Herbert Simon's Decision-Making Approach:

Investigation of Cognitive Processes in Experts

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Running head: Simon’s decision making approach

Abstract

Herbert Simon's research endeavor aimed to understand the processes that participate in human decision making. However, despite his effort to investigate this question, his work did not have the impact in the "decision making" community that it had in other fields. His rejection of the assumption of perfect rationality, made in mainstream economics, led him to develop the concept of bounded rationality. Simon's approach also emphasized the limitations of the cognitive system, the change of processes due to expertise, and the direct empirical study of cognitive processes involved in decision making. In this article, we argue that his subsequent research program in problem solving and expertise offered critical tools for studying decision-making processes that took into account his original notion of bounded rationality. Unfortunately, these tools were ignored by the main research paradigms in decision making, such as Tversky and Kahneman's biased rationality approach (also known as the heuristics and biases approach) and the ecological approach advanced by Gigerenzer and others. We make a proposal of how to integrate Simon's approach with the main current approaches to decision making. We argue that this would lead to better models of decision making that are more generalizable, have higher ecological validity, include specification of cognitive processes, and provide a better understanding of the interaction between the characteristics of the cognitive system and the contingencies of the environment.

Keywords: decision making, expertise, problem solving, bounded rationality

Introduction

Herbert Simon was one of the most important researchers in the field of behavioral studies in human decision making, and indeed all his research was aimed at understanding this phenomenon. However, despite his effort to investigate this question, his work did not have the impact in the "decision making" community that it had in other fields. In this article, we would like to show that an important research line carried out by Simon to understand decision making – his research on expertise – has been neglected by the mainstream decision-making research community.

Given that expertise participates in numerous human behaviors, it is not surprising that Simon's approach touches on different areas of psychology (e.g., perception, memory, imagery, and thinking). Simon's expertise approach is thus rarely considered an attempt to study decision-making processes, and the aim of this article is to correct this misperception by showing that these two approaches are in fact integrated. We propose that Simon's approach to decision making essentially consisted of three main assumptions: first, decisions are not performed by agents with perfect rationality, they are made by agents with bounded rationality; second, the quality of decisions vary as a function of the expertise of the decision maker; third, to understand decision making, it is paramount to investigate the cognitive processes involved; that is, an analysis based on performance only is not sufficient.

In the following section, we present Simon's rejection of the notion of perfect rationality, his proposal of bounded rationality and his conception of a research program for decision making. Following this, we briefly review the field of decision making in psychology that adopted Simon's conception of bounded rationality but not his research program. After that, we present the work of a few researchers that related the notions of expertise and decision making but did not follow Simon's approach. Then, we expound how research in Simon's tradition could shed some light into three unresolved issues in decision making: the cognitive system, the role of search, and the status of heuristics. Finally, we put forward a proposal aimed at integrating the fields of decision making and expertise.

Bounded Rationality

A key assumption of positive theory in economics is that the economic actors maximize utility, and in order to do that, they must be perfect rational agents. This means that the end result of their decisions would be the same as if they were using the rules of logic or probability perfectly, or if they were carrying out a full cost-benefit analysis with all the options available. Economic theorists do not assume that all the economic agents produce the same end results, but they avow that departures from rationality are rare when the stakes are significant, or that non-maximizing agents would disappear because they would not survive in a market (Kahneman, 2003). The problem with this view of the rational agent is that it has never been supported experimentally. On the contrary, when behavioral economists and psychologists tested the predictions of perfect rationality theories, they found that the behavior of economic agents is systematically different than what is expected by the rational agent view (e.g., Baron, 2008; Kahneman & Tversky, 1979, 1984; Tversky, 1969; Tversky & Kahneman, 1981).

Simon (1955, 1956, 1957) strongly criticized this view of perfect rationality; instead, he argued that humans have a bounded rationality. He suggested that the complexity of the environment and humans' limited cognitive system make maximization all but impossible in real-life decision-making situations. Simon proposed that people do not maximize, instead they "satisfice." This means that people have an adequacy criterion to decide whether an alternative is satisfactory, and that they choose the first option that fulfils this criterion. Hence, people do not evaluate all the available options and they do not carry out a full cost-benefit analysis of the possible options. To satisfice is to choose a good enough option, not the best option. Limitations of the human cognitive system, as well as limitations in accessing relevant information, do not allow people to make perfectly rational decisions. Contrary to what is assumed by mainstream economic theory, the adequacy criteria that people use are not fixed; rather, they vary according to the level of expertise of the decision maker, the characteristics of the environment, the attributes of the task at hand, and the current state of search, including the information that has been gained so far. This theory of bounded rationality states that decisions can be made with reasonable amounts of calculation, and using incomplete information. Hence, relatively good decisions can be made without the need of analyzing all the alternatives, which in most situations is impossible.

Having set the ground for bounded-rationality theories, Simon proposed two research endeavors. First, to test in the psychological laboratory and in the field whether people in relatively simple decision-making situations behave as decision theory predicts. Second, to carry out psychological experiments in order to scrutinize the detail of human decision makers' actual processes. The first enterprise was taken up by behavioral economists and, in psychology, by Tversky and Kahneman, who were also inspired by Edwards's (1954) introduction of decision theories to psychology. Newell, Shaw and Simon (1958; see also Newell & Simon, 1972) popularized the second endeavor. They asked participants to solve problems, and at the same time to say out loud what they were thinking of.

