Available online at www.sciencedirect.com
SCIENCE DIRECT®

ELSEVIER

Journal of Economic Psychology 24 (2003) 265–277

JOURNAL OF Economic Psychology

www.elsevier.com/locate/joep

Herbert Simon. Artificial intelligence as a framework for understanding intuition

Roger Frantz *

Department of Economics, San Diego State University, San Diego, CA 92182, USA

Abstract

Herbert Simon made overlapping substantive contributions to the fields of economics, psychology, cognitive science, artificial intelligence, decision theory, and organization theory. Simon's work was motivated by the belief that neither the human mind, human thinking and decision making, nor human creativity need be mysterious. It was after he helped create "thinking" machines that Simon came to understand human intuition as subconscious pattern recognition. In doing so he showed that intuition need not be associated with magic and mysticism, and that it is complementary with analytical thinking. This paper will show how the overlaps in his work and especially his work on AI affected his view towards intuition.

PsycINFO classification: 2140, 4120
JEL classification: B21, B30
Keywords: Herbert Simon; Intuition; Artificial intelligence; Bounded rationality; Economics and psychology

1. Introduction

Herbert Simon made overlapping substantive contributions to the fields of economics, psychology, cognitive science, decision theory, and organization theory. Simon's work was motivated by the belief that neither the human mind, human thinking and decision making, nor human creativity need be mysterious. His life work was devoted to proving this point. His motto was "Wonderful, but not

* Corresponding author. Tel.: +1-619-594-3718; fax: +1-619-594-5062.
E-mail address: rfrantz@mail.sdsu.edu (R. Frantz).

0167-4870/03/$ - see front matter
doi:10.1016/S0167-4870(02)00207-6

incomprehensible" (Simon, 1969, p. 4). Where he carried this out was at the intersection of economics, psychology, cognitive science, and organization theory. A major part of this intersection was creating computer programs which allow machines to "think" and make choices.

It was after he helped create "thinking" machines that Simon came to understand human intuition as subconscious pattern recognition. In doing so he showed that intuition need not be associated with magic and mysticism. [1] He also showed that "intuition is not a process that operates independently of analysis; rather the two processes are essential complementary components of effective decision-making systems" (Simon & Gilmartin, 1973, p. 33).

Intuition is often described by what it is *not*: intuition is a residual concept. Intuition is not a conscious analytical – logical, sequential, step-by-step, and reasoned – process of thinking. The most common terms used for intuition reveal intuition's residual nature: gut feeling, educated hunch, sixth sense. Bunge (1962), in his book *Intuition and Science* states that intuition is what we call "all the intellectual mechanisms which we do not know how to analyze or even name with precision, or which we are not interested in analyzing or naming" (p. 68). The intellectual mechanisms Bunge cites include rapid reasoning, synthesizing disparate elements into a grand vision, and sound judgment. Simon's preference was to refer to intuition as subconscious pattern recognition.

Although the logical and analytical nature of economic thinking has kept intuition in the background of the profession, Simon is not the first economist to discuss intuition. Adam Smith (Frantz, 2000), John Stuart Mill (Frantz, 2001), Alfred Marshall (Frantz, 2002b), John Maynard Keynes (Moggridge, 1995), Schumpeter (1954), and Frank Knight (Frantz, 2002a) are other famous names who wrote about intuition. For the past 25 years it has become almost commonplace for an economist to state during a presentation that, "The intuition behind the model (and/or result) is ..." In, *The Making of an Economist*, Klamer and Colander (1990) interviewed graduate students from various departments throughout the US. Students consider both mathematics and intuition to be important, and they express an appreciation for the intuitive elements in the work of their professors.

This paper will show some of the overlaps among Simon's work on economics, psychology, cognitive science, and organization theory, and how these overlaps affected his view towards intuition.

[1] Simon had his own intuitive experiences. His preliminary exam in statistics for the University of Chicago in 1940 required that he produce a derivation of the chi-square statistic: he provided two derivations. He says, "While taking my shower on the morning of that exam, it came to me with blinding and unaccountable certainty that there would be a question on chi-square, and I boned up on it before setting out for the exam room. On no other occasion have I had such loving attention from my guardian angel" (Simon, 1996, p. 84). Simon had been contemplating programming computers to simulate chess playing since the early 1950's. In 1955 during a walk on the campus of Columbia University he says, "Suddenly, I had a clear conviction that we could program a machine to solve such problems" (p. 203). Speaking about government employees specializing in security he said, "Intuitively, they know that intellectuals seek to be loyal to abstractions like 'truth,' 'virtue,' or 'freedom,' rather than to a national state or its flag" (Simon, 1989a, p. 133).

