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Striving towards Coherence in Decision-Making: Theoretical and Computational Models

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"In our description of nature the purpose is not to disclose the real essence of phenomena, but only to track down as far as possible relations between the multifold aspects of our experience."

Niels Bohr

Contents

Acknowledgments

To my family for their everlasting love and comfort.

To my friends without I would be nothing.

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To my supervisor Dr. Andrej Ule, for the vast commitment and support.

Preface

"Howard Raiffa is one of the founders of mathematical decision theory. One day Raiffa encounters Ernest Nagel, a distinguished philosopher of science and expert on probability theory outside his office at Columbia University, muttering: "What shall I do?" When Nagel asked him what the problem was, Raiffa said that he had a job offer and couldn't decide whether to take it. Trying to be helpful, Nagel said to Raiffa: "Howard, you're one of the world's experts on decision making. Why don't you draw up the decision tree of all the possible actions and outcomes, use probabilities to calculate expected utilities, and decide?"
Raiffa replied with annoyance: "Ernest, this is serious!""

Thagard (2010, p. 119, analogously)

The fascination of decision-making

The phenomenon has been subject of much debate within a variety of domains ranging from finance, psychology, artificial intelligence to legal affairs.
It is difficult to gain all-encompassing knowledge on the state-of-the-art of research within the respective discipline or to even get a comprehensive overview of the vast amount of accumulated literature regarding the phenomenon and I do not attempt myself in doing so here.
Alternatively, I will touch upon a few distinct aspects with the aim to elaborate on essential features of decision-making in rather complex situations that demand a combination of both, automatic and deliberate processes of thought.

Interdisciplinary aspects and scope

Within this interdisciplinary account of decision-making I argue analogously to Paul Thagard (see for example Thagard (2000)) in favor of a cognitive naturalistic viewpoint, tying together philosophy with psychology, while capitalizing on computational ideas.

First, I give an overview of different thought-process conceptions. Next, I focus on two fundamental distinct methodologies concerning the prediction and modeling possibilities of decision-making outcomes and behavior (*section 2*).

Although the outlined approaches have their validity, I then turn to the concept of coherence (*section 3*), its underlying mechanisms (*section 3.3*) and central role in decision-making.

I set forth my hypothesis with reference to the applicability and extension of coherence-based consistency maximizing principles as being key within complex decision-making circumstances. I call attention to take into account the interaction of conscious, and perhaps even more important, unconscious processes of thought (*section 4*). Further, I highlight psychological evidence from the literature which undermines the proposed hypothesis (*section 5*).

Importantly, I commit towards a critical discussion of the concept of coherence-based inference in the light of decision-making, focusing on its explanatory power of utilizing automatic- and unconscious moments within the process. I further highlight existing modeling approaches that point into similar directions (*section 6.2*).

Finally, I focus on normative questions from a philosophical viewpoint concerning *process philosophy* and engage in a speculative quantum theoretical-laden discussion on the role of *potentiality* and *actuality* in the light of decision-making. By this means I hope to further advance the discussion and contribute towards an enriched understanding of the phenomenon (*section 6.4*).

Limitations

In my elaborations I declare the following questions as out of scope:

- Are we free in our decisions?;
- Decision-making in the setting of moral dilemmas;
- Decision-making processes on a neurological level;
- Decision-making processes in AI expert systems;
- Bayesian probabilistic inference models;
- The nature of consciousness.

Chapter 1

Models and theories

"My first empirical proposition is that there is a complete lack of evidence that, in actual choice situations of any complexity, these [expected utility] computations can be, or are in fact, performed...but we cannot, of course, rule out the possibility that the unconscious is a better decision maker than the conscious."

Simon (1955, p. 104)

1.1 Evolution of decision-making

Philosophers, mathematicians and economists were about the first who developed theories regarding the prediction of decision-making outcomes. Especially in the seventeenth century research in this regard became more and more popular, being grounded foremost within probabilistic theories of gambling, initiated by Blaise Pascal and Pierre Fermat. Their initial idea was to maximize the long run average value or expected value EV where p stands for probability and x for the objective outcome for some number of outcomes n (Busemeyer and Johnson, 2003).

$$EV = \sum (p_j * x_j)$$

Equation 1.0. Formula to maximize the long run average value or expected value EV (Busemeyer and Johnson, 2003).

These theories regarding behavior of decision-making understand humans as explicit rational beings who consciously anticipate consequences, evaluate risks and values and eventually decide after a careful analysis of the expected utility (Glöckner and Betsch, 2008).

Nowadays, however, it seems to be intuitive and to a certain extend clear that humans' natural decision-making abilities somewhat differ from that conception. It is hard to imagine life by strictly applying the principles of maximizing expected utilities, if one would always have to consider all possible alternatives and every consequence that follows before making a decision.

Despite the controversy that the rational tenet brings with, it dictated the field of decision research for centuries.

Herbert A. Simon, the co-founder of Artificial Intelligence and Nobel laureate, was among the first who challenged the common established assumption of people's rationality in behavior. Simon doubted that humans recognize all of their possible choices and the consequences of each selection. He claims that regarding to his observations, the "Rational Economic Man" does not exist (Simon, 1955). Simon argues that people do not choose the expected best option every single time they come to a decision simply due to limitations of human cognitive abilities.
Regarding to Simon's view, people use simple methods to do decisions based on *bounded rationality* (Simon, 1982; Augier and Feigenbaum, 2003).
It follows that decision makers use simple strategies in order to reduce the amount of information as well as the number of cognitive operations respectively to provide shortcuts within people's deliberations (Glöckner and Betsch, 2008).

The use and nature of a model Before I proceed delineating different modeling approaches, I will shed some light on the term itself.
A model is simpler and at the same time more abstract then the system or phenomenon in reality that is being modeled. Modeling makes good sense being applied in situations where the item in question is just too complex, difficult or even impossible to be directly dealt with; models can serve as an instrument of investigation since they allow keeping system's essential features while omitting unnecessary details (Fum et al., 2007).

Taken together, findings and results of model investigations support the better understanding of what actually is being modeled.
One interesting characteristic of researching decision-making is that there are plenty

of different views on the topic and people tend to focus on different aspects of the phenomenon. It is essential to consider where and how to frame the object of interest. This in turn has bold implications for the applied modeling approach and the interpretation of results.

In the next section I will give an overview of two widely acknowledged, and at the same time fundamental, methodologies of modeling decision-making.

1.2 Utility theories

Since behavioral sciences get more and more interested into the field of decision-making, the phenomenon itself is becoming more behavioral, more psychological and more descriptive as well. Nevertheless its boundaries and major theoretical concerns are still related to the historically dominant Expected Utility family of theories (Hastie, 2001).

The two fundamental conditions of utility based models are *a.)* they do not object to describe the actual psychological process underlying a decision and *b.)* they focus mostly on the selectional phase of the decision process to predict specifically the outcome of a decision (Betsch et al., 2002).

Von Neumann and Morgenstern (1944) advanced Daniel Bernoulli's 1738 proposed approach (see for example Polasek (2000)) to replace the expected outcome x_i by the subjective utility of this outcome $U(x_i)$ and claimed one should maximize the Expected Utility Value $EV=\sum p_j * U(x_j)$ when making a decision, because of strong limitations of the initial Expected Value maximization idea.

Importantly, Kahneman and Tversky (1979) advanced Subjective Utility Theory into *Prospect Theory* which later was extended into *Cumulative Prospect Theory* (Tversky and Kahneman, 1992) by introducing "rank-dependent" decision-weights. Prospect Theory made it possible to explain for example why people are simultaneously attracted towards insurance and gambling. This phenomenon as an example cannot be explained by Expected Utility Theory.

One of the fundamental differences of Prospect Theory in contrast to Utility Theory is the replacement of the term "utility" with "value". This has significant impact on the predicted outcome since utility functions measure just the net wealth of a benefit, whereas “value” is bounded to the concept of gain and loss. By taking a closer look one can identify that the value function for gains on the right hand side is less steep and concave, whereas the loss function is steeper and convex in comparison.

$$U = w(p_1) * v(x_1) + w(p_2) * v(x_2) + \ldots$$

Equation 1.1. Prospect Theory function where x_1, x_2 are the potential outcomes and p_1, p_2 the corresponding probabilities, v is the s-shaped value function and w corresponds to the probability weighting function (Kahneman and Tversky, 1979).

This implicates that for people it is not the same in terms of relative scale to win 100$ or to loose 100$. Loosing 100$ is felt much more in comparison than winning 100$.

Next, it is important to notice that gains and losses are relative to some functions’ reference point that may vary from situation to situation.
Another major difference to the Expected Utility approach is that Prospect Theory handles probabilities not in probabilities but in “decision-weights”. It assumes that these weights do not always correspond to probabilities. Specifically, Prospect Theory postulates that decision weights tend to overweight small probabilities and underweight moderate and high probabilities (Plous, 1993).

Limitations Even though Utility Theories have developed remarkably from the first ideas of rationality towards the much improved (cumulative) Prospect Theory, there are still strong limitations regarding their usage and power to predict or explain the behavior of human decision-making.

In the following I point out some major issues and paradoxes regarding human decision-making capabilities which remain challenging for utility models.

Hastie (2001) describes two major issues coming along concerning the Expected Utility framework, namely *incompleteness* as well as *lack of valid description* of decision-making processes.

Further, the author argues that many aspects of the decision process lie outside of this analysis. No statements are made about how the decision situation is comprehended or what sources feed into the process. Hastie (2001) delineates that the utility framework focuses mainly on the outcome of a decision and therefore lacks to describe the detailed underlying mechanisms responsible for the decision.

Next, the vital aspect of *context-dependent preferences* is being discussed. This class of *human choice paradox* set forth that decisions are not only depended on changes in the *task*, but also in *changes in the context* produced by the choice set for a single task (Busemeyer and Johnson, 2003). At the same time these preference reversals involve violations of a principle called *independence from irrelevant alternatives* (Busemeyer and Johnson, 2003).

Essentially, the principle is used widely by many different utility approaches. Generally speaking, it assumes that if an option A is chosen more frequently over a second option B, then the first option would also be chosen more often over option B in a larger choice set, like for example if there is an additional option C.
However there is compelling evidence that this is in fact not the case. Busemeyer and Johnson (2003) outlines three well known paradoxes that violate the principle of independence. Those include the:

- similarity effect,
- attraction effect,
- compromise effect.

In the following part the three paradoxes are explained and illustrated.

Similarity effect The similarity effect as shown in Figure 1.2 on page 6 is the first paradox initially described by Tversky (1972). It describes how two similar options hurt each other in terms of the probability being chosen compared to a different option B. This happens even if the probability of the choice between A or B (without S) is equal and between S and B (without A) is equal as well.

In this example buying one car out of three options (depending on different parameters) is being considered (Busemeyer et al., 2007, analogously).
Let's assume there is only car A and car B which are pretty different regarding the

parameters "economy" and "quality". The probability of being chosen is equal. By adding an additional option (car S) that is similar to car A, the probability of buying car A decreases in contrast to car B because the similar option S hurts option A.

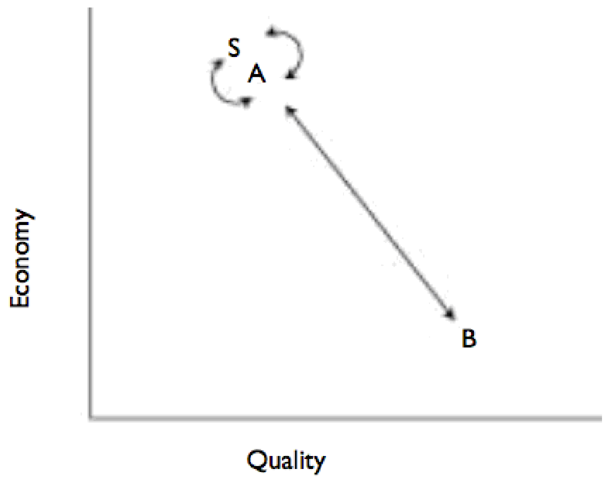

Figure 1.1: The similarity effect (Tversky, 1972).

Attraction effect The attraction effect as shown in Figure 1.2 on page 7 violates the rational principle of regularity. That is, in a choice set of A and B the additional option C would either leave the probability of A and B untouched (in the case C is never chosen) or it would decrease the probability of A and B in a similar way (C is sometimes chosen).

However the attraction effect shows that the opposite is the case. Ariely (2008) delineates the effect comprehensively by an example where two choice sets are available with three faces containing either a slightly uglier version of Jerry (Jerry') or a slightly uglier version of Tom (Tom'). In his experiment people were asked to choose whom they would like to date. The question was: would the similar, but slightly uglier "brothers" that are also dominated by Tom or Jerry would help them being dated? The results say absolute yes. If ugly Jerry' was present Jerry was more popular, if ugly Tom' was available, Tom was more popular. This irrational behavior of human decision-making has distinct impacts on live in general, like for example if you ask yourself whom to take with you if you are going bar crawling (Ariely, 2008).