Simon's legacy in how to investigate decision making is threefold. First, human decisions should not be assumed a priori to follow logical, statistical or any other formal models; rather, they should be investigated empirically. Second, there are three factors to take into account in decision making: the type of task; the characteristics of the environment; and the distinct features of the cognitive system that makes the decision. The latter includes the previous knowledge or expertise of the decision maker. Third, only in conjunction with the collection of empirical data should formal computational models of decision-making processes be developed, and their predictions should be compared with human behavior.

In the following section, we briefly review the research field commonly identified with decision- making research, which has specialized journals such as *Journal of Behavioral Decision Making* and *Judgment and Decision Making*. This important research field mainly followed the first component of Simon's approach – the empirical study of decision making – but did not pay much attention to the role of expertise in decision making and the direct investigation of the processes that participate in making a decision.

The Field of Decision-Making Research

Simon's rejection of formal decision making models of economic theory inspired researchers in psychology to develop research programs to study decision making empirically. The most important of these endeavors was Tversky and Kahneman's approach, which we call here "biased rationality." After presenting this approach, we discuss two approaches under the term "ecological rationality" – rational analysis and the fast and frugal approach. These approaches were also inspired by Simon's views, but they disagreed with Tversky and Kahneman's pessimistic view of rationality.

Biased Rationality

Tversky and Kahneman agreed with Simon that economic agents are not perfectly rational. But while Simon focused on studying the processes of the cognitive system in order to develop a bounded-rationality theory of decision making, Tversky and Kahneman's tested the predictions of perfect rationality theories. In their prolonged research program, they were able to show many ways in which people systematically diverge from what would be expected by maximization theories.

Tversky and Kahneman's approach was also influenced by Edwards's (1954, 1962) views on decision theory. Edwards, Lindman, and Savage (1963) had proposed that the assumption in economics that human beings follow Bayes theorem in their probability judgments might have been misleading. Edwards researched on how to improve decision making by using tools such as decision analysis (Phillips & von Winterfeldt, 2007), whereas Tversky and Kahneman's dedicated their efforts to test whether humans make probability judgments following Bayes theorem. Tversky and Kahneman showed that people, when dealing with options or outcomes, pay attention to irrelevant features, to the point that this affects their preferences. For example, the way in which a piece of information is presented affects the alternative chosen by people (Tversky & Kahneman, 1981; McNeill, Pauker, Sox & Tversky, 1982). This phenomenon was called the *framing effect* and violates a tenet of perfect rationality: extensionality (Arrow, 1982), also known as invariance (Tversky & Kahneman, 1986).

Tversky and Kahneman also investigated decision making under risk. The prevailing perfect rational model in this field is Expected Utility Theory (EUT). The first EUT model, proposed by Bernoulli (1738/1954), postulates reference-independence: it “assumes that the value that is assigned to a given state of wealth does not vary with the decision maker's initial state of wealth” (Kahneman, 2002, p. 460). Kahneman and Tversky (2000) showed that decision makers take into account gains and losses instead of considering only states of wealth; therefore, contrary to Bernoulli’s model, the initial state of wealth affects choice. They proposed a different model called *Prospect Theory* (Kahneman & Tversky, 1979), in which preferences are reference-dependent: utility is linked to changes in wealth instead of states of wealth. The model describes a value function that favors risk aversion for gains and risk seeking for losses (Tversky & Kahneman, 1992).

Tversky and Kahneman also studied judgments about uncertain events, and in particular the way people use numbers when making predictions and assess diverse types of probability (see Tversky & Kahneman, 1974, for a review). In the same vein as Simon’s concept of bounded rationality, they proposed that people cannot really carry out the tasks of correctly making numerical predictions and calculating probabilities, and that they cope with the complexity of these tasks by using heuristics. Sometimes these heuristics are useful, but sometimes people make critical and systematic errors or biases. For this reason they called this research program “heuristics and biases approach” (Kahneman, Slovic, & Tversky, 1982). In their early works they identified three heuristics – representativeness, availability and anchoring – and a dozen of systematic biases. They proposed that these heuristics explain the type of judgments of probability or frequency that people make. The biases are not random errors, which perfect rational theories accept; instead, they are errors that follow a particular pattern.

The importance of Tversky and Kahneman's research program is beyond doubt. They succeeded in showing that the perfect rationality models criticized by Simon do not pass the test of empirical research. They also proposed alternative models based on their own research. The impact in economics is more difficult to assess. On the one hand, Kahneman was awarded the Economics Nobel Prize in 2002 (Tversky had passed away by 2002); on the other hand, perfect rational models are still the prevailing models in economic analysis. Our criticism of Tversky and Kahneman's approach is that, although they did carry out research with experts (e.g., Redelmeier, Koehler, Liberman & Tversky, 1995), they did not take into account the results obtained by researchers that followed Simon's expertise approach. Probably as a consequence of this, Tversky and Kahneman proposed models of bounded rationality that assume that human cognition is fixed. They did not give importance to the capacity of experts, documented in the expertise literature, to improve their heuristics and other kinds of knowledge. As we shall see in the next section, Tversky and Kahneman's research program has been criticized on other grounds as well.

Ecological Rationality

While the biased rationality view dominated behavioral research in decision making in the 70s and 80s, many researchers started to feel disappointed with the view that humans make systematic mistakes and therefore are irrational. Contrasting with this view, a number of researchers emphasized that humans adapt very well to their environment; hence, they could not be that irrational after all. We present two approaches that follow this view: rational analysis and fast and frugal heuristics.

