Constraint Satisfaction Processes in Social Reasoning

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Abstract

We show that constraint satisfaction processes (coherence based reasoning) play an important role in social reasoning, and that social reasoning violates key assumptions of classic models of judgment and decision-making. Constraint satisfaction models predict a bi-directional flow of influence between evaluations of evidence for a judgment and the judgment itself, such that an evolving judgment can influence the evaluation of evidence. In contrast, models of judgment and decision-making, such as Bayesian models, SEU and Information Integration Theory assume that the direction of influence is only from the evaluations to the judgment. We examined two very different social reasoning tasks, a judgment about whether a young dating couple would get married, and a legal case about the guilt of a defendant charged with murder. In both studies, subjects exhibited strong coherence effects, such that the evaluation of evidence shifted over time to become more coherent with the final judgment. We note the similarity of constraint satisfaction models to classic cognitive consistency theories in social psychology, such as Cognitive Dissonance Theory.

Introduction

Everyday social judgments, such as whether a couple we know is likely to get married or whether someone is guilty of a crime, often rely on integrating multitudes of pieces of evidence and inferences to arrive at a choice. Despite the ubiquity and importance of these kinds of judgments, the reasoning processes underlying them are not well understood.

The aim of the current research is to shed further light on these kinds of reasoning processes. We propose that reasoning in these kinds of social judgments can be understood in terms of constraint satisfaction processing (Holyoak & Simon, 1999; Holyoak & Thagard, 1989; McClelland & Rumelhart, 1986; Read & Miller, 1994; Read, Vanman, & Miller, 1997; Thagard, 1989, 2000). In a constraint satisfaction network, nodes (representing concepts) have positive and negative links with each other, representing the nature of the relationships among them. Activation spreads through such a network so as to satisfy the constraints imposed by the relationships and the activation of the concepts, and maximize the coherence or Harmany (Thagard, 1989) of the network (or alternatively, minimize its energy (Hopfield, 1984).

We explicitly contrast the predictions of such constraint satisfaction or consistency models with classic models of decision-making, such as Norman Anderson's (1996) Information Integration Theory (IIT), Bayesian decision models, and Subjective Expected Utility Theory (SEU). At the core of Information Integration Theory is the tenet that human cognition can be described by simple algebraic rules: judgments of complex phenomena are the mathematical product – typically a weighted average – of the respective psychological valuations. Bayes theorem is based on the sequential multiplication of probabilistic values and SEU is based on the multiplication of probabilities and utilities.

IIT explicitly (and the other models implicitly) assume two central syntactic rules. The first is *meaning invariance*: each piece of evidence is evaluated on its own terms, and is not affected by the other pieces of evidence (unless there is a pre-existing relationship of interdependency). The second rule, *valuation-integration independence*, posits complete separation between the processes of evaluation and integration; the evaluation of a piece of evidence is assessed independently from how it is combined to form the ultimate conclusion.

This pair of rules logically implies what we describe as the property of uni-directionality: inferences flow from the individual pieces of evidence towards a computed judgment, but the evaluation of the evidence should not be affected by the emerging conclusion (valuation-integration independence), and there should be no interactions among the pieces of evidence (meaning-invariance). In contrast to these assumptions of the classic models, we will show that decision-making in these kinds of tasks proceeds *bi-directionally*. That is, not only does the evidence influence the conclusions, but at the same time, the emerging conclusion affects the interpretation of the evidence. Such a finding would be consistent with cognitive consistency and constraint satisfaction models, but strongly inconsistent with IIT, SEU theory, Bayesian models, and with other classes of models that make the same assumptions.

We also examine the possibility that decision-making affects not only the specific evidence relevant to the task, but also related beliefs. Constraint satisfaction models raise the possibility that changes in the evaluation of evidence may also affect the associated beliefs that are used to interpret the evidence.

