Trend

Herbert Simon's Silent Revolution

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Abstract

Simon's *bounded rationality* (BR), the first scientific research program (as opposed to a purely philosophical one) to seriously take the cognitive limitations of decision makers into account, has often been conflated with his more restricted concept of *satisficing*—choosing an alternative that meets or exceeds specified criteria, but that is not guaranteed to be unique or in any sense "the best." Proponents of optimization often dismiss bounded rationality out of hand with the following "hallway syllogism" (as formulated by Bendor 2003: 435, who disagrees with it): bounded rationality "boils down to" satisficing; satisficing is "simply" a theory of search for alternatives that takes into account the costs of computation. Hence, bounded rationality is "just a minor tweak" on optimal search theory.

This article complements a psychologist's plea for "striking a blow for sanity" in theories of rationality (Gigerenzer 2004). I amplify his argument that bounded rationality is *not* optimization under constraints from a more biological perspective. In order to do so, I first call attention to Simon's evolutionary understanding of the nature of bounded rationality as grounded in the interactions between organisms and their environments, which has implications for niche construction and evolutionary theory generally. I then discuss the debate between "optimizers" and "satisficers" with particular attention to modeling in biology. I round off by briefly assessing the relevance of a ramification of bounded rationality, the *near-decomposability* of hierarchical systems, for modular theory, which predicts that hierarchical developmental processes generate hierarchical phenotypic units that can change independently. Interspersed are some remarks on Simon's philosophical views.

Keywords

biology, bounded rationality, development, evolution, heuristics, naturalized epistemology, near-decomposability, procedural rationality, satisficing, Herbert A. Simon

April 17, 2007; revised and accepted April 26, 2007

Biological Theory 2(1) 2007, 76–86.

[B]ounds on rationality are a Good Thing, especially—but not only—in infancy.

— Margaret Boden (2006)

En travaillant à l'unification des méthodes de pensée, qui ne sauraient être à jamais irréductibles pour les différents domaines de la connaissance, on contribue à la recherche d'une harmonie intérieure qui est peut-être la condition véritable de toute sagesse.

— Claude Lévy-Strauss (1955)

In 1978, at the zenith of a peripatetic career that engendered a plethora of substantive contributions to public and business administration, decision theory, economics, cognitive psychology, artificial intelligence, computer science, philosophy of science, and more,[1] Herbert Alexander Simon (1916–2001) was awarded the Bank of Sweden Prize in Economic Sciences in Memoriam of Alfred Nobel for "his pioneering research into the decision-making process within economic organizations." In his acceptance lecture, he criticized "the rather weak and backward development of the descriptive theory of decision making . . . , the sparse and scattered settlement of its terrain, and the fact that many, if not most, of its investigators are drawn from outside economics—from sociology, from psychology, and from political science" (Simon 1979b: 494).[2]

Simon developed the concepts of bounded rationality and satisficing, which are embedded in his *behavioral theory of decision making*, in the 1940s, if not earlier still (Simon 1979b: 500). He kept elaborating this research program throughout his lifetime. Note that his behavioral approach (sometimes also referred to, somewhat misleadingly, as "behavioralism") is not to be confused with behaviorism, from which Simon, who also embraced Gestalt psychology, had moved far away by the mid-1950s (Boden 2006: 429). *Bounded rationality* refers to the individual collective rational choice that takes into account "the limits of human capability to calculate, the severe deficiencies of human knowledge about the consequences of choice, and the limits of human ability to adjudicate among multiple goals" (Simon 1997a: 270). In most natural situations, optimization is computationally intractable "in any implementation, whether machine or neural" (Gigerenzer 2004: 2). If the alternatives for choice are not given initially to the decision maker, she must search for them; hence, a theory of bounded rationality must incorporate a theory of *search* (Simon 1979b: 502). *Satisficing* refers to choosing an alternative that meets or exceeds one's (one- or multidimensional) "aspiration level," but that is not guaranteed to be either unique or "the best" in the sense of a *global optimum* in mainstream rational choice theory. Simon's original satisficing criterion (Simon [1955], Ch. 1 in 1979a) introduced a *stop rule*: "Stop searching as soon as you have found an alternative that meets your aspiration level." In its dynamical version, the aspiration level is lowered or raised in function of previous failure or success, respectively (cf. note 11). Satisficing had its roots in the empirically based psychological theories of the Gestalt psychologist Kurt Lewin and others on aspiration levels (Starbuck 1963a,b; Simon 1979b: 503). It is *one* realistic substitute for utility maximization (Simon 1997a: 271; see, e.g., Sauermann and Selten 1962; Radner 1975; Wierzbicki 1980; Rubinstein 1998; Posch et al. 1999; Tyson 2005; Stirling 2007), but others, such as the "fast and frugal heuristics" toolkit (Gigerenzer et al. 1999; Gigerenzer and Selten 2001), have been envisaged as well.

Almost 20 years after he received the "Nobel Prize in Economic Science," Simon still wondered why his call for realism in the study of decision making, whether human, animal, or artificial, was received with "something less than unbounded enthusiasm," if not "largely ignored as irrelevant for economics (and as probably wrong) for many years" (Simon 1997a: 269).[3] Dominated by neoclassicists who persist in predicting the collective behavior of "rational man" while avoiding any empirical investigation of human psychological properties, the economics profession, he felt, had become dull. In his contacts with academics he encountered "a high level of discontent, and even cynicism, with the existing state of affairs." That many students viewed the sophisticated tools of mathematical economics with "distrust" and deplored the necessity of devoting their research time to formalisms they regarded as "mainly sterile" (Simon 1997b: 90) made him unhappy (see also Day 2004).

