Rationality in Context: An Analogical Perspective

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Abstract. At times, human behavior seems erratic and irrational. Therefore, when modeling human decision-making, it seems reasonable to take the remarkable abilities of humans into account with respect to rational behavior, but also their apparent deviations from the normative standards of rationality shining up in certain rationality tasks. Based on well-known challenges for human rationality, together with results from psychological studies on decision-making and from previous work in the field of computational modeling of analogy-making, I argue that the analysis and modeling of rational belief and behavior should also consider context-related cognitive mechanisms like analogy-making and coherence maximization of the background theory. Subsequently, I conceptually outline a high-level algorithmic approach for a Heuristic Driven Theory Projection-based system for simulating context-dependent human-style rational behavior. Finally, I show and elaborate on the close connections, but also on the significant differences, of this approach to notions of "ecological rationality".

1 Introduction

At times, human behavior seems erratic and irrational. Still, it is widely undoubted that humans can act rational and, in fact, appear to act rational most of the time. In explaining behavior, we use terms like beliefs and desires. If an agent's behavior makes sense to us, then we interpret it as a reasonable way to achieve the agent's goals given his beliefs. I take this as indication that some concept of rationality does play a crucial role when describing and explaining human behavior in a large variety of situations.

Based on ideas from vernacular psychology, in many cases rational beliefs are interpreted as a foundation of rational behavior. Therefore, in what follows, I will mostly be concerned with beliefs and knowledge, i.e. the epistemic aspects of rationality. Combining and further developing work separately presented in [1, 2], I want to shed light on some aspects of situated rationality (i.e., rationality and rational behavior as it happens in given situations and contexts, as opposed to purely theoretical and abstract notions of rationality) from a mostly computational cognitive science point of view. Although, even in psychology or economics there is no generally accepted formal framework for rationality, I will argue for a model that links rationality to the ability of humans to establish analogical relations based on contextual and situational clues. This is an attempt for further developing a non-classical perspective and framework for rationality implementing principles of the "subject-centered rationality" meta-framework [3]. Furthermore, in the course of a mostly overview-like presentation, I want to give some hints at how already existing frameworks for computational analogy-making integrate some aspects considered characteristic for human decision making, and how the proposed view connects to the better known high-level framework of "ecological rationality" [4].

2 Rationality Concepts and Challenges

2.1 Rationality

Many quite distinct frameworks for modeling rationality have been proposed, and an attempt at clustering these frameworks to the best of our knowledge results in at least four classes: logic-based models (cf. e.g. [5]), probability-based models (cf. e.g. [6]), heuristic-based models (cf. e.g. [7]), and game-theoretically based models (cf. e.g. [8]).

Several of these models have been considered for establishing a normative theory of rationality, not only trying to model "rational behavior", but also to offer predictive power for determining whether a certain belief, action, or behavior may be considered rational or not. Also, every of these theories specifies some sort of *definition* of rationality. Unfortunately, when comparing the distinct frameworks, it shows that these definitions are in many cases almost orthogonal to each other (as are the frameworks). Therefore, in this paper, I will propose certain cognitive mechanisms for explaining and specifying rationality in an integrated, more homogeneous way.

2.2 Well-Known Challenges

Although the aforementioned frameworks have gained merit in modeling certain aspects of human intelligence, the generality of each such class of frameworks has at the same time been challenged by psychological experiments. For example, as described in detail below, in the famous Wason-selection task [9] human subjects fail at a seemingly simple logical task (cf. Table 1). Also, experiments by Byrne on human reasoning with conditionals [10] indicated severe deviations from classical logic (cf. Table 1). Similarly, Tversky and Kahneman's Linda problem [11] illustrates a striking violation of the rules of probability theory (cf. Table 1). Heuristic approaches to judgment and reasoning [12] are often seen as approximations to a rational ideal and in some cases could work in practice, but often lack formal transparency and explanatory power. Game-based frameworks are questioned due to the lack of a unique concept of optimality in game-theory that can support different "rational behaviors" for one and the same situations (e.g. Pareto optimality vs. Nash equilibrium vs. Hick's optimality etc., [13]).