Cognitive Consistency Theories and Constraint Satisfaction

One strand of research that earlier attempted to explore processing in such tasks involving multiple variables was cognitive consistency theories, such as Heider's balance theory (1946, 1958), Festinger's Cognitive Dissonance Theory (1957) and a number of neo-balance theories (Abelson & Rosenberg, 1958; Cartwright & Harary, 1956). At the heart of cognitive consistency theories is the Gestaltian tenet that human cognition proceeds by mutual interaction among pieces of psychological knowledge (Asch, 1946; Wertheimer, 1922).

Cognitive consistency theories were animated by four principles of structural dynamics. First, cognitive states are determined holistically through the interaction of cognitive elements, rather than elementally. Second, structural properties are dynamic -- the interrelation of cognitive elements generates forces that determine the configuration of the structure. Third, the dynamic character of mental processes is such that they tend to settle at states of "good" structural properties, namely "Prägnanz" (Wertheimer, 1923), "good figure" (Heider, 1960), consonance (Festinger, 1957), or equilibrium (Rosenberg & Abelson, 1960). These are quite similar to ideas of coherence found in work on constraint satisfaction networks (e.g., Thagard, 1989, 2000). Fourth, and most pertinent to the current experimental project, these dynamical changes that occur at the structural level often involve changes, or "reconstructions" (Rosenberg & Abelson, 1960) of the cognitive elements, which may involve such things as changes of meaning of elements or the introduction of new elements.

This fourth aspect is of crucial importance to the proposed understanding of human cognition: reasoning tasks that require the integration of multiple pieces of evidence into a global judgment entail not only making inferences from the evidence to the conclusion, but they also entail reverse effects, by which the structural forces that push the system towards *good form* impose changes on the values of the evidence itself. Hence, the dynamical character of cognitive consistency theories can be characterized as operating in a bidirectional manner – from evidence to conclusions and from conclusions back to evidence (Read, Vanman, & Miller, 1997; Holyoak & Simon, 1999; Simon & Holyoak, 2002).

Readers should recognize these principles from recent work in cognitive science on coherence based and constraint based reasoning. Read, Vanman, and Miller (1997) have extensively discussed the similarities between the Gestalt principles that formed the basis of much of social psychology and constraint satisfaction processes.

Cognitive consistency theories were developed as part of an attempt to develop a general theory of cognition. However, they were crippled by their inability to represent rich and complex phenomena, and by the lack of a formal model for evaluating and computing consistency (Read & Miller, 1994; Read, Vanman, & Miller, 1997). As a result, work on cognitive consistency theories largely came to a standstill by the early 1970s. However, several authors (e.g., Read & Miller, 1994; Read, Vanman, & Miller, 1997; Shultz & Lepper, 1996, 1998; Spellman & Holyoak 1992) have recently demonstrated that constraint satisfaction processes provide an explicit computational realization for these classic consistency theories.

Goals

The primary objective of the current research is to illuminate the nature of making decisions that are based on multiple judgments and inferences. Specifically, we intend to test whether the process can be understood as governed by the Gestaltian principles of structural dynamic models. Such a finding could support an extension of the classic cognitive consistency theories to larger, semantically rich, and more complex tasks than previously conceived. This examination will also help determine whether the process conforms to the syntactic rules of meaning invariance and valuation-integration independence, or whether it is better characterized as a coherence-driven construction of the cognitive representation.

In the following experiments, participants were asked to evaluate a number of pieces of evidence and background knowledge, first in isolated vignettes that shared no apparent relationship, and then again as pieces of an overall case about which they were to make a decision.

In Study 1, the materials recounted a variety of facts about the relationship of a young dating couple (Jenny and Mark) and participants were to judge whether they thought the couple would stay together and get married or would split up, and they were also asked their evaluation of the recounted facts. In Study 2, the materials recounted a murder case against a defendant, Tim O'Reilly, and participants were to decide whether the defendant was guilty or innocent of the murder, and to indicate their evaluation of the pieces of evidence presented in the case. In both experiments there was sufficient ambiguity so as to support either outcome.