Much of Simon's work in economics was concerned with unearthing the weaknesses of mainstream theory; I will discuss several of these arguments later on. For the empiricist "working for the 'hardening' of the social sciences" that he was (Simon was Rudolf Carnap's student), economics lacked foundations that were "sufficiently solid without bounded rationality to bolster them" (Simon 1997a: 269; see also the section on "Limits to Reason" below).[4] Provisionally, I offer Simon's short explanation for the large indifference to his behavioral approach, which chastises a *Zeitgeist* in which economic considerations overrule everything else, and even shape scientific career paths: "Writing theory papers is seen as the route to a lengthy publication list, with a much larger output per hour than is obtainable from carrying out time-consuming experiments or field studies and analyzing voluminous data" (Simon 1997b: 90–91).[5]

What are the prospects of bounded rationality today, a decade after Simon found "joylessness" in the economic profession? Has his "behavioral revolution" (Mingus 2007) died with him? I want to suggest that when we move from economics to a larger picture of science, the answer is a qualified but encouraging *no*. With the ABC (Adaptive Behavior and Cognition) research group (Gigerenzer et al. 1999; Gigerenzer and Selten 2001), bounded rationality already occupies center stage in cognitive science. Bounded rationality ("BR" henceforth) has been gradually but incessantly conquering the sciences of decision and action, including game theory (e.g., Rubinstein 1998; Gigerenzer and Selten 2001; Stirling 2007) as well as the dismal science itself, in particular evolutionary economics (e.g., Dopfer 2005) and the new institutional economics (Williamson 2000), to which Simon's work is usually said to belong. BR has also entered evolutionary and developmental biology (see below).[6] I want to propose that this movement is part of a wider wave of "naturalization," enabled by advances in the neurosciences (cf. the advent of neuroeconomics), computer science, etc. that is also beginning to affect our understanding of consciousness, language, meaning, culture, morality, religion, and other complex coevolutionary phenomena. (See, e.g., Cherniak 1986; Hooker 1994; Sperber 1996; Henrich et al. 2001; Goodenough and Deacon 2003; Harms 2004; Delancey 2007. Giere [2006] offers an excellent aperçu of the naturalistic stance.) The biological, cognitive, and decision sciences increasingly turn out to be intimately related, both conceptually and methodologically (e.g., Gilman 1996; Wang 2001; cf. Day 2004 on the role of *consilience* in Simon's work). Sociologically speaking, this trend is but the continuation (or culmination?) of Max Weber's "disenchantment of the world"—the progressive intellectualization of the human worldview that began thousands of years ago. This process has now reached a point where philosophical naturalists of various plumage are in a position to "technically" attack the presumed apriority of Reason itself (see, e.g., Maddy 2007), which since the dawn of western philosophy has been the bulwark of formalists playing down the importance of the world of experience, be they mathematicians, idealistic philosophers, or economists.[7] Philosophical naturalization will make increasingly implausible immunizing strategies suggesting that ultimately optimality arguments are, or even *must* be, untestable such as, "The global-optimum model is not so much a predictor of nature as a definition of nature," or "the existence of a global-optimum point is . . . a deep axiom: a tautology that guarantees logical consistency at the core of [a] theory" (Nonacs and Dill 1993: 371).

This trend article complements a cognitive psychologist's plea (Gigerenzer 2004), in a volume commemorating Simon's intellectual achievements, for "striking a blow for sanity in theories of rationality." Invoking more biological work, I amplify Gigerenzer's arguments to the effect that BR must not be confused with optimization under constraints (see also Bendor 2003). In order to do so, I first call attention to Simon's evolutionary understanding of the nature of BR as grounded in the interactions between organisms and their environments, which has implications for niche construction and evolutionary theory generally. I then critically review the main episodes in the half-century debate between "optimizers" and "satisficers," paying particular attention to modeling in biology. I round off by briefly analyzing the relevance of a ramification of BR, the *near-decomposability* of hierarchical systems, for modular theory, which predicts that hierarchical developmental processes generate hierarchical phenotypic units that can change independently. In parallel, I assess Simon's philosophical views against the background of contemporary naturalized philosophy.

Why the Environment Is Crucial to the Organism

Simon did not think that "people are dumb," as students occasionally claim (Bendor 2003: 435), let alone that it is animals' "laziness" that prevents them from foraging optimally (Herbers 1981). But he pondered seriously the circumstance that

> . . . the capacity of the . . . mind for formulating and solving complex problems is very small compared with the size of the problems whose solution is required for objectively rational behavior in the real world—or even for a reasonable approximation to such objective rationality. (Simon 1957: 198)

This classic statement of the principle of BR crucially points to the joint effects of the computational capabilities of the actor *and* the structure of task environments, which Simon likened to the blades of scissors.[8] (*Irrationality*, on this image, is like cutting paper with a single blade.) Critics of BR often overlook its relational nature, whereas theories of BR "have cutting power . . . only when both blades operate" (Bendor 2003: 435; cf. Boden 2006: 430). In *The Sciences of the Artificial*, Simon ([1969] 1996a) described an ant negotiating difficult terrain. Its behavior appears complex (Figure 1), but the *mechanisms* underlying it presumably are not: the ant simply responds to the environmental cues it happens to encounter. (More recent research confirms that there are actually quite many such cues; Camazine et al. 2001.) And so it is with humans, Simon said:

