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WORKING PAPER SERIES

Simon's Bounded Rationality. Origins and use in Economic Theory

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Working paper No. 09/2005

Università di Torino

Simon's Bounded Rationality. Origins and use in Economic Theory

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Abstract. The paper aims to show how Simon's notion of bounded rationality should be interpreted in the light of its connection with artificial intelligence. This connection points out that bounded rationality is a highly structured concept, and sheds light on several implications of Simon's general views on rationality. Finally, offering three paradigmatic examples, the article presents the view that recent approaches, which refer to Simon's heterodox theory, only partially accept the teachings of their inspirer, splitting bounded rationality from the context of artificial intelligence.

JEL Classification: B4; B21; D80; D89

Key words: bounded rationality; artificial intelligence, intuition, creativity, heterodox approaches

Introduction

The aim of this paper is to discuss Simon's notion of bounded rationality in the light of its connections with artificial intelligence (AI).

In the following sections, bounded rationality will be analyzed along with the concepts of "intuition", "insight", and "creative thinking", which Simon explored in a mature phase of his research on AI, since, in my opinion, this perspective allows one to emphasize certain problematic aspects of Simon's approach to rationality. In fact, intentional bounded rationality, as a decision-maker's conscious activity, and intuition (as an unintentional, cognitive process) represent two extremes of rational behavior, which belong to the same information processing mechanism. Creativity, in turn, presents a challenge to the information processing approach, since human thinking and problem-solving procedures cannot be adequately represented if this essential phenomenon is left out. Finally, the last part of the paper will briefly discuss how "bounded rationality" has been used by some representative authors such as Kahneman, Tversky, March, Gigerenzer and others, who have acknowledged their intellectual debt to Simon, and whose work has been profoundly influenced by this author.

The concept of bounded rationality emerged in essential terms in *Administrative Behavior* (1947), and was subsequently specified as an economic notion in the mid-1950s, during the initial

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phase of Simon's interest in AI. The general impression is that over time the problem of how individuals make decisions was considered in the light of those disciplines (administrative, organization, economic, AI theories, and later cognitive psychology), which jointly contributed to providing a unitary answer, although AI and cognitive psychology had become increasingly important in Simon's scientific search. In this way, concepts such as the "limited computational capacities" of decision makers and "information processing", were conceived in an interdisciplinary perspective. Yet, the notion of "information processing" was accurately defined within the context of AI; therefore, it seems plausible to analyze how AI contributed to providing new tools for Simon's economic theory, and, more precisely, how AI sheds light on some aspects of bounded rationality. This perspective points out that bounded rationality is a highly structured concept, embodying some features partially shared with those disciplines which Simon included as an essential part of the "Zeitgeist" of the 1940s and early 1950s. In many respects, Simon considered his scientific experience to be the result of this climate, in which cybernetics, formal logic, information theory and many other scientific approaches emerged.

Finally, given these premises, two problems will be briefly discussed in this paper: 1) how bounded rationality is dealt with by contemporary authors, who have accepted Simon's non-standard approach to economics; 2) how they have received the implications deriving from the peculiar interrelations between different disciplines in Simon's work. A short survey, presenting three paradigmatic cases, suggests that Simon's teaching has been only partially accepted, and many recent studies essentially do not refer to AI. Important and stimulating perspectives emerge from such theoretical approaches, which share Simon's view of providing an alternative to neoclassical economics, but introduce non-marginal shifts with respect to the original program of their inspirer.

1. Bounded rationality and Artificial Intelligence: some interrelations.

Theories of bounded rationality, Simon maintains, dealt with the limits of "information processing capacities". More precisely, the definition of information processing stresses two constraints on individuals: 1) the limits of information, which is gathered and processed; 2) the limits of computational capacities, which emerge when agents face complex situations (Simon, 1955; 1972; 1976b; 1978; 1996).

Given these limits, the decisional process applies when problems requiring solutions occur. More precisely, Simon and March emphasize that actors (organizations, in this case), upon receiving an external input or stimulus, react by either replicating past behaviors (*routines*), if they do not encounter unforeseen situations, or by following new courses of action, in order to solve new and unexpected situations (Simon and March, 1993 [1958]). In the latter case, *problem-solving* procedures are activated, and agents treat complex problems sequentially. In particular, they reach a node (a choice point) using information collected in the previous steps, and this latter, in turn, allows them to gather new information. Since uncertainty prevails in the real world, neither all the alternatives nor the consequences that would follow from them are evaluated, and heuristics are adopted for simplifying search processes. Therefore, decision-makers look for a "satisficing", rather than an optimal, alternative, and the criteria, which perform this role in decision-making processes, are called "aspiration levels". Finally, problem-solving (sequential) procedures are attained by breaking down the problem into smaller components. In fact, problems are often too complex for the agents' computational capacities, and this requires their decomposition into sub-problems that are less computationally complex.