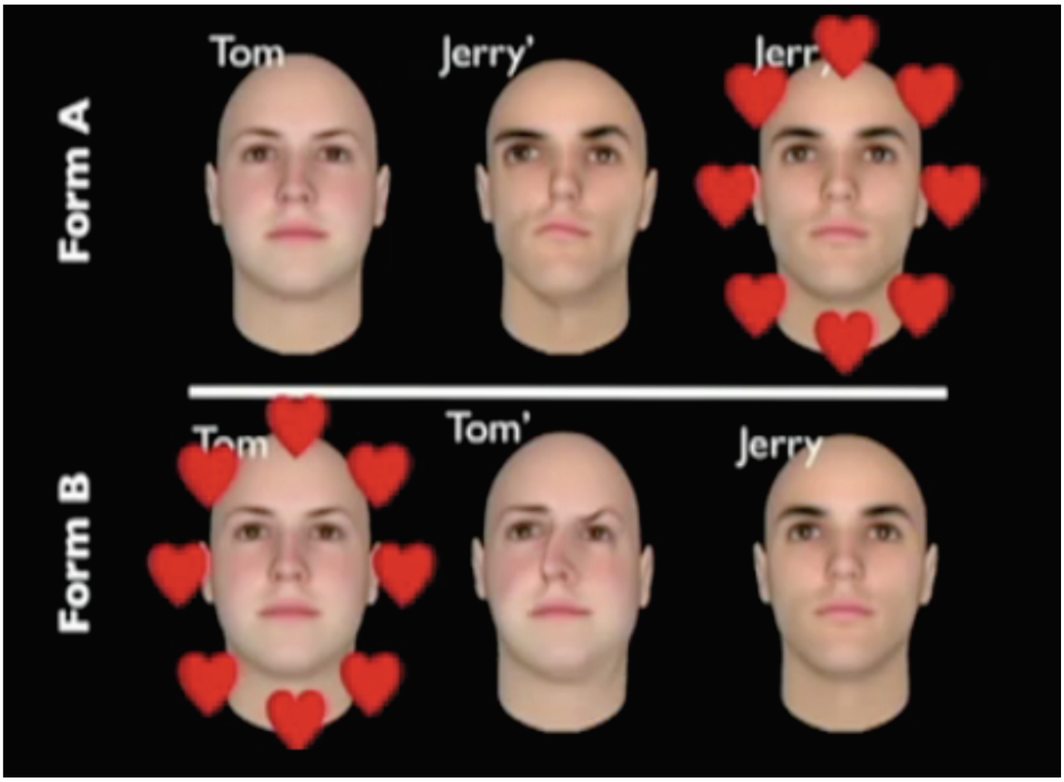

Figure 1.2: The attraction effect illustrated by this "similar faces" example (Ariely, 2008).

Compromise effect This effect as shown in Figure 1.3 on page 8 is another violation of the principle of independence from irrelevant alternatives. The effect occurs if there are two equal likely options B and C, and a more extreme option A is added making C the middle option. In that case it reveals that option C becomes more popular and likely being chosen in contrast to option B.

Heuristic rule-based systems A prominent family of Utility Theory which is subject to much ongoing debate, as we will further discuss in *section 6.1*, are heuristics.

These rule-based systems ground within the above delineated picture of Herbert Simon and his proposed approach to "bounded rationality" (Simon, 1982). Accord-

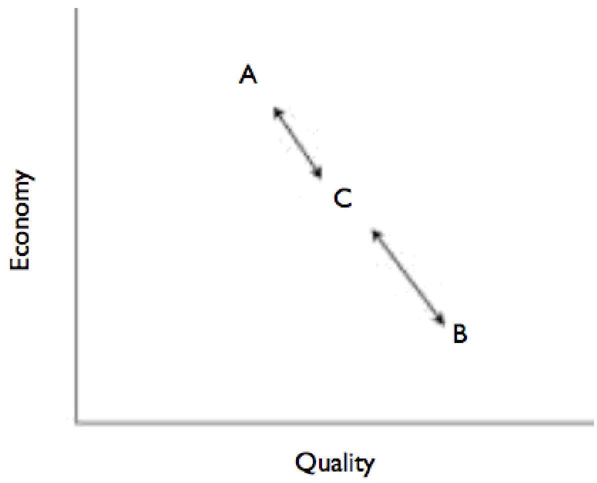

Figure 1.3: The compromise effect as outlined by (Busemeyer et al., 2007).

ingly, people use simple strategies or heuristics that reduce the amount of information given and the number of cognitive operations when they choose or decide. Heuristics therefore can be seen as mental shortcuts towards decisions.

It is assumed that people use heuristic rules as strategies depending on the given situation. Thus, it is assumed that one would use a cognitive less intensive strategy finding a decision in any situation involving for example extreme time pressure or when addressing trivial problems. On the other hand in important situations the decision-maker would use a mentally more demanding heuristic to achieve better performance and more accurate "thought-through" results.

Taken together, heuristic rule-based approaches apply decision selection as a trade-off between mental effort required to apply the strategy and the overall accuracy of the selected strategy (Busemeyer and Johnson, 2008).

Well known examples of heuristics are the *lexicographic rule, LEX* (Fishburn, 1974) which is concerned only about the most important feature, the *equal-weight strategy, EQW* (Payne et al., 1988) which essentially evaluates and weights different alternatives but neglects differences in probability or significance, and the "take the best" strategy (Gigerenzer and Goldstein, 1996; Gigerenzer et al., 1999) where rules can be defined for information search, search stopping and option selection.

The advantage of heuristic rule-based strategies are that they are capable of explaining different effects when making decisions under time pressure or with less/ more effort.

It seems that these sensible estimation procedures are "irrational" since heuristics appear to be "quick and dirt" solutions, but may draw on highly sophisticated underlying processes like memory retrieval or feature matching; consequentially heuristic processes are not extraordinary responses to problems of huge complexity or an overload of information, but normal intuitive responses to even the simplest questions about likelihood and prediction (Gilovich et al., 2002).

On the other hand, however, heuristics lack to account for choice paradoxes like for example the previously described compromise or attraction effect. Further it is by no means always clear which strategy the decision-maker has been using in a given situation.

1.3 Computational models

Utility models were undoubtedly successful in aforementioned specific domains to predict decision outcomes. Yet the utility framework remains challenging. It faces ongoing criticism mainly from behavioral sciences where there is increasing evidence about the existence of a variety of factors that are inevitable for the human decision-making *process*. These are for example emotional evaluation, unconscious processing or the relevance of people's underlying goals or beliefs within (see for example Damasio (1994); Dijksterhuis and Nordgren (2006); Thagard (2000)). Those criteria have been widely ignored or left out within utility theoretical considerations.

Therefore computational models follow a different modeling approach, namely to focus on decision-making *behavior* rather than just on the *outcome* of the decision. In this sense computational models to some extend "behave" themselves which can be described and measured.

The connectionist approach In contrast to the aforementioned utility framework, connectionism aims to describe behavioral phenomena as an emergent processes that results from an interconnected network (see for example McClelland and

Rumelhart (1986); Hopfield (1982); Read et al. (1997).

Behavioral phenomena may also be referred to as mental phenomena. One of the central principles of connectionism is that mental phenomena may in fact be described by a network model which consists of neuron-like, simple units. Those units can vary greatly in their amount but are richly interconnected and capable to send signals to connected neighbors determined by their current level of activation.

There are different kinds of connectionist models. The most well known are perhaps distributed connectionist models of mental representations which are also known as parallel distributed processing, or artificial neural network models (McClelland and Rumelhart, 1986). It is important to note that none of the single units represent a meaningful concept by itself. Rather it is the overall interplay of the network with its activated units where activation pattern emerge. In this way meaningful concepts can be represented.

Accordingly, Thomas and McLelland (2008) identify within *The Cambridge Handbook of Computational Psychology* four connectionist key aspects, namely:

- that processing is simultaneously influenced by multiple sources of information at different levels of abstraction, operating vi-soft constraint satisfaction;
- that representations are spread across multiple simple processing units operating in parallel;
- that representations are graded, context sensitive, and the emergent product of adaptive processes;
- that computations similarity-based and driven by the statistical structure of problem domains, but it can nevertheless produce rule-following behavior.

Ule (2012) gives a compelling and depictive account of the theoretical applicability of a connectionist approach to model mental phenomena. From the author's explanations it follows how artificial neuronal networks approach to some extend cognitive processing within a "conscious brain":

> "We can thus conceive of the human mental structure as a dynamic system which is incredibly sensitive to different aspects of events in the world. We can comprehend this sensitivity as the permanent restoration

> of structural similarity between the informative aspects of change that a conscious being is aware of and its mental states.
> In order to do that, the "conscious brain" must be enormously flexible to acquire similarities and differences between its own processes, processes in its body and outer processes which it is sensitive to. Some models of parallel distributed processing and neural network models (connectionist models) of the brain can help us with modeling that kind of flexibility. Connectionist models of cognitive processing incorporate a constant comparison of the behavior of outer objects ("targets") and the activity of an individual cognitive agent.
> These models contain different layers of "hidden" computation units or aggregates of units (e.g. neurons and groups of neurons) that are not directly connected to the environment and whose purpose is, in effect, to detect statistical patterns in the activity of the "visible" units (e.g. sensory inputs which "depict" the behavior of outer objects)" (Ule, 2012, p. 31).

The above considerations clearly outline the psychological plausibility of neuronal network models due to their close ties with the neuroscientific conception of the brain. At the same time the difference in methodology compared to a utility framework becomes evident.

Decision Field Theory Busemeyer and Johnson (2003) describes the decision process in the human brain as a mechanism of stimuli input accumulation towards a specific threshold. In this sense, the option which exceeds this threshold first is been chosen.

This idea is formalized in Decision Field Theory by Busemeyer and Johnson (2003) and represents one concrete example of a neuronal network model towards approaching human decision-making behavior inspired by neuroscientific findings. Thus, Decision Field Theory is a connectionist model of decision-making that behaves in regard to the stimulus accumulation principle. The underlying idea is shown in Figure 1.3 on page 12.

The illustration depicts the evaluation of three options that are considered. The threshold bound is shown in the upper graphic area whereas the options A, B and C are shown in the main part. Each option differs in its preference state at any

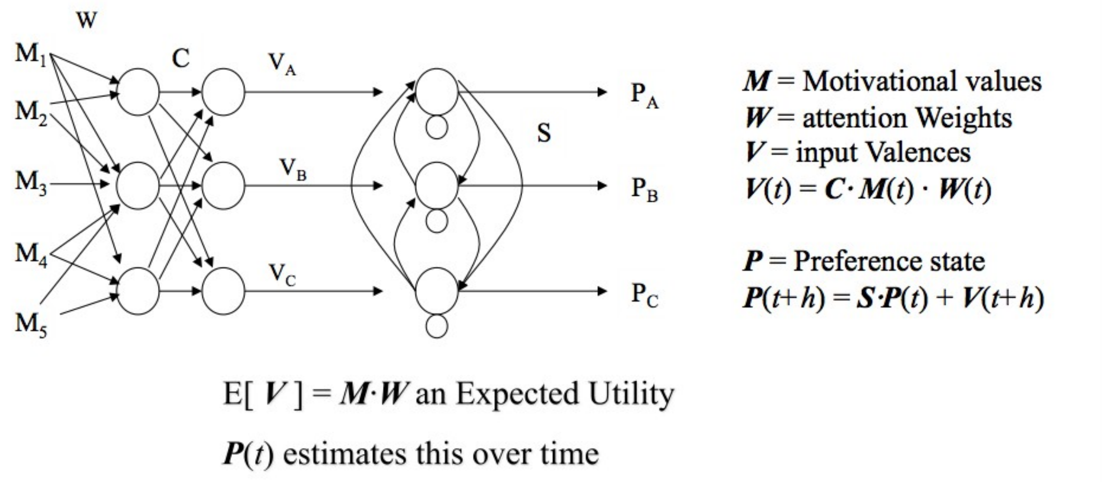

Figure 1.4: The connectionist Decision Field Theory model (Busemeyer and Johnson, 2003).

given time of deliberation through cognitive demanding option evaluation. As soon as one option exceeds the threshold bound, it is being chosen from the decision-maker. The high of threshold can vary regarding to the situation or the personality of the decision-maker. Is the latter for example characterized by impulsiveness, the threshold bound would be lower compared to the careful deliberation favoring decision-maker. The schematic structure of the neuronal network represents Decision Field Theory whereas the underlying formulas are given in Figure 1.3 on page 12.

In principle a first momentary attention-weighted evaluation of each of the options' payoff is evaluated at the first layer of nodes. By means of this the affective evaluation of each payoff is given by

$$U_i(t) = \sum W_{ij}(t) * m_j$$

Equation 1.2. Decision Field Theory where $W_{ij}(t)$ is the attention weight at time t for a payoff j offered by prospect i (Busemeyer and Johnson, 2003).

This process fluctuates over time. The second layer's responsibility is to evaluate and compare the different options' prospects and pay-offs regarding to their valence *V(t)* over time.

In the third layer, the valences are used as an input to a dynamical system that generates the preference state *P(t)* for a distinct option over time. Furthermore the principle of lateral inhibition within the network known from human physiologic structures (e.g. vision) serves as methodological tool of an important mechanism in describing context effects on preference (Busemeyer and Johnson, 2003).

Taken together, this described connectionist approach representing Decision Field Theory provides explanatory power of the human decision-making phenomenon that cannot be achieved by either algebraic utility models or simple heuristic models.
For instance, Decision Field Theory can account for all three context depended preferences (similarity-, compromise-, and attraction effect). Further it can explain the influence of time pressure regarding those effects.

Interestingly, these accumulation-to-threshold theories seem to be potent enough to play an important role in the rising field of neuroeconomics.
Recent studies are able to explain the phenomenon that people buy more in shops with less variety of choice than in shops with extensive product variety. This might be due to the demand of less mental effort when choosing one specific kind of product (Schwartz, 2005).

Chapter 2

Processes of thought within decision-making

"One might almost believe that half of our thinking takes place unconsciously . . . . I have familiarized myself with the factual data of a theoretical and practical problem; I do not think about it again, yet often a few days later the answer to the problem will come into my mind entirely from its own accord; the operation which has produced it, however, remains as much a mystery to me as that of an adding-machine: what has occurred is, again, unconscious rumination."

Schopenhauer (1973, p. 123-124)

2.1 Types of cognitive operations

Since decades researchers investigate human thinking and their underlying processes. A comprehensive unifying theory of human thought acknowledged by the scientific community seems not to be in reach yet for some time to come.
However there is wide agreement on the existence of two different systems of reasoning (see for example Sloman (1996) for an overview). This issue is still subject of ongoing debate in cognitive psychology and rises the following questions: Can human thinking be understood as parallel information processing along vague lines of associative connections? Or is it more the case that the nature of our thinking is based on serial and deliberate symbolic manipulation on mental representations?