> Human behavior, even rational human behavior, is not to be accounted for by a handful of invariants. It is certainly not to be accounted for by assuming perfect adaptation to the environment.[9] Its basic mechanisms may be relatively simple, and I believe they are, but that simplicity operates in interaction with extremely complex boundary conditions imposed by the environment and by the very facts of human

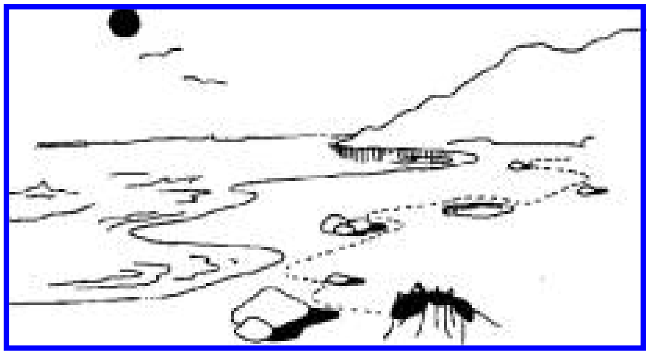

Figure 1.
Simon's "situated ant." (Source: http://www.balint.ch/geschichten.htm)

long-term memory and of the capacity of human beings, individually and collectively, to learn. (Simon 1979b: 510)

Long-term memory itself, Simon suggested, should be conceived as part of the environment to which it adapts rather than as part of the organism. Boden (2006) tells the fascinating story of the adventures of Simon's "situated ant" in the history of cognitive science in painstaking detail.

In his autobiography, Simon recalls that the idea of an automatic response to the environment had arisen when he read Lewis Mumford's *The Culture of Cities* while teaching at the Illinois Institute of Technology in Chicago. (The chairman of the architecture department, Mies van der Rohe, felt that a client "was to be educated, persuaded—I won't say *duped*—to contribute the resources necessary to produce a great work of art, as defined by the architect"; Simon 1996b: 99.) Mumford apotheosizes the medieval city, which was not planned but whose beauty grew "out of the interaction of many natural and social forces" (p. 98). Unbeknownst to Mies, Simon used this idea to convey to his architecture students that market forces "could not do the whole job of structuring the functional and beautiful cities": one also had to take into account externalities such as "noxious odors wafted from the stockyards to surrounding neighborhoods," which require action by local planning agencies (pp. 98–99).

The fitness of an organism depends on how effectively it makes decisions in an uncertain and changing environment, and brains are thought to be adapted for fitness-increasing decision making (Simon 2005; Gintis 2006). When we replace the aforementioned "objectively rational behavior" by biological fitness, Simon's view of the organism–environment relationship may be seen to have wider implications for evolutionary theory.[10] Lewontin (1982, 1983) is sometimes credited for pioneering the theory of niche construction that is now flourishing, but Simon (1983) is a close contender. He pointed to a neglected aspect in the population-genetic theory of niche elaboration: instead of competing fiercely for an existing niche with other creatures that are trying to occupy it, try "to find a wholly unoccupied niche, or to alter and specialize [your]self in order to be able to occupy efficiently (fitly) a niche that is not now occupied effectively by anyone else" (Simon 1983: 44). The Malthusian principle, then, "is not the whole story":

> Evolution can produce new organisms capable of exploiting energy and other resources that were previously wasted or used inefficiently. And this has in fact happened as animal life came to occupy the new niches provided by plants, and as living forms extended their occupancy of the earth's environment from sea to land. One would suppose that, perhaps on a smaller scale, this kind of extension continues today. There is no reason to think that we are near a stable equilibrium. (p. 53)

Simon anticipated that explaining the proliferation of niches in addition to the proliferation of organisms will complicate niche construction theory considerably. Moreover, an important part of each organism's environment consists of the other organisms that surround it. "The very creation of niches" and the eventual evolution of creatures to fill them thus "alters the system in such a way as to allow the development of still more niches" (p. 45). His own picture of niche construction began with "a largely inorganic earth" offering a limited range of different microenvironments, and envisioned "a process whereby new environments, and new differences among environments, are constantly created as new species come into being" (p. 46). Simon concluded:

> If this alternative picture is valid, or even partially valid, the proliferation of species may continue indefinitely; whereas if the picture of a fixed supply of niches is valid, we would expect the evolution of new, fitter species sooner or later to require the obliteration of older, less fit ones." (pp. 46–47)

Simon realized that the evidence on this point is conflicting. While most species that once existed are now extinct, stasis also occurs: "One can say that some species established their fitness very early, a fitness that has never been successfully challenged, but that these offered no barrier to the emergence of large numbers of new species that found new and unoccupied niches" (p. 47). At any rate, such considerations provide a very different picture of evolutionary history from "nature red in tooth and claw," resonating better with the important work by biologists and others on the evolution of cooperation that was to come.

From Substantive to Procedural Rationality

This section critically reviews the main episodes in the half-century debate between "optimizers" and "satisficers," paying particular attention to applications of rationality theory, bounded and unbounded, in biological modeling, and to methodological reflections on these modeling strategies. BR is *procedural*, not *substantive* rationality: it is concerned with how rather than what to decide (Simon 1979b: 498; 1997a: 271). Because predicting real-world human behavior from the optimal behavior in a given environment is but seldom possible, the actors' rationality will be defined by the processes they (presumably) *actually use* in making their decisions rather than the substance of the decisions they reach (Simon 1997a: 271). This will exclude, for instance, sophisticated probabilistic reasoning (Bayesian or other), which nontrained humans have been shown not to be good at.