The theory of bounded rationality is closely interlaced with Simon's research in both economics and AI. As Klaes and Sent have recently maintained

> in a series of writings between 1947 and 1957, [Herbert Simon] consciously refined and replaced concepts such as "approximate rationality" and "limited rationality" until settling for "bounded rationality. (Klaes and Sent, 2005, p. 37)

During those years, Simon provided many fundamental contributions, from administrative and organizational to economic theories. However, his scientific interests led him to explore new fields. In 1952, Simon met Allen Newell at the *System Research Laboratory* of the RAND Corporation, and in the same period started to work out the hypothesis of a chess program inspired by the idea that chess players use not the best, but rather satisfactory strategies[1]. By the beginning of 1955, along with Clifford Shaw, the group was concerned with the programming systems on the JOHNNIAC, the computer built at RAND in the early fifties, and, between 1955 and 1957, they made great advances in computer science: specifically, the definition of the *Information Processing Languages* (IPL), and the creation of both *Logic Theorist* (LT) and *General Problem Solver* (GPS) programs. Finally, in June 1956, a fundamental seminar for the further development of AI was held in Dartmouth, participating, among others, were J. McCarthy, M. Minsky, C. Shannon, H.A. Simon and A. Newell. Simon describes 1955 and 1956 as the most important years of his scientific life, and so it must have been, if we consider that, besides his activity in the field of AI, two very

[1] Cordeschi (2002, p. 178).

important articles devoted to (bounded) rationality in economics were published in those years: *A Behavioral Model of Rational Choice* (1955) and *Rational Choice and the Structure of the Environment* (1956). In passing, let us remark that, in a note in the latter essay, as if he wished to stress his unitary research program, Simon declared himself "indebted to Allen Newell for numerous enlightening conversations on the subject of this paper" (Simon, 1956, p. 259).

In short, the research on "human problem solving" became the core of a wide-ranging theoretical project in which AI, economics, and cognitive psychology were closely intertwined. In addition, Simon connected all this to a long intellectual tradition, which included, among other things, the "influence of formal logic", cybernetics and the information theory of Wiener and Shannon. This tradition, as regards the decades prior to World War II, is described in terms of

> a powerful, growing Zeitgeist, having its origins around the turn of the century, involving a deep faith in mathematics as the language of science, but, more crucially, focused upon symbols and their manipulation in logical inference (if not in "reasoning") and decision. Symbols became, for the first time, tangible – as tangible as wood or metal. (Newell and Simon, 1972, p. 878)

2. **AI and Human Thinking**

Simon has continually emphasized the analogy between human thinking and computer intelligent behavior[2]. In this perspective, the first step consists in considering the human thought and problem-solving process in terms of an *information processing system* (IPS), that is, a system consisting of a set of memories, a processor, effectors, and receptors (Newell and Simon, 1972, p. 20). Memories contain data, symbolized information, and programs for information processing, so that the state of the system is determined by data and programs contained in these memories, with stimuli received by receptors. Symbols are the bases for both intelligent behavior and the comprehension of mind, since both computer and mind belong to "physical symbol systems".

[2] "Like a modern digital computer's, Man's equipment for thinking is basically serial in organization […] there is much reason to think that the basic repertoire of processes in the two systems [human thought and computers] is quite similar. Man and computer can both recognize symbols (patterns), store symbols, copy symbols, compare symbols for identity, and output symbols. These processes seem to be the fundamental components of thinking as they are of computation." (Simon, 1976b, p. 430, see also Simon and Shaw, 1958).
I assume that a close relation exists between the terms "intelligence", "thought" and "rationality", as well as between "intelligent behavior" and "bounded rationality". Simon explains such a link, as follows: "Because of the limits on their computing speeds and power, intelligent systems must use approximate methods. Optimality is beyond their capabilities; their rationality is bounded." Because of this fact Simon uses the expression "limits of human and computer rationality" (Simon, 1990, pp. 17 and 8). In other words, the computer must operate with bounded rationality. In general, Simon applies bounded rationality to every sphere in which decision theory take place, particularly economics, psychology, and AI, in fact, "[e]conomics is one of the sciences of the artificial" (Simon, 1976b, p. 441). See also, Newell and Simon (1981, pp. 52-54).

Symbols are "physical patterns" which can be components of entities called "expressions", which are symbolic structures capable of producing "internal representations" of the external environment (Newell and Simon, 1981). More precisely, when an environment is coupled with a problem or goal, we have a "task environment", which represents a set of facts about the world at a given moment such as, for example, the position of chess pieces on a chess-board. The subject represents the environment internally (internal representation), and the space in which his problem-solving activities take place is called "problem space". In addition to the current situation, problem space includes the possibilities for changing that situation, and binds behavior in many ways: defining admissible moves (the set of possible sequential courses of action adopted for accomplishing specific goals), specifying the aim, and interacting with short- and long-term memories.

Task environment, internal representation and space problem are crucial concepts, since they determine the relation between the state of the world and individual subjectivity, so that

> However difficult or impossible it may be to describe the task environment neutrally – that is, independently of its representation in terms of a particular problem space – the fact that it possesses certain structure – hence certain information that may be relevant to solving problems – *is an objective fact*, not dependent on the representation. Moreover, this structural information can be defined without reference to any properties of a problem solver who might use it. (Newell and Simon, 1972, p. 824, emphasis added)

In short, a real world exists out there, but it can be only represented subjectively.

Given these premises, problem solving implies that information is extracted from a problem space and used for seeking a solution, by means of heuristics. Consequently, the problem-solving procedure implies having a "test" (the solution to a problem, even if we do not know how to achieve it)[3], and a "generator" of symbol structures, that is a move generator for a potential solution. A problem will be solved if the generator produces a structure which satisfies the test (Newell and Simon, 1981, pp. 52-53).

[3] It means that we know what we want to do, but we do not know how to accomplish it. If symbol systems were not characterized by limited computational capacities, for example, the test for checkmate would be a strategy that achieves this aim for all counter strategies of the other player. But this is impossible in the real world. Once again, man and computer exhibit the same limitations, as regards computation, intelligence and rationality (Newell and Simon, 1981, p. 53).

3. The “complex algorithms of thought”[4]

Intelligence (and in general IPS), as the work of symbol systems, exhibits logic and computational features (specifically limited computational capacities), and this leads to the notion of bounded rationality[5].