2.1.1 Deliberate processes

The conception of the human as *"Homo Oeconomicus"* is the understanding that people act as rational decision-makers that constantly anticipate all possible alternatives to a decision problem, evaluate and weight their options accordingly – eventually deciding after a thorough analysis of the expected utility of each outcome option (see for example Van Der Rijt (2006)).
Needless to say this modus of decision-making includes the consumption of much resources as for example cognitive load and time. As mentioned above, Herbert Simon was among the first who doubted those rational models of choice behavior (see for example (Simon, 1955, 1982) for an overview). Based on his work, researchers identified many of specific heuristic strategies which people seem to use in order to reduce the demand of cognitive resources, operations and information necessary when deciding (see for example Beach and Mitchell (1978); Payne (1982); Gigerenzer et al. (1999); Payne et al. (1988); Gigerenzer (2004)).

Importantly, most of the decision-strategies brought forward by researchers in the field were concerned about deliberate processes of thought and information processing within the phenomenon and widely neglected the potential of automatic processes (see for example Frederick (2002)).

However it should be noted that Herbert Simon already speculated about the importantness of the automatic system nearly 60 years ago:

> "My first empirical proposition is that there is a complete lack of evidence that, in actual choice situations of any complexity, these rational computations can be, or are in fact, performed [...] but we cannot, of course, rule out the possibility that the un-conscious is a better decision maker than the conscious" (Simon, 1955, p. 104).

2.1.2 Automatic processes

It turned out that it would take the field of decision-making research another couple of decades in order to pay attention towards the unconscious, automatic component within the attempt to account for behavioral choice (see for example Damasio (1994); Finucane et al. (2000); Lieberman (2000); Hogarth (2001); Haidt (2001); Dougherty et al. (1999)).

It has been shown that the automatic system performs operations of quick and simultaneous information integration of various bits of information when people decide for example on the basis of recognition of a certain situation or by identifying rules of learned behavior (Klein, 1999).

Finucane et al. (2000) highlights that memory processes which are involved within affect-based decision-making are widely governed by the automatic system via feedback learning loops. Essentially, it is also assumed that the automatic system may not only guide operations of recognition, affect generation and activation of behavioral knowledge from memory, but may also direct subsequent processes that pertain to information integration and choice (Glöckner and Betsch, 2008).

As I will discuss in *section 3.2* and *section 6.2*, it is crucial to highlight that so-called *consistency maximizing models* assume the governing of the automatic system and processes of information integration and choice.

2.1.3 Dual-process theories

The question if we are living with *two minds in one brain* where one mind acts in accordance with the slow but holistically operating automatic system and another mind, governed by structured and deliberate thinking, has sparked much debate among researchers. The topic raised voices against (see for example Keren and Schul (2009)) or in favor (see for example Evans (2003)) of such a conception (see for example additionally Osman (2004) for an overview).

The existence of a “double-mind” are the assumption of dual-process theories which have been summarized within a two-systems framework (see for example Kahneman and Frederick (2002)). Within it has been assumed that the two systems, labeled as *System 1* and *System 2* by Stanovich and West (2000) serve different purposes.

System 1 is described as the evolutionary old part that comprises of a set of autonomous subsystems including both, innate input modules and domain-specific knowledge acquired by a domain-general learning mechanism; System 2 in comparison is evolutionarily recent and distinctively human. It permits abstract reasoning and hypothetical thinking capabilities, constrained by working memory capacity and correlated with measures of general intelligence (Evans, 2003).

Evans (2003) elaborates further on the interplay of System 1 and System 2:

> "The stream of consciousness that broadly corresponds to System 2 thinking is massively supplemented by a whole set of autonomous subsystems in System 1 that post only their final products into consciousness and compete directly for control of our inferences, decisions and actions. However, System 2 provides the basis for hypothetical thinking that endows modern humans with unique potential for a higher level of rationality in their reasoning and decision-making."

It follows that System 1 and System 2 are connected by two different cognitive systems with different distinctive process characteristics.
The characterization of those different processes is tricky business and far from simple. Kahneman and Frederick (2002) delineate the following overview (Table 2.1 on page 18) on which there has been reached considerable agreement (but see for example Marewski et al. (2009) for a critical elaboration on the practice of those categorizations).

System 1 (Intuitive)	**System 2 (Reflective)**
Process characteristics	
Automatic	Controlled
Effortless	Effortful
Associative	Deductive
Rapid, parallel	Slow, serial
Process opaque	Self-aware
Skilled action	Rule application
Content on which processes act	
Affective	Neutral
Causal propensities	Statistics
Concrete, specific	Abstract
Prototypes	Sets

Table 2.1: Two cognitive systems. Analogously to Kahneman and Frederick (2002).

For an additional comprehensive discussion on the interplay of the two systems see for example Plessner et al. (2007) or Glöckner and Witteman (2010). The arising key question becomes obvious: if there are really "two minds within one brain", how do this minds interact? And further, how can these interaction processes and their underlying mechanisms be adequately described and modeled?

This remains a challenging task indeed. In consequence one of the goals within this work is to capitalize on ways forward.

Chapter 3

The concept of coherence

"The coherentist approach, working within the theory of coherence as constraint satisfaction, is psychologically realistic and computationally feasible, yet it can contribute to the traditional goal of philosophy to be prescriptive as well as descriptive of human thought and action. Philosophy and cognitive science can thrive together in the twenty-first century."

Thagard (2000, p. 286)

3.1 Introduction into the subject

The following chapter describes the concept of coherence. Within, I outline the theory and mechanisms on which coherence is based upon within the light of decision-making research.

Over the past decades connectionist theories of cognition, and in particular constraint satisfaction mechanisms reformulated established consistency theories. Connectionist constraint-satisfaction models were first applied to lower-level cognitive processes and further advanced to be applied towards a variety of higher-level cognitive processes, including analogical mapping (Spellman et al., 1993), evaluation of competing explanations (Thagard, 1989, 1992) and decision-making (Thagard and Millgram, 1995; Thagard and Kroon, 2006).

Thagard and Millgram (1995) propose a coherence theory of decision. The theory conveys that people not only decide between specific decision options but base their decisions on a holistic set of complex concurring goals and actions in parallel.

Thagard (2000) proposes a general theory of coherence as the satisfaction of multiple interacting constraints and shows that the theory has numerous psychological and philosophical applications since much of human cognition can be understood in terms of coherent constraint satisfaction principles.
Within, Thagard discusses how people make sense of each other and the world they live in on the basis of fitting something puzzling into a coherent pattern of mental representations including propositions like concepts, beliefs, goals and actions.

Thagard's cognitive naturalistic viewpoint on coherence draws on the central hypothesis of cognitive science that thought can be understood in terms of computational procedures on mental representations. This approach strives towards an understanding of the mind in terms of rules, concepts, analogies, images and neural networks.

Coherence theory is about how different pieces fit together in order to form a whole. It assumes that there are various kinds of associations between the pieces or the elements of a set. Those are primarily positive or negative, where a positive association suggests that the two elements support each other while a negative association indicates their mutual exclusion.
Thagard views the associations as constraints between elements and proposes a theory of coherence as globally maximizing the satisfaction of those constraints. Generally speaking, Thagard sets forth to partition the set of elements into accepted or rejected ones so that overall coherence is achieved, or constraint satisfaction maximized (for a detailed description see *section 3.3*).

3.2 Cognitive consistency theories

The prominence of consistency theory and interrelated constraint satisfaction principles that undergo the concept of coherence as a paradigm to describe much of human behavior in a psychological plausible way – including decision-making – appears appealing but does not come by chance. As I will show in the following, connectionist modeling principles share striking similarities with cognitive consistency theories and "Gestalt" principles which mark a cornerstone in modern social psychology (for a comprehensive overview see for example Read et al. (1997) and Read et al. (2003)).

Cognitive consistency theories aim to shape the base for a theory of cognition in that Lewin (1935) for instance strives to develop a "psychology of knowing" (Rosenberg and Abelson, 1960). Within a framework can be found that would explain how "[...] one idea leads to another psychologically" (McGuire, 1960, p. 140).

3.2.1 Gestalt principles

In one of the initial pieces of work in the area of cognitive balance theory, Heider (1946) speculated that mutual interdependence amongst elements of thought forms states of *order* and *coherence* which undergo principles of structural dynamics:

> "These conceptions, symmetry, consonance, balance, and simplicity, are, of course, implied in that idea with which Gestalt theory started and which always was central to it, namely, the idea of a "good" figure [...] This model implies a number of different entities with certain properties and standing in certain relations, which make up a constellation of factors tending toward a standard state (Heider, 1960, p. 168)."

Coherence has been proposed to be a state within a dynamic system in which tension is at a minimum and different notions like consistence, balance, equilibrium or harmony have been suggested (Simon and Holyoak, 2002). Gestaltian figures illustrate that psychological processes act in distinct ways in that they increase the state of coherence within the system due to decreasing inconsistent factors.

Gestaltian figures A very prominent "good" figure within Gestalt psychology is the "Kanizsa Triangle" (Figure 3.1 on page 24) in which an illusionary white triangle appears to be on top of a black triangle and three black circles:

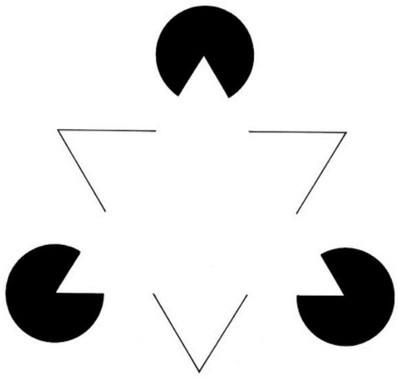

Figure 3.1: The Kanizsa Triangle illusion by Kanizsa (1955).

The illusion is often used to point out the principle that objects which are grouped together in a certain way are seen as a consistent whole. Thus, gaps within the figure are suppressed and illusionary contours are constructed by our brains.

Similar, the following Rabbit-duck illusion Figure 3.2 on page 24 is often used as a metaphor for consistency maximizing principles:

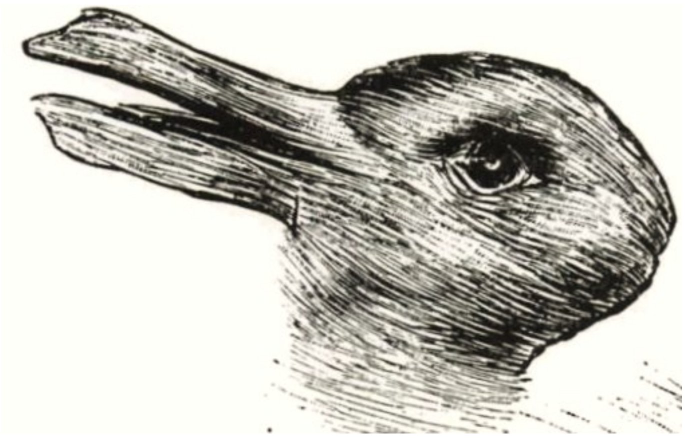

Figure 3.2: The rabbit-duck illusion by Kuhn (1970, p. 126).

It demonstrates how our brain organizes information in a way that *makes sense* to us. In this attempt the visual stimuli are, again, perceived as a meaningful whole. Thus, the image switches forth and back from being a rabbit into being a duck while it is not possible to see the rabbit and the duck at the same time.

Relevance of consistency theories Leading researchers in the field acknowledge the consistency maximizing principle as a mechanism for actively making sense of a diverse world. Its significance has been repeatedly highlighted by consistency theory advocates as delineated below:

Heider (1979, p. 16) assumes that states of stability and balance undergo the aspiration

> "to have our cognitive food prepared so that it is easy to swallow, to assimilate".

Abelson (1968, p. 133) anticipates that cognitive function is in need to

> "*organize* [italics added] the information stored by the individual in a way that is likely to be useful to him, directly or indirectly, for affective or behavioral purposes".

Pepitone (1966, p. 270) emphasizes the significance of consistent structures in that they

> "are simpler to maintain than distinctions, discrepancies and contradictions".

Tannenbaum (1968, p. 346) elaborates on this standpoint further:

> "The reasoning behind [the consistency position] relates to the organism's presumed need to apprehend and comprehend things and events about him. In monitoring, processing, and interpreting information from the environment, some degree of consistency and equilibrium is seen as essential for reasons of parsimony and economy of effort, as well as to allow for the predictability of, and hence adaptability to, subsequent encounters [...] most assume a universal value for the organism in his having a stable predictable view of his environment".

The influence of structural dynamics on cognitive consistency theories Simon et al. (2004b) summarizes four concepts of cognitive consistency theories that were inspired by the principles of structural dynamics as outlined in the following:

Holistic rather than elemental determination of cognitive states The first principle assumes that cognitive states are not only determined by their own properties but through their formed interaction structures. This claim becomes explicitly evident within the above outlined Gestalt figures and their holistic visual perceivable structures. Heider (1960, p. 168) clarifies:

> "The properties of these configurations which determine their meaning and their fate are whole-qualities. Consonance or simplicity of the structure cannot be derived in an additive way from the properties of the parts".

Likewise, Festinger (1957, p. 279) makes clear that a state of dissonance

> "is not anything which exists all by itself. It is a characterization of a relationship between cognitive elements".

Dynamic properties of structure As Zajonc (1983) explains, the interrelatedness between elements within structures generate forces that determine the configuration of the structure. This is especially interesting as those forces also delimit the stability of the structure and allows it the possibility to change, as we have seen in Figure 3.2 on page 24.

Mental processes settle at specific structural properties Distinct structural properties tend to let mental processes settle. Within, they transfer into a stable state where:

> "[...] all parts of a unit have the same dynamic character (i.e., all are positive, or all are negative), and entities with different dynamic character are segregated from each other" (Heider, 1946, p. 107).

Reconstructions of cognitive elements This principle brings forward the intriguing claim that cognitive elements are being "reconstructed" by dynamic changes that occur on the structural level (Rosenberg and Abelson, 1960). Further Wertheimer (1924, p. 2) clarifies that

> "the part-processes [of Gestaltian principles] are themselves determined by the intrinsic nature of the whole".