Limits to Reason

Most evolutionary epistemologists have invoked in-principle "evolutionary limitations" hypotheses, e.g., concerning self-knowledge or phenomena sharply at variance with our phylogenetic experience of the environment, which echo Kant's epistemological pessimism. Simon's view of the limits of reason, although equally informed by evolutionary considerations,[11] appeals to a priori constraints on thinking beyond those that are dictated by the intrinsic limitations of symbolic processing systems.

For Simon (1983: 7), reason is entirely instrumental: "It cannot tell us where to go; at best it can tell us how to get there." Instrumental rationality is the "default theory" of rationality (Robert Nozick) in that it is the only theory of rationality that is not in need of justification.[12] According to Simon, an "Original Sin" corrupts the reasoning process and its products: *no conclusions without premises*. To deliver symbolic outputs, any reasoning process requires inputs. Axioms (initial inputs) are not derived by logic, but induced by empirical observations or simply posited. Rules of inference are introduced by fiat. Neither axioms nor inference rules can be justified, for this would involve an infinite regress of logics, "each as arbitrary in its foundations as the preceding one" (p. 6). This "ineradicable element of arbitrariness" implies the impossibility of both reliable induction and deriving normative statements independently of inputs that also contain *should's* (Hume's problems). Reason then "goes to work only after it has been supplied with a suitable set of inputs." If it is to be applied to discovering and choosing courses of actions, then those inputs must include a set of *should's* (values to be achieved) and a set of *is's* (facts about the world in which the action is to be taken).

Still, despite these and other complications, Simon (1983: 11) believes that it is possible to reason about conduct. *De gustibus est disputandum* if, say, satisfying values have consequences for other values or if they are instrumental to other values. An "impressive body of formal theory" or "elegant machine" erected by mathematical statisticians and economists, he grants, helps us reason about these matters (Simon 1979b, 1983).

Homo oeconomicus: A Moving Target

The target of the BR critique is substantive rationality in any of its incarnations. *Homo oeconomicus*, the rational actor or rational choice model/theory, subjective expected utility (SEU), maximization, and optimization[13] (the list in not exhaustive) all share a reliance on the "rationality postulate." Because the technical definition of "rationality" in most of these accounts deviates considerably from the standard, nontechnical meanings of the term (see Michalos 1973), the label "*beliefs, preferences, and constraints* (BPC) model" (Gintis 2006) may be the most appropriate, and is certainly more informative. Like many recent authors, Gintis stresses that the applicability of the BPC model depends substantively only on *choice consistency* ("if you prefer A over B, when both are available, and B over C, then you will also prefer A over C when both are available") over sets of probability distributions.

Nontechnically speaking, substantive rationality boils down to assuming that a decision maker (1) has a well-defined *utility function*, (2) is confronted with a well-defined *set of alternatives* to choose from, (3) can assign a consistent *joint probability distribution* to all future sets of events, and (4) will maximize the *expected value*, in terms of her utility function, of the set of events consequent on the strategy. (A more exact characterization is provided, e.g., in Simon 1979a: 9.) Simon's critique, again in a nontechnical nutshell, came down to this:

> The SEU model assumes that the decision maker contemplates, in one comprehensive view, everything that lies before him. He understands the range of alternative choices open to him, not only at the moment but over the whole panorama of the future. He understands the consequences of each of the available choice strategies, at least up to the point of being able to assign a joint probability distribution to future states. He has reconciled or balanced all his conflicting partial values and synthesized them into a single utility function that orders, by his preference for them, all these future states of the world. (Simon 1983: 14)

Theories of substantive rationality generally finesse both the origins of the values that enter into the utility function and the processes for ascertaining the facts of the states of the world. "At best, the [SEU] model tells us how to reason about fact and value premises; it says nothing about where they come from" (p. 14). It should be clear, then, that theories based on the rationality postulate as such can never be applied in the real world. If specialists are far from finding optimal solutions to such restricted problems as the management of a network of warehouses under conditions of uncertain demand, winning a game of chess, or administering a university department, it is probably not a "good advice to a manager to recommend adoption of the solution of an optimization problem that there is no prospect of solving in the next hundred years" (Radner 1975: 253). Models have to be fashioned with an eye to the effective availability of data and to practical computability (procedural rationality!). To the extent that SEU etc. *can* be applied, they are used as approximations or idealizations.