From this point of view, analogously to the concept of intelligence in computer science, bounded rationality owes an intellectual debt to formal logic. In fact, the origin of the concept, according to which intelligent machines are symbol systems, is explicitly ascribed to the program of Frege, Whitehead and Russell for formalizing logic (Newell and Simon, 1972 p. 877; 1981, p. 42; Simon, 1996 [1991], pp. 192-194)[6]. The debt regarding the “logicians” is summarized as follows:

> The fundamental contribution was to demonstrate by example that the manipulation of symbols (at least *some* manipulation of *some* symbols) could be described in terms of specific, concrete processes quite as readily as could the manipulation of pine boards in a carpenter shop. The formalization of logic showed that symbols can be copied, compared, rearranged, and concatenated with just as much definiteness of process as boards can be sawed, planed, measured and glued […] Formal logic, if it showed nothing else, showed that ideas – at least some ideas – could be represented by symbols, and these symbols could be altered in meaningful ways by precisely defined processes. (Newell, Simon, 1972, p. 877)[7]

Newell and Simon specify that thought must not be confused with logic, because the former is not as rigorous as the latter, yet formal logic provided an important tool for conceiving symbol processing[8]. From this point of view, they essentially include their work in that intellectual tradition, whose characteristic was the conception that mathematics could derive from logic. In fact, in Russell’s view, the complete formalization of mathematics by means of a symbolic logic system was possible. More generally, they seem to accept the project for the construction of a human thinking alphabet, whose origin was in “Leibniz’s dream”, that is the dream of a general science of reasoning, which can be applied in every field of knowledge (Kline 1972; Davis 2000). Simon and collaborators stress that their approach does not concern homologies between a computer and the nervous system. On the contrary, it describes how both intelligent behavior and his *general*

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[4] Simon (1976b, p. 442).

[5] Bounded rationality can be explained in terms of a symbolic system: “It is precisely when we begin to ask *why* the properly motivated subject does nor behave in the manner predicted by the rational model that we recross the boundary again from a theory of the task environment to a psychological theory of human rationality. The explanation must lie inside the subject: in limits of his ability to determine what the optimal behavior is, or to execute it if he can determine it. In simple concept attainment experiments, for example, the most important mechanism that prevents from adopting an efficient strategy is usually the limit on the number of symbols he can retain and manipulate in short-term memory.” (Newell and Simon, 1972, pp. 54-55). Cf. Newell and Simon (1981, pp. 53-54)

[6] This point is also emphasized in Dreyfus H.L. and Dreyfus S.E. (1990).

[7] See Newell and Simon (1981, pp. 42-43).

[8] As regards distances between Simon and formal logic approach, see Mirowski (2002, p. 462).

properties emerge, and this implies explaining and treating, so to speak, the *language of thought*, by means of symbol logic. Moreover, formal logic determines a "new operationality of symbols", although symbol manipulation refers to broader areas of knowledge with respect to deductive logic (Newell and Simon, 1972, p. 877). According to Newell and Simon, there are a number of figures who contributed to linking, in different ways, formal logic, mathematics, and symbol manipulation; they include Turing, Carnap, Church, Shannon, Lotka, Wiener, Pitts, McCulloch, and many others.

In passing, we remark that Simon attended Carnap's lessons at the University of Chicago. The philosopher, he pointed out, "was particularly important to me, for I had a strong interest in the logic of the social sciences" (Simon 1996 [1991], p. 53**)**. This influence was not marginal, since Simon affirms that Carnap's theory had an important role in conceiving his thesis project, which culminated in *Administrative Behavior*. In fact, in the beginning this study concerned the logical foundations of administrative science[9].

As is well-known, Carnap was among the founders of the logical positivism, the philosophical school connected to the Vienna Circle in the early decades of the 20th century, which was inspired by the formal logic of Frege, Whitehead and Russell. Therefore, the following statement, quoted from *Administrative Behavior* is unsurprising:

> the conclusions reached by a particular school of modern philosophy – logical positivism – will be accepted as a starting point, and their implications for the theory of decisions examined. (Simon 1976 [1947], p. 45)

Given these premises, several points can be emphasized:

1) rationality involves intelligence, and in its turn intelligence implies *physical symbol systems*. Consequently, rationality can be represented in symbolic form, and as a sequence of unambiguous operations. In other words, non-conscious elements and tacit procedures for facing unexpected events, are either not considered or are reduced to the logic of symbol manipulation[10].
2) Bounded rationality is instrumental in nature; it is essentially evoked for solving problems, which often exhibit a logical form (see next sections) (Hargreaves Heap *et al.*1992).
3) Studying how problem solvers face a cognitive task implies that "we are observing *intendedly rational behavior* or behavior of *limited rationality*" (Simon 1947; Newell and

[9] A further sign of this influence was the dedication to Carnap and Henry Schultz, another university teacher, of his book *Models of Discovery*, in 1977. However, it is evident that Simon's intellectual history cannot be reduced to the elements above mentioned, for a historical and theoretical interpretation, see Mirowski (2002).

[10] Simon, for example, criticized Michael Polanyi's "tacit knowledge", with reference to the so-called "Meno Paradox", (Simon, 1976a).

Simon, 1972, p. 55). Therefore, the attention is focused on deliberate, conscious, and intentional rationality, which is limited, as matter of fact. In this sense, Winograd and Flores maintain, Simon does not contest the "rationalistic tradition", but only the version that implies perfect knowledge, perfect foresight, and optimitization criteria (Winograd and Flores, 1986, p. 22, see also O'Neill, 2005, p. 296).