Wason Selection Task: This task shows that a large majority of subjects are seemingly unable to verify or to falsify a simple logical implication: "If on one side of the card there is a D, then on the other there is the number 3". In order to check this rule, subjects need to turn D and 7, i.e. subjects need to check the direct rule application and the contrapositive implication. After a slight modification of the content of the rule (content-change), while keeping the structure of the problem isomorphic, subjects perform significantly better: In [14], the authors show that a change of the abstract rule "$p \rightarrow q$" to a problem accommodated in a more natural and familiar context than the mere card checking setup significantly increases correct answers of subjects. The authors use the rule "If a person is drinking beer, then he must be over 20 years old." The cards used in the task were “drinking beer”, “drinking coke”, “25 years old”, and “16 years old”. Solving this task according to the rules of classical logic comes down to turning “drinking beer” and “16 years old”.

Wason-Selection Task [15]: Subjects are given the rule “Every card which has a D on one side has a 3 on the other side.” and are told that each card has a letter on one side and a number on the other side. Then they are presented with four cards showing respectively D, K, 3, 7, and asked to turn the minimal number of cards to determine the truth of the sentence.
Inferences and Conditionals [10]: 1. If Marian has an essay to write, she will study late in the library. She does not have an essay to write. 2. If Marian has an essay to write, she will study late in the library. She has an essay to write. 3. If Marian has an essay to write, she will study late in the library. She has an essay to write. If the library stays open, she will study late in the library.
Linda-Problem [11]: Linda is 31 years old, single, outspoken and very bright. She majored in philosophy. As a student, she was deeply concerned with issues of discrimination and social justice, and also participated in anti-nuclear demonstrations. Linda is a teacher in elementary school. Linda works in a bookstore and takes Yoga classes. Linda is active in the feminist movement. (F) Linda is a psychiatric social worker. Linda is a member of the League of Women Voters. Linda is a bank teller. (T) Linda is an insurance salesperson. Linda is a bank teller and is active in the feminist movement. (T&F)

Table 1. The Wason-selection task questions whether humans reason in such situations according to the laws of classical logic. Byrne’s experiments on how humans handle conditionals also shed doubt on a logic-based model. Tversky and Kahneman’s Linda problem questions the ability of humans to reason according to the laws of probability theory.

Inferences and Conditionals: Also Byrne’s observations question whether human reasoning can be covered by a classical logic-based framework. Presented with the information given in Table 1, from 1. 46% of subjects conclude that Marian will not study late in the library, erring with respect to classical logic (as denial of the antecedent does not validate a negation of the consequent). Also, from 2. 96% of subjects conclude that Marian will study late in the library, whilst only 38% of subjects reach the same conclusion from 3. Thus an introduction of another antecedent (without any indication that the antecedent should not hold) dramatically reduced the number of subjects applying a simple modus ponens in their process of forming a conclusion.

Linda Problem: With respect to the Linda problem it seems to be the case that subjects are amenable to the so-called conjunction fallacy: subjects are told a story specifying a particular profile about the bank teller Linda. Then, eight statements about Linda are shown and subjects are asked to order them according to their probability (cf. Table 1). 85% of subjects decide to rank the eighth statements “Linda is a bank teller and active in the feminist movement" (T & F) as more probable than the sixth statement "Linda is a bank teller" (T). This ranking contradicts basic laws of probability theory, as the joint probability of two events (T & F) is less or at most equal to the probability of each individual event.

Classical Resolution Strategies: Strategies that have been proposed to address the mentioned challenges include non-classical logics for modeling subjects' behavior in the Wason-Selection task [16], or a switch from (syntactic) deductions to reasoning in semantic models [17]. Still, these are only individual case-based solutions, which do not (or only hardly) generalize, and thus do not provide a basis for a unified theory or the genesis of a generally accepted broad concept of rationality.