Model construction under these stringent conditions, Simon stated in his "Nobel Prize" acceptance speech, has taken two directions:

> The first is to retain optimization, but to simplify sufficiently so that the optimum (in the simplified world!) is computable.[14] The second is to construct satisficing models that provide good enough decisions with reasonable costs of computation. By giving up optimization, a richer set of properties of the real world can be retained in the models. Stated otherwise, decision makers can satisfice either by finding optimum solutions for a simplified world, or by finding satisfactory solutions for a more realistic world. (Simon 1979b: 498)

Superficially, on this "coexistence view" of optimizing and satisficing (as I shall call it), neither of the approaches dominates the other, and both can happily continue to coexist. Recall, however, Simon's two blades: BR's significance turns not on *absolute* cognitive levels, but on the *difference* between cognitive resources and task demands. (According to Gigerenzer [2004: 5], the work on cognitive illusions and errors à la Kahneman and Tversky [see, e.g., Piattelli-Palmarini 1994; Gilovich et al. 2002; Kahneman 2003] "studies only the cognitive blade, and compares it with laws of probability rather than with the structure of the environment," situating it outside the realm of BR proper.) Bendor's (2003: 435–437) comparison of the different ways in which substantive and procedural theories of rationality handle tic-tac-toe and chess playing is illuminating here. For classical game theory, which ignores cognitive constraints, chess and tic-tac-toe are both zero sum, finite games of perfect information. In the real world, though, these games are not equivalent—normal adults do not play tic-tac-toe, because it is pointless, but they do play chess. The mental abilities of normal adults are a *binding constraint* in chess, but not in tic-tac-toe. Accordingly, BR and optimality theory make observationally equivalent predictions about the latter but not the former. But BR theories have cutting power in chess; knowing the players' cognitive limits (most notably, novices versus experts) gives them "predictive leverage" (p. 436). The upshot is what Bendor calls a *scaling principle* of modeling:

> What matters in a model is not so much how sophisticated the agents are assumed to be or how hard the problems are, but rather the difference between the two. Typically, real humans are more sophisticated than agents in BR models, but real problems are also harder; both are scaled up. And as long as both are scaled up symmetrically, the model in question may be plausible, even though the agents are rather "dumb." (Bendor 2003: 436–437)

Notice also that satisficing "either by finding optimum solutions for a simplified world or by finding satisfactory solutions for a more realistic world" turns the table on the view, common among proponents of optimization, that BR is but optimization under constraints, and hence all rationality is optimizing rationality. Following George Stigler, optimization can be made more realistic by adding to one's models one or a few constraints (too many would make the mathematics intractable), such as costs of information search (the constraint most discussed in the economic and psychological literature) or historical contingencies in biological evolution (Lewontin 1987). Introducing constraints makes the approach more realistic, but maintaining the ideal of optimization, namely, calculating an optimal stopping point, does not (Gigerenzer 2004: 2). Simon criticized (and presumably even considered suing) economists like Thomas Sargent who "have paid the phrase 'bounded rationality' the compliment of borrowing it in titles of books or papers" for missing the point of it "when they continue to base their models on *a priori* hypotheses about behavior instead of grounding them in fact established by direct observation" (Simon 1997a: xii). The point is, again, a procedural consideration: the search for an optimum position would be of indeterminate length and the notion that the actor searches for such a position is "either meaningless or hopelessly impractical" (Winter 1964: 228). This *infinite regress* problem constitutes the basic objection to any attempt to subsume satisficing as a special type of optimizing behavior that is appropriate for certain "optimum search" problems. Of course, Winter continues,

> any behavior can in one way or another be rationalized as maximizing behavior. But to identify satisficing behavior with optimum search behavior is merely to push the crucial problem back a stage: How does it happen that the task of learning about the relevant probability distributions, the ability to identify the problem as one of requiring a certain type of search procedure, and the ability to determine the precise procedure required, are within the limited information obtaining-and-processing resources of the decision maker? (Winter 1964: 228)

Unless one can prove—and no advocate of optimization has been able to show how one *could* prove—that the deviation from the "real" optimum converges to zero, or at least becomes smaller for each new level in a hierarchy of information structures,

> there must be a cut-off point [in every decision] where calculation stops and you simply have to make an unsupported choice, but also . . . *this point might as well be as close to the action itself as possible*. Why, indeed, seek for precision in the second decimal if you are uncertain about the first? (Elster 1979: 59)

Further Blurring the Distinction

Aiming at more realism by including constraints in optimization models ("making actors dumber") has the paradoxical effect that the modelers must become smarter, because their models become mathematically more demanding (Gigerenzer 2004: 2). Related to this is the problem of *overfitting*, which is by no means specific to optimization models: when a model has numerous free parameters that can be adjusted ad libitum, a good fit between model and data may well be a mathematical truism rather than an empirical result (Gigerenzer 2004: 4; see also Lewontin 1987). (But notice that even relatively simple optimality models of, say, animal behavior, in which the functional analysis consists of a hypothesis concerning the behavioral dispositions of the organisms under study combined with a hypothesis concerning the constraints to which the manifest behavior of the organisms is subject, may be underdetermined; Kitcher 1987: 80.) In light of the problem of overfitting, claims that theories based on satisficing rather than optimizing "sometimes suffer from lack of falsifiability" (Carmel and Ben-Haim 2005: 638) must be qualified. At the metalevel of the debate between optimizing and satisficing, neoclassical economics similarly becomes "essentially tautological and irrefutable" (Simon 1997a: 382). Because of its preoccupation with utility maximization, it fails to observe that the force of its predictions mostly derives from the (usually untested) auxiliary assumptions that describe the environment in which decisions are made. It fails to notice that the conclusions it draws can usually also be drawn, with the aid of the auxiliary assumptions, from the postulate that people are procedurally rational.