In short, decision-making emerges as a procedure connoted by the symbolic and deliberate activity of problem-solving, and can be explained in terms of information processing, where the latter implies performing a number of definite, unambiguous operations (Simon and Shaw, 1958, p. 6). As a consequence, part of Simon's monumental project was devoted to showing how phenomena such as intuition, insight, "aha" and creativity (and, in general, perception and emotions) [11] were not mysterious, and that they implied neither vagueness nor tacit procedures (that is to say, procedures that cannot be explained in terms of symbolic information processes). More generally, intentional bounded rationality (as a conscious activity of the decision-maker) and intuition can be considered to be the opposite poles of rational behavior. Yet, they only appear to be opposing cognitive tools; on the contrary, they share the same fundamental information processing mechanism. Creativity, in turn, represents an important challenge for IPS, since human thinking and problem-solving procedures cannot be adequately represented without including this crucial phenomenon.

4. Intuition and Insight: embodying the ineffable

Logical and intuitive thought can be easily unified, therefore phenomena as intuition, insight, "aha" and creativity can be explained by means of computer programs (Simon, 1997, p. 174-5; 1983b, chap. 1).

Insight and intuition, which are almost synonyms, appear when "someone solves a problem or answers a question rather suddenly […] without being able to give an account of how the solution or answer was finally attained" (Simon, 1987, p. 482). Intuition is not a mysterious phenomenon, and consists in an act of "recognition". In particular, we recognize something of our previous

[11] As regards perception, Simon maintains: "a wide range of the known phenomena of visual perception can be accounted for by a mechanism that encodes information from the stimulus into an internal representation having certain efficient characteristics from an information processing and retrieval stand-point." (Simon, 1967b, p. 361). In turn, emotion is considered to be an "interruption mechanism", which "allows the processor to respond to urgent needs in real time". Given this framework, Simon affirms that these mechanisms have been basically embodied in "the current information-processing theories of human cognition." (Simon, 1967a, p. 38).

experience, and as consequence of this recognition we arrive at long-term memory, where the knowledge of this phenomenon is located (Simon, 1997, p. 179). Knowledge and information (about the familiar pattern and the cues for recognition) are stored and have a suitable and defined form.

Recognition (and intuition), as a process that is not accessible to consciousness and not reportable, characterized the EPAM program, which was able to report the symbols which reached its memory and, for example, to recognize a pathology[12]. In fact, the symbol representing the stimulus that has been recognized is placed in EPAM short-memory, and hence provides access to knowledge about the stimulus that had been previously stored in the long-term memory (Simon, 1987, p. 482). In short, intuition is the recognition of past experience, which takes the form of "stored information", it is guided by rules, and it explains the ability of chess grand masters, managers and, in general, experts who face situations requiring rapid decisions (Simon, 1983a, p. 4570; March and Simon, 1993 [1958], p. 10-13).

Finally, recognition implies bounded rationality. In fact,

> A major strategy for achieving intelligent adaptation with bounded rationality is to store knowledge and search heuristics in a richly indexed long-term memory in order to reduce computational requirements of problems […] When recognition does not suffice, because a great space of possibilities must be explored, they resort to highly selective search, guided by rich stores of heuristics. (Simon, 1990, p. 17)

In conlusion: intuition, being based on "stored information", is not something else with respect to explicit information, which is normally processed by physical symbol systems. Therefore, intuition implies a kind of rationality which, although limited, is instrumental, and is not connoted by ambiguity or vagueness, because it processes well-defined information encapsulated in unambiguous symbols.

5. Creative thinking

Creativity too is included in the domain of AI. In particular, "creativity appears simply to be a special class of problem-solving activity characterized by novelty, unconventionality, and difficulty in problem formulation" (Newell, Shaw, Simon, 1962, pp. 145-146). Novelty, in turn, derives from the combination and re-combination of primitive elements. This is a universal mechanism: matter re-combines with 92 stable elements in nature, language re-combines with a given number of letters

[12] EPAM program was in the process of construction in 1958 and was successively modified.

of alphabet, etc., and Simon maintains that such a mechanism, called "generator and test" in AI, is represented by the BACON program (Simon, 1997, pp. 185-186).

Creativity, as a recombination of base elements, can be explained in terms of symbol systems; there are neither tacit nor non-specifiable procedures, therefore it is a by-product of normal heuristic search. Yet Simon and collaborators introduce a limitation: if creativity means activity for problem-solving, then programs that simulate the human problem solving already exist, but

> [i]f we reserve the term "creative" for activities like discovery of the special theory of relativity or the composition of Beethoven's Seventh Symphony, then no example of a creative mechanism exists at the present time. (Newell, Shaw, Simon, 1962, p. 145).

Such a limitation is relevant. In fact, if problem space is *closed* by definition, then search activity can be performed in terms of problem-solving, and the basic elements can be creatively re-combined. In this case, the problem has to be defined and well-formulated, in order to apply heuristics, tests and generators for solutions. Kinds of problems like these are: demonstration of a theorem, achieving checkmate, finding the right combination for a safe, solving a crossword puzzle, etc. They are problems of the type: "given expression *a* and a set of admissible operators, to derive expression *b*" (Newell, Shaw, Simon, 1962, p. 157), to which specific programs correspond, which can be used as problem-solving heuristics (Newell, Shaw, Simon, 1962, p. 157). Generally speaking, this view was censured by some critics. In fact, when General Problem Solver (GPS) was available (successively to the Logic Theorist (LT), to which the authors referred in 1962), critics observed that GPS dealt with only logical-mathematical problems, that is *closed* problems, while most human decisional problems cannot be expressed in these terms (Gardner, 1985, p. 151). Winograd and Flores commented on an example, originally described by Keen and Scott-Morton: if a large dog suddenly crosses the road when you are driving a car at 55 miles per hour, there is no time for searching for information, therefore there is no time for evaluating the suitable course of action (as *satisficing* alternative). In this case, Winograd and Flores maintain, the driver's reaction cannot be adequately described in terms of bounded rationality (Winograd and Flores, 1986, p. 146).