Festinger (1957) illustrates a central issue within structural dynamics which remains key for consistency theory and ultimately the comprehension of human cognition in that *consonance* is restored by changing the elements that are in dissonant relations, adding consonant ones, or decreasing the importance of the dissonant elements.

I will further discuss those implications and evidence of reconstruction principles within coherence-based reasoning in more detail in *section 5.1.*

Challenges and prospects of consistency theories Even though consistency theories experience much support from the Gestaltian discourse deeply rooted within psychology, research after 1960 on most topics within the field came to a practical halt.
Main reasons therefore were that the theories were not able to live up to their highly ambitious goals of formulating a new psychology of inference explaining complex phenomena which admittedly feels to be a conflicting manifold endeavor.

The proposed consistency theories suffered severely from limiting drawbacks. The theories were adversely designed to explain relatively limited and small structures. Cognitive dissonance theory for example constraints the amount of involved elements to only two (Festinger, 1957, p. 13). Furthermore the strength of units and relations between structures were restricted to unitary levels (see for example Heider (1946)).

The lack of explanatory power for evaluating and computing consistency made an advancement towards research in comprehensive modeling of cognitive phenomena impossible (Read et al., 1997; Read and Miller, 1994).
It is only until recently that new methods and potent techniques emerged to conceivably overcome some of the obstacles eventually by the appearance of connectionist theories of cognition and parallel constraint satisfaction mechanisms (see *section 3.3* for more details).

3.3 The concept of parallel constraint satisfaction (PCS)

The intuition behind this approach according to Thagard (1989); Thagard and Millgram (1995); Thagard (2000) is that the interaction of mental representations can be modeled as entities within a neuronal network where there are various degrees of coherent and incoherent relations between the established nodes. If there is a strong negative association between two nodes, coherence may be increased by deciding to accept one of the nodes while rejecting the other.

If there is a strong positive association, coherence will be increased when either both nodes are accepted or both are rejected.
Thus, we can construct a partition of the set of nodes with one set of nodes in the partition being accepted and the other rejected in a way to maximize the coherence of the entire set. Such accepted sets are for example denoted by A and the rejected sets by R. The "coherence value" is calculated by considering positive associations within nodes of A and within nodes of R, and negative associations between nodes of A and R.

3.3.1 Structure and principles of PCS

Parallel constraint satisfaction models contain structures of nodes and interconnected links between as outlined schematically above within a connectionist modeling approach *section 3*. The nodes within stand for various kinds of mental representations as for example concepts, beliefs, hypothesis or actions whereas links describe relationships between representations (see also Read et al. (1997) for an introduction).
Importantly, those links can be excitatory or inhibitory in nature. Nodes either support or inhibit each other regarding the structure of the network and the constellations as well as meaning between representations.
Activation of a node within the network is determined by values which vary within the parallel constraint satisfaction network. They are represented by the acceptability of the hypothesis or the degree of trust within a represented concept in the network.

The process of consistency maximizing can be described as spreading of activation within the network. Thus, activation enters into the system through a specific source node and propagates further to connected nodes through the network structure. Nodes that are connected through excitatory links will be activated whereas nodes connected through inhibitory links are going to be inhibited due to the propagation of negative activation.

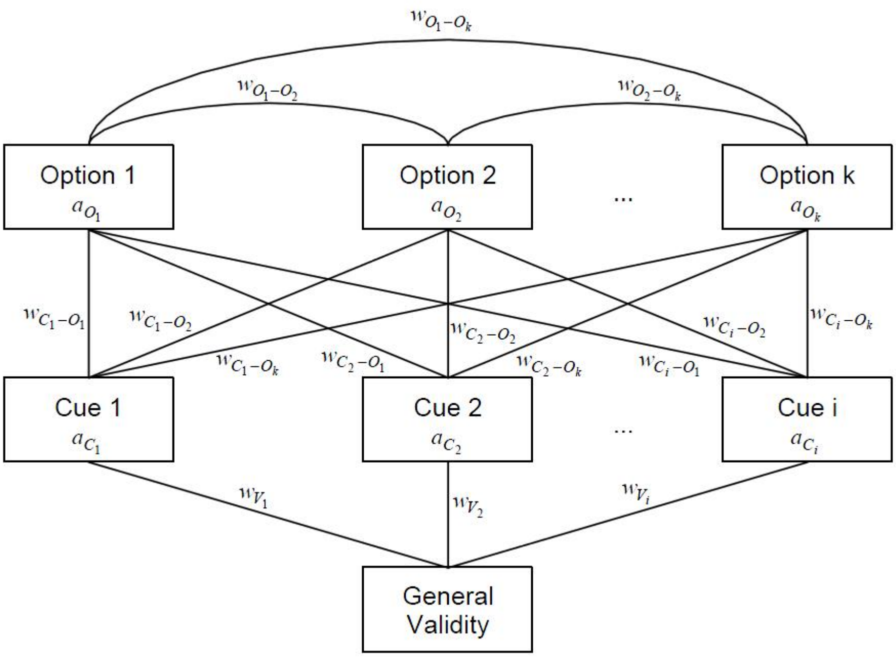

Figure 3.3: This is the general network structure of a PCS model by Glöckner and Betsch (2008, p. 7)

.

It is vital to mention here that all links within parallel constraint satisfaction models are bidirectional. Therefore activation spreads from node A to node B (and all other interconnected nodes to A as well) and vice versa. The network nodes influence each other mutually through the same links whereas the activation of nodes changes as the iterative updating cycles progress.
The updating algorithm of the network is active till the network reaches a status of stability. The nodes of the network after a certain amount of cycles do not change anymore, the system reached through self-organization mechanisms a coherent state in which the node containing the highest activation represents the "solution" to the decision problem.
This solution is the most consistent option within the scenario given the considered mental representations and their mutual relationship structure. The network "behaved" in a sense that maximal satisfaction within the network is obtained while considering the system's constraints in a parallel fashion.
Read et al. (1997) set forth that the system's found solution equals to a local minimum within the system's energy and hence represents a state of maximal consistency.

To summarize, the principles of constraint satisfaction assume that the perception of a decision-making situation triggers PCS mechanisms among mental representations.
Those representations consist of options and cues that relate to each other given the decision scenario's circumstances. If for example an individual decides between two options, then relevant cues will be incorporated into mental representations (nodes within the network) which in turn are being activated regarding to the decision circumstances.
The activation of the network results in a certain degree of inconsistency and tension within the system. Consequently this is the result of inconsistency in the network due to interrelated constraints between specific representations that fit or do not fit together given the decision situation.

3.3.2 Mathematical description of PCS mechanisms

The positive or negative activation of nodes within the network follows a mathematical function that determines the spreading of activation in the system.

The following sigmoid activation function Figure 3.4 on page 31, has been suggested frequently:

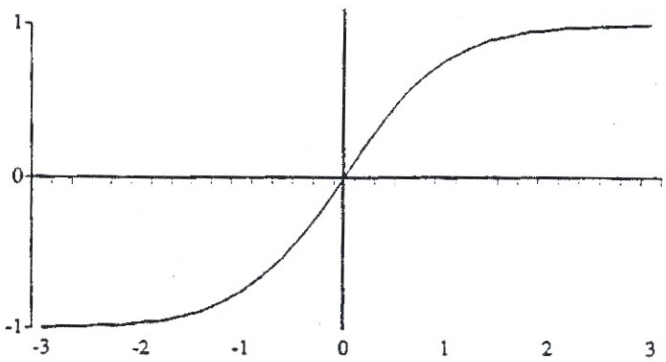

Figure 3.4: Graph of the general form of a nonlinear, sigmoid-shaped function. Originally proposed by McClelland and Rumelhart (1986), adopted from Read et al. (1997, p. 29).

$$a_i(t+1) = a_i(t)(1 - decay) + \begin{cases} \text{if } input_i(t) < 0 & input_i(t)(a_i(t) - floor) \\ \text{if } input_i(t) \geq 0 & input_i(t)(ceiling - a_i(t)) \end{cases}$$

Equation 3.0. Non-linear model node activation function. Originally proposed by McClelland and Rumelhart (1986), adopted from Glöckner and Betsch (2008, p. 6).

The activation of a node i at time *t+1* results from the product of activation of the same node at the previous time step t and an inhibitory parameter *1-decay*. Additionally input activation from all other interlinked nodes is summed-up and multiplied with a scaling factor. This guarantees the sigmoid shape of the function Figure 3.4 on page 31 as activation intensity shrinks the closer the node's activity is located at the floor or ceiling parameter.
The incoming activation of a system's node input *i(t)* is calculated by the sum of the product of the activation of all the node's interlinked nodes j multiplied by the strength *wij* of the connection between the two nodes i and j.

$$input_i(t) = \sum_{j=1 \to n} w_{ij} a_j(t)$$

Equation 3.1. Description of the incoming activation of a connectionist system's node input initially proposed by McClelland and Rumelhart (1986). Adopted from Glöckner and Betsch (2008, p. 6).

According to this procedure for every point in time from *t=1* to n the activation of a node within the system is calculated on its previous degree of activation as well as on its incoming activation. After a certain amount of updating iterations the system finds a solution as it settles at a status of minimal energy or inconsistency. Read et al. (1997, p. 30) explains that if the product of the activation of two nodes is consistent with the constraint between them, energy decreases; whereas, if the activation of two nodes is inconsistent with the constraint between them, energy increases. Thus, the authors continue, "[...] this energy function essentially measures the extent to which the pattern of activations of the nodes is inconsistent with the relations between them".

$$Energy(t) = -\sum_i \sum_j w_{ij} a_i a_j$$

Equation 3.2. Description for the system's state of energy after settlement proposed by Hopfield (1982).

3.3.3 Description of (automatic) consistency maximizing principles

The above outlined PCS mechanisms within decision-making are importantly based on automatic processes and intuitive moments within the phenomenon. The key principle is the holistic way of taken into account information consideration and the mutual influence of representations.

The decision-making phenomenon as described here can be understood as the construction of a representation of the decision-making scenario due to information modification in a specific way that makes maximum sense to the decision-maker.

The network has reached a state of maximum coherence between conflicting information through modification of elements (see also *section 5.1*).

The advantage of this process is for the decision-maker to arrive at quick decisions that are embedded within complex circumstances and information constellations.

To build upon previously outlined PCS principles and to summarize the framework, the following section delineates according to Glöckner and Betsch (2008, p. 222) the three stages of *activation*, *consistency maximization* and *decision* where automatic moments are key:

Activation PCS processes start with the activation of the parallel constraint satisfaction network when facing a decision. The perception of the decision situation activates the integration of relevant options, cues and cue information into a temporal mental representation. Both, new as well as already stored information through experience can feed into this process. Relevant mental representations form a PCS network which has been schematically outlined above (see *section 3.3.1*).

Maximizing consistency In a next step representations of relevant information is being evaluated by automatic processes in a holistic way and combined to form a maximal coherent picture of the information constellation. In this process concepts including consistent information are being strengthened whereas inconsistency among representations will result in loss of their influence. Consistency maximizing mechanisms in decision scenarios may be simulated by the spreading of activation within the network.

Decision Finally the decision-maker perceives the most consistent representation of the network as it results as the most coherent option among alternatives which is in turn selected accordingly.

Betsch (2005) conveys that parallel constraint satisfaction principles which are foremost based upon *automatic processes* may be also deliberately influenced in the process of making a decision:
First, deliberate processes can draw explicit attention to specific information. This in turn can lead to information integration within the network, modification of information validity and changes within the linkage between concepts.
Second, partly conscious processes might be relevant in modifying representations and last, the author points out that the decision-maker chooses the most coherent option deliberately based on underlying representations.

Simon and Holyoak (2002) claim that the capability of connectionist representations capture rich and large conceptual structures whereas the relation to the person's background knowledge constitutes important progress over the restrictive dyads and triads of yesteryear. Furthermore the author argues that interactive constraint-satisfaction algorithms provide a more realistic and nuanced means of resolving consistency than the crude mathematical rules used by consistency theorists. Accordingly, as suggested by Read and Miller (1994); Read et al. (1997), connectionist-based models of thought building upon constraint satisfaction, offer a conceptual framework that overcomes the limitations that hobbled cognitive consistency theories, most notably, the difficulty of generalizing such theories to achieve coherence

among large networks of beliefs.
These findings lend support to the assumed likeliness that coherence-driven mechanisms of constraint satisfaction may also be applied in connectionist terms for approaching inferences in the setting of unconscious decision-making processes.

Dijksterhuis and Nordgren (2006) argue in the same direction:

> "Up to now, we have discovered that unconscious thought leads to polarization and that people are better able to organize information in memory with unconscious than with conscious thought. This knowledge, however, represents no more than the tip of the iceberg, and there is much more about the processes involved that remain to be discovered. For now, it is perhaps best to conceive of unconscious thought as a computational process, as slowly calculating what is best."

Chapter 4

Hypothesis

"From its seeming to me – or to everyone – to be so, it doesn't follow that it is so. What we can ask is whether it can make sense to doubt it."

Ludwig Wittgenstein in Moyal-Sharrock and Brenner (2005)

Herewith I offer the following hypothesis:

1. Decision-making can be described by the evolvement of (parallel) processes that maximize coherence under given constraints and is the result of interactions of automatic- as well as deliberate processes;

2. Unconscious moments within the thought-process involved in complex decision-making follow a function of maximal coherence among the underlying inferences and are key for a better understanding of the phenomenon.

Chapter 5

Evidence

"'I refuse to prove that I exist,' says God, 'for proof denies faith, and without faith I am nothing.'
'But,' says Man, 'The Babel fish is a dead giveaway, isn't it? It could not have evolved by chance. It proves you exist, and so therefore, by your own arguments, you don't. QED.'
'Oh dear,' says God, 'I hadn't thought of that,' and promptly disappears in a puff of logic."

