction was conducted for both dependent variables *hCall* and *hX.Y*. See Tables A.1 and A.2 for an overview of the ANOVA results. All factors or interactions with at least medium effect sizes<sup>9</sup> were considered strong enough to interpret.

Table A.1.: Two-Way Independent Analysis of Variance for *hCall*

Source	df	F	$\omega^2$	p
domSize (d)	1	529.98***	.01	<2.2e-16
sub (s)	1	40094.72***	.98	<2.2e-16
d x s	1	7.09**	<.00	.01
error	116	(0.0003) <sup>1</sup>		

\*\*  $p < .001$ .

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

<sup>9</sup>The measure  $\omega^2$  was calculated. It's square root is equal to Pearson's  $r$ , and magnitudes have been set for the latter:  $r = .10$  (small),  $r = .30$  (medium),  $r = .50$  (large; Field, 2005, p. 32).

Table A.2.: Two-Way Independent Analysis of Variance for  $hX.Y$

Source	df	F	$\omega^2$	p
domSize (d)	1	1365.50***	.20	< 2.2e-16
sub (s)	1	4258.00***	.64	< 2.2e-16
d x s	1	926.70***	.14	< 2.2e-16
error	116	(0.0019) <sup>1</sup>		

\*\*\*  $p < .0001$ .

<sup>1</sup> The value in parentheses is the mean square error.

#### A.4.4. Discussion

The following observations were made after studying Figures A.69 - A.78 and the ANOVA tables (A.1 & A.2):

##### hCAII

- The distribution of  $hCAII$  differs visibly according to the low and high settings of substantial independent variables (Figures A.69, A.71, A.73, A.75).
- The visible differences between  $hCAII$ 's steady-state levels are larger when comparing the values of the substantial independent variables (high, low) than when comparing the values of  $domSize$  (64, 512).
- The effect sizes ( $\omega^2$ ) calculated in the ANOVA (Table A.1) support these first two observations. Despite the fact that all factors ( $domSize$ ,  $sub$ ) and their interaction are significant, the main factor  $sub$  explains 98% of the variance in  $hCAII$  and has a large effect size.

In summary, neither  $domSize$  nor its interaction with  $sub$  affect the dependent variable  $hCAII$  systematically (see Table A.1 and Figures A.77 - A.78). A measure of relative information,  $hCAII$ 's magnitude is just slightly larger when  $domSize = 64$  compared with  $domSize = 512$ . This is mathematically due to the fact that 64 categories are more quickly "filled", or exhausted, than 512. The difference, however, is negligible. More importantly and as intended with CRESY-I, the substantial independent variables affect  $hCAII$  in a systematic manner.  $hCAII$ 's level visibly and statistically differs according to their values, and the variance in both subsamples do not overlap (Figure A.78).

##### hX.Y

- The distribution of  $hX.Y$  differs visibly according to the low and high settings of substantial independent variables (Figures A.70, A.72, A.74, A.76).
- $hX.Y$ 's steady-state level in condition *CI-2a-SupplExp 64 High* (Figure A.72) differs visibly compared with its level in the other three conditions (Figures A.70, A.74, A.76).

- The effect sizes ( $\omega^2$ ) calculated in the ANOVA (Table A.2) support these first two observations, and the significance levels indicate hybrid interaction between the factors *domSize* and *sub*. As such, the main effect of *sub* can be globally interpreted, but not without additionally and firstly taking the interaction between *domSize* and *sub* into consideration.

The statistically significant interaction between *domSize* and *sub* has a medium effect size ( $\sqrt{\omega^2} = .37$ ). After studying the interaction and mean plots (Figures A.77 - A.78), the following observation can be made: In the *sub* level low, the differences between *hX.Y*'s levels when *domSize* is varied are barely noticeable. This could be an initial basis for *sub*'s global effect on *hX.Y* ( $\sqrt{\omega^2} = .80$ ). On the other hand, in the *sub* level high, there are distinct differences in *hX.Y*'s levels depending on *domSize*'s value (64 or 512). Particularly, *hX.Y* has a comparably low level in condition *64 High* (Figure A.72). Why do the high values of substantial independent variables (*sub* = *high*) combined with a domain of 64 categories lead to such a low value of *hX.Y*? That is, why is it so difficult to discriminate creator types in this condition? The condition encompassed three *C3* affected by a high *imagination* value and one *Cx* all producing patchworks which could only be classified with 64 different categories. The group of creators were, therefore, extremely divergent in their behaviour, and they were embedded in a highly diverse environment (*predefine-r/-g/-b* = 256). On the other hand, the observer (domain) was not as complex. It could assess the abundance of informational diversity only with relatively few categories (Figure A.72). This makes it hard to discriminate the two creator types from each other, especially when the less divergent type *Cx* is embedded in a diverse world: *Cx* does behave in a very predictable and stable manner, but when the environment is unstable – in CRESY-I this means colourful – *Cx* adapts its behaviour to the environment by producing many more colours than expectations based only on its personal mechanisms would allow. Assessing *Cx*'s and *C3*'s patchworks with only 64 categories is, in a highly diverse environment, too coarse to draw distinctions between these two behavioural types. The observer / domain requires a certain amount of internal complexity to recognize external diversity, i.e. behavioural differences in creator types as reflected by the measure *hX.Y*.

**Concluding remarks** *domSize* affects the dependent variables in different ways. Firstly, its effect on *hCAII* is negligible. Additionally, the fact that the substantial independent variables have a large effect on *hCAII* has two positive implications: 1) The substantial independent variables seem to work, i.e. they produce differences in this dependent variable. 2) Given the first implication, this is an initial sign of their validity.

Secondly, *domSize* does exert an effect on *hX.Y* depending on the values of the substantial independent variables. In particular, if *domSize* is small *and* the other variables are set to produce high diversity, creator types cannot be discriminated. These results have at least two implications: 1) CRESY-I does not seem to sustainably "work" with a small *domSize*, because the creator types should be discriminated by

the model in any other independent variable combination. 2) For further experiments, a larger *domSize* should be used to make sure creator types can be "recognized". Therefore, *domSize* = 512 will be used in Experiment CI-2b.

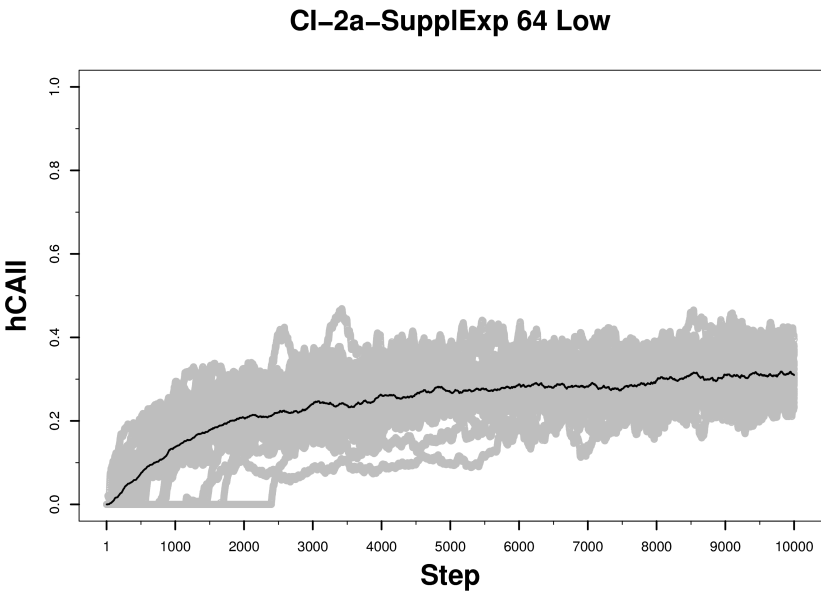


Figure A.69.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a-SupplExp 64 Low)

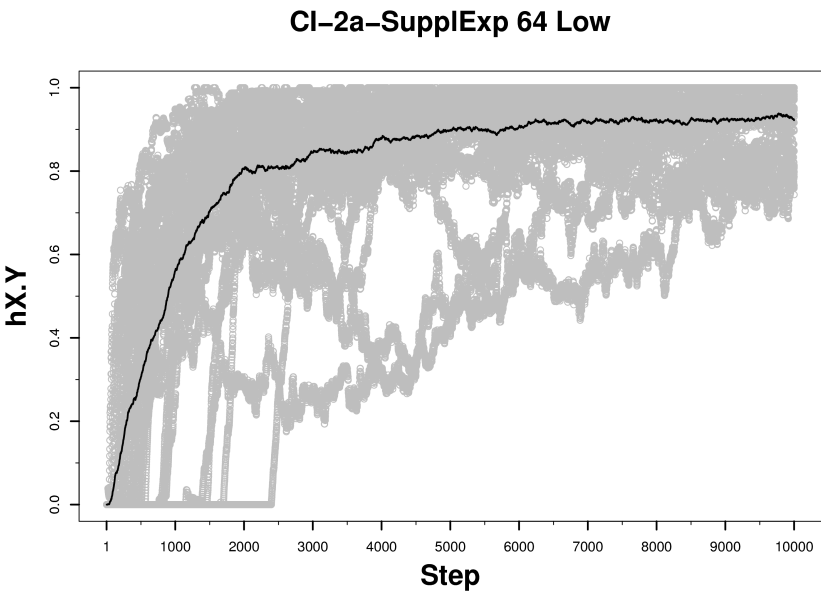


Figure A.70.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a-SupplExp 64 Low)



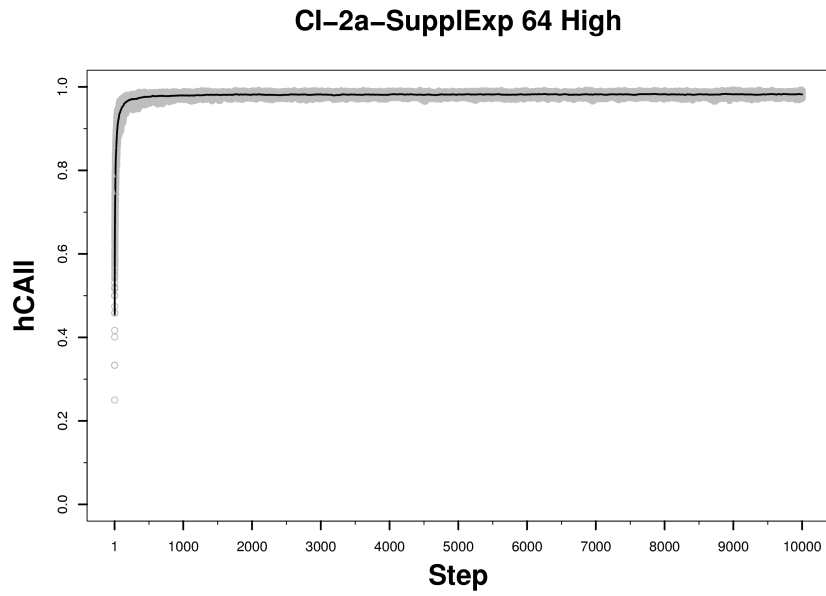


Figure A.71.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a-SupplExp 64 High)

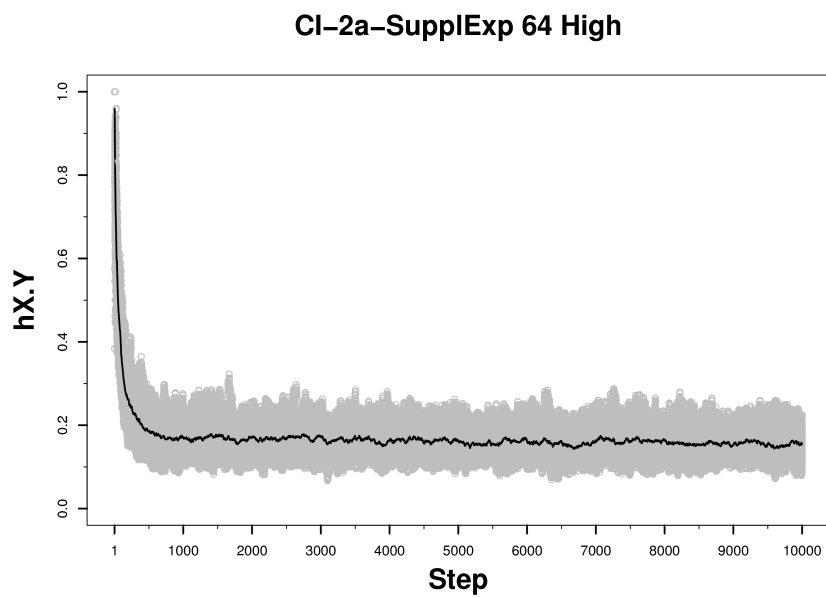


Figure A.72.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a-SupplExp 64 High)