However, as regards creativity, a new framework takes shape if we assume that human agents face an *open* problem, which cannot be defined either delimiting a space problem or fixing the ideal final point of the search, in terms of the solution to the problem (for example, theorem demonstrations, puzzle solutions, etc.). Discovering the special theory of relativity or composing the Seventh Symphony are not activities which can be circumscribed in a specific problem space. On the contrary, only *generic* tasks can be performed, such as composing music or writing a novel.

In this case, when the task domain has little structure or is unknown, problem solvers apply “weak methods”. *Satisficing* is a weak method, and this means we halt the search process when a solution meets our expectations (Simon, 1983a, p. 4570; 1990, p. 9). But, evidently, there is no assurance of creating a masterpiece or a revolutionary scientific theory.

The LT computer program, which Simon and collaborators used for their study on creativity, was “capable of discovering proofs for theorems in elementary symbolic logic, using heuristic techniques similar to those used by humans” (Newell, Shaw, Simon, 1962, p. 146), that is, its task domain was highly structured. Moreover, other programs were considered, i.e., for composing music, designing engineering structures, playing chess, etc. It is important to emphasize that, in this view, creativity is closely connected to the problem-solving procedure. In particular, LT was considered creative, since it reinvented “large portions of chapter 2” of Whitehead and Russell’s *Principia Mathematica*, “rediscovering in many cases the very same proofs that Whitehead and Russell discovered originally” (Newell, Shaw, Simon, 1962, p. 147). Yet, the doubt that creativity cannot be embodied only in this limited context emerges when the authors affirm: “perhaps the real creativity lies in the problem selection” (Newell, Shaw, Simon, 1962, p. 147), an activity that LT could not perform. The implicit consequence is that *problem setting* must precede *problem-solving*. In fact, LT has a pre-fixed configuration (a specific “space problem” externally provided by the experimenter, which coincides with the space of theorem or sub-theorem proofs). Also the set of rules for problem-solving activity, whose aim is a theorem demonstration, is pre-defined. But LT cannot choose or select the problems. In short, some problems emerge as regards the nature of creativity. Creativity, for Simon and collaborators, consists in rediscovering and reinventing Whitehead and Russell’s theorems, for someone else it may consist in determining original questions, inventing the original theoretical structure of both problems and analytic methods, and establishing relevance criteria, by means of which defining what set of hypotheses and assumptions constitute an interesting problem for science. In this perspective, creativity implies defining how thought defines its own objects without external intervention (i.e., the experimenters, who select problems and provide instructions for the machine). In short, in this perspective, creativity is related more to the *problem setting*, than to the *problem-solving*[13].

In accordance with AI theoretical hypotheses, “verbal protocols” that the subjects of an experiment produce when they solve formal problems have special relevance. By means of this method, subjects verbally explain the steps that led them to the problem’s solution, following the rules provided by the experimenter. In this way, a correspondence is assumed between the conscious (and declared) course followed for producing answers, and the thought process. If this is

[13] This problem can be evaluated with reference to the general framework described by Gardner (1985, pp. 150-151).

so, no gaps exist between the two dimensions: on the one hand, the self-organizing thought and on the other hand, its perception by the subject, which is translated into verbal form. Moreover, both dimensions exhibit reciprocal coherence, since sequential thought processes have as counterparts the sequential, conscious, and explicit steps performed by problem-solvers. This vision engenders some problems. Nowadays, for example, neuroscientists emphasize the role of unconscious (neural) mechanisms in determining decisions and courses of action, which cannot be perceived by consciousness (Bechara *et al.*, 1997). Therefore, processes that produce thought, especially as regards unconscious neural activities, cannot be described verbally. As a consequence, they do not trust in "thinking-aloud protocols" (LeDoux, 1999).

These arguments lead to the problematic relation between internal and external representations. Firstly, Simon and Newell affirmed that the external environment (as task environment) must take the shape of an internal representation, that is to say an interpretation of the task environment. Secondly, this representation is a collection of symbol structures, which has both internal and external form. Thus the expression $(p \vee q) \supset p$ is an "external representation" corresponding to an internal one. Yet, these representations differ "topologically", because the internal representation does not exhibit a linear array, as does the external (written) one, and elementary symbols would look like those of Fig. 1.

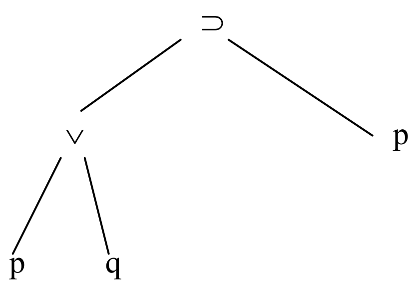

Fig. 1

(From Newell, Shaw, Simon, 1962, p. 163)

Consequently, the "main lesson […] is that the internal representation may mirror all the relevant properties of the external representation without being a 'picture' of it in any simple or straightforward sense" (Newell, Shaw, Simon, 1962, p. 164). The "correspondence" between representations is a complex phenomenon, and Simon and collaborators show prudence in treating such a theme. Internal representation is not a "picture", nonetheless it implies a "correspondence"; symbolic mind language differs from conventional language (formal language, in this case), even if it mirrors the relevant properties of the former. Yet, all this induces some questions about the links between information processing and its representation by means of verbal protocols. In fact,

> It is not at all clear whether a human subject would be aware that his internal representation of a logic expression 'carried' the information about the expression in quite a different way from the string of symbols on paper, or that if he were aware, he could verbalize what the differences were. (Newell, Shaw, Simon, 1962, p. 164)

This reasoning introduces the important and recent debate about the ability of intelligent machines (including human beings) to work by means of representations, but we cannot treat this subject here. We merely remark how, in Simon's view, the symbol processing mechanism and its appearance as concrete acts (as written logic formulas) are characterized by clarity and intelligibility. The nature of internal and external representations is the same, and is adequately expressed by unambiguous symbols. The difference between the two representations is merely topological. As Simon reminds us once more, neither tacit dimensions nor unconscious (mysterious) mechanisms have to be evoked for explaining how the mind works.