Douglas Adams in "The Hitchhiker's Guide to the Galaxy."

5.1 Coherence shifts

Evidence for the existence of coherence mechanisms within decision-making processes under complex circumstances comes foremost from Dan Simon and colleagues (Holyoak and Simon (1999), Simon et al. (2001), Simon et al. (2004a); Simon (2004)).

Holyoak and Simon (1999) show that tasks such as deciding which job offer to accept involve sets of complex inferences that need to be integrated within the decision. They examine inference-based decision-making by asking college students to render a verdict in a complex legal case. Their principle finding is that the decision-making process is accompanied by a systematic change in the evaluation of the inferences towards a pattern of coherence in the emerging decision.

Simon et al. (2001) replicate and extend these findings in delineating that the processing of complex tasks is accompanied by changes in inferences that increases

coherence with the decision made, leading to a coherent representation of the situation.
That is, the inferences which support the chosen decision becomes stronger, and the inferences that support the rejected decision decreases in their level of acceptance.
The authors conclude that when people are facing tasks of high ambiguity, conflict and complexity – conditions that might otherwise be experienced as insuperable – the increase of coherence in support for one of the decision alternatives enables and facilitates the making of confident decisions.
Further, Simon et al. (2004a); Read et al. (2003) highlight that people increase coherence even in the process of making a decision.
This is especially crucial as those coherence shifts cannot be explained by models of rational choice nor heuristics. Those models assume the stability of presented stimuli throughout the process of deciding (Glöckner et al., 2010).

Glöckner and Betsch (2008) summarize findings regarding consistency maximizing principles in various decision-making scenarios delineated by Simon et al. (2004a) as outlined in the following:

- With the emergence of the decision task, the mental representation of the task shifts towards a state of internal consistency (coherence shifts): the information that supports the emerging decision is accepted, and the information that supports the alternative is devalued or ignored;
- People are not aware of these coherence shifts, and the ensuing decision is "experienced as rationally warranted by the inherent values of the variables, rather than by an inflated perception imposed by the cognitive system" (outlined by Simon (2004, p. 545));
- These coherence shifts, which are caused by consistency maximizing processes, "play an operative role in the decision process" (outlined by Simon (2004, p. 546));
- Consistency maximizing processes influence information directly involved in the decision, as well as beliefs and background knowledge;
- Changes in one aspect of the mental model may trigger changes in other information throughout the model because pieces of information are interdependent;

- Motivation and attitudes can influence the direction of coherence shifts;
- Coherence shifts caused by consistency maximizing processes are of a transitory nature since they are produced to solve the decision task at hand, but usually disappear after a certain time;
- Deliberate instructions to consider the opposite position reduce the size of coherence shifts.

According to these findings it seems likely that human cognition incorporates mechanisms of *automatic consistency maximizing principles* in order to "make sense" by arranging information in a way that constructs the most coherent picture of the (decision-) situation.

5.2 Parallel Constraint Satisfaction predictions

Evidence in regard to the existence and predictions of parallel constraint satisfaction mechanisms come additionally from Glöckner (2006); Holyoak and Simon (1999) and are delineated by Glöckner (2008):

High computational capacity Individuals are able to integrate quickly a multitude of information by relying on automatic processes.

Coherence shifts The decision process is inherently constructivist. Subjective cue validities are changed in the decision process to fit the emerging representation of the decision task, resulting in coherence shifts (Simon, 2004): cues that point away from the favored option are devalued and cues that support the favored option are strengthened. Thus, resulting cue validities depend on the structure of the decision task and differ from initial cue validities.

Approximation of weighted compensatory models Choices roughly approximate the weighted compensatory integration of cue values and cue validities.

Decision time differences Decision time increases with a decrease in the initial consistency between the pieces of information. If all cues point towards the same option, consistency is high and decision time short. If almost equally strong sets of cues favor different options, consistency is low and decision time long.

Confidence judgment differences The subjective confidence in a choice is higher in decision tasks when the consistency among pieces of information that cannot be resolved in the PCS process is low. If a highly consistent solution is found, confidence is high; if the resulting interpretation is still rather inconsistent, confidence in the decision remains low.

Chapter 6

Discussion

"As the emerging consensus in cognitive science, it [the review] begins with the observation that the mind consists of many independent modules doing their own things in parallel."

Anderson et al. (2004, p. 1057)

As much of this discussion bases upon recent research within a reasonable young field of research, the author concedes in advance that the discussion remains speculative.

6.1 Single-strategy or multiple-strategy decisions?

There is intensive ongoing debate about the feasibility of multiple-strategy decision-making processes like the fast-and-frugal heuristics (FFH) program (Gigerenzer et al. (1999); Gigerenzer and Brighton (2009)) on the one hand, and the applicability and descriptive potential of a single-strategy as for example proposed by the parallel constraint satisfaction model by Glöckner (2008) on the other.

According to the latter, the FFH program lacks the potential to deal with instable cues. That is, heuristics assume that people reason starting off from the evaluation and validation of presented or already incorporated cues *first* before making a choice but not the other way around (Glöckner et al., 2010, p. 441; p. 455). This pinpoints the nature of unidirectional information processing and serves as common ground for a variety of heuristics described in the literature as for example by Tversky (1972); Simon (1955); Payne et al. (1988); Gigerenzer et al. (1999). Those heuristics only differ within their approaches to describe information search, integration, stopping search and, ultimately, choice. To that end they assume that only given information at hand account for underlying constraints, inferences and the evolvement of the decision process.

Glöckner et al. (2010) fundamental critic targets the assumption that heuristics proposed so far do not have the potential to account for the empirical evidence of coherence shifts (see *section 5.1*). They demand a bidirectional, reciprocal processing approach as for example within a connectionist framework to be accounted for. Specifically Marewski (2010) argues that Glöckner et al. (2010) incorrectly assert that their proposed connectionist PCS model is comprehensive enough to account for decision-making on a wide scale across various scenarios and tasks. In his belief several key aspects of the PCS model do not hold or are misconceived. Marewski defends the position that heuristics are in fact suitable to make quantitative, well studied predictions to address the phenomenon and conjectures:

> "[...] (i) contrary to their [Glöckner et al. (2010)]assertions the FFH and other multi-strategy frameworks have developed a number of approaches to strategy selection, tackling a difficult modeling problem that the PCS model disguises but cannot solve itself. Moreover, (ii) in contrast to the PCS model, which has not been completely spelled out, the repertoire of strategies assumed by the FFH framework is precisely defined, allowing researchers to make quantitative predictions about behavior. I conclude that Glöckner et al. (2010) critique may actually apply more to the PCS approach and less to the FFH framework."

Marewski anticipates that the PCS model as described as an all purpose mechanism still runs into the strategy selection problem. According to him, the model lacks the description of processes determining the information search or stopping rules which are not described by parallel constraint satisfaction mechanisms as stated by for example Glöckner (2008). He highlights that the FFH program in return hypothesizes that people select different heuristics as a function of the environment:

> "[...] In doing so, it asks (i) when and why a given heuristic would help a person to behave adaptively, for example, by enabling that person to make accurate or fast inferences and (ii) under what conditions people rely on a heuristic" (Marewski, 2010).

Marewski proceeds in his claim that critics in regard to the FFH framework and its inability to account for bidirectional reasoning processes is wrong. He highlights that the adaptive toolbox does include compensatory integration strategies - such as tallying - as well as models that allow for bidirectional reasoning and changes in cues (Hoffrage and Hertwig, 1999).

Betsch and Glöckner (2010) critically discuss Marewski (2010) raised objections against the single-strategy parallel constraint satisfaction (PCS) approach to decision-making. The former come to the conclusion that the aforementioned raised issues by Marewski (i) the FFH frameworks' factual ability to account for coherence shifts and (ii) the critique that ultimately the PCS model runs into a strategy selection problem due to underspecification of underlying processes do not hold and are misconceived.

Betsch and Glöckner (2010) acknowledge Marewski's initially raised point that the "Reconstruction after Feedback with Take The Best" (RAFT) heuristic is capable of modifying cue values. However, and this is crucial, the cue values get modified only after the decision is made. This entails that RAFT cannot account for the empirical findings of coherence shifts. Bidirectional reasoning, the assumed underlying mechanism for coherence shifts, happens already *during* the decision-making process. Secondly, Betsch and Glöckner (2010) underline the nature of the PCS model - against Marewski's assertion - as a sufficient single strategy approach to decision-making. They claim that according to the PCS rule persons translate provided information into an internal mental representation according to a specific monotonic transformation function and elaborate their argument further (Betsch and Glöckner, 2010, p. 470):

> "To conceptually deal with this phenomenon, we suggested a differentiation between an information integration and decision rule, on the one hand, and processes of information search, generation, and change on the other. We subsumed the latter operations under the concept of deliberative construction. We propose that there is only one-all-purpose rule for the core processes of decision making (information integration and choice), whereas there is a variety of different methods of deliberative construction."

Betsch and Glöckner (2010) reject the critics regarding their delineated PCS model in that it has to deal with the strategy selection problem while it treats processes of information search, generation and change like different forms of behavior that are selected by the applied single PCS rule. In an advanced version of the model, Glöckner (2008) draw a more elaborate picture on the interplay of decision mechanisms among different choice options and the concept of deliberate construction.

Ultimately, the connectionist PCS model of choice and decision-making is based upon an automatic parallel processing mechanism which operates on information cues that are integrated holistically to form the most coherent picture of the decision-making scenario based upon maximizing constraints (see *section 3.3*).

On a more general level the PCS approach assumes that information cues do not only exclusively affect the criterion evaluation, but that this evaluation has an influences back on how the information cue is evaluated. This resonates with empirical evidence from crucial real life scenarios, like for example in legal affairs where arguments from complex criminal cases are evaluated (Holyoak and Simon, 1999).

The PCS model holistically assumes that cognitive processes interact with information cues in a bidirectional way. They influence each other in a reciprocal fashion by taking into account unconscious elements. This in turn marks a significant difference between heuristic strategies and the parallel constraint satisfaction approach within decision formation.

6.2 Intuitive moments in complex decision-making

6.2.1 Potential of automatic-intuitive decision-making strategies

On a general note it should be highlighted that the current state of research in the area of intuitive moments within the phenomenon of decision-making is still in an early stage. Hence, it is difficult to generalize findings and one has to be very cautious in making claims and predictions.

Nevertheless it appears legitimate to assume that automatic-intuitive decision strategies can in fact result in good decisions under distinct circumstances: Dijksterhuis Loran F (2006) suggest that decision-making works best by integrating conscious and unconscious thought within complex decision circumstances.
The parallel constraint satisfaction (PCS) model (see for example Glöckner (2008)) start to lead the way towards a descriptive framework aiming to shed light towards a

better understanding of the power of an intuitive component within the phenomenon (see Figure 6.1 on page 45 and Figure 6.2 on page 46 accordingly).
It delineates a framework that the human decision maker does perform high capacity information- and integration processing due to the interaction of both, deliberative and automatic processes in order to maximize overall coherence. This conception might have its origin within evolution theory as assumed by Glöckner (2008), and is schematically outlined in Figure 6.1 on page 45 and Figure 6.2 on page 46.

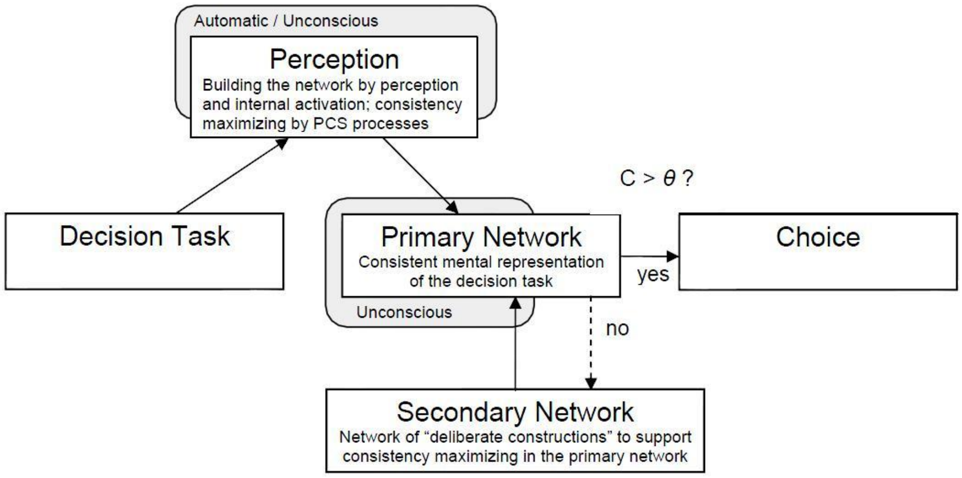

Figure 6.1: The figure summarizes the mechanisms of the proposed PCS rule within a PCS network according to Glöckner (2008).

In order to highlight the relevance, I will set out for a more detailed overview of advantages in regard to automatic-intuitive moments within the decision-making phenomenon:

Dealing with complexity and inconsistent environments There is compelling evidence in the literature (see *section 2.1.2*) that people are able to successfully deal with complex and dynamic problems with the use of internal, automatic processes. Those internal processes are assumed to be describable by parallel constraint satisfaction principles aiming at maximizing overall consistency among the decision scenario. In this regard a reductionist approach lead by heuristics following principles of reduced minimal information processing appears less compelling. Results have shown that automatic-intuitive decision strategies are capable to deliver good results even within complex environments which are prone to inconsistent and missing information (Nordgren et al., 2011).