3 Non-Standard Interpretations of Challenges for Rationality

An immediate reaction to the challenges for rationality depicted above may be to deny that humans are always able to correctly reason according to the laws of classical logic or the laws of probability theory. Still, concluding that human behavior therefore is irrational in general does not seem convincing. The most that can be concluded from the experiments is that human agents are neither deduction machines nor probability estimators, but perform their indisputable reasoning capabilities with other means. From our point of view, subjects' behavior in the described tasks is connected to certain situation-sensitive cognitive mechanisms that are used by humans in such reasoning tasks, giving rise to the emergence of behavior commonly described as rational.

3.1 Interlude: Analogy and Analogical Reasoning

Analogy-making refers to the human ability of perceiving dissimilar domains as similar with respect to certain aspects based on shared commonalities in relational structure or appearance. Analogy and analogy-making research has received growing attention during the last decades, changing the perception of analogy from interpreting it as a special and rarely applied case of reasoning to placing it in the center of human cognition itself [18]. The literature on analogies knows a distinction between two subcategories of analogical mapping: attribute mappings (surface mappings) and relational mappings [19]. Whilst both mapping types are standardly assumed to be one-to-one, attribute mappings are based on attributes or surface properties, such as shape or color (i.e., two objects can be said to be similar with respect to a particular attribute or set of attributes), whilst relational mappings are based on relations between objects, such as having the same role or the same effect (i.e., two objects can then be said to be similar with respect to some relation to one or more other objects). Once such an analogical bridge has been established between two domains, analogical reasoning now allows for carrying over inferences from the base to the target domain in order to extend knowledge about the latter, i.e., an inference which holds between elements in the base domain is also assumed to analogically hold between the corresponding elements of the target domain. Formalizing different situations and accompanying contexts in a natural way as distinct domains, analogical reasoning thus offers a by now well-developed framework for modeling cross-situational and cross-contextual reasoning processes.

3.2 How Analogy-Making Enters the Rational Picture

In a short reply to Colman's article "*Cooperation, psychological game theory, and limitations of rationality in social interaction*" [20], Kokinov challenges traditional views on rationality [21]. Taking an initial stance similar to Colman's, agreeing on that rationality fails as both, descriptive theory of human-decision making and normative theory for good decision-making, Kokinov reaches a different, more radical conclusion than Colman did before. Instead of trying to fix the concept of rationality by redefining it, adding formerly unconsidered criteria for optimization of some kind, he proposes to replace the concept of rationality as a theory in its own right by a multilevel theory based on cognitive processes involved in decision-making. Where Colman proposes a collection of ad-hoc strategies for explaining the deviations from rationality which people exhibit in their behavior, Kokinov proposes analogy as means of unifying the different, formerly unconnected parts of Colman's attempt at describing the mechanisms of decision-making. In Kokinov's view, the classical concept of utility making has to be rendered as an emergent property, which will emerge in most, but not all, cases, converting rationality itself in an emergent phenomenon, assigning rational rules the status of approximate explanations of human behavior.

Also psychological studies on decision-making and choice processes provide evidence for a crucial role of analogy. An overview by Markman and Moreau [22], based on experiments and observations from psychological studies, amongst others on consumer behavior and political decision-making, reaches the conclusion that there are at least two central ways how analogy-making influences choice processes. Analogies to other domains can provide means of representation for a choice situation, as generally speaking the making of a decision relies on a certain degree of familiarity with the choice setting. In many cases of this kind, analogy plays a crucial role in structuring the representation of the choice situation, and thus may strongly influence the outcome of a decision. Also, structural alignment (a key process of analogy-making) plays a role when comparing the different possible options offered by a decision situation, with new options being learned by comparison to already known ones. An experimental study by Kokinov [23] demonstrated that people use analogies in the process of decision-making, with significant benefit already if only one case is found to be analogous to the choice situation under consideration. Furthermore, evidence has been found that there is no significant difference between close and remote analogies in this process, and that people are not limited to relying only on analogous cases from their own experience, but that also cases which were only witnessed passively (e.g., by being a bystander, or learning about a situation from reports in the media) may have beneficial influence.