Rational analysis was initiated by Anderson (1990, 1991). Its starting point is the evolutionary view that the cognitive system is adapted to the environment. Therefore, formal logic cannot be used as the standard for evaluating the quality of decisions. Instead, one has to specify the problem for which the cognitive system is adapted to solve, and then construct a model of its environment. Moreover, rational analysis assumes minimal computational limitations of the cognitive system. Taking into account the characteristics of the environment and the cognitive system, rational analysis involves deriving an optimal behavioral function and testing its predictions with empirical data. This approach is becoming increasingly popular (e.g., Oaksford & Chater, 2009). However, some of its assumptions go against the spirit of Simon's approach. First, rational analysis does not provide a theory of processes that lead to the achievement of goals. Second, it can only apply to situations in which an optimal solution can be found (Chase, Hertwig & Gigerenzer, 1998). As the optimal model of behavior is mathematical and not psychological, it is a model of how behavior should be rather than what it is. And third, by assuming optimization, rational analysis is at variance with Simon’s view that adaptation is not necessarily optimization (e.g., Simon, 1969).

Gigerenzer (1996a, b) initiated the fast and frugal heuristics approach to decision making. He criticized Tversky and Kahneman’s heuristics and biases approach in, at least, three aspects: first, use of probability, statistics, and logic as norms of rationality; second, lack of importance of the environment; and third, under-specification of heuristics (see Gigerenzer, 1996a; Gigerenzer & Goldstein, 1996). For example, Gigerenzer (1996a) argued that heuristics (e.g., representativeness) “remain vague, undefined and unspecified with respect both to the antecedent conditions that elicit (or suppress) them and also to the cognitive processes that underlie them” (p. 592). Gigerenzer also stated that the norms used by Tversky and Kahneman to test rationality (e.g., Bayesian theorem) are too narrow.

Gigerenzer was inspired by Brunswik’s (1955) functional psychology and by Simon’s notion of bounded rationality. Brunswik (1955) stated that humans make judgments (e.g., the salary that a particular person earns) based on proximal cues of the environment (e.g., name of the company in which that person works). The accuracy of a judgment depends on one’s skill in weighing cues appropriately and how well the cues predict the parameter to be judged. Regarding Simon’s influence, Gigerenzer and Goldstein (1996) stated that there are two main factors in Simon's rejection of perfect rationality. First, humans have cognitive limitations (e.g., Simon, 1947); and second, minds are adapted to real-world environments (e.g., Simon, 1956). They affirmed that psychological researchers focused on the cognitive limitations but almost ignored the adaptation of the individuals to the environment. For example, Tversky and Kahneman's approach used simple and unrealistic tasks in order to test the rationality of the individuals. Gigerenzer considers that this is misleading: participants' rationality should be tested in real-world tasks because they are adapted to the real world and not to unrealistic situations.

Gigerenzer's approach to decision making systematically addressed the three criticisms to the biased rationality research program we have just mentioned. Instead of using probability, statistics and logic as a norm of rationality, he considered that the parameter of rationality is how well a cognitive process helps an individual to adapt to the environment. For example, he asked participants which of a pair of cities have a larger population. Gigerenzer and Goldstein (1996) suggested that the use of this task also addresses the issue of the environment. An educated guess of a particular characteristic of the environment (e.g., the population of a given city) based on incomplete information is what epitomizes human rationality. Human beings are adapted to their environment only if they are able to perform these types of educated guesses.

Goldstein and Gigerenzer (2002) also addressed the issue of under-specification of heuristics. Their proposal was that heuristics should have a number of ecological characteristics such as being fast and frugal, which gives the individuals skills to survive in a continuously changing environment. One of the heuristics they proposed was the recognition heuristic, for which they produced a computational model. Compared with statistical models (e.g., multiple regression), the computational model of the recognition heuristic fitted the human data better in some tasks.

Finally, Gigerenzer's approach revived Simon's proposal of studying both the characteristics of the cognitive system and those of the environment, and also dovetailed with Brunswik's ecological approach. He also specified the proposed heuristics formally, which is an important improvement in comparison to the under-specified heuristics proposed by Tversky and Kahneman. However, Gigerenzer’s approach has recently faced a number of criticisms. Dougherty, Franco-Watkins and Thomas (2008) stated that some assumptions of the priority heuristic (one of the “fast and frugal” heuristics proposed by Gigerenzer) are flawed. Birnbaum (2008) avowed that this heuristic does not fit risk decision data properly. Rieger and Wang (2008) stated that the priority heuristic is an "as if" model and not a model of what goes on in people's cognitive systems. Therefore, in this respect, it is not an improvement compared to Prospect Theory or Expected Utility Theory, which are assumed to be "as if" models. Finally, Johnson, Shulte-Mecklenbeck and Willemsen (2008) recognize that Gigerenzer proposed process models but argue that he tested them with product data (i.e., data obtained at the end of the task, such as decision choices) instead of using process data (i.e., data obtained during the entire task, from the beginning to the end, such as eye movements).

Our own criticism to Gigerenzer’s approach is that, although he carried out research with experts (e.g., Gigerenzer, 1996b; Hoffrage, Lindsey, Hertwig & Gigerenzer, 2000), he did not use the potential of Simon’s expertise approach. In the expertise approach, both the cognitive system and the environment are independent variables that adopt different levels. Gigerenzer used ecological environments (which is a positive aspect of his approach) but did not vary them. Consequently, the importance of fast and frugal heuristics might be an artifact of the range of tasks and individuals used in these experiments. In other words, decision making is likely to require more than fast and frugal heuristics, in particular when expertise increases.

In sum, we claim that the approaches presented above focused on only one of the aspects of Simon’s approach: the empirical study of decision making. However, they did not study variations in decision-making ability due to expertise and they did not investigate directly decision-making processes. In the following section, we describe an attempt by decision-making researchers to focus on the role of expertise in decision making.