2. Intuition. The "problem" illustrated

Simon's philosophy of intuition may be said to begin with the publication of Chester Barnard's *The Functions of the Executive* (Barnard, 1942), specifically an appendix titled "Mind in Everyday Affairs" in which Barnard discusses intuition. Herbert Simon, in his lecture given in Stockholm upon receiving the Nobel Prize in Economics, referred to Barnard as an "intellectually curious business executive who distilled from his experience as president of New Jersey Bell Telephone Company ... a profound book on decision making ..." (Simon, 1965, p. 25). Yet, when it came to Barnard's philosophy of intuition, Simon says that Barnard, "presents an interesting, but perhaps too optimistic view of the 'intuitive' elements in administrative decisions ..." (Simon, 1965, p. 60). What makes Barnard's presentation too optimistic for Simon?

Barnard's philosophy about intuition was stated matter-of-factly. First, intuition may seem abstract because it arises from the subconscious, but it is not abstract. Intuition is a non-logical process, defined by Barnard as a process which takes place in the subconscious or is so rapid as to seem subconscious, and hence also seems to be instantaneous and devoid of reasoning. Examples of intuition cited by Barnard include studying a complex balance sheet for only a few minutes or seconds before being able to derive a coherent picture of the company.

Second, intuition is as much an expression of intelligence as is logic. Third, intuition is useful and so people should use it. Fourth, many people use intuition at work but it is "frequently scorned" (Simon, 1996) because of psychological reasons. The reason is that many people feel the need to rationalize their beliefs and have them appear plausible, and hence do not want to admit using something that is unexplainable. The "most interesting and astounding contradiction in life" he says, is that regardless of intellect, people's insistence upon using logic is coupled with their inability to use it and to accept it when used by others. The bias against intuition among scientists is understandable, among non-scientists it is "unintelligent" (Simon, 1996).

Fifth, intuition is most appropriate when working with short time horizons and data which is either of poor quality and/or very limited. This covers according to Barnard the majority of situations used in every day affairs in both business and government. He says that it is "impossible effectively to apply the logical reasoning process to material that is so insecure that it cannot bear the weight of ponderous logic ... The much ridiculed 'women's intuition' is the only mental process that can apply to it" (Simon, 1996, p. 310). Understanding organizations also calls for intuition. He says, "Our logical methods and our endless analysis of things has often blinded us to an appreciation of structure and organization ... You cannot get organization by adding up the parts ... To understand the society you live in, you must *feel* organization – which is exactly what you do with your non-logical minds ..." (Barnard, 1942, p. 317).

Simon's approach was very different. As a scientist he needed to understand the phenomenon we call intuition. In the early part of his career there was not a scientific – rational, logical – theory of intuition, and so Simon considered intuition to be a mystery. In time and with advances in cognitive science and AI as a framework, Simon concluded that intuition is subconscious pattern recognition. Simon did not consider intuition to be irrational, he considered it to be a rational but not a conscious analytical method of decision making (Simon, 1987).

3. Rationality

For Simon, problem solving was a "search through a vast maze of possibilities, a maze that describes the environment" (Simon, 1982h, p. 66). Rationality is *bounded rationality* or limited by the vast maze of possibilities which is our environment. The maze makes the *procedures* we use in decision making, one of which is subconscious pattern recognition, more important than traditionally given in economics. And it means that the decisions we make are more *satisficing* than maximizing. Thus, Simon challenged the economic orthodoxy on the definition of rationality by proposing the concepts of bounded and procedural rationality, and satisficing.