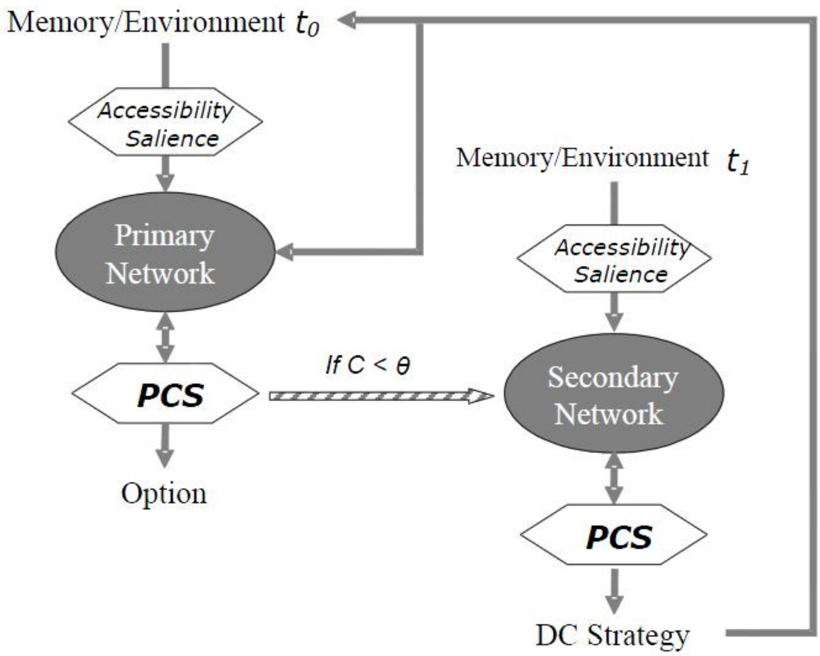

Figure 6.2: The figure outlines the interaction mechanisms between the primary and secondary network within a PCS network model (Glöckner and Betsch, 2008).

Importance of social dimension and creativity Intuitive moments seem to be highly relevant also within social perception. Read et al. (2003); Simon et al. (2004b) argue in a plausible way that parallel constraint satisfaction mechanisms are active in order to integrate vast amount of information quickly including subtle signals in the process of social interaction and the establishment of relationships.
It is further assumed that the activation of partly automatic consistency maximizing processes form out similar concepts, mental representations and changed information constellations. Therefore it seems plausible that the discussed PCS approach triggers information synthesis processes that increase the likelihood of constructing creative solutions to decision problems (Thagard and Stewart, 2010).

Tight relation to own value system The application of automatic-intuitive decision-strategies act upon unconscious goals, beliefs and values of the decision-maker. Consequently those strategies exercise a much closer relation and tight connection to a person's value system as that might be the case for example with deliberate-rational decision processes. This implies that intuitive driven decision approaches activate relevant representations similar to the already incorporated value system of this person. On the contrary, reductionist strategies might not be able to account for basic underlying goals and values due to limitations in the depth of alternative evaluations (see for example Tversky and Kahneman (1974)). This might explain the reason for sharing a personal, subjective deep commitment to automatic strategies and hence intuitive decisions. Needless to say this behavior might comprise also substantial downsides. To trust only decisions that base on incorporated goals and values can also be radically misleading especially if the decision taken deals with a situation with limited or no previous experience (see for example Klein (1999)). Negative aspects of automatic-intuitive decision-strategies are further discussed in *section 6.2.2*.

6.2.2 Automatic-intuitive decision-making strategy challenges

Biased representation through activation and salience factors Glöckner and Witteman (2010, p. 16) describe the influence of salience factors which may result in increased activation of respective information cues. This can be challenging since salience factors might influence the information cue in a manner disproportional to its ecological validity. In other words the validation of a cue might be unreasonably increased from a set of given information because it is weighted stronger due to its prominent positioning. This in turn results in biased mental information representations leading to decisions with decreased quality.

The pitfall of conditioning Another risk factor in intuitive decision strategies are conditioning affects which may result as an example from advertisements. Walther (2002) for example suggests that conditioning processes may trigger inadequate emotional reactions connected to specific cues which may result in a biased representation of the overall decision situation thus leading to suboptimal decision outcomes.

The role of experience Experience is valuable and highly desirable, but can be misleading especially in the context of automatic-intuitive decision strategies. Fiedler (2000) outlines the necessity that information which is integrated and activated within mental representations is correct. Thus it is suggested that experts use and trust their intuition in a context where decisions have to be made based on a wide range of experience whereas novices are better off in using a deliberate-rational decision making approach (Klein, 1999; Kahneman and Frederick, 2002; Dijksterhuis Loran F, 2006).

6.3 PCS processes and their descriptive potential

6.3.1 Why should intuitive decision-making be predictive?

In the following section I discuss different positions regarding the question if, and to what extend, decision-making processes may be predictable.

The following authors argue against the predictability of a decision-making outcome:

Thomae (1960) suggests that decision-making processes exist rather as functions of an actual experienced situation in which they are shaped and continuously modified by the situations' direction, intensity and meaning. Further, memories, feelings or thoughts are unique entities that do not exist in the exactly same way twice. For this reason, Thomae asserts it is impossible to describe the relation between an action and the mental state that caused it in a law like fashion.

Spaemann (1996) argues that it is wrong to assume ideas, desires or motives as independent variables. According to him, the decision-making process must be seen as a dynamic process that encompasses the modification and the reciprocal influence of those variables. Crucially, they cannot exist as fixed determinants.

Fuchs (2005) highlights the crucial interaction of a conscious (explicit, verbalization) and an unconscious (implicit, intuitive) component which mutually influence and expedite one another. Fuchs further explains that decision-making processes cannot be the product of deliberate thought and reasoning by itself. In his view reasons rather serve the purpose to justify decisions for oneself and are not enough to reach a *"sound"* felt decision outcome.

Fuchs concludes that decision-making cannot be described as either a rational-discursive nor as an irrational-blind process, but rather as an emerging form of *felt congruity* which he describes as a form of *incomputable sense-making.* Therewith Fuchs argues against a psychological deterministic viewpoint in which the calculation of decision outcomes in advance becomes in practice possible. Yet his narration and understanding of decision-making remarkably comprises in my view of striking analogies to the concept of coherence and parallel constraint satisfaction principles according to Thagard (2000).

Thagard proposes *cognitive naturalism* as the rising approach to philosophy that finds close ties between philosophy and the cognitive sciences, including psychology, neuroscience, linguistics and artificial intelligence (Thagard, 2000). Cognitive naturalism is intended to supersede behavioral and logical naturalism, but is compatible with non-exclusionary social and physical naturalism. Within, Thagard sees philosophical ideas about coherence to be highly relevant to the understanding of important psychological phenomena, while computational ideas greatly enrich the understanding of coherence and offer a formal account to model and predict decision-making including intuitive and emotional shares (Thagard, 2008).
In this regard Thagard argues that cognitive naturalism in fact supersedes analytic philosophy as well as phenomenology and points the way towards ongoing cooperation and co-evolution of philosophy and psychology. For a more detailed critical discussion of Thagard's position please see *section 6.3.2*.
Dijksterhuis and Nordgren (2006) propose a theory about human thought named the "Unconscious Thought Theory" (UTT). In comparison their model distinguishes the thought process into an unconscious and a conscious mode of thought. Within, conscious thought is defined as a cognitive thought process that is object-relevant or task-relevant and occurs while the object or task is in one's conscious attention. In contrast unconscious thought is an object-relevant or task-relevant thought process that occurs while conscious attention is directed elsewhere. The two modes differ in its characteristic and are ergo preferable under different circumstances.
Interestingly, the theory suggests that when dealing with simple issues one should use conscious thought, whereas decisions in complex circumstances should be tackled by unconscious thought.

Dijksterhuis and Nordgren (2006) suggest this conclusion based on the identification of key principles pertaining to the nature of two types of thought:

1. The capacity principle states that conscious thought is constrained by the low capacity of consciousness whereas the unconscious capacity is much higher. It follows that conscious thought processes take into account only a subset of the information that it should;

2. The bottom-up-versus-top-down principle that claims the unconscious works aschematically bottom-up to slowly integrate information to form an objective summary judgment while conscious thought works schematically top-down and

is guided by expectancies and schemas;

3. The weighting principle that suggests that unconscious naturally weights the relative importance of various attributes whereas conscious thought often leads to suboptimal weighting because it disturbs this natural process;

4. The rule principle suggests that conscious thought is precise and can follow strict rules while unconscious thought gives rough estimates;

5. The convergence-versus-divergence principle which claims that conscious thought is focused and convergent while unconscious thought operates more divergent.

Dijksterhuis and Nordgren (2006) further set out to describe circumstances in that different modes of thinking lead to different kind of results. Even if their framework has not yet been spelled out in precise mathematical detail, it takes a bold stand on the importance of the interrelatedness between deliberative and intuitive thought, whereas parallels to PCS mechanisms become increasingly evident.

6.3.2 Objections against a Thagardian coherentist position

The connectionist implementation of parallel constraint satisfaction principles is based upon the concept of coherence. The field is pioneered by the idea of *"explanatory coherence"* by Thagard (1989) who later applied the model specifically to the phenomenon of decision-making (Thagard and Millgram, 1995).

Coherentism as such has undergone severe opposition especially from the position of foundationalism.
In a coherentist view no foundations of knowledge exist. Hence the certainty of knowledge does not base upon foundations but by the strength of interlinkage of propositions. The coherent position's assumption is that mutual inference mark the cornerstone of empirical beliefs. It follows that the degree of justification of a belief emerges from as to what extend it coheres with other beliefs one holdes. Thus, the coherent position rejects the view that there do exist foundations of knowledge as basic belief itself does not exist as foundationalists claim.

Laurence BonJour became one of the most prominent defenders of the foundationalist position. He concludes that *"coherentism is pretty obviously untenable, indeed hopeless"* (BonJour, 1999). Contrary to this view Thagard (2000) strengthens the position of coherentism in that *foundationalism does not have a chance of* *competing with coherentism in an account of human consciousness with its various manifestations* (Amini, 2003). In opposition to BonJour, Thagard observes that *"the foundational search for certainty is pointless, and that what matters is the growth of knowledge, not its foundations"* (Thagard, 2000, p. 90). Thagard asserts the key to the growth of knowledge and to its very understanding is nothing other than coherence, where in a similar epistemic exercise foundationalism *"has undoubtedly failed"* (Thagard, 2000, p. 8).

To shed some more light on the criticism and discussion regarding the theoretical foundation of coherence, some more considerations shall be outlined:

> "There has not been much of an account what exactly coherence itself is. The problem were not synonymous or words or phrases like if ones beliefs cohere if they "hang together" or ones goals make up a coherent plan if they "fit well with one another" - the problem was not even that of itemizing the ingredients of coherence such as appropriateness of means to ends or logical consistency. The problem was the lack of any specification of how these ingredients were to be calculated and combined with respect to a set of propositions. That is, how one was supposed to work out the degree each item on the list would contribute to the overall coherence of a theory or strategy (Amini, 2003)."

It is evident, however, that without a detailed and sufficient account on how to compute to choose the most coherent set of thoughts or actions, the theory of coherence is not capable in order to contribute to a deeper understanding of human thinking and behavior. Putnam (1981) claims that *"[...] coherence is not something for which we have an algorithm, but is something that we ultimately judge"* and was convinced that feeding the basic concept of coherence into a computer program to do simulations is beyond of reach. Against this background Thagard's attempt to characterize coherence *"as mathematically precise as the tools of deductive logic and probability theory"* (Thagard, 2000, p. 16) becomes interesting and appealing.

Thagard is well aware of the fact that there are several objections against his coherence theory. The majority of critics are directed towards vagueness, indiscriminateness, isolation, conservatism, circularity and truth of the theory (Thagard, 2000, p. 69). Even though Thagard most convincingly defends the theory of coherence regarding aforementioned raised issues, it is vital to add to the discussion that to

some extend fuzziness about the interrelation of coherence and truth still remains since approximating maximum coherence is not yet the same thing as approximating truth (Amini, 2003).
To defend coherentism against this blind spot Thagard acknowledges that one inherently needs *"to see a much fuller account of the conditions under which progressively coherent theories can be said to approximate the truth"* (Thagard, 2000, p. 280).

To sum up, Thagard is able to set the scene for coherence in a constructive and insightful way. Yet it has to be added that this is only achieved by *"extensively curtailing traditional claims of coherentism"* (Amini, 2003), which Thagard demonstrates convincingly even by confessing that *"the formation of elements such as propositions and concepts and the construction of constraints relations between elements depend on processes to which coherence is only indirectly relevant"* (Thagard, 2000, p. 24).

6.4 Differentiation between "implicit" and "explicit"

Preliminary considerations A decision is an interesting process. Not only from a technical or psychological point of view where we strive to understand the various mechanisms that undergo the process of actively deciding, or more passively arriving at a decision.
From a phenomenological stand we know how it feels to face a decision that has to be made in a complex situation we do not fully understand, in an environment too ambivalent to fully comprehend. An yet, we end up deciding within those circumstances, resulting in either good or rather not as good as envisioned outcomes.

The point I would like to make here is that in the process of deciding we seem to commit ourselves to one option while cutting off all others. My understanding is we experience a transition within the decision process from a context of uncertainty towards certainty. Metaphorically speaking, our implicit selves *become* explicit within the process of deciding.
But how does his jump of quality come about, when does the decision arrive in the external world, affecting the world?

This *subjective* view on the issue is contrasted by a materialistic position that describes the world in exclusively naturalistic terms.

Some neuroscientists (see Doyle (2009) for an overview) argue in favor of this conceptualization. In their perception neuronal processes are purely physical deterministic actions. In this view the act of deciding is represented exclusively by neuronal activity which only could have happened this way. Subjective feelings and thought are rather seen as an epiphenomenon, an accessory by-product ruling out any chance of subjectivity.
Within this exclusively naturalistic description it seems likely to believe the decision was already determined and therefore always explicit – no transition from the subjective to objective, from implicit to explicit is taking place.