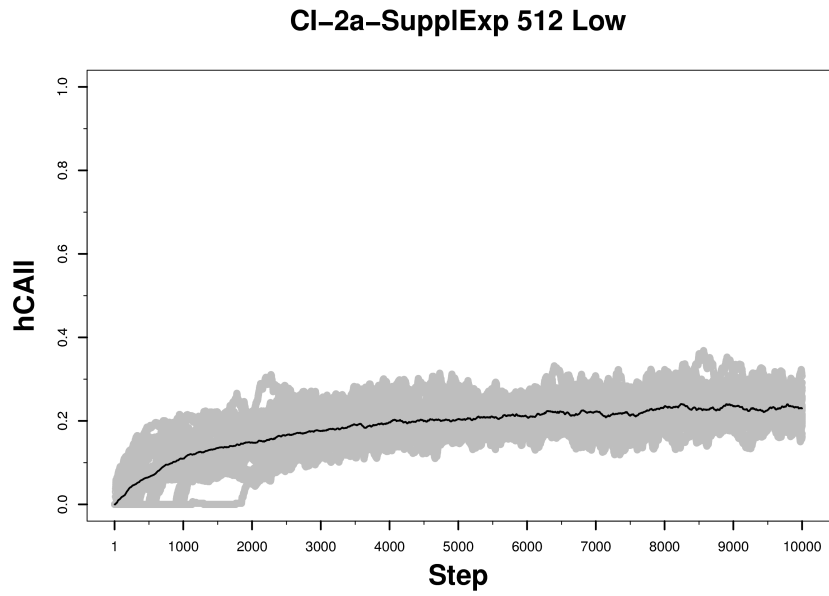


Figure A.73.: Scatterplot of  $hCAII$  including moving averages (Condition CI-2a-SupplExp 512 Low)

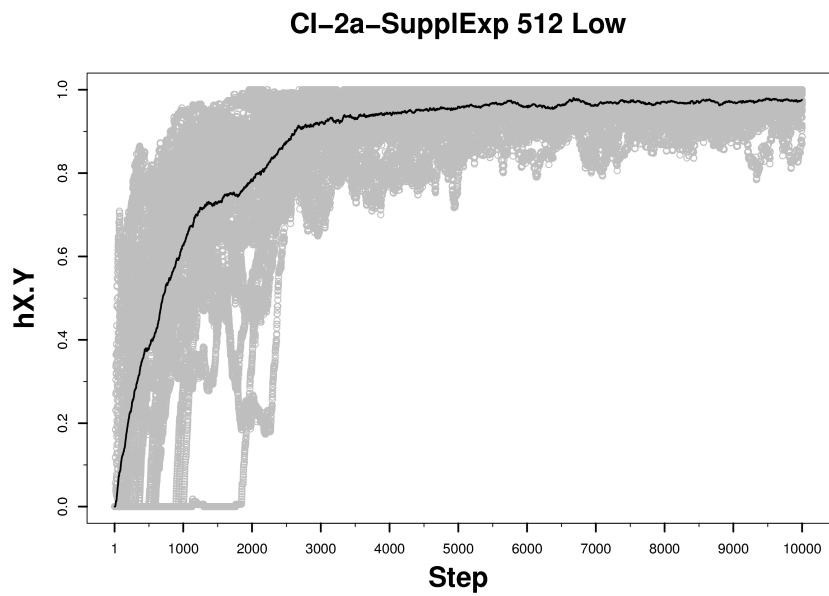


Figure A.74.: Scatterplot of  $hX.Y$  including moving averages (Condition CI-2a-SupplExp 512 Low)

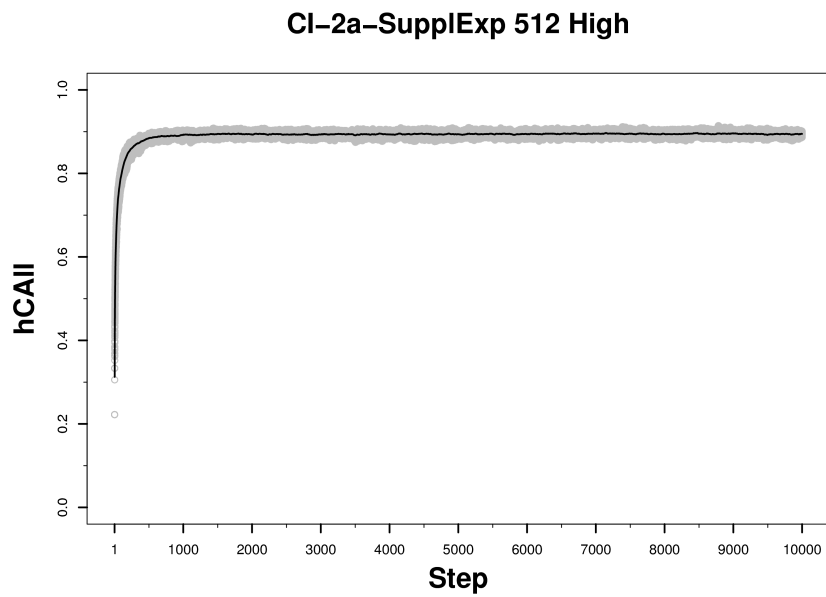


Figure A.75.: Scatterplot of *hCAII* including moving averages (Condition *CI-2a-SupplExp 512 High*)

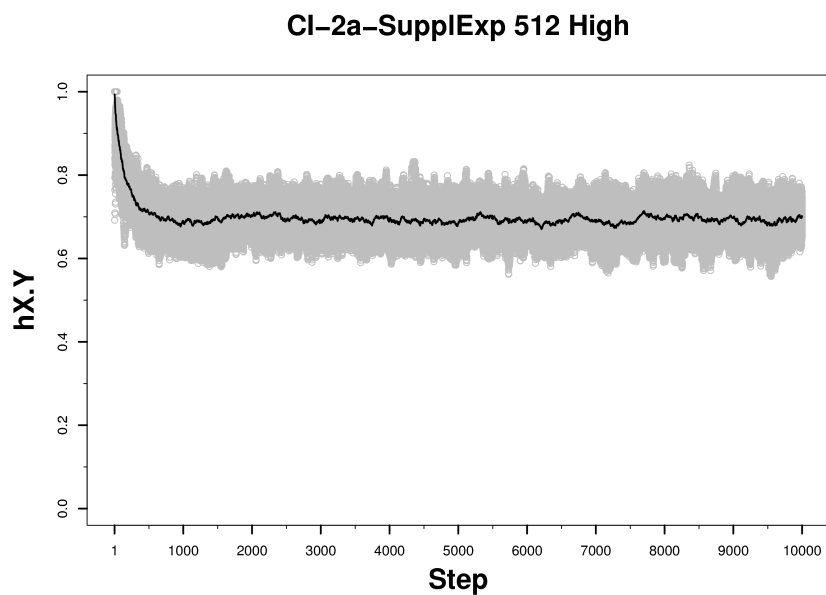


Figure A.76.: Scatterplot of *hX.Y* including moving averages (Condition *CI-2a-SupplExp 512 High*)

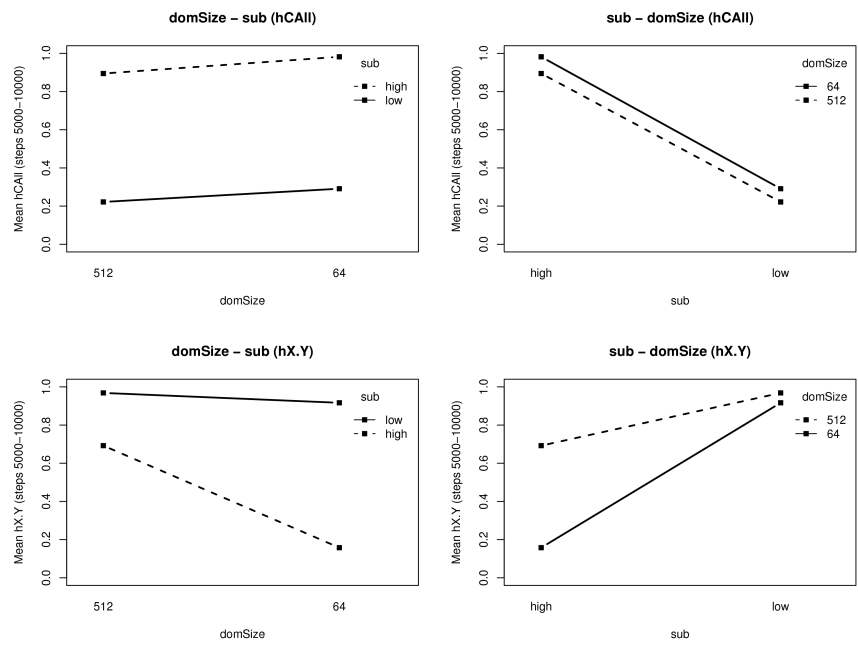


Figure A.77.: Interaction plots for hCAII and hX.Y

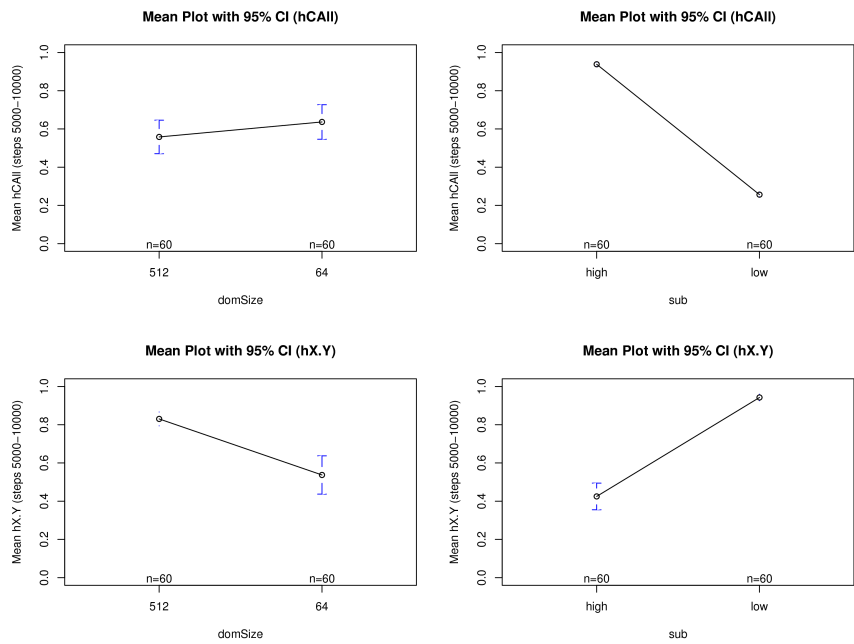


Figure A.78.: Mean plots for hCAII and hX.Y

## A.5 Experiment CII-1a

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This section contains the experimental design and results of Experiment CII-1a (see Chapter 8). Its purpose is to explore the behaviour of the dependent variables specifically in order answer the following technical questions.

### A.5.1. Research questions

The research questions to be answered in this experiment are:

- How many runs per experimental condition should be used in Experiment CII-1b?
- How many steps per run should be used in Experiment CII-1b?
- How many evaluators should be used in Experiment CII-1b?

### A.5.2. Experimental design

Experiment CII-1a has a total of 18 conditions (see Figure A.79). Three sets of parameters were varied: a) environmental variables (macrosystem and creator microsystem; low, high), b) number of runs (30, 60, 90) and c) number of evaluators (15, 30, 45). The exact values of the environmental variables (*predefine-r/g/b*, *cRatio*) in the low and high conditions are listed in Figure A.79.

The low and high values of the environmental variables were chosen based on the following reasoning: All values have been tested in experiments conducted with CRESY-I. They literally constitute the numerical parameter space in which CRESY-I has been explored. As CRESY-II encompasses CRESY-I plus the procedure *rate-patchwork* as well as additional dependent variables (creativity, "*crea*"; reliability, "*rel*"), it is assumed reasonable to continue exploration on the basis of what is already known about the first model's behaviour. The extreme values, as designated in CRESY-I, for the macrosystem variables (*predefine-r/g/b*) and creator microsystem (*cRatio*) were selected for the low and high conditions in this experiment.

The rest of the experimental set-up should resemble settings for CRESY-I as much as possible, because they have already been explored and a carry-over facilitates subsequent model-to-model comparisons. Therefore, the following variables were held constant in this experiment: In each condition, there were four creators in a 21x21 torus (*density*). The *info-rate* was set to *n8*, meaning creators and evaluators collected information about patchworks from eight neighbouring patches every step. These agents moved in the world based on the *any8* strategy, meaning they could move to any of the eight neighbouring patches, as long as they were empty. Creators' *imagination* was set to *0.05*, which allowed for maximum differences in the dependent variables when creator sample compositions (*cRatio*) were compared in a previous experiment (CI-2b; Chapter 7). Evaluators' state variable *domSize* was set to *512*,

Environment																	
Low									High								
predefine-r/-g/-b																	
1									256								
cRatio																	
3:0:0:1									1:0:0:3								
# runs																	
30			60			90			30			60			90		
number-evaluators																	
15	30	45	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45
Experimental Condition CII-1a-																	
Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Lo	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi	Hi
30	30	30	60	60	60	90	90	90	30	30	30	60	60	60	90	90	90
15	30	45	15	30	45	15	30	45	15	30	45	15	30	45	15	30	45

Figure A.79.: Experimental design for Experiment CII-1a. The bottom two rows include the names of conditions (CII-1a Lo 30 15, ..., CII-1a Hi 90 45)

as this value was used in CRESY-1 as well and is expected to lead to similar values for the dependent variables *hCAII* and *hX.Y. novelty-stringency* was set to 0.25 and *appropriateness-stringency* to 0.75. These values are an operationalization of the demand that creative work must be sufficiently novel and appropriate. Only evaluator type *Ena* was used in this experiment. The following dependent variables were recorded at every step of every run: *hCAII*, *crea*, *rel*.