Taking all this together, I strongly argue in favor of taking into account cognitive mechanisms centered around the concept of analogy and their situation- and context-dependent nature when analyzing and modeling rational belief and behavior in humans. In the following, I want to provide an analogy-inspired point of view on the aforementioned well-known challenges for rationality.

3.3 The Wason-Selection Task and Cognitive Mechanisms

As mentioned above, according to [14] subjects perform better (in the sense of more according to the laws of classical logic) in the Wason-Selection task, if content-change to a more natural situational framing makes the task easier to access for subjects. In our reading, subjects' performance is tightly connected to establishing appropriate analogies. Subjects perform badly in the classical version of the Wason-Selection task, simply because they fail to establish a fitting analogy with an already known situation. In the "beer drinking" version mentioned above, i.e. the re-contextualized version of the task, the situation changes substantially, because subjects can do what they would do in an everyday analogous situation: they need to check whether someone younger than 20 years is drinking beer in a bar. This is to check the age of someone who is drinking beer and conversely to check someone who is younger that 20 years whether he is drinking beer or not. In short, the success or failure of managing the task is crucially dependent on the possibility to establish a meaningful analogy, which in turn intrinsically is tightly linked to the provided situational and contextual clues.

3.4 The Inferences and Conditionals Problem and Cognitive Mechanisms

The results concerning conclusions drawn by the subjects in Byrne's experiments can also be explained through analogy-making and context dependence. People faced with the information given in 1. will recall similar conversations they had before, using these known situations as basis for their decision on what to conclude. According to Grice [24], in conversations speakers are supposed to provide the hearer with as much information as is needed for exchanging the necessary information, a rule which goes in accordance with our everyday observation. Thus, when being given the additional information that "Marian does not have to write an essay.", the set of candidate situations for establishing an analogy is re-oriented towards situations in which this information had an impact on the outcome, resulting in the conclusion that Marian would not study late in the library either. Regarding 2. and 3., a similar conjecture seems likely to hold: By additionally mentioning the library, similar situations in which the library might actually have played a crucial role (e.g., by being closed) will be taken into account as possible base domains of the analogy, causing the change in conclusions made.

3.5 The Linda Problem and Cognitive Mechanisms

For Tversky and Kahneman's Linda problem, a natural explanation of subjects' behavior is that people find a lower degree of coherence between Linda's profile (i.e., the context) and the statement "Linda is a bank teller", than they do with the expanded "Linda is a bank teller and is active in the feminist movement". In the latter case, at least one conjunct of the statement fits quite well to Linda's profile. In short, subjects prefer situations that seem to have a stronger inner coherence. Coherence is important for the successful establishment of an analogical relation, as it facilitates the finding of a source domain for an analogy. I conjecture that in order to make sense of the task, humans rate statements with a higher probability where facts are arranged in a contextual theory with a higher degree of coherence. Now, seeing coherence as a means for facilitating situated analogy-making, and taking into account that analogy has been identified as a core element of human cognition, the decision for the coherence-maximizing option is not surprising anymore, but fits neatly into the contextualized analogy-based framework, and can, thus, also be predicted (providing inductive support for our general claim).[1]

4 Rationality, Decision-Making and Analogy-Making Systems

In the following I want to give an overview-like sketch of how computational analogy-making systems can be related to some of the discussed challenges for rationality, as well as to context-sensitive decision-making and choice in general, demonstrating their value as models also in this domain. This prepares the ground for the presentation of a high-level algorithmic approach to simulating context-dependent human-style rational behavior (based on the Heuristic-Driven Theory Projection framework for computational analogy-making) in the following section.