The orthodox definition is represented by economic person (EP) who is a *substantively* rational maximizer of subjective expected utility. Substantive rationality occurs when behavior is appropriate to attain a given goal, under given conditions (constraints). In other words, substantive rationality is about *outcomes*. EP is substantively rational because she is assumed to have at least a sufficient amount of information about all relevant aspects of their environment, the ability to compute benefits and costs of available alternative courses of action, information about the probability of each outcome of each chosen behavior, and a willingness and ability to understand and consider simultaneously all current and future available alternatives. Assuming that individuals are substantially rational, and that they have a definite goal, economics can be "done" with calculus. And, it can be done without psychology. But, Simon says, "... there is a complete lack of evidence that, in actual human choice situations of any complexity, these computations can be, or are in fact, performed" (Simon, 1982a, p. 244).

Simon's ideas on bounded rationality (BR) were initially contained in the first (1947) and subsequent editions of *Administrative Behavior* (Simon, 1965), and in more formal models published in 1955 in the *Quarterly Journal of Economics* (Simon, 1982a), and in 1956 in the *Psychological Review* (Simon, 1982f). In 1956 Simon wrote a short story as an attempt at a "transmigration of the soul" of his model of BR. The story, "The Apple: A Story of the Maze" (Simon, 1989a), is about a young man named Hugo who lived alone in a large castle. Hugo's problem was that he had to find food, which, mysteriously, was being left on the tables in some of the rooms. Some of the food left was of a variety he had never seen, so he had to discover his tastes and preferences for food. He also needed to save time at finding the right room so he began looking for *clues* to tell him which room had which variety of food. For example the rooms containing his favorite foods had various paintings on the wall. His preference for certain paintings had developed *unconsciously* as an *association* with certain preferred foods. With experience, finding his preferred foods became easier. Hugo's search for food did not continue until he found his favorite food. Hugo was often hungry and he did not know when he would find food again, so his searches ended when he found food which was satisfactory. His experience showed him that finding the right food depended upon the number of turns or choice points in the maze, the number of available paths at each choice point, the number of moves or steps between choice points, the number of moves and choice points the individual can see ahead, and the ability of the individual to find clues (patterns) in order to avoid walking around in circles. The hungrier he was, the greater the number of food types and groups fell under the category of satisfactory. Hugo was a satisficer whose rationality was bounded by the shape of his world and the circumstances of his life. Associations or patterns were stored in memory and retrieved automatically from memory when it served to satisfy his goal. Hugo engaged in subconscious pattern recognition, that is, he engaged his intuition. Substantive rationality and global maximization in a maze is possible, but only when the maze is very small.

3.1. Substantive vs. bounded and procedural rationality

In contrast to EP, "bounded rational person" (BRP) lives in a world which offers a set of objectively available behavior alternatives, but a more limited set of "perceived" behavior alternatives. BRP lacks both the information and the computational capacities to be globally rational. RWP lives in a world with too much uncertainty – unintended consequences, and computational limits. Given our computational limits the environment that we are aware of is only a fraction of the "real" environment within which decisions are made. The number of possible alternatives is so immense that they cannot be examined. The best and only feasible solution is to find a satisfactory solution.

In psychology it is aspiration levels which perform this function. And "problem solving and decision making that sets an aspiration level, searches until an alternative is found that is satisfactory by the aspiration level criterion, and selects that alternative" (Simon, 1982j, p. 415) is called *satisficing*. The concept of satisficing is common within psychology (Simon, 1982c). It is part of a model of behavior in which the motivation to act comes from "drives," and the termination of action occurs when the drive is satisfied. The definition of drive-satisfaction varies upon aspirations and experience. Satisficing in economics is assumed to be less important because standard economics assumes that individuals are objectively or globally substantively rational expected utility maximizers. Of course these assumptions amount to nothing more than assuming away the importance of satisficing.

However, in the real world inhabited by BRP perception and cognition do not merely passively filter only a small part of the entire environment into our consciousness. Of the entire amount of new information generated by our entire environment, our senses filter out 99%+ before it reaches our consciousness. Given these facts, human behavior is in most cases restricted to satisficing behavior. Rationality is thus *bounded* by the complexity of the world we live in relative to our cognitive abilities. It seems intuitively obvious to the casual observer that BR is more descriptive of the way people with modest computational abilities make decisions, stay alive, and even thrive (Simon, 1983). Intuitive rationality (IR) is a subset of BR, but more about this later.

Because rationality is bounded the process we use in making the best decisions we can becomes more important. Simon thus considers behavior to be rational when it is the outcome of an appropriate deliberation *process*. Behavior is procedurally rational when it is the outcome of an appropriate deliberation process. Behavior is procedurally irrational when it is the outcome of impulsive behavior (Simon, 1982d, p. 426).