### A.5.3. Analyses

Each experimental condition produced an output file which was subsequently analysed with R (Version 2.13.0). The following steps were taken:

1. Line plots of each dependent variable's average run per condition were made.
2. Violin plots of each dependent variable were made per condition.

#### Step 1:

Line plots Line plots were made for the dependent variables *hCAII* (product diversity), *crea* (creativity) and *rel* (reliability). They depict each variable's average run per condition (figures A.80 - A.82).

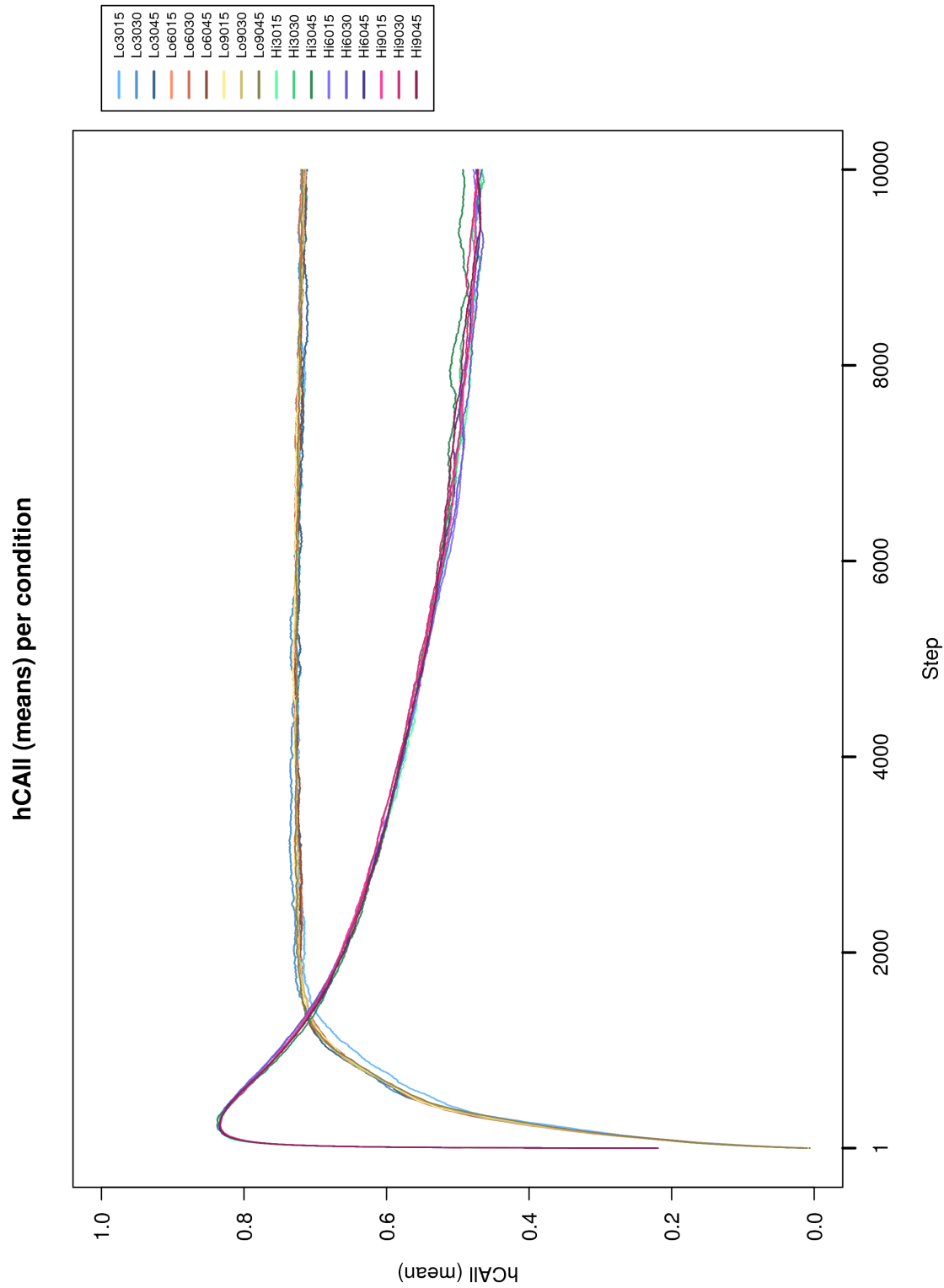


Figure A.80.: Mean runs per condition for hCAII (diversity)

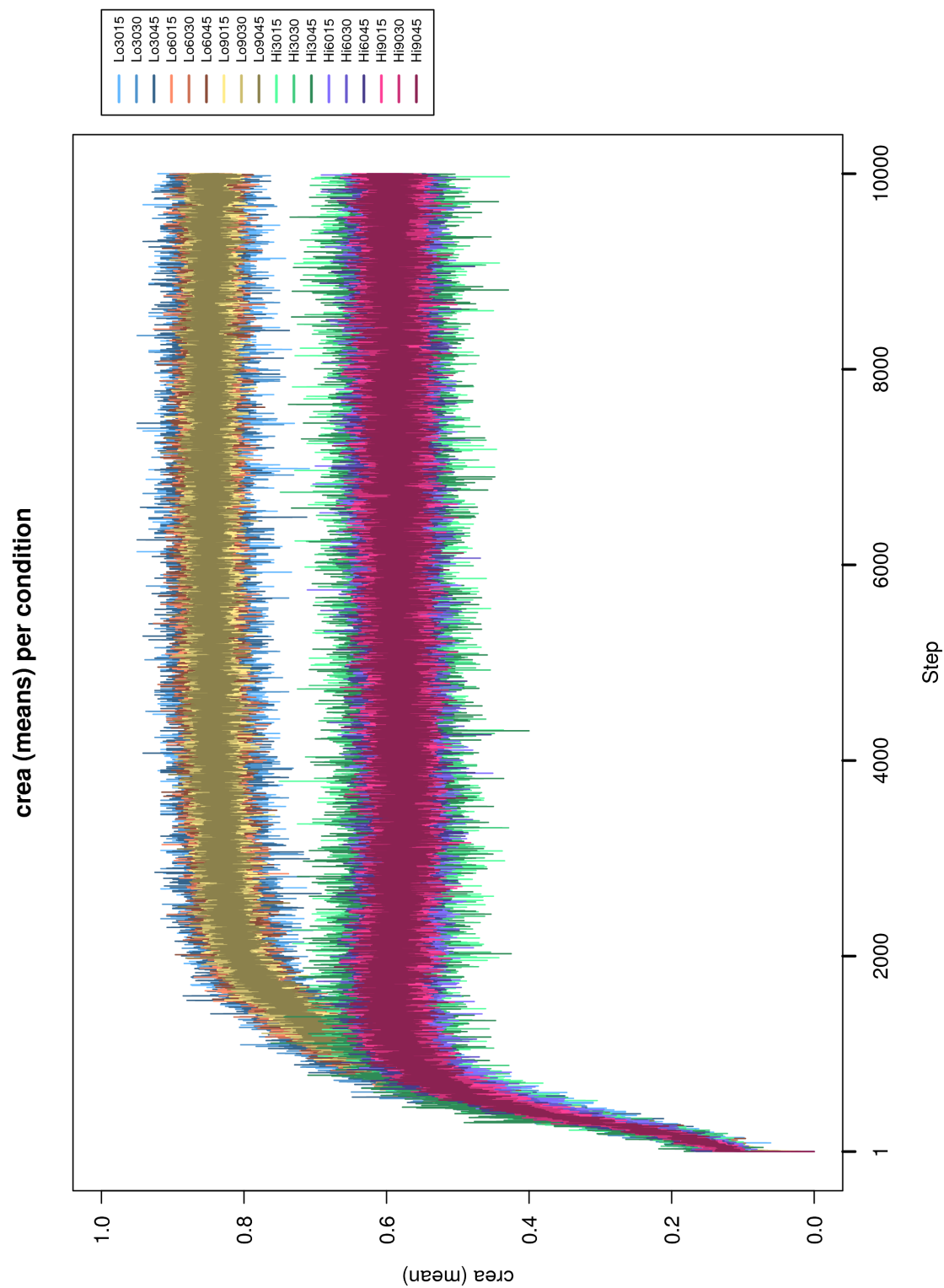
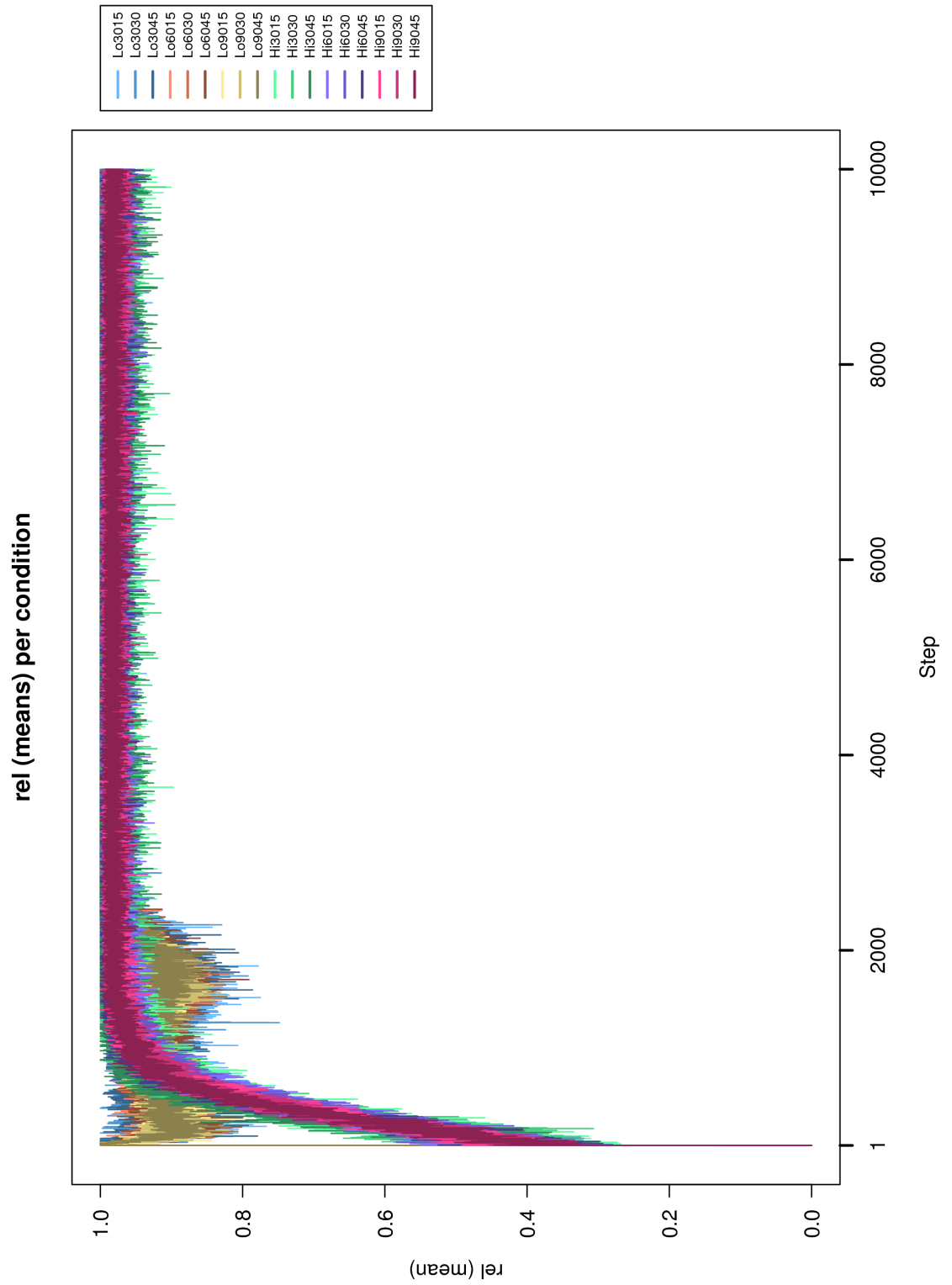


Figure A.81.: Mean runs per condition for crea (creativity)



Figure A.82.: Mean runs per condition for *rel* (reliability)

### Step 2: Violin Plots

Violin plots were made for the dependent variables *hCAll* (product diversity), *crea* (creativity) and *rel* (reliability). Each plot depicts all runs of one experimental condition. The white dot represents the median, and the thick black line the interquartile range (IQR). The thin black lines extend to the lowest datum still within 1.5 IQR of the lower quartile and to the highest datum still within 1.5 IQR of the upper quartile, respectively. Outliers of any kind are not depicted with extra symbols in violin plots as the additional density plots to each side of the inner boxplot indicate the data's range. See Figures A.83 – A.88 for the results.