Decision Making and Expertise

Within the field of decision making, there have been two ways in which decision making and expertise have been related. In the first approach, researchers studied how experts make decisions. In the second approach, researchers investigated whether people can be experts in making decisions. In other words, they tried to determine whether decision-making expertise or competence (as opposed to expertise in a specific domain) exists.

How Experts Make Decisions

Klein (1989, 1998) and other authors (see Klein, Orasanu, Calderwood, & Zsambok, 1993) developed the naturalistic decision making approach, which consists of studying real-world decision-making behavior. In particular, they studied the decisions made by experts under time pressure. This approach has shed important light on the question of decision making. A striking result is that experts can understand problem situations and make decision rapidly, in a matter of seconds. With routine problems, these decisions tend to be the correct ones, or at least reasonable ones. This phenomenon – often referred to as intuition – was first documented with chess masters (De Groot, 1946), and then uncovered in domains as different as physics (Larkin, Mc Dermott, Simon, & Simon, 1980), nursing (Crandall & Getchell-Reiter, 1993), management (Patton, 2003), fire fighting (Klein, 1998), and decision making in combat situations (Klein, 1998), to mention just a few. It is generally accepted that this rapid decision making is made possible by the perceptual knowledge that experts have acquired over years of practice and training (Chase & Simon, 1973, De Groot, 1946, Gobet & Chassy, 2008, 2009). Klein (1998) goes as far as claiming that, in certain domains and situations, experts consider *only one* course of action that they carry out, thus not even choosing among two or three possible options. Obviously, this is contrary to what is taught by expected utility theory.

This approach has proven successful in the industry. (In fact, Klein founded an institute focused on applications of his decision-making framework.) On the other hand, it was criticized for its lack of formal models of internal processes (see Herbig & Glockner, 2009). It is paradoxical that there are so few cross-citations between Klein and Gigerenzer, given that both approaches stress the importance of studying ecologically valid phenomena. It could be argued that Gigerenzer provided the formal models and laboratory data and Klein the real-world data.

As we have seen, Klein studied experts in the field, but this was not the first attempt to do research with experts. For example, Hammond (1955) carried out a study in which clinical psychologists had to estimate the IQ of 78 people measured with the Wechsler-Bellevue test using as cues the responses of those people to a Rorschach test. Hammond interpreted these data and those of subsequent studies using Brunswik's (1952) lens model. One of the most important findings was that the judgment of professionals could be predicted using simple multiple-regression models rather than by models postulating sophisticated thinking processes. Like Tversky and Kahneman's, this approach to decision making presented a pessimistic view of the human kind: we are not rational. Even worse, experts – who are supposed to reside in the pinnacle of rationality – are not reliable.

In a review of the literature, Shanteau (1989) stated that experts' judgments lack in validity (Oskamp, 1965) and reliability (Trumbo, Adams, Milner & Shipper, 1962); that experts' ability does not correlate with their amount of experience (Meehl, 1954); that they have deficiencies in calibration (Christensen-Szalanski & Bushyhead, 1981) and in coherence (Chan, 1982); and that they do not use all the relevant information (Goldberg, 1970). In a way of reconciling the conclusions of the previous studies with experts and the ones realized by Simon's approach (in which experts outperform novices in many tasks) – Shanteau (1992) emphasized the role of task characteristics in expert performance using his *Theory of Expert Competence*. Shanteau proposed that experts make competent judgments in tasks that have clear-cut characteristics. These tasks tend to be static (rather than dynamic), which makes it possible for experts to know what constitutes important stimuli. They can be decomposed into sub-problems, which increases their level of predictability. They also tend to be repetitive, and while errors will happen every so often, this is compensated by the fact that it is possible to obtain feedback and to carry out an objective analysis of the task. Finally, decisions are about things, rather than behavior, and decision aids can be used. On the other hand, experts do not make competent judgments in tasks that have the opposite features.

There are two main features of this approach that greatly contribute to the understanding of human decision making. First, like Simon's expertise approach, experts participate in its studies. Investigating the decisions that experts make in their own domains of expertise – rather than studying the decisions that university students make in unfamiliar domains – is ecologically more valid. Second, it tests issues of rationality in decision making at the right level. A university student may make an incoherent or unreliable decision regarding a specific topic, but that does not mean that humans are not rational. On the other hand, if experts make incoherent or unreliable decisions in their own domain of expertise, then this can be seen as a telltale sign of lack of rationality. Furthermore, Shanteau's analysis of the tasks in which empirical data were obtained helps to understand why experts are more competent in some domains than in others.

Yates and Tschirhart (2006) criticized Shanteau (1992) for considering that experts are those who are named as such by a community, instead of somehow measuring the degree of expertise of people in a representative task. Moreover, those investigators also criticized the small sample sizes of the studies. Our criticism to this approach is that it makes inferences about the cognitive processes involved in decision making based on experts' judgments, but it does not collect the type of process data, such as think-aloud protocols and reaction times, that are crucial for testing process theories (Johnson et al., 2008; Simon & Gobet, 2000). The presence of process data would help the development of less speculative inferences about decision-making processes. Moreover, the proposed cognitive processes are not formally specified in computational models.

What Makes an Expert in Decision Making?

There is increasing interest in determining what makes an expert decision maker. Stanovich and

West (2000) showed that good solvers of reasoning problems tend to be better in tests of cognitive ability. This is an important result because the ecological approach to decision making claimed that the paper and pencil reasoning problems are not good tests of good thinking in the real world. Stanovich and West (2000) claimed that the fact that those who make decisions according to formal models tend to be more intelligent, is an indication that following formal models is a hallmark of rationality. This view was criticized by Sternberg (2000), who stated that it is not surprising to find correlations between IQ tests and reasoning problems, since IQ tests include reasoning problems.