3.2. Rationality and chess

There are about 30 legal moves in a chess game. Each move and its response creates an average of about 1000 contingencies. In a 40 move chess game there are about 10^{120} contingencies. Chess masters are believed to look at no more than 100 contingencies, only 10% of the possibilities existing for *one* move and a response (Simon, 1982j). Beginning with an inordinately large number of possibilities, chess masters, and humans in general, humans search for outcomes whose utility values are at least satisfactory. Once found, the search stops. In other words, chess masters are satisficers, and their rationality is bounded by their limited cognitive capacity relative to their environment.

Chess grandmasters take so little time to decide on a move that Simon says that it is not possible for their moves to be the product of "careful analysis" (Simon, 1983, p. 133). A grandmaster takes 5 or 10 s before making a strong move, which 80–90% of the time proves to be correct and one that is "objectively best in the position" (Simon, 1983, p. 25). Their skill barely diminishes when they play 50 opponents at once rather than one opponent. How do they do it? When grandmasters are asked how they play they respond with the words intuition and professional judgment. Simon says that intuition is a "label for a *process*, not an explanation of it" (Simon, 1982h, p. 105; emphasis added). The process is subconscious pattern recognition based on experiences stored in memory and retrieved when needed. While short term memory can store only a relatively small amount of information, long term memory is, metaphorically speaking, a large encyclopedia with an elaborate index in which information is cross-referenced. Cross-referencing means that information is associative with one piece of information linked or associated with other associated thoughts. Cross-referencing and chunking makes subconscious pattern recognition or intuition easier.

Studies on recognition among chess masters have used eye movements to assess recognition abilities. Chess masters examining a previously unknown board position taken from an actual game immediately – within 2 s – shift their eyes to the most relevant part of the board. This means that they immediately grasp or "see" the most important relationships on the board. Simon concludes that it is sufficient to state that a chess master's performance is based on a knowledge of chess and an act of (subconscious) pattern recognition. In fact, Simon helped develop a computer program with the ability to mimic the eye movements of a chess master. His computer program and human chess masters make the same mistakes, and both recover in a similar way. For example, in one program a queen who was in trouble did exactly what a human would do to not only save their queen but to get their opponent in checkmate. Simon adds that the ultimate nature of human intellectual activity is best known through a chess playing machine. Human or machine experts at chess or in any field of activity experts are expert (in part) because of their ability for subconscious pattern recognition.

4. Artificial intelligence

Writing in 1966, Simon (1966a, 1966b) believed that the word mysterious was the adjective most often used to describe thinking, but that mysterious no longer applied. The reason was increases in knowledge about the process of thinking based on AI, that is, computer programs which mimic human problem solving (Simon, 1966b). Simon's view of thinking affected by AI is that thinking is a form of information-processing. Both human thinking, and information-processing programs perform three similar operations: they scan data for patterns, they store the patterns in memory, and they apply the patterns to make inferences or extrapolations. In fact, some programs reproduce and even outperform human experts at problem solving. Simon concluded that there is sufficient reason to believe that some kinds of human thinking closely parallel the operations of an information-processing computer program. AI also led him to conclude that intuition is a subset of thinking. The fact that the mind is a serial information processor, it performs one (or only a very few) operations at a time, places severe limits on human attention, binds our rationality, and limits our capabilities for problem solving to a set of satisficing rather than maximizing solutions.

Problem-solving thus involves two generalizations. First, a selective trial-and-error search is made which by necessity can only consider a relatively few possible solutions. The solution is thus a satisficing solution and the search is based on rules-of-thumb or heuristics. Second, one of the basic heuristics is means–end analysis. Means–end analysis involves three steps. First, the current situation is compared to a goal, and differences between them are noted. Second, a memory search is performed to identify an *operator* which can bring the current situation more in line with the goal. Third, the operator is applied in the hope of getting closer to the goal.