Another paradoxical result of the debate between optimizers and satisficers concerns the *nonuniqueness of outcomes*. According to Simon (personal communication, September 1980), a major reason why so many people resist BR is the (unrealistic) expectation that any serious problem must have a *unique* best possible solution, which BR cannot guarantee. From a satisficing perspective, there are good grounds to argue, for example, that judges in child custody cases who try to do the best for all parties would often do better to toss a coin instead—shortening the process, reducing the damage, and thus producing as good a result as we can hope for anyway (Ryan 1991: 19). But optimization as a process does not imply a unique, optimal outcome as a product either (Gigerenzer 2004: 3; cf. Lewontin 1987); so what is the point of the disagreement?

To cut a long story (Callebaut 1998) short, I think it is fair to say that the classical program "patches the rationality principle with ad hoc assumptions of bounded rationality" (Simon 1997a: 362). Suggesting that "unfortunately," Simon's work has often been "misinterpreted" and "misused" as a denial of maximization behavior (Jensen and Meckling 1976, quoted in Callebaut 1998: 88), or that the criticism that optimization assumes costless information-processing capacity is "quite misplaced" because basic information theory (Shannon) "shows that the concept of costless information processing is self-contradictory" (Gintis 2006: 125) is but adding epicycle on epicycle.[15] But Ptolemaios is dead, and maximizing behavior is just what Simon has long sought to reject (Freedman 2003). If Gintis believes that claiming that "*all* rationality is bounded rationality" counts as an argument *against* the behavioral approach, then rationality goes on a holiday.

An assumption many satisficers and optimizers share, but which usually remains tacit, is that having more cognitive capacities is better than having less. Hertwig and Todd (2003) have challenged this, arguing that processing limits may have evolved *because* they are required by the simple heuristics in Gigerenzer et al.'s toolkit, rather than the other way around. On their view, which reminds on of the "enabling constraints" dear to EvoDevo adepts, *specific* limits of brains, human, or animal, are not inevitable ("way back in our phylogenetic history, they did not exist"; Boden 2006: 450) but have evolved, with the successful heuristics driving the limits. Boden notes that this is a special case of a more general phenomenon documented in language development and, in fact, learning in general. I leave it to future historians of cognitive science to verify if her judgment that thus "Simon's insistence on bounded rationality has been stood on its head" (p. 450) is a fair one.

Optimizing and Satisficing in Biology

Bioeconomists (e.g., Wang 2001) and others have emphasized the deep affinity between economics and biology. The game theorist Ross (2006: 31) puts it daringly: "In the absence of competition for resources, there would be no selection, and all biological change would be random." On the other hand, without returns to strategic cooperation and coordination, "there would be no multicellularity or sexuality, and therefore no development." Although biology (EvoDevo in particular) is notorious for its attention to *constraints* (e.g., Oster and Wilson 1978; Lewontin 1987; Pigliucci and Kaplan 2000), references to BR and satisficing are surprisingly rare in the biological literature (including the optimality debate), and are mostly limited to (behavioral) ecology.

The debate between Ward, Nonacs, and others in the journal *Oikos* (e.g., Ward and Blaustein 1992; Nonacs and Dill 1993), reviewed in Carmel and Ben-Haim (2005), reiterates the impression of the "subtlety of the contest" between BR and optimality (Bendor 2003: 436) and illustrates the danger of "overfitting" we have encountered before. For instance, the literature on optimal foraging reveals that data supporting its (quantitative) predictions are scarcer than those contradicting such predictions. But when one or another factor is added to the model, predictions can be made to agree with the data. Ward and Blaustein (1992) urged consideration of alternative models to provide the optimization program "with the much needed competition that is considered necessary for the progress of science." Carmel and Ben-Haim (2005) now offer a framework that allows us to systematically compare the predictions of optimizing and satisficing models of foraging behavior (cf. also Nolet et al. 2006). A large number of the studies they cite tend to support their own "robust-satisficing" model.

The "sophisticated" have always been aware that "appeals to optimality must be treated with caution" (Kitcher 1987: 77). Oster and Wilson put it this way:

> Rather than a grand scheme for predicting the course of natural selection, optimization theory constitutes no more than a tactical tool for making educated guesses about evolutionary trends. If we wish to view evolution as an "optimizing" process, and to retain mathematical modeling as an analytic tool, we are at least forced to admit that an element of teleology has entered the theorizing. . . . The prudent course is to regard optimization models as provisional guides to further empirical research, and not necessarily as the key to deeper laws of nature." (Oster and Wilson 1978: 311–312)

Lewontin (1987: 151–152) listed an impressive number of arguments that might disable the application of optimality arguments in evolutionary studies, and stressed the role of contingency. "The answers lie in detailed analysis of particular cases" (p. 152). For instance, natural selection may be extremely sensitive and efficacious in molding the amino acid composition of enzyme X, while being at best coarse and indiscriminating for another enzyme Y in the same species. The "currently accepted generalization" concerning the power of natural selection is that because of constraints, "complex genotypic architectures are less, not more, amenable to being altered by natural selection" than was previously thought (Pigliucci and Kaplan 2000: 67). Another problem Lewontin pointed out is that an optimal state can only be the optimum over a *specified set* of alternatives, so it is never *the* optimum. All evolutionary reconstruction suffers to some degree from this problem, but in contrast to optimality theory, population genetics makes this contingency explicit (p. 157). He concluded rather pessimistically:

> The optimization claim must be ambitious enough to exclude a good deal of accident or it becomes empirically vacuous. It must, however, not be so ambitious as to exclude all historical contingency, since then we would know it to be untrue a priori. Between these two it is not clear to me how much space is left for enlightenment. (Lewontin 1987: 159)

Simon, who liked to think of his own behavioral economics as a "historical science," could not have agreed more.