In the same direction of research, Frederick (2005) developed a "cognitive reflection test." This test consists of three problems, the solutions of which are counter-intuitive and in which there are intuitive (but incorrect) possibilities that the subjects have to refrain from giving as a response. He found that there is a correlation between this test and the choice of "good" options in typical preference tasks such as risk preferences (e.g., Kahneman & Tversky, 1979). Just like Stanovich and West (2000), Frederick (2005) proposed that the fact that the participants that are good at solving counter-intuitive problems also tend to choose the presumably good options in preference tasks, is a suggestion that paper and pencil artificial decision-making tasks are good indicators of rationality in decision making.

In related research, Parker and Fischhoff (2005) elaborated a decision-making competence test and evaluated it with a sample of young males. This test contains a number of typical decision-making tasks that tap four components of decision making: belief assessment, values assessment, integration of beliefs with values in order to identify choices, and metacognition (Edwards, 1954; Raiffa, 1968). The authors looked for validation of this laboratory test with measures of good decision making in real life and with cognitive tests. They found that people who score high in the decision-making competence test also score high in cognitive ability tests, tend to have constructive and introspective cognitive thinking, belong to more intact social environments, and engage in fewer maladaptive risk behaviors. Bruine de Bruin, Parker and Fischhoff (2007) took up the previous study, improved the internal validity of the test and used an adult sample of men and women. They found that decision-making competence was positively correlated with cognitive ability, socio-economical status, and avoidance of bad decision outcomes. In another study, Parker, Bruine de Bruin and Fischhoff (2007) found that people who score high on the decision-making competence test tend to be "satisficers" (in Simon's terms) rather than "optimizers."

The decision-making competence test gives an aggregate score and also provides scores in seven subtests that, as mentioned earlier, tap four decision-making skills. The analysis of decision making into components was also carried out by Yates and Tschirhart (2006), with the same purpose of identifying indicators of expertise in making decisions. They suggested that the two criteria that are usually considered to determine decision-making expertise – performance and coherence – have problems. Rather, they proposed a process-decomposition perspective, which consists in evaluating ten components of the overall decision-making process, instead of evaluating only the outcome of such process. Yates and Tschirhart (2006) suggested that there are some indications in previous literature of specific behaviors that contribute to decision-making expertise. Nevertheless, they stated that, overall, their review showed that much is still unknown about those behaviors. We agree with their conclusion but we are surprised how little of Simon's approach is considered in their review. They only mentioned a contribution of Simon's work to the "investment" component, but there is no acknowledgement of his contribution to the "options," "possibilities," "judgment," and "value" components for which Simon's investigation of search processes is very informative.

Reyna and Brainerd (1991) proposed a developmental study of decision making. Although it is not strictly an expertise approach, it is in the spirit of Simon's approach as it investigates the change of decision-making skills. Their research findings do not match those of Stanovich's and Parker's research groups. Instead of finding a correlation between capacity measures and reasoning, they found independence. In order to account for this discrepancy, they proposed the fuzzy-trace theory (Reyna & Brainerd, 1995). This theory states that there are two types of memory representations: verbatim and gist. Memory tests usually rely on verbatim representations whereas the reasoning tasks rely on gist representations. They also proposed that there is a progression from analytical verbatim-based reasoning to intuitive gist-based reasoning from children to adults and from novices to experts (see Reyna, 2004).

This section showed the interest of investigators in studying the issue of expertise in decision making, either by studying experts making decisions or by correlating the performance in typical decision making tasks with other measures. In the following section, we will present Simon's full approach for the study of decision making which includes the examination of expertise, the assumption of limitations of the cognitive system, and the direct investigation of cognitive processes.

Simon's Decision-Making Approach

Simon's rejection of the formal models of economic theory made him adopt the methods of an experimental science: psychology. Not only did Simon move to psychology to answer economic and organizational issues, but he also revolutionized psychology by the introduction of the information-processing paradigm. This led to the so-called cognitive revolution in the 1950's (see Gardner, 1985, for description and discussion of the cognitive revolution). Since the cognitive revolution, psychology added to its experimental tradition the use of computational formal models of cognitive processing. These models are developed and tested to account for the human data obtained in experiments.

In order to understand, with an experimental approach, how (economic) agents make decisions, Simon and colleagues utilized puzzles (e.g., the Tower of Hanoi). They asked participants to solve a particular puzzle while thinking out loud. The think-aloud protocols obtained by this method were used to look for typical patterns in the thinking process. The main characteristic of the puzzles was that there was always an initial state and a well-defined goal state that the problem solver had to attain. From the initial state to the goal state there are a number of intermediate states that vary in number according to the difficulty of the task. Newell and Simon (1972) found that participants do not explore all the problem space – the number of states is often simply too large to enable this. Instead, participants use strategies that allow them to reduce the number of states they have to explore to reach the final state. Newell and Simon called these strategies *heuristics*. Heuristics are “rules-of-thumb” that do not guarantee the solution of the problem, but are frequently successful and save much time and effort. One of the most important heuristics proposed by Newell and Simon was means-end analysis. This heuristic consists of creating a sub-goal that would reduce the difference between the current state and the goal state, and then selecting the actions that would solve this sub-goal. Kotovsky, Hayes and Simon (1985) found another violation of perfect rationality in problem solving. Participants had difficulties to solve problems that had the same structure but were superficially different to the Tower of Hanoi. This matches Tversky and Kahneman’s (1981) finding of framing effects.