Since computers solve problems as humans do using heuristics and means–end analysis, Simon concluded that computers display intelligence, defined as behavior which is appropriate to the goal and adaptive to the environment. Intelligence allows the limited processing capacity of the organism, be it man or machine, to use efficient search procedures to generate possible solutions, with the most likely solutions being generated early in the search process (Newell & Simon, 1990). In order to test whether machines display intelligence, Simon (and his colleagues) identified tasks requiring intelligence and then built computer programs which carried out these tasks. These tasks include playing chess, solving math and physics problems, diagnosing disease, making discoveries in science, and even formulating hypotheses and testing them empirically. In doing these things, Simon showed that computers "think," and that they possess (artificial or man made) intelligence.

4.1. Machines who "think"

Simon's machine think in that they recognize patterns and apply "if–then" rules in making decisions. Boden (1990), in her book *The Creative Mind. Myths and Mechanisms*, uses the example of soybean diseases to show that a set of "if–then" rules incorporated into a computer program allows it to find patterns in a maze of data on soybean symptoms and then correctly diagnose soybean diseases. Programs such as the ID3 algorithm not only diagnose soybean diseases with an accuracy which would make any psychic jealous, but it does so with maximum efficiency. That is, it asks the right questions in the right order so as to make the right diagnoses in the minimum amount of time. ID3 has discovered patterns in data which humans have not, and it has discovered strategies in chess previously unknown by chess masters. Computer programs have been developed which input and output words, formula, images, and musical notations. These computer programs have been said to display creativity.

The first AI program, developed by Simon, is the logic theorist (LT). Written in 1956, LT discovers proofs for theorems contained in Alfred North Whitehead and Bertrand Russell's *Principia Mathematica* (Whitehead & Russell, 1962). In order to do this LT mimics expert human decision-makers by working "backward." Both LT and expert human decision-makers use information about the goal to eliminate many paths without having to try them. Human novices, on the other hand, solve problems in a more time consuming inefficient "forward" manner.

Work on LT demonstrated to Simon that trial-and-error (a procedure of science) and insight (an apparent discontinuity, or mystery) are complementary with each other. LT also lead Simon to conclude that the human brain is analogous to a digital computer. The value of the brain-as-computer metaphor is that it takes the mystery out of concepts such as intuition and insight (Simon, Newell, & Shaw, 1989b,p. 7).

The general problem solver (GPS), an early program developed in 1957 engaged in means–end analysis, a basic heuristic in problem-solving. The EPAM program (Feigenbaum & Simon, 1989) simulates human recognition or learning, while the MAPP program (Simon, 1989b) which simulates the ability to recognize patterns in a manner similar to chess (grand) masters. The "adaptive production system" (APS) program engages in learning-by-doing, and learning-by-example. The APS program learns-by-example to solve algebraic problems by inspecting each step in an algebraic problem placed in its memory. When faced with any algebraic problem it goes through the steps and arrives at a solution to a particular problem. APS programs learns-by-doing an algebraic problem, and then uses that example to learn how to solve other algebra problems.

Simon and his colleagues also developed several programs which make discoveries in science including BACON, BLACK, GLAUBER, and STAHL. BACON analyzes data sets and derives quantitative relationships among data sets. BACON "discovered" many well known scientific laws including Galileo's law of uniform acceleration, Kepler's third law, Boyle's law, and Ohm's law (Langley, Simon, Bradshaw, & Zytkow, 1987). And it does by considering the simplest explanation (pattern) first before moving on to more complex explanations. BLACK, named after Joseph

Black, works on situations in which two substances are additive. If analyzing the data show that the two substances are not additive then BLACK finds one or more *unobservable* properties of the substances to explain non-additivity.

GLAUBER, named after the chemist Johann Glauber, divides substances into groups according to their observable properties. Similar to Glauber, GLAUBER uses a *sample* of acids and alkalis to infer correctly that *every* acid reacts with alkalis to form salt. STAHL, named after chemist Georg Stahl, is given a set of heuristics used by chemists and a list of experimental results on the nature of combustion in historical sequence. Similar to human chemists, STAHL's hypotheses about combustion are sometimes incorrect, but similar to human chemists STAHL reviews previous experimental results and corrects its mistakes. The result is that STAHL correctly reproduced the approximately 80 year development of the oxygen theory of combustion from the phlogiston theory.