### A.5.4. Discussion

The dependent variables *hCAll*, *crea* and *rel* were observed to make decisions about the research questions posed in this experiment. After inspecting all graphs depicted in section A.5, the following is concluded:

**Diversity** Product diversity (*hCAll*) varies depending on the low and high conditions, i.e. values set for the substantial independent variables. The number of evaluators as well as the number of runs do not make a difference. After approximately 2,000 steps, the measure appears to reach a steady state in the low conditions. *hCAll* does not reach a steady state in the high conditions until approximately 8,000 – 10,000 steps.

**Creativity** Product creativity (*crea*) as rated by evaluators varies depending on the low and high conditions, i.e. values set for the substantial independent variables. The number of evaluators as well as the number of runs do not make a difference. After approximately 3,000 – 4,000 steps, the measure appears to reach a steady state in all conditions.

**Reliability** This measure (*rel*) varies with the low and high conditions only in the beginning of runs. It consistently reaches a high level after approximately 3,000 – 4,000 steps in each condition. After that time, therefore, the investigated parameter values do not affect reliability levels.

Given the above data interpretations, the following parameter values were selected for use in the subsequent Experiment CII-1b:

**Number of runs:** 30

**Number of steps per run:** 6,000

**Number of evaluators:** 15

The violin plots indicate that the number of runs as well as the number of evaluators do not affect the dependent variables in a systematic manner. The lowest tested values of these variables are selected for reasons of research economy. All dependent

variables appear to reach a steady state by 6,000 steps at the latest except for  $hCAII$  in the high conditions (CII-1a-Hi3015 – CII-1a-Hi9045; Figure A.80). The reason for choosing 6,000 steps anyway is intentional: The idea is to demonstrate that the high conditions *do not* reach a steady state in a period in which all other conditions do.

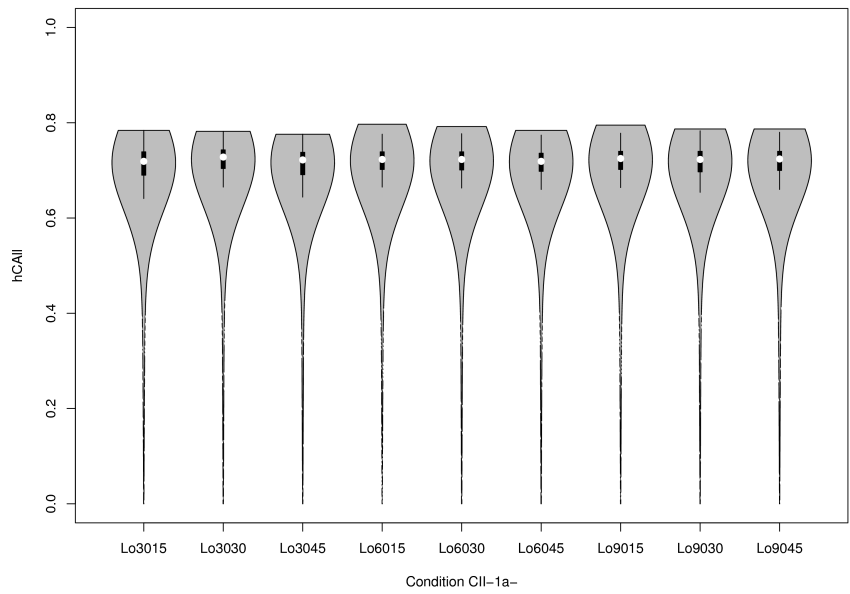


Figure A.83.: Violin plots for *hCAII* (diversity) for conditions Lo3015 to Lo9045

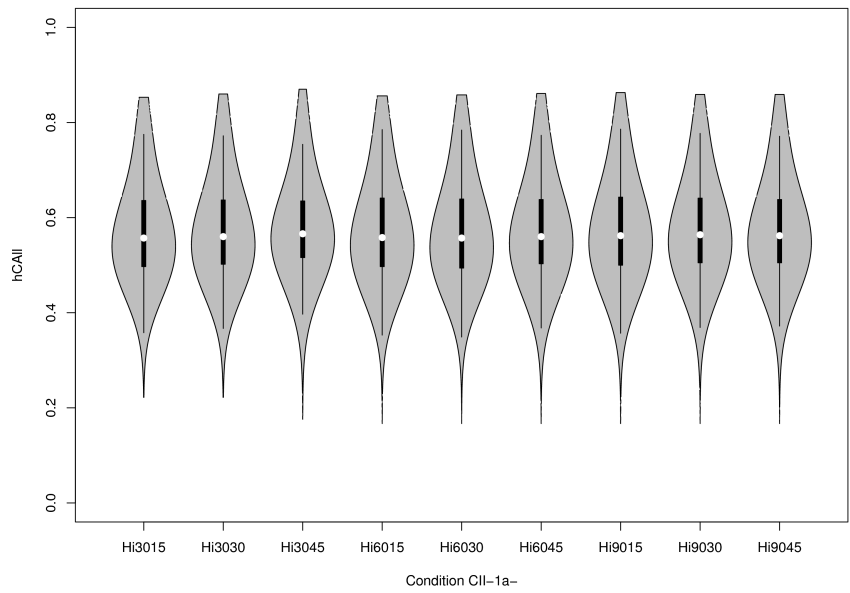


Figure A.84.: Violin plots for *hCAII* (diversity) for conditions Hi3015 to Hi9045

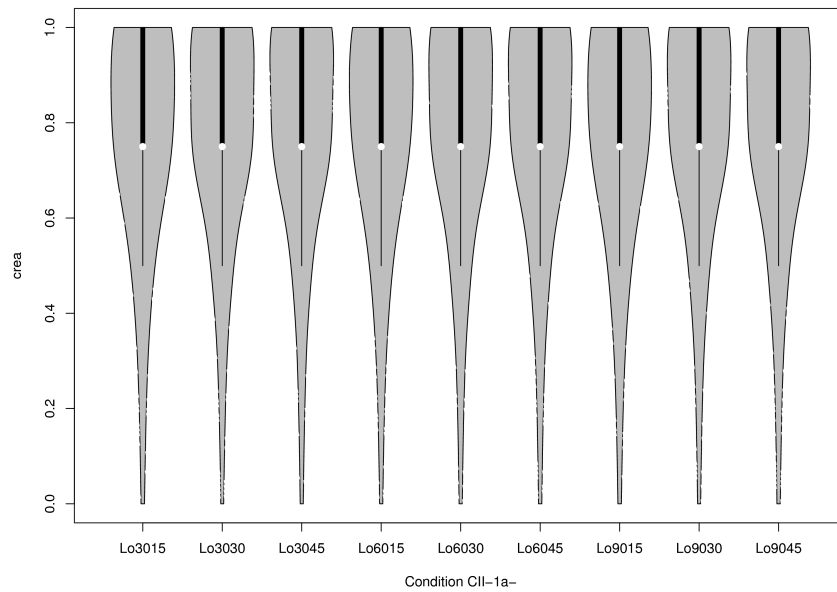


Figure A.85.: Violin plots for *crea* (creativity) for conditions Lo3015 to Lo9045

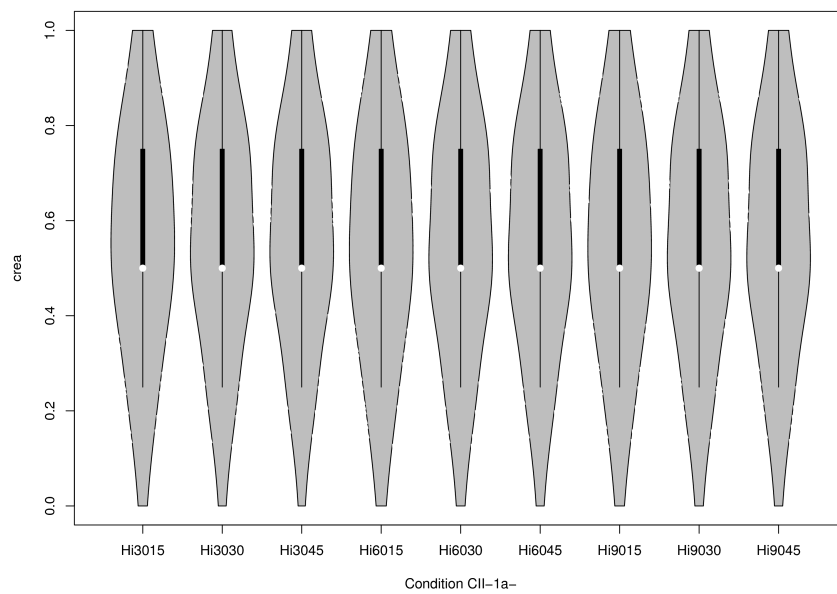


Figure A.86.: Violin plots for *crea* (creativity) for conditions Hi3015 to Hi9045

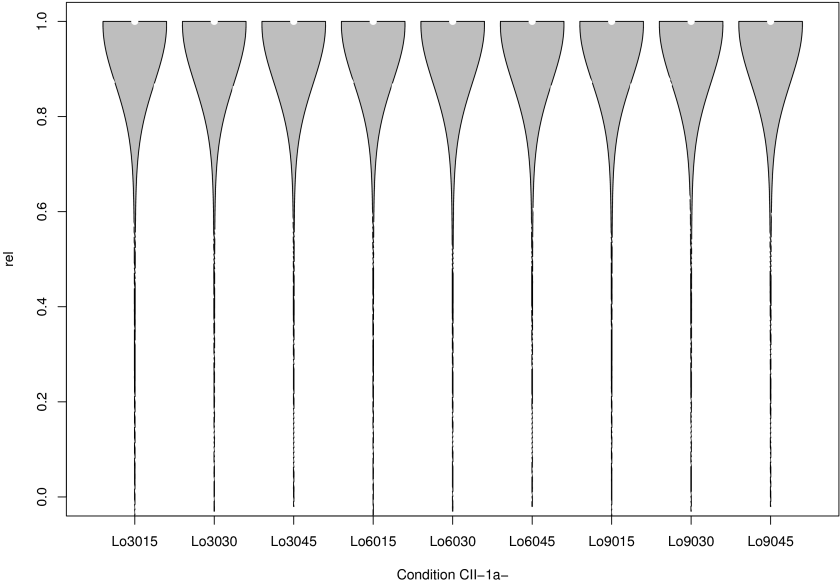


Figure A.87.: Violin plots for *rel* (reliability) for conditions Lo3015 to Lo9045

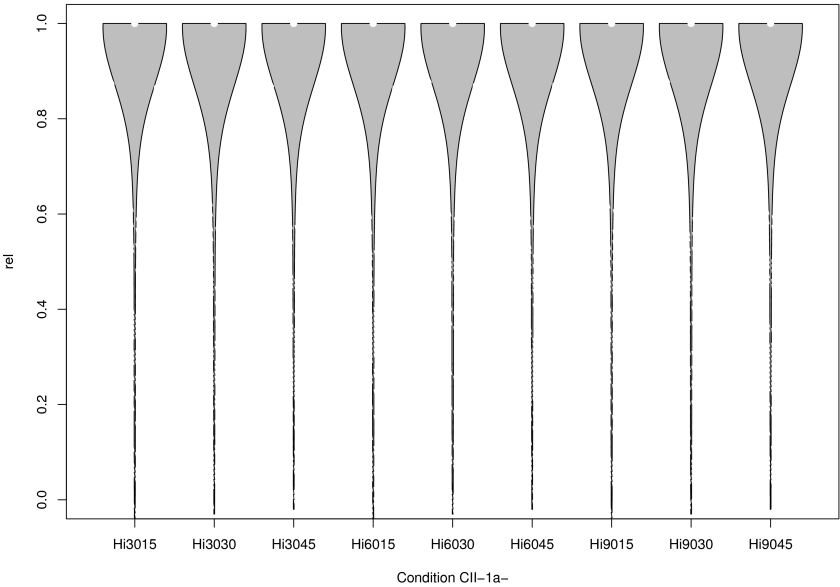


Figure A.88.: Violin plots for *rel* (reliability) for conditions Hi3015 to Hi9045

# Bibliography

- Abuhamdeh, S. & Csikszentmihalyi, M. (2004). The artistic personality: A systems perspective. In R. Sternberg, E. Grigorenko, & J. Singer (Eds.), *Creativity. From potential to realization*. Washington, D.C.: American Psychological Association.
- Adarves-Yorno, I., Postmes, T., & Haslam, S. (2006). Social identity and the recognition of creativity in groups. *British Journal of Social Psychology*, 45, 479–497.
- Albert, R. & Runco, M. (1999). A history of research on creativity. In R. Sternberg (Ed.), *The handbook of creativity* (pp. 16–34). Cambridge, UK: Cambridge University Press.
- Amabile, T. (1982). Social psychology of creativity: A consensual assessment technique. *Journal of Personality and Social Psychology*, 43(5), 997–1013.
- Amabile, T. (1996). *Creativity in context*. Boulder, CO: Westview Press.
- Amabile, T. (1998). How to kill creativity. *Harvard Business Review*, Sept-Oct, 77–87.
- Amabile, T. & Mueller, J. (2007). Psychometric approaches to the study of human creativity. In J. Zhou & C. Shalley (Eds.), *Handbook of organizational creativity* (pp. 33–64). New York: Lawrence Erlbaum Associates.
- Antona, M., Bommel, P., Bousquet, F., & Le Page, C. (2002). Interactions and organization in ecosystem management: The use of multi-agent systems to simulate incentive environmental policies. In C. Urban (Ed.), *3rd workshop on agent based simulation* (pp. 85–92). Erlangen, Germany: SCS-European Publishing House.
- Antonelli, C. & Ferraris, G. (2011). Innovation as an emerging system property. *Journal of Artificial Societies and Social Simulation*, 14(2), 1.
- Attneave, F. (1959). *Applications of information theory to psychology*. New York: Henry Holt and Company.
- Axelrod, R., Riolo, R., & Cohen, M. (2002). Beyond geography: Cooperation with persistent links in the absence of clustered neighborhoods. *Personality and Social Psychology Review*, 6(4), 341–346.
- Backhaus, K., Erichson, B., Plinke, W., & Weiber, R. (2000). *Multivariate Analysemethoden [Multivariate analyses]*. Berlin, Germany: Springer.
- Balci, O. (1994). Validation, verification, and testing techniques throughout the life cycle of a simulation study. *Annals of Operations Research*, 53, 121–173.
- Baldus, B. (2002). Darwin und die Soziologie [Darwin and sociology]. *Zeitschrift für Soziologie [Journal of Sociology]*, 31(4), 316–331.