Taken together, these findings support Simon’s notion of bounded rationality. Perfect rationality assumes that participants solve problems using a procedure guaranteeing the selection of the optimal move. Already in 1944 von Neumann and Morgenstern had proved mathematically that the rational solution to choose a move in adversarial games such as chess is minimaxing. This consists of computing the evaluation of all leaf nodes (checkmate and drawn positions in chess), and then backing up the information to the current position; in doing so, one chooses the moves that minimize the value of the position when dealing with the opponent’s moves, and the moves that maximize this value when dealing with one’s own moves. Unfortunately, as also noted by von Neumann and Morgenstern, the size of the search space in chess prohibits such an approach (chess is estimated to have 10^{43} different positions). Approximations to this optimal behavior are possible, most notably by limiting the depth of search (rather than always reaching leaf nodes) and approximating the true value of a position using an evaluation function. But even so, chess players’ search behavior is much closer to means-ends analysis and its aims to reach intermediate goals than to minimax.

In the problem-solving approach, Simon used problems that did not require previous knowledge to be solved. By contrast, in his research on expertise, he utilized problems whose solution required domain-specific knowledge. Moreover, he investigated how differences in previous knowledge between participants affect their decision making process. He studied individuals of different levels of expertise solving domain-specific problems. Although Simon's expertise studies have had a considerable impact in psychology (see Charness, 1992), decision making scholars rarely use participants of different levels of expertise in their studies.

Simon and other researchers found important differences between experts and novices in the way they make decisions in domain-specific problems. De Groot (1946/1978) observed that, in problem solving situations, chess grandmasters choose to analyze moves more selectively than intermediate level chess players. Chi, Feltovich and Glaser (1981) found that expert physicists concentrate on deep and abstract aspects of problems, whereas novices pay more attention to superficial aspects. Larkin et al. (1980) identified differences in heuristics used by expert and novice physicists. Experts tend to move forwards to a solution, whereas novices tend to work backwards from goals to givens. In their chunking theory, Chase and Simon (1973) proposed that novice chess players perceive a chessboard as a group of unconnected pieces. By contrast, chess experts perceive it as a collection of chunks, each chunk being a group of around 4 pieces. This way of representing chess positions is made possible by domain-specific knowledge stored in long-term memory.

Chase and Simon (1973) also proposed that experts' cognitive system does not differ from that of novices; for example, parameters such as short-term memory capacity and learning rate are invariant across skill levels. The only difference is the knowledge experts acquire by experience and training through around 10 years of effortful dedication to their domain of expertise. Effort and experience do not change the architecture of experts' cognitive system, they make it more efficient. Expert knowledge saves experts' time by avoiding exploring useless alternatives. In other words, experts are more selective in their decision making process.

Chase and Simon's (1973) chunking theory was updated by Gobet and Simon's (1996) template theory. This theory states that experts' chunks develop into more complex structures called templates. Templates are stored in long-term memory and are larger than chunks; they also have slots in which additional information could be added. This theory was implemented in a computational model and is the theory that best explains data obtained in experiments with expert chess players, physicists and computer programmers (Gobet, Lane, Croker, Cheng, Jones, Oliver, & Pine, 2001; Simon & Gobet, 2000). It has also been successful to account for first language acquisition (Freudenthal, Pine, & Gobet, 2006; Jones, Gobet, & Pine, 2007), which can be seen as a form of expertise acquisition. Simon's expertise approach has shown that experts are more selective, use better heuristics and evaluation functions, and therefore choose better options. On the other hand, their cognitive system is not different than that of novices. This suggests that experts are able to use higher satisfaction thresholds not by exercising perfect rationality, but by being more efficient and selective in that they focus early on likely solutions, while less expert individuals tend to consider alternatives that are irrelevant. In other words, experts are more refined satisficers than novices but they are not perfect rational agents.

Due to unknown reasons, decision making researchers in psychology have only paid attention to the lack of rationality of agents but not to the fact that agents can increase their problem-solving efficiency and thus their aspiration thresholds by extended practice. Psychological researchers tend to consider decision-making processes as invariable, but evidence shows that decision-making processes vary with knowledge. Incidentally, Simon's expertise approach to study decision making was not embraced by mainstream economics. This is probably because the assumption of perfect rationality of economic agents implies that they have full computational capacity and unlimited access to information. This assumption is simply inconsistent with the assumption of the expertise approach that computational capacity is a function of the amount of knowledge, which varies among individuals.

Relevant findings in expertise research for issues in decision making

Research into the nature and acquisition of expertise has uncovered a large number of important phenomena, not only for understanding expertise per se, but also to understand cognition in general. We cannot review this extensive literature here (see Ericsson, Charness, Feltovich, & Hoffman, 2006, for pointers) and limit ourselves to showing how this research can shed light on three important issues in the field of decision-making research. These issues are: (a) the cognitive system; (b) the role of search; and (c) the status of heuristics.

The Cognitive System

Decision making theorists put forward models of characteristics of the cognitive system of the decision maker. The most popular proposal is that the cognitive system possess two subsystems: a subsystem 1 that functions automatically, with little effort, uses heuristics; and a subsystem 2 that requires volition, effort, and is rule-based (e.g., Epstein, 1994; Sloman, 1996; Chaiken & Trope, 1999; Kahneman & Frederick, 2002; Stanovich & West, 2000). Note that some theorists propose that there are two types of processes instead of two subsystems (e.g., Evans, 2008). The dual-system models were criticized (see Keren & Schul, 2009; Gigerenzer & Rieger, 1996; Newstead, 2000) and two main alternative proposals had been put forward. On the one hand, Kruglanski and Thompson (1999) proposed that a general-purpose system could account for decision-making phenomena. On the other hand, evolutionary psychologists propose that the cognitive system contains multiple domain-specific modules (Cosmides & Tooby, 2002; Raab & Gigerenzer, 2005).