5. Intuition. Simons early and later views

In the second edition of *Administrative Behavior* (Simon, 1965) Simon recognized the value of experience and habit in decision-making. Experience becomes human capital; habit becomes internalized as unconscious and automatic reflex actions. Decision-making using experience and habit relies on "clues." Whether clues are recognized consciously or known only to the subconscious, they enhance our understanding of particular situations, and improve decision-making. Experience and habit become part of effective procedures in decision making. Simon comments that "human rationality relies heavily upon the psychological and artificial associational and indexing devices that make the store of memory accessible when it is needed for the making of decisions" (Simon, 1965, p. 87). In the fourth edition of *Administrative Behavior*, 1997, and having AI as his framework, Simon (1996) would refer to the associational and indexing devices of memory as intuition.

Another value of experience and habit in performing purposive or rational behavior is that it "permits conservation of mental effort by withdrawing from the area of conscious thought those aspects of the situation that are repetitive" (Simon, 1965, p. 88). And it permits similar stimuli or situations to be met with similar responses or reactions, without the need for a conscious rethinking of the decision to bring about the proper action (p. 88). In the fourth edition, Simon (1997) would also refer to this as intuition.

In the earlier additions of *Administration Behavior*, Simon did not discuss intuition because he was uncertain about the nature of subconscious thinking processes. In the fourth edition he introduced material about intuition because, he says, "... we have acquired a solid understanding of what the judgmental and intuitive processes are" (Simon, 1997, p. 31).

These processes are subconscious and/or rapid, and based on experience which by-passes a conscious "orderly sequential analysis" of a situation. Simon went so far as to say that intuition is actually analytical thinking "frozen into habit and into the capacity for rapid response through recognition of familiar kinds of situations"

(Simon, 1997, p. 139). Intuition and analysis are complementary with each other and almost always present in all human decisions, including those of scientists. Thinking about the use of intuition among scientists in general and physicists in particular Simon spoke about "physical intuition," [2] that is, intuition used by physicists or scientists in general.

The combination of intuition and analysis is present in chess grandmasters because chess "is usually believed to require a high level of intellect" (Simon, 1987, p. 28), and grandmasters use the word intuition when describing how they do what they do in chess. Chess grandmasters take only a very few seconds to decide on their next move and then a longer period of time verifying that their "educated hunch" is correct.

One test for the use of unobservable physical intuition was done with the use of protocol analysis in which a novice and an expert were given a physics problem to solve, and each person verbalized what they were thinking. The results showed that the more experienced person solved the problem in less time, required fewer steps to solve the problem, spent less time per step, did not write down as many relevant facts or equations to solve, and expressed more confidence in themselves. In essence, the skilled person took a series of appropriate short cuts and avoided conscious calculation of how to solve the problem. This is possible because an expert's knowledge is similar to an encyclopedia with a large index in which entries are cross-referenced. That is, not only does the expert have more knowledge than the novice, but the expert can more rapidly elicit relevant facts from memory. The expert exhibits "the usual appearance of intuition," while the novice uses more "conscious and explicit analysis" (Simon, 1996, p. 136). The conclusion Simon reaches is that experience allows people to make decisions intuitively, or judgments "without careful analysis and calculation" (p. 136).

Simon says that intuition "... is no deeper than the explanation of your ability, in a matter of seconds, to recognize one of your friends whom you meet on the path tomorrow as you are going to class" (Simon, 1983, p. 26). Experience and knowledge is the key to intuition because paraphrasing Poincare, "inspiration comes only to the prepared mind" (p. 27). In other words, while the expert's approach is more "physical" or "primitive" (Simon & Simon, 1989, p. 224), the novice's approach is more algebraic. This capacity when observed among chess grandmasters and expert decision-makers in general is called intuition; when observed among physicists is called physical intuition.

5.1. Intuitive rationality

Intuition is useful, and it is a subset of BR. IR and BR are consistent with each other, and all "serious thinking" uses both. Both use search-like processes both lead to sudden recognition of underlying patterns, and the focus of one's attention plays a major role in the choices one makes. Intuition is said to be what is responsible for peo-

[2] In "New Age," and spiritual literature, physical intuition refers to physical sensations in your body. For example, when you meet someone for the first time, feeling an ache in your gut (gut feeling) is your intuition "telling" you that this person is to be avoided. The difference in the use of the term physical intuition between Simon and New Age/spiritual literature is both startling and revealing of differences in approach to the topic of intuition.