- Bechtoldt, M., De Dreu, C., & Choi, H. (2010). Motivated information processing, social tuning, and group creativity. *Journal of Personality and Social Psychology*, 99.
- Beghetto, R. & Kaufman, J. (2007). Toward a broader concept of creativity: A case for "mini-c" creativity. *Psychology of Aesthetics, Creativity, and the Arts*, 1(2), 73–79.
- Bergius, R. & Engemann, A. (1985). Umsetzung von energiewirtschaftlichen Anforderungen in ein Modell zur Simulation der Wahl von Heizsystemen [Implementing energy and economic requirements in a model to simulate choices for heating systems]. In P. Day, U. Fuhrer, & U. Lauken (Eds.), *Umwelt und Handeln [Environment and action]* (pp. 86–104). Tübingen, Germany: Attempto.
- Bickel, D. (2002). Robust estimators of the mode and skewness of continuous data. *Computational Statistics & Data Analysis*, 39, 153–163.
- Bischof, N. (1995). *Struktur und Bedeutung [Structure and meaning]*. Bern, Switzerland: Verlag Hans Huber.
- Boden, M. (1991). *Computer models of mind. Computational approaches in theoretical psychology*. Cambridge, UK: Cambridge University Press.
- Boden, M., Ed. (1996). *Artificial intelligence. Handbook of perception and cognition*. London: Academic Press.
- Boden, M. (1999). Computer models of creativity. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 351–372). Cambridge, UK: Cambridge University Press.
- Boden, M. (2004). *The creative mind. Myths and mechanisms*. London: Routledge.
- Boden, M. (2011). *Creativity and art. Three roads to surprise*. New York: Oxford University Press.
- Boero, R. & Squazzoni, F. (2005). Does empirical embeddedness matter? Methodological issues on agent-based models for analytical social science. *Journal of Artificial Societies and Social Simulation*, 8(4), 6.
- Bortz, J. & Döring, N. (2002). *Forschungsmethoden und Evaluation [Research methods and evaluation]*. Berlin, Germany: Springer.
- Bortz, J., Lienert, G., & Boehnke, K. (2008). *Verteilungsfreie Methoden in der Biostatistik [Non-parametric methods in biostatistics]*. Heidelberg, Germany: Springer Medizin Verlag.
- Bradshaw, G., Langley, P., & Simon, H. (1983). Studying scientific discovery by computer simulation. *Science*, 222, 971–975.



- Brower, R. (2003). Constructive repetition, time, and the evolving systems approach. *Creativity Research Journal*, 15(1), 61–72.
- Bryson, J. (2008). The role of modularity in stabilizing cultural evolution: Conformity and innovation in an agent-based model. In A. Davis & J. Ludwig (Eds.), *Proceedings of the AAAI Fall Symposium on Adaptive Agents in Cultural Contexts / AACC '08* (pp. 8–17). Menlo Park, CA: AAAI Press.
- Bryson, J. (2009). Representations underlying social learning and cultural evolution. *Interaction Studies*, 10(1), 77–100.
- Buss, D. (2004). *Evolutionäre Psychologie [Evolutionary psychology. The new science of the mind]*. München, Germany: Pearson Studium.
- Campbell, D. (1960). Blind variation and selective retention in creative thought as in other knowledge processes. *Psychological Review*, 67(6), 380–400.
- Chattoe, E. (1998). Just how (un)realistic are evolutionary algorithms as representations of social processes? *Journal of Artificial Societies and Social Simulation*, 1(3), 2.
- Chiu, C. & Leung, A. (2007). Do multicultural experiences make people more creative? If so, how? *The INquisitive MIND*, 4, retrieved July 30, 2010, from [<http://beta.in-mind.org/node/86/>].
- Cioffi-Revilla, C. (2010). A methodology for complex social simulations. *Journal of Artificial Societies and Social Simulation*, 13 (1), retrieved October 20, 2010, from [<http://jasss.soc.surrey.ac.uk/13/1/7.html>].
- Cohen, J. (1969). *Statistical power analysis for the behavioral sciences*. New York: Academic Press.
- Couger, D., Higgins, L., & McIntyre, S. (1989). Differentiating creativity, innovation, entrepreneurship, intrapreneurship, copyright and patenting for I.S. products / processes. *Proceedings of the Twenty-Third Annual Hawaii International Conference on Systems Sciences*, 4, 370–379.
- Cropley, D. & Cropley, A. (2010). Functional creativity: "Products" and the generation of effective novelty. In J. Kaufman & R. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 301–320). New York: Cambridge University Press.
- Cropley, D., Cropley, A., Kaufman, J., & Runco, M., Eds. (2010). *The dark side of creativity*. New York: Cambridge University Press.
- Csikszentmihalyi, M. (1988). Society, culture, and person: A systems view of creativity. In R. Sternberg (Ed.), *The nature of creativity. Contemporary psychological perspectives* (pp. 325–339). Cambridge, UK: Cambridge University Press.

- Csikszentmihalyi, M. (1999). Implications of a systems perspective for the study of creativity. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 313–338). Cambridge, UK: Cambridge University Press.
- Csikszentmihalyi, M. & Getzels, J. (1971). Discovery-oriented behavior and the originality of creative products: A study with artists. *Journal of Personality and Social Psychology*, 19(1), 47–52.
- Csikszentmihalyi, M. & Sawyer, K. (1995). Creative insight: The social dimension of a solitary moment. In R. Sternberg & J. Davidson (Eds.), *The nature of insight*. Cambridge, MA: MIT Press.
- Cziko, G. (1998). From blind to creative: In defense of Donald Campbell's selectionist theory of human creativity. *Journal of Creative Behavior*, 32, 192–209.
- Dasgupta, S. (2004). Is creativity a Darwinian process? *Creativity Research Journal*, 16(4), 403–413.
- David, N., Caldas, J., & Coelho, H. (2010). Epistemological perspectives on simulation III. *Journal of Artificial Societies and Social Simulation*, 13(1), retrieved October 20, 2010, from [<http://jasss.soc.surrey.ac.uk/13/1/14.html>].
- Davis, J. & Eisenhardt, K. (2007). Developing theory through simulation methods. *Academy of Management Review*, 32(2), 480–499.
- de Heus, P. (2000). Do reciprocal strategies work in social dilemmas? *Personality and Social Psychology Review*, 4(3), 278–288.
- Dennett, D. (1995). Intuition pumps. In J. Brockman (Ed.), *The third culture* (pp. 181–197). New York: Simon & Schuster.
- Dennis, A. & Williams, M. (2003). Electronic brainstorming. In P. Paulus & B. Nijstad (Eds.), *Group creativity* (pp. 160–178). New York: Oxford University Press.
- Dewett, T. & Williams, S. (2007). Innovators and imitators in novelty-intensive markets: A research agenda. *Creativity and Innovation Management*, 16(1), 80–92.
- DiPaola, S. & Gabora, L. (2009). Incorporating characteristics of human creativity into an evolutionary art algorithm. *Genetic Programming and Evolvable Machines*, 10(2), 97–110.
- Doran, J. (2001). Intervening to achieve co-operative ecosystem management: Towards an agent-based model. *Journal of Artificial Societies and Social Simulation*, 4(2), retrieved October 20, 2010, from [<http://jasss.soc.surrey.ac.uk/4/2/4.html>].

- Dörner, D. (1994). Heuristik der Theorienbildung [Heuristics of building theories] . In T. Herrmann & W. Tack (Eds.), *Enzyklopädie der Psychologie. Themenbereich B: Methodologie und Methoden. Serie I: Forschungsmethoden der Psychologie. Band I: Methodologische Grundlagen der Psychologie [Encyclopedia of psychology. Subject: Methodology and methods. Series I: Research methods in psychology. Volume I: Methodological basics in psychology]* (pp. 343–388). Göttingen, Germany: Hogrefe.
- Dresler, M. & Baudson, T., Eds. (2008). *Kreativität [Creativity]*. Stuttgart, Germany: S. Hirzel.
- Duffy, J. (2006). Agent-based models and human subject experiments. In L. Testfatsion & K. Judd (Eds.), *Handbook of computational economics* (pp. 949–1011). Amsterdam, The Netherlands: North-Holland.
- Edmonds, B. (1999). Gossip, sexual recombination and the El Farol Bar: Modelling the emergence of heterogeneity. *Journal of Artificial Societies and Social Simulation*, 2(3), 2.
- Edmonds, B. (2005). Towards good social science. *Journal of Artificial Societies and Social Simulation*, 8(4), retrieved October 20, 2010, from [<http://jasss.soc.surrey.ac.uk/8/4/13.html>].
- El-Murad, J. & West, D. (2004). The definition and measurement of creativity: What do we know? *Journal of Advertising Research*, June, 188–201.
- Esser, H. & Troitzsch, K. (1991). Einleitung: Probleme der Modellierung sozialer Prozesse [Introduction: Problems with modelling social processes]. In H. Esser & K. Troitzsch (Eds.), *Modellierung sozialer Prozesse. Neuere Ansätze und Überlegungen zur soziologischen Theoriebildung. Ausgewählte Beiträge zu Tagungen der Arbeitsgruppe Modellierung sozialer Prozesse der Deutschen Gesellschaft für Soziologie [Modelling social processes. New approaches to building sociological theory. Selected contributions from conferences of the working group "Modeling Social Processes" of the German Society of Sociology]* (pp. 13–25). Bonn, Germany: Eigenverlag Informationszentrum.
- Falkenhainer, B., Forbus, K., & Gentner, D. (1989). The structure-mapping engine: Algorithms and examples. *Artificial Intelligence*, 41, 1–63.
- Feist, G. (1999). Influence of personality on artistic and scientific creativity. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 273–296). Cambridge, UK: Cambridge University Press.
- Feldhusen, J. & Goh, B. (1995). Assessing and accessing creativity: An integrative review of theory, research, and development. *Creativity Research Journal*, 8(3), 231–247.
- Field, A. (2005). *Discovering statistics using SPSS (2nd ed.)*. London: SAGE.

- Fink, A. (2008). Kreativität aus Sicht der Neurowissenschaften [Creativity from the neuroscientific perspective]. In M. Dresler & T. Baudson (Eds.), *Kreativität [Creativity]* (pp. 37–42). Stuttgart, Germany: S. Hirzel.
- Finke, R., Ward, T., & Smith, S. (1996). *Creative cognition*. Cambridge, MA: MIT Press.
- Flaherty, A. (2005). Frontal and dopaminergic control of idea generation and creative drive. *The Journal of Comparative Neurology*, 493, 147–153.
- Fleiss, J. (1971). Measuring nominal scale agreement among many raters. *Psychological Bulletin*, 76(5), 378–382.
- Ford, C. & Kuenzi, M. (2007). Organizing creativity research through historical analyses of foundational administrative science texts. In J. Zhou & C. Shalley (Eds.), *Handbook of organizational creativity* (pp. 65–94). New York: Lawrence Erlbaum Associates.
- Förster, J., Marguc, J., & Gillebaart, M. (2010). Novelty categorization theory. *Social and Personality Psychology Compass*, 4/9, 736–755.
- Gabora, L. (1995). Meme and variations: A computational model of cultural evolution. In L. Nadel & D. Stein (Eds.), *1993 Lectures in Complex Systems* (pp. 471–486). Boston: Addison Wesley.
- Gabora, L. (2004). Ideas are not replicators but minds are. *Biology and Philosophy*, 19(1), 127–143.
- Gabora, L. (2008a). EVOC: A computer model of cultural evolution. In V. Sloutsky, B. Love, & R. McRae (Eds.), *30th Annual Meeting of the Cognitive Science Society* (pp. 1–6). North Salt Lake, UT: Sheridan Publishing.
- Gabora, L. (2008b). Modeling cultural dynamics. In *Proceedings of the Association for the Advancement of Artificial Intelligence (AAAI) Fall Symposium 1: Adaptive Agents in a Cultural Context* (pp. 18–25). Menlo Park, CA: AAAI Press.
- Gabora, L. & Kaufman, S. (2010). Evolutionary approaches to creativity. In J. Kaufman & R. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 279–300). New York: Cambridge University Press.
- Galan, J., Izquierdo, L., Izquierdo, S., Santos, J., del Olmo, R., Lopez-Paredes, A., & Edmonds, B. (2009). Errors and artefacts in agent-based modelling. *Journal of Artificial Societies and Social Simulation*, 12(1), 1.
- Galton, F. (1865). Hereditary talent and character. *Macmillan's Magazine*, 12, 157–166, 318–327.
- Gangadharbatla, H. (2010). Technology component: A modified systems approach to creative thought. *Creativity Research Journal*, 22(2), 219–227.