If reasoning in this task can be characterized by a constraint satisfaction process, we would expect that the evaluation of the evidence would shift toward providing support for whichever judgment was made. Thus, in both studies we would expect that the evaluations of the evidence would shift from pre test to post test to become more coherent with the final judgment.

Study 1

Method

Participants. 183 people participated in this study through the WWW. Ads were posted on the website "About.com". To attract participants, an entry in a $200 lottery was given to each participant (odds of winning 1/200). Participants ranged in age between 18 and 65 with a mean of 38.

Procedure. After reading and accepting the online informed consent, participants either moved immediately to the first set of materials or were first told that their ability to accurately determine whether Jenny and Mark stayed together or split up would be diagnostic of their level of social intelligence. We hoped that this would motivate people to think harder about the material so that we could see if greater motivation would lead to stronger coherence

effects.

All participants were presented with a series of web pages containing the materials. The sequence of presentation involved two online questionnaires separated by a distracter task containing 20 verbal analogies. Once all of the materials had been completed, participants completed a series of demographic questions.

The first questionnaire, consisting of a series of unrelated vignettes involving people in romantic relationships and people in legal disputes, contained 1 to 4 questions related to each vignette. Participants responded to these questions using an 11 point scale ranging from –5 (strongly disagree) to +5 (strongly agree). Each vignette had 1 to 2 Fact questions such as, "Zoe's assessment of Michelle is correct. The fact that Michelle broke up previous relationships suggests that she is not going to commit herself to a stable relationship in the near future." Also included with each vignette was 1 to 2 Belief questions such as, "Generally speaking, people who break off a number of lengthy relationships do so because they have a problem making commitments."

After completing the first questionnaire (pretest), participants then responded to the distracter task, consisting of 20 verbal analogies from the Miller Analogies Test, on a new web page. This task was then followed by the second questionnaire (post test) on a new web page.

The second questionnaire asked participants to imagine that they were friends with two people named Jenny and Mark who were romantically involved with each other. Participants then read a large vignette about Jenny and Mark that incorporated the same factual elements conveyed separately in the pretest vignettes. After reading the vignette, participants were asked if they would be willing to spend $50 on a necklace as an engagement gift for Jenny. If a participant chose to buy the necklace, it implied that he or she felt that the couple would stay together. Not buying the necklace implied a break up. Following their decision about the purchase, participants were asked to rate their level of confidence regarding their decision from low to high, using a five point scale. The last part of the second questionnaire asked the same Fact and Belief questions as were asked in the pretest, but now the questions pertained exclusively to the relationship between Jenny and Mark. These questions were either in support of the couple staying together or breaking up. An example of a Fact question is, "Karen's assessment of Jenny is correct. The fact that Jenny broke up previous relationships suggests that she is not going to commit herself to a stable relationship in the near future." An example of a Belief question is, "Generally speaking, people who break off a number of lengthy relationships do so because they have a problem making commitments." Once the second questionnaire was completed, participants were presented with a series of demographic questions on a separate web page. A final web page debriefed participants.

For analyses, participants were divided up into those who decided to Buy the Necklace and those who decided Not to Buy the Necklace. Further, responses to questions consistent with breaking up were reverse coded so that higher responses were consistent with the couple staying together. These were averaged with the stay together items to create an overall Stay Together index, in which higher scores indicated responses consistent with a belief that the couple would stay together. Therefore, the design of the study was a 2 (Social Intelligence versus Control, between subjects) X 2 (Buy Necklace versus Not Buy Necklace, between subjects) X 2 (pretest questions versus post test questions, within subjects) factorial. Fact and Belief questions were analyzed separately.

Results

As expected the implications of the events were somewhat ambiguous and open to interpretation, as indicated by the fact that there was a fair amount of disagreement as to what to do. Sixty-seven subjects (37%) decided to buy the necklace and 115 (63%) decided to not buy the necklace. Nevertheless, subjects were quite confident in their decisions: the distribution of confidence was highly bimodal with almost no subjects in the middle of the distribution.