Near-Decomposability

To round off this trend article I will briefly discuss Simon's work on near-decomposability, a ramification of BR. In his influential paper, "The architecture of complexity," Simon ([1962), Ch. 8 in 1996a) suggested that "in the face of complexity, an in-principle reductionist may be at the same time a pragmatic holist." In coping with a complex world, cognitive agents (including scientists) as well as economic agents make an extensive use of its decomposability, for only decomposable systems lie within the reach of human cognitive skills (Marengo et al. 2005). Simon and Ando ([1961], Ch. IV.2 in Simon 1982, Vol. 1) argued that nearly decomposable (ND) systems possess special properties that lend themselves to separating short-term from long-term behavior. Each of the parts of a ND system has strong internal links among its subparts, but the several top-level parts are bound together only by comparatively weak linkages. NC "allows the long-term behavior to be studied on an aggregative basis without concern for internal details of the parts, and allows the short-term behavior of each part to be studied independently of the behavior of the other parts" (Simon 1997a: 5).

The methods that Simon and colleagues have developed for dealing with the ND of large systems, although originally conceived in the context of econometrics, have received a great deal more attention in engineering, computer science, and biology than in economics. Simon's argument in "The architecture of complexity" to the effect that evolved structures tend to be hierarchically organized and ND for dynamical reasons (his parable of the watchmakers Hora and Tempus) has gained renewed currency in discussions of modularity in EvoDevo, where modular theory (e.g., Bolker 2000) predicts that hierarchical developmental processes generate hierarchical phenotypic units that can change independently (Buchholtz 2007 is a representative case study in morphology). Natural selection only evaluates the fitness of organisms as a whole, not the fitness of their individual organs except as they contribute to the whole. Evolvability thus requires ND or "quasi-independence" (Lewontin) in development (Callebaut 2005).

Interestingly, this influence of Simon on EvoDevo was anticipated by Donald T. Campbell. In an unpublished letter to Simon, Campbell (October 4, 1982) wrote:

> You are already a major contributor to evolutionary theory—broadly conceived. . . Moreover the field is moving in directions you pioneered. I think of satisficing as an alternative to optimizing . . . , and even more [of] the subunit assembly argument in *The Sciences of the Artificial*, analogues for which evolutionary theory as it integrates more with embryological control must borrow or reinvent. On both issues [Gould 1982] is relevant.

Shortly before his death, Simon was very excited about the paper by Frenken et al. (1999), which provides a formal definition of the (near) decomposability of a problem and uses a genetic algorithm (inspired by Kauffman's NK model) and simulated organisms to test the tradeoff between optimality and complexity. In their simulation, the ND organisms soon reach higher fitness than the non-ND organisms, and displace them. Simon himself (1996: 204–205) was aware of some of the complications having to do with development. He described a variety of allometric mechanisms that can balance capacities through an entire organism by size adjustments of components without damaging their basic independence of design.

Wimsatt (1974: 78), inspired in part by Richard Levins' critique of Simon's view of ND and invoking developmental considerations, has questioned that hierarchical organization resulting from selection processes can be decomposed into the different levels of organization *relevant at the time of aggregation*, as Simon suggested is possible. Developmental Ascendency similarly rejects such reductionism and provides an alternative explanation for system-level change, which typically follows a trajectory that becomes "decreasingly dependent" and "increasingly constraining" on the behavior of individual system components (Coffman and Ulanowicz 2007). Griesemer (2007) now questions Simon's parable of the two watchmakers itself, arguing that Simon's account is dynamically insufficient and suggesting that "scaffolding" helps answer the developmental question.

The verdict is open. . .

Notes

1. Simon was "at once the technical scientist and the philosophical critic and analyst," as Bob Cohen and Marx Wartofsky put it (in Simon 1977: VII). Working "about nine hours a day but only seven days a week," he even found time to question the "foundational assumptions" of literary criticism (Simon 1995). The bibliography (1937–2002) on his departmental web page (http://www.psy.cmu.edu/psy/faculty/hsimon/hsimon.html) lists 973 items, to which a number of posthumous publications must be added. His major papers in economics up to the early 1980s are reprinted in Simon (1982), now unfortunately out of print; (1997a) assembles more recent economic papers. Simon (1979a, 1989) collect a number of his contributions to cognitive science, while Simon (1977) and Langley et al. (1987) document his and his coworkers' studies of problem solving in science.

2. Simon was originally trained as a political scientist at the University of Chicago. Once asked how a negative event changed his life in a positive way, he related that in college he discovered that he would have to take an accounting course to earn an economics major, "so I switched to political science, thereby avoiding brainwashing by orthodox neoclassical economics" (http://www.acm.org/crossroads/dayinlife/bios/herbert_simon.html).

3. Simon did not live to see Daniel Kahneman and Vernon Smith, whose work he much admired (see, e.g., Simon 1997a; Gigerenzer 2004), getting rewarded the Bank of Sweden Prize in 2002 for their integration of psychological research on human judgment and decision making under uncertainty into economic science, and establishment of experimental economics, respectively.