- Garner, W. & Hake, H. (1951). The amount of information in absolute judgments. *Psychological Review*, 58, 446–459.
- Gilbert, N. (2008). *Agent-based models*. Los Angeles: SAGE.
- Gilbert, N. & Troitzsch, K. (1999). *Simulation for the social scientist*. Buckingham, UK: Open University Press.
- Glover, J., Ronning, R., & Reynolds, C., Eds. (2010). *Handbook of creativity. Perspectives on individual differences*. New York: Plenum Press.
- Glück, J., Ernst, R., & Unger, F. (2002). How creatives define creativity: Definitions reflect different types of creativity. *Creativity Research Journal*, 14(1), 55–67.
- Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S., Huse, G., Huth, A., Jepsen, J., Jorgensen, C., Mooij, W., Müller, B., Pe'er, G., Piou, C., Railsback, S., Robbins, A., Robbins, M., Rossmanith, E., Rüger, N., Strand, E., Souissi, S., Stillman, R., Vabo, R., Visser, U., & DeAngelis, D. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling*, 198, 115–126.
- Grimm, V., Berger, U., DeAngelis, D., Polhill, G., Giske, J., & Railsback, S. (2010). The ODD protocol: A review and first update. *Ecological Modelling*, 221, 2760–2768.
- Gruber, H. (1988). The evolving systems approach to creative work. *Creativity Research Journal*, 1, 27–51.
- Gruber, H. & Wallace, D. (1999). The case study method and evolving systems approach for understanding unique creative people at work. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 93–115). Cambridge, UK: Cambridge University Press.
- Guilford, J. (1950). Creativity. *The American Psychologist*, 5, 444–454.
- Guilford, J. (1956). The structure of intellect. *Psychological Bulletin*, 53, 267–293.
- Haller, C., Courvoisier, D., & Cropley, D. (2011). Perhaps there is accounting for taste: Evaluating the creativity of products. *Creativity Research Journal*, 23(2), 99–108.
- Hare, M., Medugno, D., Heeb, J., & Pahl-Wostl, C. (2002). An applied methodology for participatory model building of agent-based models for urban water management. In C. Urban (Ed.), *3rd workshop on agent based simulation* (pp. 61–66). Erlangen, Germany: SCS-European Publishing House.
- Hargreaves, D., Galton, M., & Robinson, S. (1996). Teachers' assessments of primary children's classroom work in the creative arts. *Educational Research*, 38(2), 199–211.

- Heider, F. (1958). *The psychology of interpersonal relations*. Hillsdale, NJ: Lawrence Erlbaum.
- Hellhammer, D. (1989). Systematische Exploration als Strategie klinisch-psychobiologischer Forschung [Systematic exploration as a clinical, psychobiological research strategy]. In G. Jüttemann (Ed.), *Qualitative Forschung in der Psychologie [Qualitative research in psychology]* (pp. 147–160). Heidelberg, Germany: Roland Asanger.
- Hennessey, B. (2003). Is the social psychology of creativity really social? In P. Paulus & B. Nijstad (Eds.), *Group creativity* (pp. 181–201). Oxford, UK: Oxford University Press.
- Hennessey, B. & Amabile, T. (2010). Creativity. *Annual Review of Psychology*, 61, 569–598.
- Henshon, S. (2010). Explorations in creativity: An interview with Mark Runco. *Roeper Review*, 32(1), 2–4.
- Herman, A. & Reiter-Palmon, R. (2011). The effect of regulatory focus on idea generation and idea evaluation. *Psychology of Aesthetics, Creativity, and the Arts*, 5(1), 13–20.
- Hintze, J. & Nelson, R. (1998). Violin plots: A box plot-density trace synergism. *The American Statistician*, 52(2), 181+.
- Hocevar, D. & Bachelor, P. (1989). A taxonomy and critique of measurements used in the study of creativity. In J. Glover, R. Ronning, & C. Reynolds (Eds.), *Handbook of creativity* (pp. 53–75). New York: Plenum.
- Hong, Y., Levy, S., & Chiu, C. (2001). Special Issue: The contribution of the lay theories approach to the study of groups. *Personality and Social Psychology Review*, 5(2), 98–106.
- Howell, D. (2007). *Statistical methods for psychology*. Belmont, CA: Thomson Wadsworth.
- Hunt, L., Robson, M., Lemelin, R., & McIntyre, N. (2010). Exploring the acceptability of spatial simulation models of outdoor recreation for use by participants in public participation processes. *Leisure Sciences*, 32(3), 222–239.
- Jaccard, J. & Jacoby, J., Eds. (2010). *Theory construction and model-building skills*. New York: The Guilford Press.
- Jager, W. (2000). *Modeling consumer behaviour*. Groningen, The Netherlands: Universal Press.

- Janssen, M., Alessa, L., Barton, M., Bergin, S., & Lee, A. (2008). Towards a community framework for agent-based modelling. *Journal of Artificial Societies and Social Simulation*, 11(2), 6.
- Janssen, M. & Ostrom, E. (2006). Empirically based, agent-based models. *Ecology and Society*, 11(2), 37.
- Jarboe, S. (1999). Group communication and creativity process. In L. Frey (Ed.), *The handbook of group communication theory & research* (pp. 335–368). London: SAGE.
- Jaskyte, K., Taylor, H., & Smariga, R. (2009). Student and faculty perceptions of innovative teaching. *Creativity Research Journal*, 21(1), 111–116.
- Jennings, N., Sycara, K., & Woolridge, M. (1998). A roadmap of agent research and development. *Autonomous Agents and Multi-Agent Systems*, 1, 7–38.
- Kahl, C. (2008). Creativity is more than a trait: It's a relation. *INquisitive MIND*, 5, retrieved August 1, 2011, from [<http://beta.in-mind.org/node/130>].
- Kahl, C. (2009). Modeling a social environment to investigate creativity: An agent-based model. In E. Witte & C. Kahl (Eds.), *Sozialpsychologie der Kreativität und Innovation [Social psychology of creativity and innovation]* (pp. 27–52). Lengerich, Germany: Pabst Science Publishers.
- Kahl, C., Hermes da Fonseca, L., & Witte, E. (2009). Revisiting creativity research: An investigation of contemporary approaches. *Creativity Research Journal*, 21(1), 1–5.
- Kalick, S. & Hamilton, T. (1986). The matching hypothesis reexamined. *Journal of Personality and Social Psychology*, 51, 673–682.
- Kameda, T., Takezawa, M., & Hastie, R. (2003). The logic of social sharing: An evolutionary game analysis of adaptive norm development. *Personality and Social Psychology Review*, 7(1), 2–19.
- Kaufman, J., Baer, J., Cole, J., & Sexton, J. (2008). A comparison of expert and nonexpert raters using the consensual assessment technique. *Creativity Research Journal*, 20(2), 171–178.
- Kaufman, J. & Sternberg, R., Eds. (2006). *The international handbook of creativity*. New York: Cambridge University Press.
- Kaufman, J. & Sternberg, R., Eds. (2010). *The Cambridge handbook of creativity*. New York: Cambridge University Press.
- Kenrick, D., Li, N., & Butner, J. (2003). Dynamical evolutionary psychology. *Psychological Review*, 110(1), 3–28.

- Kirton, M. (1976). Adaptors and innovators: A description and measure. *Journal of Applied Psychology*, 61(5), 622–629.
- Kleijnen, J., Sanchez, S., Lucas, T., & Cioppa, T. (2005). State-of-the-art review: A user's guide to the brave new world of designing simulation experiments. *INFORMS Journal on Computing*, 17, 263–289.
- Kleining, G. (1994). *Qualitativ-heuristische Sozialforschung [Qualitative heuristic social research]*. Hamburg, Germany: Rolf Fechner.
- Kozbelt, A., Beghetto, R., & Runco, M. (2010). Theories of creativity. In J. Kaufman & R. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 20–47). New York: Cambridge University Press.
- Kozbelt, A. & Serafin, J. (2009). Dynamic evaluation of high- and low-creativity drawings by artist and nonartist raters. *Creativity Research Journal*, 21(4), 349–360.
- Kriz, J. (1999). *Systemtheorie für Psychotherapeuten, Psychologen und Mediziner [Systems theory for psychotherapists, psychologists and doctors]*. Vienna, Austria: Facultas.
- Kroeck, K., Barrett, G., & Alexander, R. (1983). Imposed quotas and personnel selection: A computer simulation study. *Journal of Applied Psychology*, 68(1), 123–136.
- Kronfeldner, M. (2007). Is cultural evolution Lamarckian? *Biology and Philosophy*, 22, 493–512.
- Kronfeldner, M. (2009). Meme, meme, meme: Darwins Erben und die Kultur [Meme, meme, meme: Darwin's heirs and culture]. *Philosophia Naturalis*, 46, 36–60.
- Kronfeldner, M. (2010). Darwinian 'blind' hypothesis formation revisited. *Synthese*, 175, 193–218.
- Krywkow, J., Valkering, P., van der Veen, A., & Rotmans, J. (2002). Coupling an agent-based model with an integrated assesement model to investigate social aspects of water management. In C. Urban (Ed.), *3rd workshop on agent based simulation* (pp. 79–84). Erlangen, Germany: SCS-European Publishing House.
- Kwang, N., Ang, R., Ooi, L., Shin, W., Oei, T., & Leng, V. (2005). Do adaptors and innovators subscribe to opposing values? *Creativity Research Journal*, 17(2), 273–281.
- Lamnek, S. (2005). *Qualitative Sozialforschung [Qualitative social research]*. Weinheim, Germany: Beltz PVU.
- Landis, J. & Koch, G. (1977). The measurement of observer agreement for categorical data. *Biometrics*, 33(1), 159–174.



- Law, A. (2007). *Simulation modeling and analysis*. Boston: McGraw-Hill.
- Leech, N., Barrett, K., & Morgan, G. (2005). *SPSS for intermediate statistics*. Mahwah, NJ: Lawrence Erlbaum Associates.
- Leijnen, S. & Gabora, L. (2009a). How creative should creators be to optimize the evolution of ideas? A computational model. In B. Cooper & V. Danos (Eds.), *Proceedings Fifth Workshop on Developments in Computational Models - Computational Models from Nature* (pp. 108–119). Electronic Proceedings in Theoretical Computer Science 9 (EPTCS 9), retrieved March 10, 2011, from [[http://arxiv.org/PS\\_cache/arxiv/pdf/0911/0911.2309v1.pdf](http://arxiv.org/PS_cache/arxiv/pdf/0911/0911.2309v1.pdf)].
- Leijnen, S. & Gabora, L. (2009b). The artist loft effect in the clustering of 'creative types': A computer simulation. In N. Bryans-Kins (Ed.), *Proceedings of the 7th Creativity and Cognition Conference* (pp. 1–2). New York: ACM Press.
- Leijnen, S. & Gabora, L. (2010). An agent-based simulation of the effectiveness of creative leadership. In S. Ohlsson & R. Catrambone (Eds.), *Proceedings of the Annual Meeting of the Cognitive Science Society* (pp. 955–960). Austin, TX: Cognitive Science Society.
- Lenat, D. & Brown, J. (1984). Why AM and EURISKO appear to work. *Artificial Intelligence*, 23, 269–294.
- Lewis, S. & Clarke, M. (2001). Forest plots: Trying to see the wood and the trees. *British Medical Journal*, 322, 1479–1480.
- Lindsay, R., Buchanan, B., Feigenbaum, E., & Lederberg, J. (1993). DENDRAL: A case study of the first expert system for scientific hypothesis formation. *Artificial Intelligence*, 61, 209–261.
- Linville, P., Fischer, G., & Salovey, P. (1989). Perceived distributions of the characteristics of in-group and out-group members: Empirical evidence and a computer simulation. *Journal of Personality and Social Psychology*, 57(2), 165–188.
- Loh, W. & Shih, Y. (1997). Split selection methods for classification trees. *Statistica Sinica*, 7, 815–840.
- Lonergan, D., Scott, G., & Mumford, M. (2004). Evaluative aspects of creative thought: Effects of appraisal and revision standards. *Creativity Research Journal*, 16(2), 231–246.
- Lubart, T. (1999). Creativity across cultures. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 339–350). Cambridge, UK: Cambridge University Press.
- MacKinnon, D. (1978). *In search of human effectiveness: Identifying and developing creativity*. Buffalo, NY: Creative Education Foundation.