6. Is Bounded Rationality Revisited?

Many economists, from Nelson, Winter, and Williamson to March, Kahneman and Tversky have acknowledged their intellectual debt to Simon, and applied the notion of bounded rationality in their work. In turn, some of them have received scientific recognition by Simon, as is the case of Kahneman and Tversky[14]. However, in contemporary studies bounded rationality seems to undergo a shift with respect to Simon's approach. In particular, these theories on bounded rationality prevalently describe cognitive (rational) processes as events weakly connoted in terms of computation and instrumentality, where in Simon's view both computation (as limited symbol processing), and instrumentality have a relevant role. Therefore, it is difficult to find in these works the perspective which relates AI and bounded rationality, providing for the latter that highly structured form.

In this sense, as often happens with important concepts in science, their use led to slow changes with respect to the original meaning. In this case, the outcome is a notion of bounded rationality that is, so to speak, much more bounded than Simon's, and basically not influenced by the formal

[14]Here we are not considering the notion of bounded rationality used in standard approaches. See Sent (1997), Conlisk (1996).

structure of *physical symbol systems*, although in many respects the latter provided the foundation for bounded rationality.

The following survey aims to give only a few examples in this sense.

In a recent article, Kahneman summarizes the most important phases of the research shared with Amos Tversky for several decades. The "guiding ideas" are that "most judgments and most choices are made intuitively, [and] that the rules that govern intuition are generally similar to the rules of perception". He also adds that intuition acts "*without conscious search or computation*" (Kahneman, 2003, p. 1450). In fact, he distinguishes between *two alternative* modes of thinking and deciding: reasoning and intuition. The former implies computation, the latter does not; moreover, this perspective appeared in the "framing theory", where "framing effects resemble visual illusion more than computational errors" (Tversky and Kahneman, 1987, p. 76). In addition, intuition often prevails over reasoning. By way of contrast, as shown in Section 4, according to Simon intuition and rational thought are a *unique* cognitive mechanism, in which computation is fundamental, even if it is characterized as a limited capacity. The only difference, Simon maintained, is that intuition appears because "stored information" is available, and searching is not necessary, while normal problem-solving processes require a search for information. In both cases, the process consists in the manipulation of unambiguous symbols contained in memories.

Moreover, Kahneman affirms, perception and intuition are collected in "System 1", whose operations are fast, parallel, automatic, emotional, etc., while reasoning belongs to "System 2", which is characterized by slow, serial, controlled, rule-governed operations. In conclusion, "[t]he central characteristic of agents is not that they reason poorly but that *they often act intuitively*. And the *behavior of these agents is not guided by what they are able to compute, but what they happen to see at a given moment*" (Kahneman, 2003, p. 1469, emphasis added).

Kahneman's "maps of bounded rationality", here discussed emphasizing the role of intuition and computation, seem to define a notion of rationality weaker than Simon's one. Intuition is not a peculiar mechanism connoted by symbolic intelligence, and explained by referring to an AI context; and in addition it prevails over computational reasoning. As is well-known, prospect theory was presented as a formal descriptive theory of human choices, yet Kahneman mentions some mechanisms which can explain decision making, referring, for example, to the notion of "accessibility", which is linked to emotions, intuitions, and perceptions. In short, the mechanism evoked for explaining choices and behaviors seems to go beyond the computational limits in processing information. What is the relevant information, which must be processed? It depends on complex processes involving intuition, perception and emotions as alternative instruments, which are substituted for computational reasoning. In other words, the problem is whether, so to speak, the *computation of intuition* exhibits the same nature as the (limited) computation performed by physical symbol systems.

Gerd Gigerenzer and Reinhard Selten also start from Simon's vision of bounded rationality, and maintain that their work is an elaboration of his theory (Gigerenzer and Selten, 2002, p. 4). In fact, Simon introduced the notion of "*satisficing*", and pointed out two sides of bounded rationality: one cognitive and one ecological, which in turn emphasized that minds are adapted to the real world environment. The elaboration of these ideas leads to the notion of "ecological rationality" and "adaptive toolbox", which have characterized the research program of Gigerenzer and his group (Gigerenzer *et al*., 1999).