ple finding solutions to problems "suddenly" and having the "aha" experience. Having AI as a framework, Simon understood these to be genuine experiences, and to lead to judgments which "frequently are correct" (Simon, 1983, p. 25). Simon helped create computer programs which mimic expert human decision-makers who use the word intuition as a label for how they make decisions. Creating machines that think led Simon to his "explanation" for that very human phenomenon called intuition. [3]

6. Summary and conclusions

Simon made significant overlapping contributions to various fields including economics, psychology, cognitive science, decision theory, and organization theory. Simon challenged economic theory by postulating that human rationality is bounded. He emphasized the limits in human computational abilities and memory relative to the information provided continuously by the environment. This concept of BR became relevant to his work on organizations, and; human decision making, problem solving, and scientific discovery. The concept of BR may be seen as the key interface between his work in economics and psychology. [4] BR also can be seen in his work on AI. After all, if human rationality and problem solving is limited by our computational capacities and memory, can computer programs with greater computational capacity and memory help extend our problem solving abilities?

Simon's challenge to economics and his work on AI led him to view human thinking as an example of information processing. It led him to view human and artificial intelligence as depending upon information processing leading to pattern recognition. And this lead him to his understanding that human intuition is subconscious information processing leading to subconscious pattern recognition. John Stuart Mill held similar views about intuition as subconscious pattern recognition. Unfortunately for him, he lived before Simon helped developed the field of AI.

Simon makes it clear that intuition or subconscious pattern recognition is a positive externality of an extensive period of study, and is part of the process of human information processing, albeit a subconscious part. With this in mind, intuition extends our ability to use our computational capacities and memory, extends the boundary of our ability for rational behavior, and hence enhances our ability for procedural rationality. The question is, can we enhance our intuition?

7. Uncited references

Hadamard (1945), McCorduck (1979), Simon (1977), Simon (1982b), Simon (1982e), Simon (1982g), Simon (1982i), Simon, Larkin, McDermott, and Simon (1989a), Tversky and Kahemann, 1981.

[3] Simon emphasized the role of the trained intellect in intuition. For an excellent discussion of the role of emotions, please see Hanoch (2002).

[4] Augier (2001) has an excellent discussion of how Simon's concept of bounded rationality can be seen throughout his work in various fields.

Acknowledgements

I wish to thank Mie Auguier, two anonymous referees, Andrea Salanti, Ray Boddy, Art Kartman, and Nancy O'Barr for helpful comments. All remaining errors of content and judgment are my own.

References

Augier, M. (2001). Sublime Simon: The consistent vision of economic psychology's Nobel laureate. *Journal of Economics and Psychology, 22*, 307–334.

Barnard, C. (1942). *The functions of the executive*. Cambridge, MA: Harvard University Press.

Boden, M. (1990). *The creative mind. Myths and mechanisms*. London: Weidenfeld & Nicolson.

Bunge, M. (1962). *Intuition and science*. New York: Prentice-Hall.

Feigenbaum, E. A., & Simon, H. (1989). EPAM-like models of recognition and learning. *Models of thought* (Vol. 2, pp. 145–166). New Haven, CT: Yale University Press.

Frantz, R. (2000). Intuitive elements in Adam Smith. *Journal of Socio-Economics, 29*, 1–19.

Frantz, R. (2001). John Stuart Mill as an anti-intuitionist social reformer. *Journal of Socio-Economics, 31*, 125–136.

Frantz, R. (2002a). *Frank Knight on the importance and difficulty of doing behavioral economics*. Paper Presented at History of Economics Society Annual Meetings, University of California Davis, July 2002.

Frantz, R. (2002b). *Marshall's economics as an economic application of the philosophy of Henry Mansel*. Working Paper.

Hadamard, J. (1945). *Essay on the psychology of invention in the mathematical field*. Princeton, NJ: Princeton University Press.

Hanoch, Y. (2002). Neither an angel nor an ant: Emotion as an aid to bounded rationality. *Journal of Economic Psychology, 23*, 1–25.

Klamer, A., & Colander, D. (1990). *The making of an economist*. Boulder, CO: Westview Press.

Langley, P., Simon, H., Bradshaw, G., & Zytkow, J. (1987). *Scientific discovery. Computational explorations of the creative process*. Cambridge, MA: MIT Press.

McCorduck, P. (1979). *Machines who think*. San Francisco: W.H. Freeman Co.