Since I try to investigate how the implicit becomes explicit, which obviously requires a subjective component, I cannot accept a materialistic monism. In my view, Quantum Theory expands this naturalistic view and scientific explanation in that it re-introduces to some degree subjectivity through the element of randomness through quantum events. The theory entails the study of quantum mechanics which is currently at the forefront of modern science striving to shed light on ambitious matters like for example the relationship between subjective conscious moments and physical brain processes (see for example Atmanspacher (2004); Litt et al. (2006)). Evidence in this regard comes from in *section 3.2.1* described Gestalt psychology. Atmanspacher (2004) for example argues that bistable perception as in the case of the "Necker cube illusion" is formally similar to quantum entanglement.
Regarding decision-making, quantum mechanical characteristics and structural similarities have been lately highlighted by scientists (Roth, 2001; Busemeyer et al., 2006; Pothos and Busemeyer, 2009; Ule, 2009; Agrawal and Sharda, 2010).

However efforts to define and explain those concepts and functionalities all too often appear to be much of the same as nailing a pudding against a wall and should not be attempted here.
I earlier outlined the connections between the concept of coherence and its interplay and relevance in the process of decision-making.
Yet in addition I would like to put forward a few conceptual matters originating from recent argumentations in favor of the descriptive potential of quantum mechanics. This said, I hope to foster an ongoing challenging discussion in pinpointing towards some in my opinion inherent appealing quantum mechanical sentiments. This account strives to contribute towards a better understanding of how humans ultimately do decisions on various levels. Given the nature of things my thoughts

should be acknowledged as being speculative and contemplation demands caution as well as further empirical investigation.

Thus, the following discussion consequently aims to pinpoint a basic notion of discrimination between *"implicitness"* and *"explicitness"* from a philosophical perspective. Specific focus is given on their interrelated role within decision-making and the development of a notion of *process* including its relevance within.

6.4.1 Whitehead's process philosophy as a starting point for debate

A compelling discussion of quantum mechanics in regard to decision-making would go way beyond the frame and scope of this work, some thoughts touching upon the surface, however, might serve as an anchor point within the discourse. The author's intention is to add to the understanding of the fascinating broad spectrum of complexity, multi-layeredness and interdisciplinarity regarding the phenomenon.

I start with the philosophical discussion of Alfred North Whitehead's *process philosophy* and some of his metaphysical-laden thoughts on human experience and reality. Whitehead likely did not know about the developments in quantum mechanics by that time by Heisenberg, Dirac and Schrödinger since he never mentioned them in his writings. Yet there are striking parallels between Whitehead's ideas and Quantum Theory which appear to be more actual and relevant today than ever.
As a next step I investigate some very specific metaphysical Whiteheadian concepts and relate them to the process of decision-making.

The philosopher Alfred North Whitehead accounts as one of the most influential figures in modern philosophy. At the same time Whitehead is also often suspected to be (unjustly) the most neglected philosopher in 20th century history. His major philosophical work *Process and Reality*(Whitehead, 1978) contests of a metaphysical framework of process philosophy, initially intended as a *Philosophy of organism.* Within, Whiteheads concept of *process* remains key:

> "The many become one, and are increased by one. In their natures, entities are disjunctively "many" in process of passage to conjunctive unity. This category of the ultimate replaces Aristotles' category of primary substance" (Whitehead, 1978, p. 21).

Generally speaking, Whitehead maintains an understanding on how human experience might serve to understand reality which he arguably views to be a process of *becoming.*
Whitehead's view asserts that substance does not exist. One is tempted to ask how anything can exist if not substances, what else could exist? Whitehead maintains the perspective that everything is *process* and that the only thing that is real are *events.*

However, from a classical Newtonian perspective where matter is seen to be build up from atoms as building blocks of substance it appears to be at best challenging to accept the doctrine that nothing undergoes process. Whiteheadians argue the appearing of substances as enduring matter is rather the result of our limited view similar to food that rots.

Whiteheads process ontology suggests that atoms are made up of subatomic particles which in fact are build up from protons, neutrons and electrons. In turn they are made up of quarks. If we follow Whitehead, matter itself is made up of energy which is not seen as substance but rather as relationships between objects. Since objects are build up of matter which is made up of energy which is made up of relationships, we are stuck in a loop. The universe appears to be a set of relationships between relationships between relationships, which all change constantly over time and never appear to be static.

Accordingly, Whitehead argues substance does not undergo process. Rather processes and what we call substances are merely a temporary pattern produced by process.

Klose (2009) anticipates in reference to Whitehead's philosophical concepts that *distinctions must dissolve between inside and outside, consciousness and matter, object and subject.*
I will take this as a starting point in elaborating Whitehead's ideas regarding a philosophical account for the interrelation between "implicit" and "explicit" which in my view also applies to the decision-making phenomenon.

To further follow the road of quantum mechanics I turn to one of the founders of quantum mechanics, Walter Heisenberg, and his quantum ontology. Heisenberg postulates in his book *Physics and Philosophy*:

> “[...] the transition from the “possible” to the “actual” takes place during the act of observation” (Heisenberg, 1976, p. 54-55).

And further:

> “The probability function combines objective and subjective elements. It contains statements about possibilities or better tendencies (“potentia” in Aristotelian philosophy), and these are completely objective, [...] and it contains statements about our knowledge of the system, which of course are subjective in so far as they may be different for different observers. [...] The observation itself changes the probability function discontinuously; it selects of all possible events the actual one that has taken place. Since through the observation our knowledge of the system has changed discontinuously, its mathematical representation has also undergone the discontinuous change and we may speak of a ’quantum jump”’(Heisenberg, 1976, p. 53-54).

Here we arrive at the heartbeat of Quantum Theory. I believe it is key here to understand the room of subjectivity that quantum mechanics grands. Subjectivity and objectivity, implicitness and explicitness do not mutually exclude each other within this framework and understanding. Rather they are dual states which, empirically demonstrable, co-exist to some extend (French and Taylor, 1979).

Ule (2009) turns principles of quantum mechanics into a practical framework to describe elements of group decision-making and delineates the undergoing process:

> “The process [of group decision-making] can be compared to the collapse of a wave function in quantum mechanics, which due to the influence of measuring the space of potential activations of the physical system is reduced to one of the possibilities. The structure of implicit values of different possibilities (alternatives) of functioning is adequate for the space of potentiality, but these alternatives do not appear as elements of logical disjunction but rather as some sort of “entanglement” of possibilities which is resolved only by the process of decision making or more precisely by the viewpoints and arguments in the discussion and the energizing of the discussion” (Ule, 2009).

In the Whiteheadian ontology of Quantum Theory, each quantum reduction event is identified with a Whiteheadian actual entity:

> "The actual world is a process, and [...] the process is the becoming of actual entities" (Whitehead, 1978, p. 22).

> "[The actual entities] are the final real things of which the world is made up. There is no going behind actual entities to find anything more real" (Whitehead, 1978, p. 18).

Whitehead's notion of actual entities are in respect of the context also known as *"actual occasions"*, *"throbs of experience"* or *"pulses of experience"* and are according to Whitehead the *"atoms of reality"*.

Further, each Whiteheadian actual entity consists of a *"mental pole"* and a *"physical pole"*. The mental pole is an intentional ascertaining action which separates a continuum into discrete experienceable possibilities. The physical pole thereafter selects, or to use Whitehead's notion, *actualizes* one of the previously identified possibilities and destroys all others.

Whitehead continues to explain his notion of potentiality and actuality:

> "Continuity concerns what is potential, whereas actuality is incurably discrete" (Whitehead, 1978, p. 61).

> "Actual entities [...] make real what was antecedently merely potential" (Whitehead, 1978, p. 72).

> "Every decision is referred to one or more actual entities [...] Actuality is decision amid potentiality"(Whitehead, 1978, p. 43).

Within this conceptualization a mental pole comprises of an input and an output. Whitehead describes those in- and outputs as ontological characterizations of feelings, thoughts and ideas and are *"essential within the dynamical role of unifying, evaluating, and selecting discrete classically conceivable activities from among the continuous range of potentialities offered by the operation of the physically describable laws"*(Atmanspacher, 2006). As a practical example of this assertions, an actual entity, so Atmanspacher, is an event whose mental pole can be experienced by a human being within a conscious stream of events whereas its physical pole refers to the neural correlate of that experiential event. Here the parallels between a Whiteheadian process philosophy and quantum mechanical properties as entanglement become obvious:

> "When one follows, point by point, the characteristics of actual entities, one is amazed to what extend one can think of collapse as an objectivized actual entity" (Myrvold et al., 2009).

After those outlined anchor points I state the following question:
Is it possible that if we combine Whitehead's process philosophy with quantum theory and relate it to actual entities within a decision-making process, that the act of transition from the potential to the actual, which can be described as the collapse of a wave function in quantum mechanical terms be understood as the initially described blackspot where the implicit decision at stake becomes explicit? And how in specific could this look like in more coherent descriptive terms?

I will not attempt myself to ultimately answer those questions here. On a personal note I conceive Whitehead's ontologies as intuitively appealing. Yet I acknowledge its inherent speculative character and agree with Myrvold et al. (2009) in that *filling in the technical details of this ontology is the long-term task of science, which is still in its infancy. A lot of important structure is provided by the general precepts of the ontology, but this skeletal outline needs, of course, much fleshing out.*

6.4.2 From potentiality to actuality within a coherentist setting

Chalmers (1996, p. 333) asserts that quantum mechanics is deeply connected with the notion of observership, and that this notion is crucial for people believing that the two phenomena share a common source as it involves the relation between a subject's experience and the rest of the world.
Andrej Ule recently presented and discussed interrelations between the two phenomena of quantum mechanics and consciousness in his essay *"Mind in Physical Reality, its Potentiality and Actuality"* (Ule, 2012). Within, the author investigates the nature of consciousness and explores mutual explanatory benefits of the phenomena with specific emphasis on the conceptual notions of "potentiality" and "actuality" within *process*.

Andre Ule highlights that processual reasoning is often incomplete. According to his view it is not possible to know all sequences of the reasoning process phases or its result:

> "We know only parts of the successive results of the process and/or only some of its phases. In such cases, we know only a *type* or a *scheme* of the process. It presents the equivalence class of the possible processes in the given referential system of occurrences regarding a fixed sequence of times, structure of phases and/or subsequent results of processes. It is quite typical of process reasoning that we consider only some types (schemes) of processes but not the particular processes. Processual thinking is thus mostly abstract and schematic" (Ule, 2012, p. 10).

Essentially, the author argues that many occurrences in a real process are only partially being determined by previous occurrences and that for any microphysical process the possibilities of a state-change are given by the nature of the process and coded in the wave function of the quantum state or in the matrix of the probability densities of possible outcomes of measurement (Ule, 2012).

Ule elaborates further on different systems and state changes:

> "In simple referential systems (e.g. in deterministic systems), the potential for change depends only on the properties of the starting states of the system (and on the time interval for possible occurrences). In some stochastic system and other more complex systems (e.g. in the majority of life processes) the potential for change also depends on the *properties of processes which led to the given state of the system [italics added]* and not only on the properties of the system states. I am then speaking of the "potential of processes" (Ule, 2012, p. 10).

Accordingly, I believe the above mentioned "potential of process" conception plays a major role in decision-making especially when decisions are substantially based on unconscious processes as it is the case if decisions are done intuitively.
I speculate that a system change in a decision-making model which strives to not only predict but explains the decision-making process, it needs to take into account the properties of all (or more realistic as much as possible) processes which lead to a system state (decision).
I suspect that the emergent properties in place when making a decision become better understandable and traceable when appreciating the conceptual considerations

on the potential of processes. Thus we might be well advised to build and improve decision-making models respectively for better performance and improved prediction quality.

On a general note, Ule (2012) anticipates that by linking questions of consciousness with questions of quantum mechanics we are linking two mysteries in the hope they will somehow shed light on each other, thus making us a little wiser than we are now.

This said, I now turn to put forward my thoughts about the relevance of goals and goal-directed behavior within decision-making. I outlined earlier their respective vital functions within a coherentist model and framework. Yet it is evident that the model does not give any explanations about the *origin* of those goals. In the following part I intend to frame this issue and point out some directions how this flaw could be at least partially avoided.

The adoption of goals and anticipatory drive

Classic economic theory anticipates that people decide by maximizing expected utility. The utility conception has been constructed in mathematical terms to reflect people's preferences grounded within their behavior of choice. The economic decision model appears appealing to the extend to predict how people decide given their preferences, yet it fails to explain how people decide as it lacks an explanation where those preferences arise from.

Up till today economists resisted the idea to explain preferences in terms of mental processes that include utility as an emotional state or process despite the numerous experiments that have been performed to show that traditional Expected Utility theory often fails to account for human choice behavior (Thagard, 2010).

Within a more psychological and neurological appealing Thagartian coherentist framework the role of propositions such as preferences, goals and actions play a vital role. Thagard and Millgram (1997) describe a theory of decision where inferences to the best plan are drawn based on underlying goals and actions which facilitate (or not) those goals for the decision-maker in the most coherent way. The question however arises where those goals ultimately come from.

In fact we do not need to think on an everyday basis about our major goals that we have in life where we base our decisions on but evidently now and then we are facing major choices for example if we have to decide between two job offers or if we have to take a decision regarding family planning. Those choices require not only calculating the best means to established ends, but also figuring out what ends to pursue (Thagard, 2010). Further, Thagard (2010) uses the notion "telic rationality" to address normative questions about how we ought to go about adopting, abandoning and revaluing our goals.

Thagard highlights within this context that:

> "We do not get autonomously to choose our goals, because some are handed to us by our biological needs and others are transmitted socially, through mechanisms such as attachment absent learning, role modeling and altruism" (Thagard, 2010, p. 132).

In the following I explore the question concerning how people adopt goals on an implicit sublevel of our conscious being down the lines of specific quantum mechanical considerations. They build the theoretical starting point for modeling decision-making within the coherentist framework alongside with parallel constraint satisfaction principles and are thus in my understanding vital.

Ule (2012) claims in regard to the processual aspects of consciousness:

> "The processual aspect of consciousness lies in the neural informational-processes, in the flow of sensations and the change of feelings of a human being who has *become sensitive to processes around them (and themselves) and works on the basis of complex implicit and explicit anticipation models*" (Ule, 2012, p. 38).