The extent of the coherence shift, if any, was tested by a 2 (Social Intelligence versus Control, between subjects) X 2 (Buy Necklace versus Not Buy Necklace, between subjects) X 2 (pretest questions versus post test questions, within subjects) ANOVA of the Stay Together index, which is the average of the interpretation questions. Fact and Belief questions were analyzed separately. Evidence for a coherence shift would be provided by a significant interaction between the two factors of pre test – post test and whether participants decided to buy the necklace.

As expected this interaction was highly significant, F (1, 178) = 20.78, $p < .001$. As can be seen in Figure 1, for those subjects who decided to buy the necklace, their scores on the Stay Together index increased from pretest to post test, while participants who decided not to buy the necklace showed a decrease from pretest to post test on the Stay Together index.

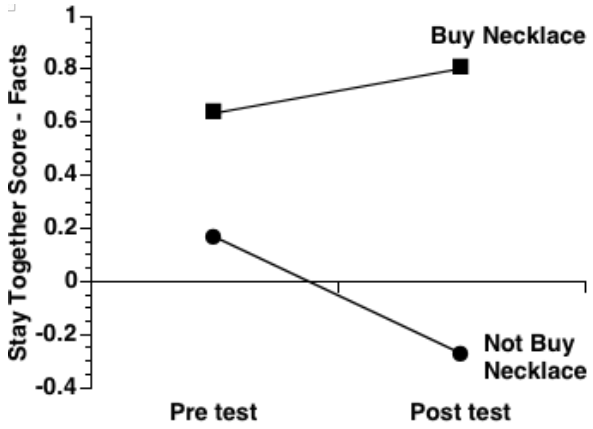

Figure 1: The Stay Together scores for those who did and did not decide to buy the necklace.

Contrary to predictions the Social Intelligence manipulation had no impact. The size of the coherence shift was equally strong in both conditions. Thus, as predicted, subjects' evaluation of the events shifted over time to

become more coherent with their final decision.

Contrary to predictions, there was no evidence of a coherence shift for the belief items. However, we will provide evidence of a shift in belief items in the legal case.

Study 2

In this study we examined the role of constraint satisfaction processing in legal decision-making. We expected that participants' interpretations of the testimony in a murder case would shift over time so as to become more coherent with their final verdict. We also expected coherence shifts in participants' background beliefs.

Method

Participants. A total of 334 people participated in this study by logging onto our study Web page. Ads were posted on the website "About.com" to advertise the study. To motivate participation, a lottery entry of $200 was granted to each participant with the odds of winning being 1/200. Participants ranged in age between 18 and 69 with a mean age of 34.

Procedure. After reading and accepting the online informed consent, participants responded to a series of unrelated vignettes describing people involved in romantic relationships or legal disputes. There were 1 to 4 questions for each vignette. These questions dealt either with the specific facts of each vignette or general beliefs about the world related to each vignette. Participants responded using an 11 point scale ranging from –5 (strongly disagree) to +5 (strongly agree). Each vignette had 1 to 2 Fact questions. For example, following a vignette about Wendy, who was asked by her girlfriend to identify the person who left flowers on her desk, participants were asked to state their agreement with the following statement: "Wendy's identification makes it likely that it was Dale who left the flowers on Jessica's desk." Also included with each vignette were 1 to 2 Belief questions such as, "In general, when people identify someone whom they've seen once or twice before the identifications are accurate."

After completing this questionnaire (pretest), participants were then administered the distracter task, consisting of 20 verbal analogies from the Miller Analogies Test on a new web page. This task was then followed by the second questionnaire (post test) on another new web page.

The post test consisted of a large legal case about a suspect in the murder of a security guard at a company. The defendant was an employee named Tim O'Reilly. This case incorporated the same factual elements conveyed separately in the pretest vignettes.