4.1 Heuristic-Driven Theory Projection

Heuristic-Driven Theory Projection (HDTP) is a symbolic framework for computing analogical relations between two domains (formalizing different situations or contexts) that are axiomatized in a many-sorted first order logic language [25]. HDTP, after being given the logic representations of the two domains, by means of anti-unification [26] computes a common generalization of both, and uses this resulting theory as basis for establishing an analogy, also involving analogical transfer of knowledge between the domains (i.e., the system provides an explicit generalization of the two domains as a by-product of the analogy-making process). Thus, conceptually, HDTP proceeds in two phases: in the *mapping phase*, the formal representations of source and target domain are compared to find structural commonalities, and a generalized description is created, which subsumes the matching parts of both domains. In the *transfer phase*, unmatched knowledge in the source domain can be transferred to the target domain to establish new hypotheses in an analogical way (cf. Fig. 1).

As an example for cross-contextual reasoning in HDTP think about the Rutherford-Bohr planetary model of the atom in analogy to a model of the solar system: HDTP, after finding commonalities in the logical representation of the solar system as base domain, and the atom model as target domain (for example, that in both cases less massive objects are somehow related to a more massive central object, or that always a positive distance and a positive force between these lighter objects and the heavier core can be found), a generalization is computed, via which known laws from the base can be re-instantiated in the target (e.g., that a lighter object revolves around a heavier

[1] Tversky and Kahneman [11] proposed the representativeness heuristic for explaining their findings, hypothesizing for the probability of an event to be evaluated by the degree to which the event is representative of a corresponding mental model. Although this notion superficially seems almost identical to a coherence-based account certain distinctions have to be noted, most prominently a difference in basic perspective: Whilst representativeness takes into account, e.g., notions of typicality, similarity in essential characteristics, but also puts significant emphasis on different degrees of salience between elements, coherence targets a maximization of achieved homogeneity and seamless integration (at first leaving levels of salience and similar aspects out of consideration).

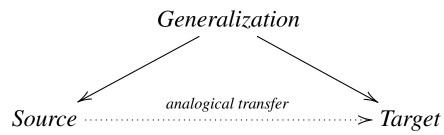

Fig. 1. HDTP's overall approach to creating analogies

one when there is negative centrifugal force between the lighter and the heavier one, yielding the revolution of the electrons around the nucleus, or that the centrifugal force between two spatially separated objects with positive gravitational force between both is equal to the negative value of that gravity, resulting in stable orbits of the electrons in the model).

HDTP implements a principle (by using heuristics) that maximizes the coverage of the involved domains [25]. Intuitively, this means that the sub-theory of the source (or the target) that can be generated by re-instantiating the generalization is maximized. Putting it the other way round, the original domain-specific information and structure shall implicitly be preserved as far as possible. The higher the coverage the better, because more support for the analogy is provided by the generalization (in a way, the higher the achieved degree of coverage, the more firmly the analogy is rooted in the underlying domains, used for creating the generalization). A further heuristic in HDTP is the minimization of substitution lengths in the analogical relation, i.e. the simpler the analogy the better [27]. The motivation for this heuristic is to prevent arbitrary associations. Clearly there is a trade-off between high coverage and simplicity of substitutions: An appropriate analogy should intuitively be as simple as possible, but also as general and broad as necessary in order to be non-trivial. Unfortunately, high coverage normally comes with higher complexity of substitutions (as a more complex generalization allows for a higher degree of re-representation of domain-specific structures and information), whilst the simplicity constraint is trying to steer the analogy-making process in exactly the opposite direction. This kind of trade-off is similar to the kind of trade-off that is usually the topic of model selection in machine learning and statistics.