Researchers following Simon's approach have tackled this issue on theoretical and experimental grounds. As mentioned earlier, theoretical accounts of expertise effects in decision making are not limited to explaining these effects, but rather they build upon general models of cognition. The chunking theory (Chase & Simon, 1973) and the template theory (Gobet & Simon, 1996) propose that the differences in decision-making quality are due to the formation and storage of knowledge patterns in long-term memory that trigger specific actions. In turn, these theories are implemented in computational architectures such as EPAM (Richman, Staszewski & Simon, 1995) and CHREST (Gobet et al., 2001), which contain a number of subsystems such as short-term memory, long-term memory and the mind's eye. Regarding processes, research into expertise differentiates pattern recognition and search. It could be argued that pattern recognition is a system 1 process and search a system 2 process. However, Gobet and Simon (1998) proposed that search is in part the recursive application of pattern recognition. Therefore, search and pattern recognition are closely interacting processes carried out by short-term memory, long-term memory, and the mind's eye.

Bilalić, McLeod and Gobet (2008) used an experimental paradigm in chess that matches Frederick's (2005) cognitive reflection test (see above). The theoretical explanation for the cognitive processes involved in solving the problems of this test is that subsystem 1 first triggers the intuitive answer; then, subsystem 2 overrules system 1 and engages in a more systematic thinking process that leads to the accurate solution. Bilalić et al. presented chess players of different levels with chess puzzles in which there was a typical but non-optimal solution and an atypical but optimal solution. ("Optimal" was defined as the minimum number of moves to checkmate the opponent's king.) They showed that top experts were able to overcome the tendency to report the typical solution. On the other hand, some able players did not perform as usual in these problems. Bilalić et al. explained these results using chunking and template theories. Since typical actions (i.e., moves) associated to chunks appear more frequently in chess games, they are more strongly associated to chunks than atypical moves; thus, they are triggered more rapidly. Top experts have more refined chunks than normal experts; therefore, the atypical moves are also triggered by their chunks and they could avoid reporting the non-optimal moves.

Summing up, researchers in the field of expertise build theories of expertise effects in decision making by using a general model of cognition rather than using a specific model for decision making. The general model of cognition contains a number of subsystems (e.g., short-term memory, long-term memory, mind's eye), but these do not coincide with those proposed by dual-systems approaches. For Simon's approach there are no domain-specific modules – as suggested by evolutionary psychologists – but domain-specific patterns of knowledge called chunks or templates that are learned through experience and are stored in long-term memory.

The Role of Search

There is a debate as to how many attributes of objects or situations are pondered in order to choose between options. A perfect rationality approach suggests that one has to assign a weight to different attributes of, say, objects. Then, one has to assign a global value to each object (e.g., by summing the value of each attribute) and, finally, one has to choose the object that has the highest value. Gigerenzer (1996 a, b) proposed that people choose options considering the minimum number of attributes as possible. Usually, the choice of an option over another is done by using only one cue that differentiates the options, regardless of the values of these options in other less important attributes. Lee and Cummins (2004) proposed an intermediate view in which there is a threshold that determines how large the difference between options should be in order to make a choice. If the comparison between options using one cue is higher than the threshold, a decision is made, otherwise more cues are considered.

Research in Simon's tradition supports the latter view. As mentioned earlier, DeGroot (1946) showed that experts are selective. Campitelli and Gobet's (2004) study suggested that in situations in which players have to make a quick decision (i.e., within 10 seconds), experts do not have the option of analyzing many options, so both experts and novices search very few options. On the other hand, when players have enough time to think, and the situation requires deep search, experts search deeper than intermediate players. Interestingly, in simple situations that require little search, expert players do not search much deeper than intermediate players, even if they have enough time to think deeply (see Charness, 1981; De Groot, 1946; Gobet, 1998). The latter is adaptive, because if players spend a long time thinking how to solve a simple situation, they would have less time to solve more complex situations that may appear later in a game. Since a chess game has time limits, time is a resource that should be allocated wisely. Altogether, this suggests that Gigerenzer's proposed strategy that a minimum of cues are used sometimes is adaptive and sometimes is displaying a lack of expertise and rationality. Given enough time, experts analyze a great number of options in some situations and very few options in others. On the other hand, novices tend to analyze few options (and not the most relevant) in every situation.

Summing up, we cannot state whether searching a lot or searching very little is adaptive or rational until we specify the characteristics of the cognitive system (i.e., previous relevant knowledge) and situational characteristics (i.e., complexity of the situation and time to make a decision).

The Status of Heuristics

As reviewed earlier, the biased rationality approach explained the numerous biases in decision making by the use of heuristics. By contrast, the fast and frugal approach postulated that the use of fast and frugal heuristics is rational because it allows human beings to adapt to their environments. Research on Simon's tradition is in line with the idea that heuristics are useful procedures. On the other hand, the use of fast and frugal heuristics is not always rational. De Groot (1946) found two main heuristics in expert problem solving. First, experts are selective, they ponder only relevant options and ignore irrelevant ones. Selectivity is possible because previous knowledge allows experts to determine which options are relevant and which are not. Second, experts search following the *progressive deepening* strategy. They revisit options already analyzed, which allow them to discover new details. As mentioned earlier, Simon identified a number of general heuristics or "weak heuristics" such as *satisficing* and *mean-ends analysis*. Satisficing implies using experience to construct an expectation of how good a solution can be reasonably achieved, and to stop searching when an option that satisfies this expectation is found. Means-ends analysis considers the distance between a situation and a goal, and then proposes intermediate goals that should be attained to, eventually, achieve that goal. Campitelli and Gobet (2004) presented data suggesting that experts adjust their heuristics according to the complexity of the situation and the time available. Therefore, experts' strategies tend to be adaptive, whereas novices' are less flexible.