This perspective is summarized as follows:

> The concept of an adaptive toolbox, as we see it, has the following characteristics: First, it refers to a collection of rules or heuristics rather than to a general-purpose decision-making algorithm […]. Second, these heuristics are fast, frugal, and computationally cheap rather than consistent, coherent, and general. Third, these heuristics are adapted to particular environments, past or present, physical or social. This "ecological rationality" - the match between the structure of a heuristic and the structures of an environment – allows for the possibility that heuristics can be fast, frugal and accurate all at the same time by exploiting the structure of information in natural environments. Fourth, the bundle of heuristics in the adaptive toolbox is orchestrated by some mechanism reflecting the importance of conflicting motivation and goals. (Gigerenzer and Selten, 2002, p. 9)

Ecological rationality, as new version of bounded rationality, exhibits some shifts with respect to the original model. This kind of rationality is not instrumental, in the sense that the focus moves from the "*intendedly rational behavior*", however limited computationally, to a rationality which emerges as a strategy adapted to a changing environment[15]. More generally, this vision suggests that (limited) rationality is less characterized by precise (sequential) choices, and is more unintentional and adaptive. In short, *intentional* (limited) rationality implies focusing attention on conscious decisional activity, where adaptive rationality implies a decision-making activity largely connoted by unconscious, adaptive mechanisms. If this is so, in the former case, individuals are considered intentional problem solvers, whose explicit rationality is limited; in the latter one, individuals are adaptive problem solvers, connoted by scarce degrees of awareness, as regards their responses to the environment.

Moreover, 1) heuristics are fast and frugal, because they do not involve much computation, and "only search for some of the available information" (Gigerenzer, Todd, 1999, p. 4); 2) they exploit

[15] In fact, "rationality is defined by its fits with reality" (Gigerenzer and Todd, 1999, p. 5).

environmental structure to make adaptive decisions, and lead to accurate and useful inferences. In short, simple heuristics use “minimal time and information”, and this happens both in basic ecological situations (as in the prey-predator case), in which fast decisions provide an advantage, and in complex social circumstances. More precisely, “fast and frugal” heuristics are characterized by recognition and ignorance, are based on the first encountered cue, combine a small number of cues to make categorical decision, stop a sequential search after encountering only a small number of alternatives (Todd, 2002, pp. 55-56).

Gigerenzer and collaborators maintain that just two forms of bounded rationality exist: “satisficing heuristics for searching through a sequence of available alternatives, and fast and frugal heuristics that use little information and computation to make a variety of kinds of decisions” (Gigerenzer and Todd, 1999, p. 7). In this way, both continuity and the differences between these approaches are pointed out. On the one hand, Simon’s heritage is widely recognized, on the other, some differences emerge as a normal by-product of this autonomous research program. Again, a further theoretical shift can be remarked. As for Kahneman and Tversky, bounded rationality is connoted in a weaker sense with respect to Simon’s view. Computation has a limited role, since the most important bounds of rationality are not computational or mental (internal) factors, but depend on the environment (external) pressures, and on how environmental forces have selected simple heuristics for making decisions (Todd, 2002, p. 52)[16]. More precisely, ecological rationality “suggests looking outside the mind, at the structure of environments, to understand what is inside the mind” (Gigerenzer, 2002, p. 39). If this is so, *internal limits are not so important*, if adaptive processes allow the use of accurate and useful inferences:

> A computationally simple strategy that uses only some of the available information can be more robust, making more accurate predictions for new data, than a computationally complex, information-guzzling strategy that overfits. (Gigerenzer and Todd, 1999, p. 20)

In a certain sense, computational limits (with respect to the information which should be gathered and processed) produce a counter-intuitive effect, since “computationally simple strategies” are better than “computationally complex” ones. On the contrary, in Simon’s view, given the computational limits of processing information, the more such limits are reduced, the more subjects are rational, and the more they carry out good strategies for solving problems[17].

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[16] The authors often refer to the two scissors blades, which, according to Simon (1990, p. 7) shape human rationality: task environments and computational capabilities. But they recognize that “[t]he neglect of one [the structure of environment] of the two sides of bounded rationality can even be traced in Simon’s writings”, although that “side” was implicitly assumed (Gigerenzer, 2002, p. 40).

[17] This view, in turn, is linked to the criticisms to Kahneman and Tversky. In fact, simple heuristics lead to reasonable decisions and accurate inferences, “[i]n contrast, the heuristics-and-biases approach views heuristics as unreliable aids

Finally, the notion of "adaptive toolbox" seems to refer to a set of concepts which are far from Simon's original perspective; consequently, computation is not treated by recourse to symbol systems, as in the AI approach. Nonetheless, as in the case of Kahneman and Tversky, fast and frugal heuristics can be seen as a complement of Simon's works.

A re-reading of the concept of bounded rationality can also be remarked in the work of J. March, Simon's well-known collaborator, who pointed out how new directions have emerged from the original Simonian context[18].

As in the case of Kahneman, Tversky and Gigerenzer the controversy is addressed to the neoclassical approach, and in particular to the assumption that preferences are coherent, stable, exogenous and unambiguous. On the contrary, March maintains, preferences are ambiguous and inconsistent.

> Choices are often made without respect to tastes. Human decisionmakers routinely ignore their own, fully conscious, preferences in making decisions. They follow rules, traditions, hunches, and the advice or actions of others. Tastes change over time in such a way that predicting future tastes is often difficult. Tastes are inconsistent. Individuals and organizations are aware of the extent to which some of their preferences conflict with other of their preferences; yet they do nothing to resolve those inconsistencies. (March, 1978, p. 596)

Preferences are ambivalent (at the same time, something is desired and not desired), and their inconsistency induces us to reverse the perspective according to which derives a coherent course of action from the preferences. In fact,

> We construct our preferences. We choose preferences and actions jointly, in part, to discover – or construct – new preferences that are currently unknown. We deliberately specify our objectives in vague terms to develop an understanding of what we might like to become. We elaborate our tastes as interpretations of our behavior. (March, 1978, p. 596)

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that the limited human mind too commonly relies upon despite their inferior decision-making performances, hence […] heuristics can be blamed for poor reasoning." (Gigerenzer and Todd, 1999, p. 20). The consequences of the debate among these scholars, evidently, cannot be discussed here. See Gigerenzer (1991); Kahneman and Tversky (1996); Gigerenzer (1996).