4.2 The Wason-Selection Task Revisited

A modeling of the Wason-Selection task with HDTP is quite simple as long as appropriate background knowledge is available, in case an analogy should be established, or the lack of appropriate background knowledge prevents analogy-making, in case no analogy should be established: On the one hand, if background knowledge for an analogous case is missing (i.e., in the case of HDTP, no domain representation which offers sufficient commonalities to the target domain as to serve as a base for the analogy process can be retrieved from memory), then there is no chance to establish an analogical relation. Hence, subjects have to apply other auxiliary strategies, possibly deviating from the expected "right" answer. If there is a source theory with sufficient structural commonalities on the other hand, then the establishment of an analogical relation is straightforward, resulting in a smooth solution process of the task.

4.3 Analogy in Choice

Coming back to Markman and Moreau's meta-study of the role analogy and analogical comparison play in the process of human choice, presented in [22], I want to show some connections of their findings to computational systems for analogy-making.

It is without doubt that the choice of options taken into account when making a decision is of crucial importance for the entire process of decision-making. Markman and Moreau present the formation of consideration sets (i.e., the set of options taken into account by a decision maker) as one of the places at which the influence of analogy on decision-making clearly shines up. An analogical reasoning process is involved when deciding on which scenarios are likely to happen, and thus have to be considered (also see [28] for related results). According to their findings, there are different factors influencing which analogies will be used in a choice situation, resulting in a set of analogies which are considered similar or familiar to the current situation. Close analogs have the advantage of probably allowing the transfer of more lower-order relations than distant analogs would, i.e., closer concepts are more likely to be considered as an option due to an easier and more fruitful analogy-making process. This goes in accordance with characteristics exhibited by many computational models of analogy-making, where again I want to use HDTP as prototypical example: As pointed out in [25], although HDTP basically aligns any entity, function or predicate, it clearly prefers literally-matching alignments over non-literally ones, and equivalent structures to structural mismatches, thus reconstructing a preference and behavior also shown by humans.

Also, experiments indicate that commonly shared surface elements of domains are more useful as retrieval cues than are connected relational systems. Also this carries over to the principles underlying HDTP, with the system trying to minimize the complexity of analogical relations whilst maximizing the degree of coverage: Connected relational systems have the strong tendency of reaching higher-order stages, whilst direct surface correspondences stay on a low level, allowing for a direct matching of features. Thus, handling common surface elements allows for a certain degree of coverage without having to escalate complexity, probably also making HDTP prefer surface elements for supporting an analogy over relational ones (if both types are equally available).

Finally, it shows that elements related to a person's individual history of experiences influence the way decisions are taken. These elements have the advantage of being (mostly) highly accessible, with base domains which form part of someone's past being more likely to have richly connected relational structures, providing good ground for eventual analogical inference. When searching for a way of computationally modeling this phenomenon, it comes to mind that a similar effect can already be found in AMBR, Kokinov's hybrid analogy-making system [29]. This system exhibits signs of priming effects in the retrieval process of a fitting base domain for an analogy's given target domain, together with a general influence of earlier memory states on later ones.

5 Cornerstones of an Architecture for Human-Style Rationality

In this section, I outline how solving a rationality puzzle can mechanistically be modeled in terms of HDTP, by this also pointing towards principles for a HDTP-based architecture for a cognitive rationality system. The described model naturally connects to previous foundational work in the field of decision theory and economics. Almost two decades ago, [30] developed an (at least partly) case-based theory and model for decision-making under uncertainty. In their model, cases are primitive and provide a simple axiomatization of a decision rule that selects an act to be performed based on the act's past performance in similar cases. Each act is evaluated by the sum of the utility levels that resulted from using this act in past cases, where the degree of (dis)similarity between the past cases and the problem at hand is accounted for by weighting the respective utility by the value of a similarity measure between both situations. Remarkably, this formal approach in a natural way gives rise to (amongst others) the notions of satisficing decisions and aspiration levels (cf. [31] for a detailed account).