After reading the case, participants came to a verdict regarding Tim O'Reilly. Based on their verdict, participants were divided up as either "Convictors" or "Acquittors". Participants were then asked to rate their level of confidence regarding their verdict from low to high, using an 11 point scale. The last part of the second questionnaire asked the same Fact and Belief questions as were asked in the pretest, but now they instead pertained exclusively to the Tim O'Reilly case. An example of a Fact question is, "The technician's identification of the defendant makes it likely that the person hurrying out of the bookkeeper's office was in fact the defendant." An example of a Belief question is, "In general, when people identify someone whom they've already seen once or twice before the identifications are accurate." These questions were worded either in favor of guilt or innocence. Responses to the questions were later recoded to create what we called a Guilt score, in which higher responses were consistent with a verdict of guilty. Therefore, the design of the study was a 2 (Convictors versus Acquittors, between subjects) X 2 (pretest questions versus post test questions, within subjects). Responses to Fact and Belief questions were separately analyzed. Upon completion of the materials, participants filled out a series of demographic questions.

Results

As in Study 1, we were successful in creating a scenario that seemed somewhat ambiguous, as there was not agreement as to whether Jason was guilty. 36.4% of the participants gave a verdict of guilty and 63.6% gave an innocent verdict.

Results were analyzed as 2 (Convictors versus Acquittors, between subjects) X 2 (pretest questions versus post test questions, within subjects) ANOVA on the Guilt score. Note that all items were recoded so that higher scores indicated that the item favored Guilt. Responses were analyzed separately for the Fact questions and the Belief questions.

For the Fact items there was a coherence shift as indicated by a significant interaction between Pre post and Verdict, $F(1, 332) = 204.17$, $p < .001$. As can be seen in Figure 2, for the Convictors, there was an increase from pre test to post test in their Guilt score, whereas for the Acquittors there was a decrease from pre test to post test.

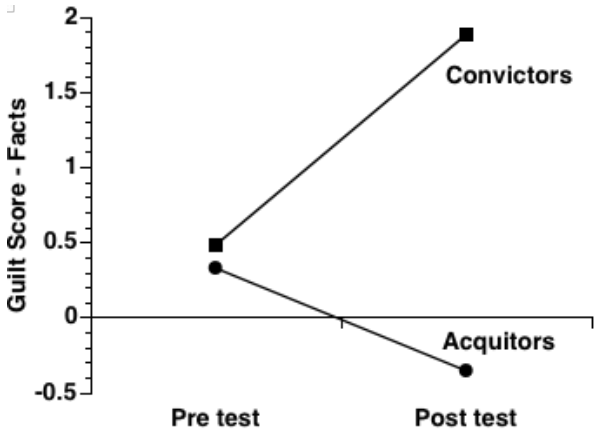

Figure 2: Agreement with Guilt Score - Facts by individuals either Convicting or Acquitting

In this study, there was also a coherence shift for the Belief items, as indicated by a significant interaction between Pre post and Verdict, $F(1, 332) = 60.68$, $p < .001$. As can be seen in Figure 3, the Belief items exhibited the same pattern as the Fact items, with Convictors exhibiting an increase from pre test to post test on the Guilt score and

Acquittors showing a decrease. Not surprisingly, this effect was somewhat weaker than the effect for Fact questions.

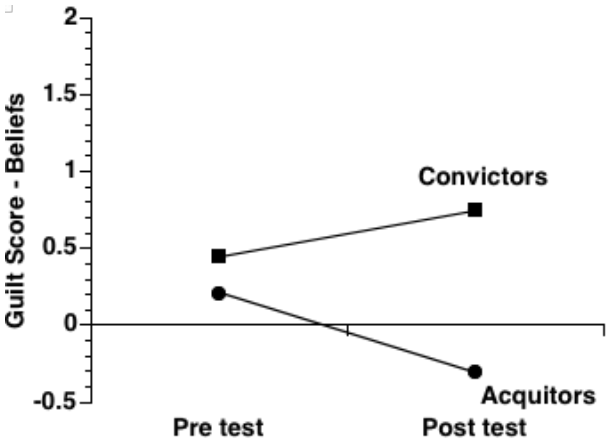

Figure 3: Agreement with Guilt Score - Beliefs by individuals either Convicting or Acquitting

Discussion

These studies provide further evidence for the important role of constraint satisfaction processes in social reasoning. Coherence based reasoning was found both in decisions about the guilt or innocence of a defendant, as well as in the predictions of the outcomes of a romantic relationship.