Summing up, Simon's approach indicates that heuristics are useful strategies but they are not fixed strategies. The choice of heuristics is a function of the available knowledge of the decision maker and the characteristics of the situation in which a decision is made.

Integration of the Decision-Making and Expertise Research Fields

After stating which aspects the decision making field and the expertise field have in common, we will present aspects of expertise literature that we think should be included in decision making literature. Both approaches started with Herbert Simon's rejection of the mainstream assumption in economics that human beings are perfect rational decision makers and his proposal of developing models of bounded rationality. Both approaches consider that human problem-solvers have a limited cognitive capacity and that they use heuristics in order to make decisions. In the expertise approach, both the level of expertise and the characteristics of the environment are independent variables. Thus, the expertise approach takes into consideration Simon's insight that there are two essential factors in human decision making: characteristics of the human cognitive system and characteristics of the environment. By using experts of different levels, expertise researchers are looking at the role of differences in knowledge in decision making. Researchers on expertise also use simple and complex (or familiar vs. unfamiliar) environments in order to investigate the role of the environment in human decision making.

We would like to make a number of suggestions as to how the expertise approach could be used fruitfully in decision making. We suggest that, just like in the expertise field of research, researchers in decision making use expert participants and non-expert participants. Within this approach, researchers could use two types of tasks. One option consists of utilizing the judgment and decision-making tasks used by Tversky and Kahneman, Gigerenzer and others, in order to test whether experts show the biases reported by the former, and whether experts use the fast and frugal heuristics reported by Gigerenzer. For example, we could present chess players of different levels with a list of pairs of names of other chess players. On each pair they would have to estimate who is the player with the highest rating. Following, Gigerenzer's approach, there would be a list of pairs in which the most known players tend to have higher ratings and another list in which the least known players tend to have lower ratings. In this way we may know whether players use the recognition heuristic and whether this happens in chess players of different levels of expertise.

The alternative is employing problem-solving tasks (typical of Simon and colleagues' approach) specific to the domain of expertise. The latter proposal has two goals: generalizability and ecological validity. Several experiments in decision making use tasks where one has to choose between alternatives that have been selected by the experimenter; it is necessary to establish whether the same phenomena are found in a different class of tasks (i.e., problem solving tasks, where participants not only select, but also generate alternatives). In general, participants are not familiar with decision-making tasks and their content; therefore, using a task of the domain of expertise of the participant enhances the ecological validity of the experiment. Following the example of the chess domain, we could ask players of different levels to solve chess problems and problems that are sign of general decision making abilities such as the cognitive reflection test (Frederick, 2005) or the decision-making competence test (Parker & Fischhoff, 2005; Bruine de Bruine et al., 2007). In this way we may gather information about the relationship between general and domain-specific decision-making abilities. A combination of these two approaches would be to ask the participants in decision-making tasks to perform also problem solving tasks. This would give information about the relation of decision-making abilities with the use of heuristics of a general nature. For example, we could identify whether participants that use the recognition heuristic are more or less capable of solving problems of general and/or domain-specific decision-making abilities.

Another suggestion is that the complexity and/or familiarity of tasks (both decision-making and problem-solving tasks) could be varied systematically, in order to test how the characteristics of the environment influence decision-making processes and how they interact with the level of expertise.

Moreover, the time limits of the task could be varied in order to find out if the type of heuristics that participants use change or remain stable.

Finally, we suggest that researchers run computer simulations of experiments utilizing existing computational models (e.g., CHREST, Gobet et al., 2001) of the entire cognitive system, which includes, among other components, short-term memory where information is stored temporarily and long-term memory where knowledge is stored. This would be a step forward towards Gigerenzer's requirement of specifying computational models of heuristics. The goal of decision-making research is to account for the cognitive processes that allow humans to make decisions rather than to account for how humans solve a particular task. Therefore, providing computational models that, with very slight modifications, could fit human data in different tasks and domains is more powerful than designing computational models that account for human data in specific tasks only.

Conclusions

Simon's criticism of mainstream economic models of perfect rationality initiated a number of research programs in psychology and behavioral economics. Unfortunately these programs developed independently with very little communication between them. The decision making program in psychology was dominated by Tversky and Kahneman's approach. This approach empirically tested Simon's suggestions and showed that they were correct. Tversky and Kahneman's conclusions are somehow sad: humans are not rational and they commit systematic biases. Scholars studying expert decision making who did not follow Simon's approach reached a still worse conclusion: not even experts are rational in their domains of expertise. Gigerenzer's ecological approach is more positive. He suggests that fast and frugal heuristics are rational because they are adaptive. Unfortunately, decision-making scholars did not exploit Simon's expertise approach and they ignored the extensive research carried out in the field of expertise.

We suggest that including the expertise approach into decision-making research could improve models developed to explain human decision making. Moreover, we proposed a number of research strategies that combine the fields of expertise and decision making. They aim to incorporate the findings from expertise literature into the field of research of decision making. We consider that by doing so, this field would gain in a number of factors: generalizability, ecological validity, specification of cognitive processes, and understanding of the interaction between characteristics of the cognitive system and contingencies of the environment.

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