- Macy, M. & Willer, R. (2002). From factors to actors: Computational sociology and agent-based modeling. *Annual Review of Sociology*, 28, 143–66.
- Magyari-Beck, I. (1990). An introduction to the framework of creatology. *Journal of Creative Behavior*, 24, 151–160.
- Martindale, C. (1999). Biological bases of creativity. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 137–152). Cambridge, UK: Cambridge University Press.
- Matthews, G. & Harley, T. (1993). Effects of extraversion and self-report arousal on semantic priming: A connectionist approach. *Journal of Personality and Social Psychology*, 65(4), 735–756.
- Mayer, R. (1999). Fifty years of creativity research. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 449–460). Cambridge, UK: Cambridge University Press.
- McCrae, R. (1987). Creativity, divergent thinking, and openness to experience. *Journal of Personality and Social Psychology*, 52, 1258–1265.
- McCrae, R. & John, O. (1992). An introduction to the Five-Factor Model and its implications. *Journal of Personality*, 60, 175–215.
- McGill, R., Tukey, J., & Larsen, W. (1978). Variations of box plots. *American Statistician*, 32(1), 12–16.
- McGill, W. (1954). Multivariate information transmission. *Psychometrika*, 19(2), 97–116.
- McIntyre, P. (2008). Creativity and cultural production: A study of contemporary Western popular music. *Creativity Research Journal*, 20(1), 40–52.
- Mednick, S. (1962). The associative basis of the creative process. *Psychological Review*, 69, 220–232.
- Merkel, A. (January 25, 2006). Rede von Bundeskanzlerin Angela Merkel auf dem Weltwirtschaftsforum am 25. Januar 2006 in Davos [Speech given by Federal Chancellor Angela Merkel at the World Economic Forum on 25/06/06 in Davos]. Presse- und Informationsamt der Bundesregierung. Retrieved December 15, 2006, from [http://www.bundestkanzlerin.de/nn\_4922/Content/DE/Rede/2006/01/2006-01-25-rede-von-bundestkanzlerin-angela-merkel-auf-dem-weltwirtschaftsforum-am-25-januar-2006-in-davos.html].
- Metzger, W. (1979/1986). Gestalttheoretische Ansätze zur Fragen der Kreativität [Gestalt psychology approaches to creativity]. In *Gestalt-Psychologie [Gestalt psychology]* (pp. 522–528). Frankfurt a.M., Germany: Kramer.

- Meyer, J. (2008). Mehr als nur herumspinnen - Die fünf großen Irrtümer über Kreativität [More than goofing around - The five biggest fallacies about creativity]. *Wirtschaftspsychologie aktuell [Current Economic Psychology]*, 4, 55–59.
- Mittenecker, E. & Raab, E. (1973). *Informationstheorie für Psychologen [Information theory for psychologists]*. Göttingen, Germany: Hogrefe.
- Moles, A. (1968). *Information theory and esthetic perception*. Urbana, IL: University of Illinois Press.
- Montgomery, D. (2005). *Design and analysis of experiments*. Hoboken, NJ: John Wiley & Sons.
- Moran, S. (2010). The roles of creativity in society. In J. Kaufman & R. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 74–90). New York: Cambridge University Press.
- Mosler, H. (2000). *Computersimulation sozialpsychologischer Theorien [Computer simulations of social psychological theories]*. Weinheim, Germany: Beltz.
- Mosler, H. & Brucks, W. (2003). Integrating resource dilemma findings in a simulation model. *European Journal of Social Psychology*, 33, 119–133.
- Mosler, H., Schwarz, K., Ammann, F., & Gutscher, H. (2001). Computer simulation as a method of further developing a theory: Simulating the Elaboration Likelihood Model. *Personality and Social Psychology Review*, 5(3), 201–215.
- Müller, C. (August 14, 2009). Hier ist es schwer, verdammt schwer [It's difficult here, extremely difficult]. *sonntaz [German Sunday Newspaper "sonntaz"]*, retrieved March 10, 2011, from [<http://www.taz.de/1/leben/kuenste/artikel/1/hier-ist-es-schwer-verdammt-schwer/>].
- Mumford, M. (2003). Where have we been, where are we going? Taking stock in creativity research. *Creativity Research Journal*, 15(2), 107–120.
- Mumford, M., Ed. (2011). *Handbook of organizational creativity*. Academic Press; *in press*.
- Nawratil, G. & Rabaioli-Fischer, B. (2010). *Sozialpsychologie leicht gemact [Social psychology light]*. Berlin, Germany: Ewald von Kleist Verlag.
- Nerb, J. (2000). *Die Bewertung von Umweltschäden: Kognitive und emotionale Folgen von Medienmeldungen [Evaluating environmental disasters: Cognitive and emotional consequences of media reports]*. Bern, Switzerland: Huber.
- Nicholls, J. (1972). Creativity in the person who will never produce anything original and useful. *American Psychologist*, 27, 717–727.

- Nijstad, B., Diehl, M., & Stroebe, W. (2003). Cognitive stimulation and interference in idea-generating groups. In P. Paulus & B. Nijstad (Eds.), *Group creativity* (pp. 137–159). New York: Oxford University Press.
- Nölke, M. (2006). *Kreativitätstechniken [Creativity techniques]*. Munich, Germany: Haufe.
- Ochse, R. (1990). *Before the gates of excellence. The determinants of creative genius*. Cambridge, UK: Cambridge University Press.
- Olejnik, S. & Algina, J. (2003). Generalized eta and omega squared statistics: Measures of effect size for some common research designs. *Psychological Methods*, 8(4), 434–447.
- Ostrom, T. (1988). Computer simulation: The third symbol system. *Journal of Experimental Social Psychology*, 24, 381–392.
- Paolucci, M. & Picascia, S. (2010). Simulating cultural dynamics in peer production environment. In *The QualityCommons: A workshop on collective quality representations* (pp. 38–40). Surrey, UK: Centre for Research in Social Simulation, University of Surrey. Retrieved March 10, 2011, from [<http://cress.soc.surrey.ac.uk/web/events/qualitycommons-workshop>].
- Paulus, P. & Brown, V. (2003). Enhancing ideational creativity in groups. Lessons from research on brainstorming. In P. Paulus & B. Nijstad (Eds.), *Group creativity* (pp. 110–136). New York: Oxford University Press.
- Paulus, P. & Nijstad, B., Eds. (2003). *Group creativity*. New York: Oxford University Press.
- Paunonen, S. (1991). On the accuracy of ratings of personality by strangers. *Journal of Personality and Social Psychology*, 61(3), 471–477.
- Picascia, S. & Paolucci, M. (2010). Diffusion of culture and the "PageRank effect". In A. Ernst & S. Kuhn (Eds.), *Proceedings of the 3rd World Congress on Social Simulation WCSS2010* (pp. 1–10; CD-ROM). Kassel, Germany: Center for Environmental Systems Research, University of Kassel.
- Pierce, J. (1980). *An introduction to information theory. Symbols, signals & noise*. New York: Dover Publications, Inc.
- Piirto, J. (2004). *Understanding creativity*. Scottsdale, Arizona: Great Potential Press.
- Plucker, J. & Renzulli, J. (1999). Psychometric approaches to the study of human creativity. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 35–62). Cambridge UK: Cambridge University Press.

- Polhill, G., Galan-Diaz, C., Gotts, N., Craig, T., Marshall, K., Sutherland, L., Kriel, A., & Fischer, A. (2010). The ODDness of modelling: Early experiences from a transdisciplinary modelling exercise. In A. Ernst & S. Kuhn (Eds.), *Proceedings of the 3rd World Congress on Social Simulation WCSS2010* (pp. 1–8; CD-ROM). Kassel, Germany: Center for Environmental Systems Research, University of Kassel.
- Polhill, J., Parker, D., Brown, D., & Grimm, V. (2008). Using the ODD protocol for describing three agent-based social simulation models of land-use change. *Journal of Artificial Societies and Social Simulation*, 11(23), 30.
- Popper, K. (1969). *Logik der Forschung [Logic of scientific discovery]*. Tübingen, Germany: J.C.B. Mohr (Paul Siebeck).
- Preisendörfer, B. (September 20, 2007). Der rote Mond [The red moon]. *Die Zeit [The Time]*, 39, p. 104.
- Preiser, W. (2006). Creativity research in German-speaking countries. In J. Kaufman & R. Sternberg (Eds.), *The international handbook of creativity* (pp. 167–201). Cambridge, UK: Cambridge University Press.
- ProQuest Dissertations and Theses (2007). ProQuest Dissertations and Theses. Retrieved Sept. 24, 2007, from [<http://proquest.umi.com/login>].
- ProQuest Information and Learning (2004). Doctoral Dissertation Agreement Form D Intl. Ann Arbor, MI: Author.
- Queller, S. & Smith, E. (2002). Subtyping versus bookkeeping in stereotype learning and change: Connectionist simulations and empirical findings. *Journal of Personality and Social Psychology*, 82(3), 300–313.
- Randel, A., Jaussi, K., & Wu, A. (2011). When does being creative lead to being rated as creative? The moderating role of perceived probability of successfully bringing ideas to a supervisor's attention. *Creativity Research Journal*, 23(1), 1–8.
- Rausche, A. (1999). *Skript Quantitative Methoden A [Quantitative methods A, Instructor's script for students]*. Würzburg, Germany: Department of Psychology, University of Würzburg.
- Read, S. & Marcus-Newhall, A. (1993). Explanatory coherence in social explanations: A parallel distributed processing account. *Journal of Personality and Social Psychology*, 65(3), 429–447.
- Reichenbach, H. (1938). *Experience and prediction. An analysis of the foundations and structure of knowledge*. Chicago: University of Chicago Press.
- Richards, R. (1977). The natural selection model of conceptual evolution. *Philosophy of Science*, 44(3), 494–501.

- Rietzschel, E., Nijstad, B., & Stroebe, W. (2006). Productivity is not enough: A comparison of interactive and nominal brainstorming groups on idea generation and selection. *Journal of Experimental Social Psychology*, 42, 244–251.
- Rietzschel, E., Nijstad, B., & Stroebe, W. (2010). The selection of creative ideas after individual idea generation: Choosing between creativity and impact. *British Journal of Psychology*, 101, 47–68.
- Rigney, D. (2001). *The metaphorical society: An invitation to social theory*. Lanham, MD: Rowman & Littlefield.
- Roby, T. & Budrose, C. (1965). Pattern recognition in groups: Laboratory and simulation studies. *Journal of Personality and Social Psychology*, 2(5), 648–653.
- Runco, M. (1991). *Divergent thinking*. Norwood, NJ: Ablex.
- Runco, M. (1997). *The creativity research handbook (Vol. I)*. Cresskill, NJ: Hampton Press.
- Runco, M. (2004a). Creativity. *Annual Review of Psychology*, 55, 657–687.
- Runco, M. (2004b). Everyone has creative potential. In R. Sternberg, E. Grigorenko, & J. Singer (Eds.), *Creativity: From potential to realization* (pp. 21–30). Washington, D.C.: American Psychological Association.
- Runco, M. (2007). *Creativity. Theories and themes: Research, development, and practice*. Burlington, MA: Elsevier Academic Press.
- Runco, M. & Albert, R. (2010). Creativity research: A historical view. In J. Kaufman & R. Sternberg (Eds.), *The Cambridge handbook of creativity* (pp. 3–19). New York: Cambridge University Press.
- Runco, M. & Albert, R., Eds. (2011). *Theories of creativity. Perspectives on creativity series*. Hampton Press; *in press*.
- Runco, M., McCarthy, K., & Svenson, E. (1994). Judgments of the creativity of artwork from students and professional artists. *The Journal of Psychology*, 128(1), 23–31.
- Runco, M. & Pritzker, S., Eds. (2011). *Encyclopedia of creativity (2nd Ed.)*. Academic Press.
- Saam, N. (2005). Modellbildung [Building models]. In S. Kühl, P. Strodtholz, & A. Taffertshofer (Eds.), *Quantitative Methoden der Organisationsforschung [Quantitative methods in organizational research]* (pp. 190–209). Wiesbaden, Germany: Verlag für Sozialwissenschaften.