[18] "The original [Simon's] articles suggested small modifications in a theory of economic behavior, the substitution of bounded rationality for omniscient rationality. But the ideas ultimately have led to an examination of the extent to which theories of choice might subordinate the idea of rationality altogether to less intentional conceptions of the causal determinants of action" (March, 1978, p. 591), and, in this sense, he indicates: March and Olsen (ed.), *Ambiguity and Choice in Organizations* (1976).

Therefore, preferences are discovered by means of behaviors, since individuals often elaborate an interpretation of what they are doing in the course of their actions (March 1988; 1994; see Tversky, 1993; Slovic 2000). This perspective points out the role of bounded rationality: unstable, inconsistent and imprecise preferences and goals at least partially assume this form "because human abilities limit preference orderliness" (March, 1987, p. 598). Yet, Simon's concept of bounded rationality seems to differ in some respects from the one generally delineated by March. In particular, Simon's limited rationality does not include such notions as "ambiguity" and "inconsistency", in March's structural sense. Information, which Simonian agents process, is not ambiguous, it is simply gathered and manipulated. As a consequence, rational courses of action, such as problem-solving activities, are not guided by a fuzzy set of information, from which the behavior takes shape. Generators of solutions, which functionally connote every problem solver, work according to logical schemes. Task environment, heuristics and goals (especially if related to *closed* problems), in turn, are not vague or incoherent, and search processes have a defined structure. Computational limits, in information processing and in intentional search, do not imply ambiguity; the space problem, internal representation, generator of solutions and test are jointly used for identifying and solving well-formulated problems, although optimal procedures are not applied. All this seems to define a framework, which differs from that of March where: "[h]uman beings have unstable, inconsistent, incompletely evoked, and imprecise goals" (March, 1987, p. 598), and both the world and the "self" are ambiguous (March, 1994). Many elements of March's work are a direct consequence of Simon's view; both authors, for example, emphasize the role of the search processes, nonetheless it is possible to note a theoretical shift that, in March's case, once again leads to a relaxation of some formal elements of bounded rationality: on the one hand, the "self" (or more precisely the problem solver) is well-structured and stable, even if computationally limited; on the other hand, the "self" does not possess a sound structure, and this is the most important limit[19].

Conclusions

[19] Kahneman points out that a conflict between System 1 (perception and intuition) and System 2 (reasoning) can engender inconsistent preferences: "we cannot take it for granted that preferences that are controlled by emotion of the moment will be internally coherent, or even reasonable by the cooler criteria of reflective reasoning. In other words, the preferences of System 1 are not necessarily consistent with the preferences of System 2." (Kahneman, 2003, p. 1463).

The simple assumption from which we started is that Simon's notion of bounded rationality is closely connected to scientific research in AI. This is not a novelty; nonetheless it stresses some theoretical consequences, the most important of which is the conception of bounded rationality as a highly structured concept, characterized in many respects in terms of physical symbol processing. Given this premise, it has been argued that formal logic was an approach capable of influencing AI, providing some tools for conceiving both symbol processing and symbol operationality. More generally, formal logic suggested the idea of a general language of thought. Such an influence, although limited, was coherent with Simon's goal of providing rigorous bases for the social sciences, a perspective which connects his scientific work with the *Zeitgeist* of the mid-20th century. Therefore, such a heritage matters, as Simon himself recognized.

All these elements have been observed from a specific point of view: Simon's aim of explaining phenomena as "intuition", "insight", "creativity" (and, more generally, perception and emotions) by means of AI. Simon's unitary vision of (bounded) rationality emerges from this perspective. Rationality works essentially in the same way when dealing with both formal (*closed*), and *open* or ill-defined problems.

Moreover, rationality is connoted by a set of well-defined symbolic operations; it does not deal with ambiguous information; it is featured by search processes, which can assume the form of explicit verbal protocols; it is instrumental, since it has to solve problems; it is computational. All these features are consistent with the most important one: rationality is bounded.

The final part of the paper suggests that some shifts connote certain theories, which share Simon's criticism of standard economic theory. These works are not homogeneous, and refer to both theoretical approaches and different methods.

A common thread seems to be the split between bounded rationality and AI. In particular, there is no reference to the rigorous structure of AI, which contributed to defining bounded rationality. As a consequence, the unitary view of rationality derived from the AI perspective disappears and, for example, intuition and perception can be separated from "reasoning". Computation is not so important if individuals prevalently act intuitively, that is in a rapid, parallel, and emotional way. In short, intuition apparently is not only the recognition of past experience, reduced to the form of physical symbols, contained in short- and long-term memories of processors. In addition, computation is not so important, if "fast and frugal" heuristics allow more accurate predictions than computationally complex strategies. On the contrary, in Simon's view, computation matters: rationality is bounded, because computational capacities are limited, without such limits the individual could be the Pareto's *homo oeconomicus*. In a trivial sense: the less computation capacities are limited, the more the individual is rational. Simon often invoked more empiricism in studying how individuals make decisions, and computational limits in his view explain their performances. But it is possible to ask if, for example, emotions, as a determining factor in decision, can be encapsulated in a computational theory: “A theory of choice that completely ignores feelings such as the pain of losses and the regret of mistakes is […] descriptively unrealistic” (Kahneman, 2003, p. 1457).

Finally, adaptive rationality seems to differ from the limited rationality of intentional problem solvers. The former seems to require unconscious and automatic mechanisms that are closer to biological-evolutionary approaches than to AI. Both the world and the self, as March reminds us, can be ambiguous and unstable, and this, as in the previous cases, induces some reflections on the trends of theories inspired by Simon’s bounded rationality.

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