Moggridge, D. E. (1995). *Maynard Keynes. An economist's biography*. London: Routledge.

Newell, A., & Simon, H. (1990). Computer science as empirical enquiry: Symbols and search. In M. Boden (Ed.), *The philosophy of artificial intelligence* (pp. 105–132). Oxford: Oxford University Press.

Schumpeter, J. (1954). *History of economic analysis*. New York: Oxford University Press.

Simon, H. (1965). *Administrative behavior* (2nd ed). New York: Free Press.

Simon, H. (1966a). Scientific discovery and the psychology of problem solving. In G. C. Robert (Ed.), *Mind and cosmos essays in contemporary science and philosophy* (pp. 22–40). Latham, MD: Center for the Philosophy of Science.

Simon, H. (1966b). Thinking by computers. In G. C. Robert (Ed.), *Mind and cosmos. Essays in contemporary science and philosophy* (pp. 3–21). Latham, MD: Center for the Philosophy of Science.

Simon, H. (1969). *The sciences of the artificial* (1st ed). Cambridge, MA: MIT Press.

Simon, H. (1977). *Models of discovery*. Boston: D. Reidel Pub. Co.

Simon, H. (1982a). A behavioral model of rational choice. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 239–258). Cambridge, MA: MIT Press.

Simon, H. (1982b). Decision making as an economic resource. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 84–108). Cambridge, MA: MIT Press.

Simon, H. (1982c). Economics and psychology. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 318–355). Cambridge, MA: MIT Press.

Simon, H. (1982d). From substantive to procedural rationality. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 424–443). Cambridge, MA: MIT Press.

Simon, H. (1982e). New developments in the theory of the firm. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 56–70). Cambridge, MA: MIT Press.

Simon, H. (1982f). Rational choice and the structure of the environment. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 259–268). Cambridge, MA: MIT Press.

Simon, H. (1982g). Rational decision making in business organizations. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 474–494). Cambridge, MA: MIT Press.

Simon, H. (1982h). *The sciences of the artificial* (2nd ed). Cambridge, MA: MIT Press.

Simon, H. (1982i). The impact of new information-processing technology. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 109–133). Cambridge, MA: MIT Press.

Simon, H. (1982j). Theories of bounded rationality. In H. Simon (Ed.), *Models of bounded rationality. Behavioral economics and business organization* (Vol. 2, pp. 408–423). Cambridge, MA: MIT Press.

Simon, H. (1983). *Reason in human affairs*. Stanford, CA: Stanford University Press.

Simon, H. (1987). Making management decisions: The role of intuition and emotion. In W. Agor (Ed.), *Intuition in organizations* (pp. 23–39). London: Sage.

Simon, H. (1989a). Otto Selz and information-processing psychology. In H. Simon (Ed.), *Models of thought* (Vol. 2, pp. 30–39). New Haven, CT: Yale University Press.

Simon, H. (1989b). The information-processing explanation of Gestalt phenomena. In H. Simon (Ed.), *Models of thought* (Vol. 2, pp. 481–493). New Haven, CT: Yale University Press.

Simon, H. (1996). *Models of my life*. Cambridge, MA: MIT Press.

Simon, H. (1997). *Administrative behavior* (4th ed). New York: Free Press.

Simon, H., & Gilmartin, K. (1973). A simulation of memory for chess positions. *Cognitive Psychology, 5*, 29–46.

Simon, H., Larkin, J. H., McDermott, J., & Simon, D. (1989a). Expert and novice performance in solving physics problems. In H. Simon (Ed.), *Models of thought* (Vol. 2, pp. 243–256). New Haven, CT: Yale University Press.

Simon, H., Newell, A., & Shaw, J. C. (1989b). Elements of a theory of human problem solving. In H. Simon (Ed.), *Models of thought* (Vol. 2, pp. 6–19). New Haven, CT: Yale University Press.

Simon, H., & Simon, D. (1989). Individual differences in solving physics problems. In H. Simon (Ed.), *Models of thought* (Vol. 2, pp. 215–231). New Haven, CT: Yale University Press.

Tversky, A., & Kahemann, D. (1981). The framing of decisions and the psychology of choice. *Science, 211*, 453–458.

Whitehead, A. N., & Russell, B. (1962). *Principia mathematica*. Cambridge: Cambridge University Press.