The subsequently proposed general architecture, on a very abstract level, can functionally be subdivided into four steps (adding a framing pre- and post-processing step to the original HDTP setting described above): Given a problem description and domain, select and retrieve analogical situations (and embedding contexts) from memory (*retrieval*). Use the problem as target domain for an analogy, the retrieved situation as source domain, and establish an analogy between both (*mapping*). Transfer solution-relevant knowledge from the source domain to the target domain via the analogical mapping (*transfer*). Apply the newly obtained knowledge in the target domain (i.e. the problem domain) for solving the problem (*application*).

As already stated before, in HDTP, source and target domains for analogy-making are represented as theories in a many-sorted first-order logical language. In the following, I additionally assume that the system has access to a library of previously formalized situations and scenes (i.e., domains that had already initially been pre-compiled, or that have been learned and acquired during runtime up to the present moment in time), corresponding to a human's (episodic) memory of previously seen and experienced happenings and events (here, constraints on human memory could e.g. be modeled by limiting the number of domains available to the system).

Given the (rationality) problem at hand as target domain for the analogy, the *retrieval* problem within HDTP comes down to selecting a fitting domain from memory as source domain. This can be done in different ways, for example by means of a separate module (similar to the MAC stage in the MAC/FAC analogy model [32]), or by forcing HDTP to construct analogies between all possible pairings of the target domain with a candidate source domain, subsequently taking the heuristic value HDTP computed when constructing the analogy as a measure for analogical distance between domains and proceeding e.g. with the analogically closest domain as source domain for the analogy. By now additionally assuming that candidate source domains had been labeled with overall satisfaction levels, a mechanism similar in output to the utility-based approach of [30] arises: Weighted by the respective analogical distance, the satisfaction level can serve as parameter for the domain selection. Also, the outcome of the retrieval process of course does not have to be unique, and always strongly depends on the heuristics or distance measures used, thereby introducing a degree of uncertainty into the system (matching the uncertainty and irregularities in human rational behavior).

Once a source and target domain have been identified, HDTP constructs an analogical relation between both, *mapping* between elements from source and target domain. The construction of this mapping is based on the previously outlined generalization mechanism, guided by a heuristic which tries to keep the analogy as simple (i.e. less general) as possible, whilst still maximizing the sub-theories of the sources which can be re-instantiated from the generalization (a trade off close in spirit to the precision/recall problem in pattern recognition and information retrieval). Also here, in most cases the mappings between elements of the respective domains do not have to be unique (e.g. different elements of the source could be mapped to one certain element of the target domain), again introducing a source of uncertainty.

In the transfer phase, knowledge from the (with respect to problem solutions richer) source domain is transferred to the target domain (i.e. the problem at hand). Making use of the mappings established in the previous step, the concepts from the source domain are re-instantiated from the generalized theory into the target domain, enriching the latter and giving additional information needed for computing a solution to the problem.

In the last step, the newly added knowledge is *applied* in the target domain (e.g. used for reasoning and inference), in most cases yielding a solution to the problem (sometimes, although additional knowledge has been provided via the analogical process, the problem solving process still will fail, a phenomenon reminiscent of human failure in seemingly familiar, in the past already mastered problem situations). This step also includes a consolidation process, integrating the transferred knowledge into the target domain, giving an expanded or richer domain.

Of course, this type of architecture leaves ample space for uncertainty and deviating behavior: Apart of the already mentioned systemic influences, a certain chance of deviation from HDTP's predicted outcome for a certain problem situation is automatically introduced by the use of logical theories as descriptive framework for contexts, situations and problems. As with every symbolic formalization, decisive information might accidentally be left out of considerations when formulating the domain descriptions. Nonetheless, I do not see this as a major drawback, but rather as a natural constraint every system trying to predict a phenomenon as complex as human rational behavior has to face, and which even holds in the case where humans try to predict each other.

6 On the Relation of Analogical and Ecological Rationality

Over the last years, "ecological rationality" [4] has become one of the most prominent new, non-classical notions of rationality. Within this framework, human reasoning and behavior are considered rational if they are adapted to the environment in which humans act: One cannot understand human cognition by studying either the environment or cognition alone, and peoples reasoning has to be seen as the result of an adaptation of the individual to his or her environment.