- Sargent, R. (2005). Verification and validation of simulation models. In M. Kuhl, N. Steiger, F. Armstrong, & J. Joines (Eds.), *Proceedings of the 2005 Winter Simulation Conference* (pp. 1–14). Retrieved April 29, 2011, from [<http://www.informs-sim.org/wsc05papers/014.pdf>].
- Satzinger, J., Garfield, M., & Nagasundaram, M. (1999). The creative process: The effects of group memory on individual idea generation. *Journal of Management Information Systems*, 15(4), 143–160.
- Savelle, M. (1957). Is liberalism dead? *The Historian*, 20(1), 3–23.
- Sawyer, R. (2006). *Explaining creativity. The science of human innovation*. New York: Oxford University Press.
- Schelling, T. (1971). Dynamic models of segregation. *Journal of Mathematical Sociology*, 1(2), 143–186.
- Schnell, R. (1990). Computersimulation und Theoriebildung in den Sozialwissenschaften [Computer simulation and building theories in the social sciences]. *Kölner Zeitschrift für Soziologie und Sozialpsychologie* [*The Cologne Journal of Sociology and Social Psychology*], 42(1), 109–128.
- Schuler, H. & Görlich, Y. (2006). *Kreativität: Ursachen, Messung, Förderung und Umsetzung in Innovation* [*Creativity: Causes, Assessment, Promotion and Transformation to Innovation*]. Göttingen, Germany: Hogrefe.
- Schumpeter, J. (1947). The creative response in economic history. *Journal of Economic History*, 7(2), 149–159.
- Shalley, C. & Zhou, J. (2007). Organizational creativity research: A historical overview. In J. Zhou & C. Shalley (Eds.), *Handbook of organizational creativity* (pp. 3–32). New York: Lawrence Erlbaum Associates.
- Shannon, C. (1948). A mathematical theory of communication. *The Bell System Technical Journal*, 27, 379–423, 623–656.
- Shoda, Y., LeeTiernan, S., & Mischel, W. (2002). Personality as a dynamical system: Emergence of stability and distinctiveness from intra- and interpersonal relations. *Personality and Social Psychology Review*, 6(4), 316–325.
- Silvia, P. (2008). Discernment and creativity: How well can people identify their most creative ideas? *Psychology of Aesthetics, Creativity, and the Arts*, 2(3), 139–146.
- Silvia, P. (2011). Subjective scoring of divergent thinking: Examining the reliability of unusual uses, instances, and consequences tasks. *Thinking Skills and Creativity*, 6, 24–30.

- Sim, J. & Wright, C. (2005). The kappa statistic in reliability studies: Use, interpretation, and sample size requirements. *Physical Therapy*, 85, 257–268.
- Simon, F. (2008). *Einführung in Systemtheorie und Konstruktivismus [Introduction to systems theory and constructivism]*. Heidelberg, Germany: Carl-Auer-Systeme Verlag.
- Simon, H. (1985). What we know about the creative process. In R. Kuhn (Ed.), *Frontiers in creative and innovative management* (pp. 3–20). Cambridge, MA: Ballinger Publishing Co.
- Simonton, D. (1998). Donald Campbell's model of the creative process: Creativity as blind variation and selective retention. *Journal of Creative Behavior*, 32, 153–158.
- Simonton, D. (2002). Underrepresented populations in creativity research. *Creativity Research Journal*, 14(2), 279–280.
- Simonton, D. (2003). Scientific creativity as constrained stochastic behavior: The integration of product, person, and process perspectives. *Psychological Bulletin*, 129(4), 475–494.
- Simonton, D. (2004). Creativity as a constrained stochastic process. In R. Sternberg, E. Grigorenko, & J. Singer (Eds.), *Creativity. From potential to realization* (pp. 83–102). Washington, D.C.: American Psychological Association.
- Skinner, B. (1972). A lecture on "having" a poem. In B. Skinner (Ed.), *Cumulative record: A selection of papers* (pp. 345–355). New York, Appleton-Century-Crofts.
- Smith, E. & Conrey, F. (2007). Agent-based modeling: A new approach for theory building in social psychology. *Personality and Social Psychology Review*, 11(1), 87–104.
- Smith, E. & DeCoster, J. (1998). Knowledge acquisition, accessibility, and use in person perception and stereotyping: Simulation with a recurrent connectionist network. *Journal of Personality and Social Psychology*, 74(1), 21–35.
- Smith, G. (2008). The creative personality in search of a theory. *Creativity Research Journal*, 20(4), 383–390.
- Smith, R. (1968). Heuristic simulation of psychological decision processes. *Journal of Applied Psychology*, 52(4), 325–330.
- Spellerberg, I. & Fedor, P. (2003). A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the "Shannon-Wiener" Index. *Global Ecology & Biogeography*, 12, 177–179.
- Stasser, G. (1988). Computer simulation as a research tool: The DISCUSS model of group decision making. *Journal of Experimental Social Psychology*, 24(5), 393–422.



- Stasser, G. & Taylor, L. (1991). Heuristic simulation of psychological decision processes. *Journal of Personality and Social Psychology*, 60(5), 675–684.
- Stasser, G. & Vaughan, S., Eds. (1996). *Models of participation during face-to-face unstructured discussion*. Mahwah, NJ: Lawrence Erlbaum.
- Stasser, G., K. N. & Davis, J. (1989). Influence processes and consensus models in decision-making groups. In P. Paulus (Ed.), *Psychology of group influence* (pp. 279–326). Hillsdale, NJ: Lawrence Erlbaum.
- Sternberg, R. (1999a). *Handbook of creativity*. Cambridge, UK: Cambridge University Press.
- Sternberg, R. (1999b). A propulsion model of types of creative contributions. *Review of General Psychology*, 3(2), 83–100.
- Sternberg, R. (2006). Creating a vision of creativity: The first 25 years. *Psychology of Aesthetics, Creativity and the Arts*, 1, 2–12.
- Sternberg, R. & Davidson, J., Eds. (1995). *The nature of insight*. Cambridge, MA: MIT Press.
- Sternberg, R., Grigorenko, E., & Singer, J., Eds. (2004). *Creativity. From potential to realization*. Washington, D.C.: American Psychological Association.
- Sternberg, R. & Lubart, T. (1996). Investing in creativity. *American Psychologist*, 51(7), 677–688.
- Sternberg, R. & Lubart, T. (1999). The concept of creativity: Prospects and paradigms. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 3–15). Cambridge, UK: Cambridge University Press.
- Stokes, P. (1999). Learned variability levels: Implications for creativity. *Creativity Research Journal*, 12(1), 37–45.
- Stokes, P. (2001). Variability, constraints, and creativity. Shedding light on Claude Monet. *American Psychologist*, 56(4), 355–359.
- Stokes, P. (2007). Using constraints to generate and sustain novelty. *Psychology of Aesthetics, Creativity, and the Arts*, 1(2), 107–113.
- Stokes, P. & Fisher, D. (2005). Selection, constraints, and creativity case studies: Max Beckmann and Philip Guston. *Creativity Research Journal*, 17(1), 283–291.
- Streicher, B., Frey, D., Jonas, E., & Maier, G. (2009). Der Einfluss organisationaler Gerechtigkeit auf innovatives Verhalten [The influence of organizational justice on innovative behavior]. In E. Witte & C. Kahl (Eds.), *Sozialpsychologie der Kreativität und Innovation [The social psychology of creativity and innovation]* (pp. 101–119). Lenrich, Germany: Pabst Science Publishers.

- Styhre, A. (2006). Organization creativity and the empiricist image of novelty. *Creativity and Innovation Management*, 15(2), 143–149.
- Taber, C. & Timpone, R. (1996). *Computational modelling*. Thousand Oaks, CA: Sage.
- Tatarkiewicz, W. (1980). *A history of six ideas*. Warsaw, Poland: PWN (Polish Scientific Publishers).
- Taylor, I. (1975). An emerging view of creative actions. In I. Taylor & J. Getzels (Eds.), *Perspectives in creativity* (pp. 297–325). Chicago: Aldine.
- Troitzsch, K. (2004). Validating simulation models. *Proceedings of the 18th European Simulation Multiconference*, (pp. 1–6).
- Tucker, P. & Smith, D. (1999). Simulating household waste management behaviour. *Journal of Artificial Societies and Social Simulation*, 3(3), retrieved October 20, 2010, from [<http://jasss.soc.surrey.ac.uk/3/3/1.html>].
- Turner, S. (1994). *The creative process: A computer model of storytelling and creativity*. Hillsdale, NJ: Erlbaum.
- Ueckert, H. (1983). Computer-Simulation. In J. Bredenkamp & H. Feger (Eds.), *Enzyklopädie der Psychologie. Themenbereich B: Methodologie und Methoden. Serie I: Forschungsmethoden der Psychologie. Band 5: Hypothesenprüfung [Encyclopedia of psychology. Subject: Methodology and methods. Series I: Research methods in psychology. Volume V: Hypothesis testing]* (pp. 530–616). Göttingen, Germany: Hogrefe.
- Unger, D. & Witte, E. (2007). Virtuelle Teams - Geringe Kosten, geringer Nutzen? Zur Leistungsverbesserung von Kleingruppen beim Problemlösen durch elektronische Medien [Virtual teams - Low costs, small benefits? On improving small group performance with the aid of electronic moderation]. *Gruppendynamik und Organisationsberatung [Group Dynamics and Organization Consulting]*, 38(2), 165–182.
- Valentine, E. (1992). Models and computer simulation. In E. Valentine (Ed.), *Conceptual issues in psychology* (pp. 131–146). New York: Routledge.
- van den Besselaar, P. & Leydesdorff, L. (2009). Past performance, peer review, and project selection: A case study in the social and behavioral sciences. *Research Evaluation*, 21(4), 273–288.
- van Overwalle, F. & Jordens, K. (2002). An adaptive connectionist model of cognitive dissonance. *Personality and Social Psychology Review*, 6(3), 204–231.
- Vandervert, L., Schimpf, P., & Liu, H. (2007). How working memory and the cerebellum collaborate to produce creativity and innovation. *Creativity Research Journal*, 19, 1–18.

- Ward, T., Smith, S., & Finke, R. (1999). Creative cognition. In R. Sternberg (Ed.), *Handbook of creativity* (pp. 189–212). Cambridge, UK: Cambridge University Press.
- Watson, J. & Crick, F. (1953). Molecular structure of nucleic acids. *Nature*, 171, 737–738.
- Wehner, L., Csikszentmihalyi, M., & Magyari-Beck, I. (1991). Current approaches used in studying creativity: An exploratory investigation. *Creativity Research Journal*, 4(3), 261–271.
- Welling, H. (2007). Four mental operations in creative cognition: The importance of abstraction. *Creativity Research Journal*, 19, 163–177.
- Westmeyer, H. (1998). The social construction and psychological assessment of creativity. *High Ability Studies*, 9(1), 11–21.
- Westmeyer, H. (2001). Kreativität: Eine relationale Sichtweise [Creativity: A relational perspective]. In E. Stern & J. Guthke (Eds.), *Perspektiven der Intelligenzforschung [Perspectives on intelligence research]* (pp. 233–249). Lengerich, Germany: Pabst Science Publishers.
- Westmeyer, H. (2008). Das Kreativitätskonstrukt [The creativity construct]. In M. Dresler & T. Baudson (Eds.), *Kreativität [Creativity]* (pp. 21–30). Stuttgart, Germany: S. Hirzel Verlag.
- Westmeyer, H. (2009). Kreativität als relationales Konstrukt [Creativity as a relational construct]. In E. Witte & C. Kahl (Eds.), *Sozialpsychologie der Kreativität und Innovation [The social psychology of creativity and innovation]* (pp. 11–26). Lengerich, Germany: Pabst Science Publishers.
- Westwood, R. & Low, D. (2003). The multicultural muse: Culture, creativity and innovation. *International Journal of Cross Cultural Management*, 3, 235–239.
- Wilensky, U. (1999). *Netlogo*. Evanston, IL: Center for Connected Learning and Computer-Based Modeling, Northwestern University. Retrieved October 20, 2010, from [<http://ccl.northwestern.edu/netlogo/>].
- Wilke, H. (2000). *Systemtheorie I: Grundlagen [Systems theory I: Basics]*. Stuttgart, Germany: Lucius & Lucius.
- Witte, E. (1989). *Sozialpsychologie [Social psychology]*. Munich, Germany: Psychologie-Verlags-Union.
- Witte, E., Ed. (1990). *Sozialpsychologie und Systemtheorie [Social psychology and systems theory]*. Braunschweig, Germany: Copy-Center Colmsee.

- Witte, E. (1991). Eine Systematisierung intendierter Anwendungsformen für sozialwissenschaftlich-psychologische Theorien [Systematizing methods for social science and psychological theories]. *Ethik und Sozialwissenschaften [Ethics and Social Science]*, 2(1), 123–133.
- Young, J. (1971). *Information theory*. London: Butterworth & Co Ltd.
- Zhou, J. & Shalley, C., Eds. (2007). *Handbook of organizational creativity*. New York: Lawrence Erlbaum Associates.
- Zysno, P. & Bosse, A. (2009). Was macht Gruppen kreativ? [What makes groups creative?]. In E. Witte & C. Kahl (Eds.), *Sozialpsychologie der Kreativität und Innovation [The social psychology of creativity and innovation]* (pp. 120–150). Lengrich, Germany: Pabst Science Publishers.

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Eidesstattliche Erklärung nach §9 Abs. 1, Nr. d der Promotionsordnung zur Doktorin / zum Doktor der Philosophie oder der Naturwissenschaften des Fachbereichs Psychologie der Universität Hamburg vom 03. Februar 2004

Hiermit erkläre ich an Eides statt, dass ich die vorliegende Arbeit selbständig und ohne fremde Hilfe verfasst habe. Andere als die angegebenen Quellen und Hilfsmittel habe ich nicht benutzt und die wörtlich oder inhaltlich übernommenen Stellen als solche kenntlich gemacht.

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