Rosen (1985) speaks of living beings as *"anticipatory systems"*. Additionally Ule (2012) highlights that some living beings may have developed sensitivity towards possible changes implied by sensed changes in that they somehow

> "[...] connect actual and possible changes in other systems of states with actual and possible changes in their own system of states. They anticipate possible changes and react to them" (Ule, 2012, p. 26).

Further, Butz et al. (2003) highlights "state anticipation" as a form of anticipation that entails:

> "[...] an explicit predictive model of the environment which directs decision-making. This kind of anticipation needs representations of goals, mental simulations of actions and a plan for achieving the goal from the given starting state."

Later, Butz (2008) characterizes his notion of an "anticipatory drive" as following:

> "To realize anticipatory behavior, we propose that brain development is predominantly controlled by an anticipatory drive, that is, a learning bias that enforces the formation of bidirectional, anticipatory brain structures.The anticipatory drive is considered the dominant force in the brain that causes the (modular) construction of predictive representations, which enable the activation of goal representations and eventually the construction of our complex inner realities and our conscious selves" (Butz, 2008).

In light of the above outlined process philosophical considerations I speculate that *"state anticipation"* plays an implicit key role in directing decision-making when considering maximizing coherence including constraint satisfaction principles as this form of anticipation needs *representations of goals, mental simulations of actions and a plan for achieving the goal from the given starting state* (Thagard, 2010, p. 27).

In this sense I believe there is an interesting structural similarity to constraint satisfaction principles which I claim may indicate a significant anchor point in the understanding of the formation of propositions on which coherence maximizing mechanisms work upon within a coherentist decision-modeling framework.

I favor the constructivist view of Butz (2008) who argues that *perceived* reality is based on the concept of a complex construct formed during stages of development. According to Butz, brain structures built by the anticipatory drive are responsible for determining explicit predictive models as well as for evolving "inner realities". This view is well expressed and conceptually similar to the concept of coherence described in *section 3* for mainly two reasons: First, the characteristic of bidirectionality within anticipatory brain structures which are essentially enforced by an anticipatory drive which is in line with the key concept in modeling coherence maximizing decision-making networks within the brain and as such is crucial. Secondly, characteristics of participatory drive appear to be functionally related to parallel constraint satisfaction models of decision-making (Glöckner and Betsch, 2008).

Within, the primary network of the model contains, likewise to Butz's notion of "anticipatory drive", representations of constructed preferences like actions, goals or other propositions on which consistency maximizing mechanisms act upon those propositions considering all information of the network by changing the elements' activation in order to deliver the result of the most coherent option for behavioral decisions.

I see the fact that Butz (2008) further relates to a neuronal network model of Tani (2008); Taylor (2008) that contest the connectionist description of anticipatory drive as another insinuation towards the relevance and its ability of integration within a connectionist parallel constraint satisfaction setting.

Thus, I stress the importance and potential of state anticipation as an element within the model of a coherence-based behaving decision-maker. In this sense especially the mechanisms in building-up the proposition representation network within an explicit predictive coherentist decision-making framework on which the coherent decision-maker acts upon as outlined earlier in *section 6.2* may indeed prove to be fruitful. Further empirical investigations are needed to verify the claim.

Chapter 7

Conclusion

"There remains the final reflection, how shallow, puny and imperfect are efforts to sound the depth in the nature of things. In philosophical discussions, the merest hint of dogmatic certainty as to finality of statement is an exhibition of folly."

Whitehead (1978, p. xiv)

To conclude, human decision-making cannot be represented as one gradual process nor might it be accurate to describe the process as one mathematical calculation. Along the lines with a Thagardian notion of coherence I acknowledge that there is substantive theoretical and empirical evidence that decision-making is rather a dynamic interactive process utilizing mental parallel constraint satisfaction of inferences based on specific propositions.

Practically speaking, in a situation where we have to decide between different options, we – often intrinsically unconsciously – evaluate our mutually competing aims and actions to facilitate our desired goals in a fashion that maximizes overall coherence of all underlying propositions connected to the decision scenario and thus makes the most sense to us.

It is important to recapitulate here that goals are emotionally valued mental representations of imagined states of the world and self which the brain processes by means of firing patterns in neural populations within and between specific functional brain areas (Thagard, 2010, p. 140). Although within this work I did not discuss and examine the extensive compelling evidence in the literature regarding the specific and critical role that emotions play when people decide, it should be emphasized that emotional value is part of the underlying propositions within the coherentist framework and are in addition represented within the weighting principles of interconnected relations among them (see *section 3*).

Decision-making modeled as parallel constraint satisfaction in order to maximize coherence offers an elaborated way to describe how people draw conclusions based on inferences on a vast amount of propositions. They are based on both, the interaction of unconscious and conscious processes as discussed in *section 6.1.*

As the parallel constraint satisfaction approach to model decision-making focuses how people actually do decisions rather than how they are ought to decide, predictions might turn out to be terrible wrong or misleading.
It is important to acknowledge one elemental critic on coherentism brought up by foundationalism, namely, that the most coherent solution might not entail that it is also true. I do think this objection is legitimate.
Yet up till today those ultimate truths could not have been identified that a foundational position would demand in order to derive other truths from truths.
Therefore it holds that the most coherent option is not necessarily true itself, but it appears likely to be. This is why we finally choose it.

The challenge remains to upscale parallel constraint satisfaction models within a cognitive architecture of increased complexity like for example ACT-R (Anderson et al., 2004) to test model behavior and its interoperability in order to "make sense" in a broader perspective.

Because of the centrality of goals to the domain of decision-making, a major part of this work has been devoted to philosophical considerations about how propositions such as goals arise and become "real" within a transition from implicitness to explicitness (*section 6.4*) by elaborating on quantum mechanical conceptions.

Scientific interest emerges for Quantum Theory for various reasons while one key aspect is supposedly the introduction of randomness through collapse-type quantum effects. This in fact, so the hope, may provide a foundation in order to describe a formalism as a common ground and starting point to understand mental events and shed light on their interaction with neural correlates favored by a dualistic perspective.

The elaborations between the connection of Whitehead's process philosophy and quantum mechanics let to the assumption that actual entities as described by Whitehead have an objective as well as a subjective aspect. Interestingly, this actual entity can – so the theory – be described as the indeterministic collapse of a wave function in quantum theoretical terms.
Following Whitehead's notion, an actual entity can be anything from the universe to the "smallest pulse of experience". My considerations conclude that essentially within the process of decision-making it is possible to think of an "event" as an actual entity within a human conscious stream of experience.
In consequence I believe that process philosophy provides an insightful starting point for an understanding about the transition between "implicit" and "explicit" in that we accept that mind-matter entanglement can be conceived as the hypothetical origin of mind-matter correlations (Atmanspacher, 2004).

The discussion about a notion of "potentiality" as conceived by Ule (2012) and its role within decision-making called attention to the important interrelated conception of "anticipation". To that end I acknowledge that "anticipatory drive" plays a key role in goal adoption and therefore various other cognitive and psychological mechanisms. Consequently, I foresee that the coherentist framework and its application within decision-making to some extend would benefit from the utilization of anticipatory drive within. To give an example, an incorporation within the parallel constraint satisfaction model as proposed by Glöckner (2008), touching upon its goal integration principles on "Network 1" may lead to an increase in predictive quality.

Nevertheless it should be also mentioned that there is the danger of jumping to conclusions that Quantum Theory provides a solution for everything that cannot be explained within our current understanding of classical Newtonian physics.

Accordingly, Ule (2012) addresses this concern as following:

> "I could not find any clear cases of a structural analogy between these quantum phenomena and quantum-mechanical laws, and the phenomena and laws of human experiential consciousness. This fact along with the fact that many lines of the structural analogy given above are incom-

> plete or are only postulated as some reasonable hypotheses show that the structural analogy between quantum physical states/processes and conscious states/processes is only partial and imperfect. In this sense, I claim that human experiential consciousness indicates some important quantum-like traits but not that it indicates some real quantum traits" (Ule, 2012, p. 64).

This work constitutes an intentional strong interdisciplinary discourse on the matter. I outlined examples how computer science implements models inspired by neuroscience (neuronal networks) based on psychological evidence (inferential reasoning, coherence shifts) enriched by philosophical considerations (process philosophy, conception of potentiality and actuality). This should not be affirmed as astonishing. Rather I see interdisciplinarity as inevitable for research and science in order to succeed.

Within this work I could only provide a mere overview of the vast research field on decision-making. Hopefully I succeeded to point out a few promising considerations on how to push the endeavour forward.

It has to be admitted that a compelling all-in-one theory of how people do decisions in a variety of circumstances across different environments and domains is not in reach yet.
This is a task still to be solved in the future. Currently we need to be content with explanations of limited scope. The floor remains wide open to explore further ways to improve the prevailing state-of-the-art.

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Appendix

Abstract

Human decision-making behavior is subject of much ongoing debate within the scientific community. The purpose of this thesis is to investigate and shed light upon the phenomenon towards a better understanding of the matter. In fact this endeavor directs much attention to the concept of coherence with specific focus on its role and interplay in the subject.
Rational Choice Theory and its modifications have dominated the field of decision-making research for decades. These theories understand humans as explicit rational beings. There is reasonable doubt that individuals are able to perform the complex calculations necessary in this regard (Simon, 1955).
Upon these considerations, the work reviews distinct models and theories that emerged within the field of decision research. It depicts the relevance of a Thagardian notion of the concept of coherence with its underlying parallel constraint satisfaction (PCS) mechanisms (Thagard and Millgram, 1997). This approach to describe decision-making behavior is based on the idea that people try to make sense of the world on the basis of fitting something puzzling into a coherent pattern of mental representations.
The centerpiece of this thesis outlines and discusses how the PCS rule fits into an explanation of decision-making behavior. The methodology aims to find the most coherent solution to the decision problem as a single-strategy approach.
The hypothesis suggests that decision-making can be described as the interaction of automatic- and deliberate parallel processes that strive to maximize overall coherence. Unconscious moments represent a vital aspect within the assumption. They appear to be key for a better and encompassing understanding oft the phenomenon.
The thesis frames empirical evidence that coherence shifts appear when individuals are confronted with decision tasks (Holyoak and Simon, 1999). This implies far

reaching consequences regarding basic mechanisms that are in place while people arrive at decision outcomes.

The validity of the hypothesis is critically investigated along the lines of its psychological plausibility. Further, philosophical considerations and quantum-theoretical thoughts in connection with the role of potentiality and actuality within the decision-making process are taken into account.

The thesis concludes by arguing in favor of a coherence maximizing single-strategy approach to decision-making within complex circumstances and highlights remaining challenges yet to be solved in the future.

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Kurzfassung

Ziel dieser Diplomarbeit ist eine interdisziplinäre Betrachtungsweise des Phänomens der Entscheidungsfindung. Spezielles Augenmerk dabei wird auf die Rolle des Begriffs der Kohärenz gelegt. In diesem Kontext werden diverse Modelle zur Entscheidungsfindung erörtert, und verschiedene Arten kognitiver Denkprozesse hervorgehoben.
Ausgangspunkt der Arbeit bildet der begründete Verdacht, dass Menschen in ihren Handlungen nicht mit jener Ausprägung rational handeln, wie lange Zeit angenommen (Simon, 1955). Weiters wird auf das Gebiet der Gestalttheorie verwiesen, aus welchem das Prinzip der "parallel constraint satisfaction" Prozesse herausgearbeitet wird. Die spezielle Bedeutung einer Konzeption der Kohärenz nach Thagard in diesem Zusammenhang bildet die Kernthematik der Arbeit (Thagard and Millgram, 1997).
Als zentraler Bestandteil wird die These vertreten, dass Entscheidungsprozesse als Resultat paralleler Abläufe beschrieben werden können. Diese haben zum Ziel, durch die Interaktion von automatischen und deliberativen Denkprozessen eine Kohärenzmaximierung der mental representierten Entscheidungssituation herbeizuführen.
Weiters wird argumentiert, dass unbewusste Momente von zentraler Bedeutung im Fällen komplexer Entscheidungen sind.
Es werden Beweise und Hinweise aus der Literatur ausgeführt, welche die eingangs erwähnte Hypothese untermauern (Holyoak and Simon, 1999). Diese wird hingehend ihrer Relevanz evaluiert. Anschliessend sind die Befunde Gegenstand einer kritischen Diskussion. Dabei wird die Hypothese auf ihre Haltbarkeit hin überprüft.
Den Abschluss bildet eine philosophische Betrachtung der Rolle des "Impliziten" beziehungsweise "Expliziten" im Entscheidungsfindungsprozess. Hierbei wird von der Prozessphilosophie ausgehend auf den Begriff der Potenzialität und Aktualität eingegangen. Es werden etwaige Analogien in Hinblick auf den Kohärenzbegriff unter quantentheoretischen Überlegungen herausgearbeitet.
Es wird der Schluss nahegelegt, dass menschlichen Entscheidungsprozessen speziell in komplexen Situationen der zentrale Mechanismus der Kohärenzmaximierung zugrunde liegt. Dieser kann grundsätzlich als dynamisch interaktiver Prozess zwischen bewussten, beziehungsweise unbewussten Momenten auf Basis von Inferenzen verstanden werden.
Es wird weiters gezeigt, dass Potenzialität einen wesentlichen Beitrag für ein verbessertes Verständnis von Entscheidungsprozessen leistet. Quantentheoretische

Überlegungen liefern dabei Denkanstösse für ein besseres Verständnis von Entstehung und Natur von Entscheidungsprozessen.

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- Conducted theoretical research about implicit and explicit knowledge within human decision-making processes and the interrelated role of coherence; results were published within Information Society 2010 conference proceedings *(http://is.ijs.si/is/is2010/zborniki.asp?lang=eng)*.
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- Conducted in a team of researchers the project: "*A quantitative comparison of fMRI resting-state data pre-processing strategies on correlation- and anti-correlation networks using MATLAB(c) technology*"; presented work at Cognitive Science Student Conference 2009 in Vienna, Austria.

References available on request.