This approach at first glance seems almost identical to the contextualized analogy approach presented in this paper. But, although there indeed are close conceptual ties and many underlying intuitions and first assumptions are shared, there still are significant differences. The insight that in order to understand cognition one also needs to explore the characteristics of the environment upon which cognition is based and within which it is happening is common to both views, but the conclusions drawn from this observation differ in their focus: Ecological rationality on the one hand mostly emphasizes the impact the environment has on the reasoner and the reasoning process in that, e.g., reasoning mechanisms have to be adaptive to the environment and that the environment imposes certain ways of reasoning on the reasoner via resource constraints and efficiency optimization. The contextualized analogy approach on the other hand is based on a certain type of mechanism which is assumed to play a crucial role in the reasoner's cognitive setup in the first place, independent of the particular environment. Clearly, at the moment of reasoning the situation and the context the reasoner currently is situated in play an important and fundamental role in providing additional clues and, thus, allowing for efficient and resource adequate reasoning. Nonetheless, the perspective stays subject-centered in that the reasoner and his or her cognitive capacities are the determining elements (placing it under the conceptual umbrella of "subject-centered rationality" [3]). Under the advocated paradigm, given an environment, it is not said that the reasoner would always (almost automatically) prefer a theoretically more efficient reasoning mechanism (as it would be the case under the ecological rationality assumption). Instead, properties and preferences specific to the situationally and contexutally situated subject have to be taken into account — where a strong bias towards analogy as core cognitive capacity is assumed.

7 Concluding Remarks

The evidence for a crucial role of analogy-making and context-sensitive forms of reasoning presented over the last pages falls far from being complete. Yet another example can be given in form of well-known studies on human decision-making under time pressure, which show a change in the applied inference procedure. In [33], the authors report that, whilst the best predicting model of human inference for decision making in an unstressed conditions was a weighted linear model integrating all available information, when time pressure was induced, best predictions were obtained by using a simple lexicographic heuristic [34]. This presumed change from a more complex strategy using complex relational structures to a simple single-attribute-based procedure also can be found in research on analogy-making: In [35], it is reported that anxiety made participants of an analogical-reasoning experiment switch from a preference for complex relational mappings to simple attribute-based mappings. Still, whilst not claiming completeness of the given overview of evidence, I am convinced that the examples and indications are sufficient as not to allow for leaving analogy and cognitive processes out of consideration.

A criticism with respect to the analogy-making approach might be a seeming lack of normativity as a theory. Although work on this topic is still in a very early stage, I am confident that this objection is partially conceptually mistaken and partially grasps at nothing: First of all it has to be noticed that the presented ideas clearly aim at a positive theory and predictive notion of situated rationality rather than at an a priori normative conception (also see [3] for further details). Secondly, normativity can a posteriori be introduced in several different ways on distinct levels, for instance in a subject-independent fashion by considering the reasonableness (or unreasonableness) of made analogies. Roughly speaking, it is obvious that different analogies may have different degrees of reasonableness, e.g., based on the level to which they result in coherent beliefs and to which they encompass both, the source and the target domain of the analogy (again see [3] for a sketch of an alternate, subject-centered proposal).

In this paper, I argued in favor of the concept of analogy and for a strengthened awareness for the importance of situation dependence and context effects in conceptual research on rationality and decision-making on a foundational level. Based on a review of some basic concepts and existing work within the fields of analogy research and research on decision-making and choice, together with an exemplifying proposal of new resolution strategies for classical rationality puzzles and a high-level conceptual sketch of an algorithmic approach for an analogy-based computational model, I advocated that the usage of frameworks for establishing analogical relations and the usage of frameworks that can maximize the situational and contextual coherence of a theory necessarily have to be taken into account when modeling (and possibly implementing) what is commonly considered rational belief in a not overly simplified manner.

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