4. At the time when philosophers tried to come to grips with Popper's and Kuhn's "theory-ladenness" of observation, Simon sought to save operationalism by showing that the theoretical terms appearing in a ("well-formulated") scientific theory, even if they are not definable, are always Ramsey-eliminable; i.e., all the empirical claims in the theory can be made without invoking the theoretical terms (Simon [1973], Ch. 6.6 in 1977). Only later did he acquiesce to "the tentative and theory-infected character of the facts themselves" (1983: 6). Countering Popper's denial of the possibility of a logic of discovery, Simon endorsed Norwood Hanson's view that *retroduction* of generalizations and explanations from data has been central and crucial in the history of science. His own gestaltist, non-Baconian "discovery as pattern induction" (e.g., Simon [1968], Ch. 1.4 in 1977) again situates him within the empiricist tradition.

5. Interestingly, biology at large displays the reverse, "data without theory" bias; cf. the Editorial to this issue (Callebaut and Laubichler 2007). I cannot pursue this seeming paradox here, but its resolution obviously has much to do with the complications engendered by experimenting with human as opposed to nonhuman living subjects.

6. Simon has also found apt spokespersons for BR in the philosophy of biology, most notably Bill Wimsatt (2007), and in the philosophy of social science, in particular Jon Elster (e.g., Elster 1979; see also Ryan 1991). Byron (2004) documents applications of BR in ethics.

7. As late as 1975, neo-Kantian economists who opposed neo-classicism advocated the view that economic theory must reflect an overarching "necessary truth," which they took to be accessible through "rational insight." Neoclassical economists (and many psychologists; Gigerenzer 2004: 2) tend to be aprioristic in a subtler way. Following Milton Friedman, they invoke an "as if" argument to justify the lack of realism in their model assumptions: "Unless the behavior of businessmen in some way or other approximated behavior consistent with the maximization of returns, it seems unlikely that they would be in business for long." On the positivistic "as if" view, *prediction*, not causal-mechanistic explanation, is what counts in science (cf. Gigerenzer 2004 and Callebaut and Laubichler 2007); for a critique, including the inappropriate use of "Occam's razor" in the debate over optimizing versus satisficing, see Simon (1979b: 495). Rather ironically, the formalism of neoclassical and mathematical economics is sometimes defended by an appeal to rhetoric (McCloskey 1998).

8. As far as I am concerned, the loci classici, Simon's "A behavioral model of rational choice" (1955) and his "Rational choice and the structure of the environment" (1956), ought to be compulsory reading for all students of biology, psychology, and the social sciences and humanities. (Both are reprinted in Simon 1979a.)

9. I discuss the relationship between BR and the adaptationist program in biology at some length in Callebaut (1998). Biologists and philosophers of biology have thought a great deal about optimality and the rigorous testing of adaptationism (e.g., Kitcher 1987; Lewontin 1987; Pigliucci and Kaplan 2000; Orzack and Sober 2001), but usually without paying any attention to BR.

10. Simon (1996b: 5) recalls that he was deeply interested in biology during his undergraduate years at the University of Chicago, but decided against following up that interest professionally because of his colorblindness and "awkwardness" in the laboratory. In his little acknowledged *Reason in Human Affairs*, he explored "some byways that seemed to me interesting and important, but that had until now been off the main paths of my own explorations" (Simon 1983: vii). These included a new mechanism for the evolution of altruism *sans* kinship or structured demes, which he called "docility." Docility he defined as "the human propensity for accepting information and advice that comes through appropriate social channels" (see also Simon 1997a, Pt. III, "Motivation and Theory of the Firm," and 2005). The notion has become widely accepted in the literature; see, e.g., Richerson et al. (2003) on conformism as an adaptive heuristic for biasing imitation under a wide variety of conditions.

11. Simon's economic arguments were often inspired or backed by evolutionary considerations. For example, "any organism that's going to survive in a world that has its ups and downs is going to have to set targets that are realistically related to its environment. It must be prepared to lower those targets—at least, within limits—when the environment gets tougher, and it has to be prepared to raise those targets if the environment becomes more benign." That is the way, Simon (in Roach 1979: 11) believed, "targets get fixed in business decision making" as well. More generally, he suggested (like the economist Alfred Marshall a century earlier) that economists and social scientists generally could benefit from drawing inspiration "from biology rather than physics," and in particular from evolutionary and molecular biology, which display "the role in science of laws of qualitative structure, and the power of qualitative as well as quantitative explanation" (1979b: 510–511). Behavioral economics, which he regarded as a "historical science," is "substantially less deductive, *more inductive*, than what neoclassical theory has been. It resembles molecular biology, with its myriads of complex structures and processes, far more than it resembles physics, with its powerful deductions from broad general laws" (Simon 1997a: 271).

12. See Nieuwenburg (2007) for a discussion of the roots of Simon's view in Hume and Aristotle, and Byron (1998) for a discussion of the interrelations between maximizing, satisficing, and instrumentalism with respect to values.

13. Lewontin (1987: 152) usefully distinguishes between optimization and maximization/minimization. Whereas maximality/minimality is an internally defined characterization of a metric scale, optimality is "a qualitative characterization of some particular state among a list of alternatives, but without a metric." The latter is not internally defined; for example, "a birth weight of 7 pounds is optimal for a human infant" cannot be asserted sensibly from a list of all possible birth weights.

14. Following Selten, optimal solutions may be knowable for simple, familiar problems, but complications arise when problems are unfamiliar and/or time is scare (Gigerenzer 2004: 3).

15. To be crystal clear, optimizers often *do* assume "omniscience for free"; an arbitrary example is models of patch use and forager distributions in foraging theory as discussed by Eliassen et al. (2007: 513).

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