In Study 1, subjects' evaluations of the events in the life of Jenny and Mark shifted from pre test to post test to become more coherent with their decision as to whether or not to buy the necklace and therefore, implicitly, with their judgment as to whether Jenny and Mark were likely to marry or split up. And in Study 2, using a quite different kind of task, a legal decision making task, we found the same pattern: Evaluations of the evidence in the murder trial against Tim O'Reilly shifted over time to become more coherent with the verdict of guilt or innocence.

The systematic change in the evaluation of the events from the pre test to the post test in both studies pose a strong challenge to the two syntactic rules that are central to Anderson's (1981, 1996) Information Integration Theory, Bayesian models of information integration, and SEU models. These models assume both *meaning invariance* and *value-integration independence*: the meaning of one attribute should not influence the meaning of another attribute and the integration of information to make a judgment should not affect the meaning of the information going into that judgment.

However, the coherence shifts indicate that our participants violated both principles. The shift of the interpretation of the evidence towards the participants' final judgment is completely inconsistent with both weighted averaging and the multiplication of probabilistic values of the isolated information in the pre test (see also Pennington & Hastie, 1992). A better interpretation is that during the reasoning process that led to the final judgment, the pieces of information interacted dynamically with each other and with the emerging decision, leading to a change in their meaning.

Our findings and our explanation of them, share some features with Roe, Busemeyer, and Townsend's Multialternative Decision Field Theory, which uses a recurrent neural network to choose among alternatives (Roe, Busemeyer, & Townsend, 2001). However, their recurrent network only applies to alternatives for which valences have already been calculated by an earlier step in the model. That is, the network does not represent the relationships among the attributes that underlie those valences. Thus, in their model, the evaluation of the different alternatives by the recurrent network cannot effect the evaluation of the attributes of the different choices. In contrast, we have shown that the participants' judgments influence the evaluations of the events and evidence.

Our findings are consistent with many of the central features of Pennington and Hastie's Story Model. They support the idea that decisions are determined by the representation constructed rather than by the "raw evidence", that the confidence in the decision is a function of the coherence of the representation, and that the judgments in a trial cannot be explained by means of formal mathematical models (Pennington & Hastie, 1992).

Our findings in the study on legal decision making suggest that coherence processes can also affect general beliefs about the world. Shifts in background beliefs from pre test to post test indicate that these beliefs shifted to become more coherent with the final verdict. Such shifts in background beliefs, which we argue are due to the spread of activation during constraint satisfaction processing, provide further evidence against formal mathematical models, such as IIT and Bayesian models. These models have no way of predicting such shifts in background beliefs.

Our results are clearly consistent with computer simulations of constraint satisfaction processing (Holyoak & Simon, 1999; Holyoak & Thagard, 1989; Read, Vanman, & Miller, 1997; Thagard, 2000), and with the role of constraint satisfaction mechanisms in a number of experimental settings, including causal reasoning (Read & Marcus-Newhall, 1993), analogical reasoning (Spellman & Holyoak, 1992), attitude change (Spellman, Ullman, & Holyoak, 1993), and abstract legal reasoning (Holyoak & Simon, 1999; Simon, Pham, Le, & Holyoak, 2001). Finally, given the similarities between constraint satisfaction processes and the Gestaltian principles underlying classic cognitive consistency theories, this research also suggests that insights from classic cognitive consistency theories in Social Psychology can be extended to larger and more semantically rich tasks than previously conceived.

Acknowledgments

This research was funded by NSF grant SES-0080424 to Dan Simon and Stephen J. Read.

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