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Multidisciplinary creativity: the case of Herbert A. Simon

Subrata Dasgupta*

Institute of Cognitive Science, University of Louisiana at Lafayette, Lafayette, LA 70504-3772, USA

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Abstract

In the twentieth century, no person epitomized more dramatically the "Renaissance mind" than Herbert A. Simon (1916–2001). In a working life spanning over 60 years, Simon made seminal contributions to administrative theory, axiomatic foundations of physics, economics, sociology, econometrics, cognitive psychology, logic of scientific discovery, and artificial intelligence. Simon's life of the mind, thus, affords nothing less than a "laboratory" in which to observe and examine at close quarters the phenomenon of *multidisciplinary creativity*. In this paper, we attempt to shed some light on the nature of Simon's creativity and the nature of his particular Renaissance mind. In particular, we have attempted here to articulate the *cognitive style* underlying *Simon's* multidisciplinary creativity.

Keywords: Creativity; Renaissance man; H.A. Simon; Case study method; Multidisciplinarity; Cognitive style

1. Introduction

In modern times, the term "Renaissance man" is virtually an anachronism. To straddle multiple cultures of knowledge, be creative in and influence not one or two but several disciplines is so rare that when we encounter such a being, he or she compels our attention. We want to understand the mind of this person, to know how it achieves creativity across disciplines.

In the twentieth century, few people epitomized the concept of the Renaissance man more forcefully than *Herbert Alexander* Simon (1916–2001). His working life spanned some 60 years of continuous creative work which lasted literally until the very eve of his death in February 2001. Simon's life affords nothing less than a "laboratory" in which to observe and

* Tel.: +1-337-482-1131; fax: +1-337-482-1222.
E-mail address: subrata@louisiana.edu (S. Dasgupta).

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examine, at very close quarters, the phenomenon of *multidisciplinary creativity*. The purpose of this paper is to shed light on the nature of Simon's creativity. Toward this end, we will be using the *cognitive-historical case study* as our method of investigation.

2. The cognitive-historical case study

The cognitive-historical case study approach is a symbiosis of the methods of historical and biographical research, and the theoretical framework (or one of the frameworks) of cognitive science. The term "cognitive history" is originally due to Nersessian (1995). Relating it to science, she viewed it as the focus on the "thinking practices" by which "scientists create, change and communicate their representations of nature." Generalizing this, we take cognitive history to be a program of inquiry that (a) attempts to understand aspects of, and episodes in, the history of the creative tradition from a cognitive perspective, and (b) draws on historical and biographical studies of creativity to shed light on the cognitive nature of the creative process.

We believe that in certain types of creativity studies, this approach has distinct merits. First, it is the most obvious strategy when a researcher is interested in some seminal act of creation performed by a *specific individual* (Gooding, 1990; Gruber, 1974; Tweney, 1989). In Gruber's study, for example, the issue at hand was: "How did Darwin arrive at his theory of natural selection?" Second, the cognitive-historical case study can be used to *empirically corroborate* or *falsify* some general hypothesis—as, for example, our examination (Dasgupta, 2002) of Simonton's (1999) theory that the creative process is Darwinian in nature. Third, cognitive-historical case studies are invaluable for shedding light on the mechanics of a particular *genre* of creativity, for example, in the realm of technology (Dasgupta, 1996; Vincenti, 1992; Weber & Perkins, 1992), science (Holmes, 1989) and literature (Jeffrey, 1989). Our study of Simon straddles the first and third categories. The genre of interest is multidisciplinary creativity, and what light is shed on it by Simon's long creative life.

An aspect of the cognitive-historical case study approach needs to emphasized: It entails *historical* research; as such, the most significant kind of evidence we draw upon is from what historians call *primary sources*—that is, unpublished documents, correspondence, memoranda, diaries along with published material that are contemporary to the time in which a subject's creativity is being studied. Thus, we draw heavily upon the archives of the library in Carnegie Mellon University which holds the bulk of Simon's unpublished documents. We have augmented this primary source with electronic mail correspondence between this author and Simon. However, we have drawn upon this correspondence mainly to *confirm* or *contradict* certain inferences or hypotheses we might have formulated based on the primary sources. We do not use this correspondence itself as a primary source.[1]

3. Simon's multidisciplinarity

A native of Milwaukee, WI, Simon went to the University of Chicago and majored in political science for his Baccalaureate degree in 1937. In 1942, Chicago awarded him a Ph.D. in political science, for a dissertation on decision making in administrative organizations.

A revised form of this dissertation was published in 1947 as the book *Administrative Behavior* (Simon, 1947/1976).[2] This book went into four editions. And 30 years after it first appeared in print, Simon was awarded the Nobel Prize in economic science for work that had begun in his dissertation work (Carlson, 1979). In the course of these 30 years, Simon would publish extensively on social theory, economic theory, mathematical economics and econometrics in the most impeccable "mainstream" journals in these diverse fields (Simon, 1945, 1951, 1952a, 1952b, 1952c, 1955, 1956a, 1956b, 1957, 1982, 1999).

In contributing to economic and social thinking, Simon had not abandoned his original focus on administrative theory. He continued to publish articles in the relevant journals on administrative science, and in the three decades between the first edition of *Administrative Behavior* and the Nobel Prize, he authored or co-authored several books in the field (March & Simon, 1958; Simon, 1957, 1965, 1977; Simon, Smithburg, & Thompson, 1950).

But the social sciences of administrative and organizational theory, sociology, political science and economics formed just one arena in Simon's creative life. Very early in his post-graduate days, he also became embroiled in psychology. The second major group of fields in his *oeuvre* lay in the study of thinking, human intelligence and problem solving, and along with his social sciences inquiries, a parallel stream of publications appeared in the literature in academic psychology. These articles were not within the behaviorist paradigm that so dominated American psychology between the two world wars, but rather in the realm of the "new" cognitive psychology, which, countering behaviorism, espoused the belief that mental processes could be scientifically investigated. Simon was not *the* progenitor of the "cognitive revolution," but his contributions to it was enormous. In fact, it was Simon, along with his long-time collaborator Allen Newell (1927–1992) and a small handful of others who would create and consolidate this new, post-World War II scientific revolution. The specific contributions made by Simon and Newell is best exemplified by their massive, collaborative work *Human Problem Solving* (Newell & Simon, 1972).

From a very early stage in their collaboration, Simon and Newell shared an interest in the digital computer which, in the 1950s, was emerging as a formidable scientific tool. For Simon, the computer was not just a very fast calculating machine. Rather, he viewed it as both a means for modeling thinking and for creating a new form of intelligent beings.

And so, another strand in Simon's creative life concerned the invention and development of artificial intelligence (AI). Later, AI would be assimilated into the new discipline of computer science. Such was their contributions as two of the "founding fathers" of AI, Simon and Newell would share the Turing Award (the "Nobel" of computer science) in 1976 (Newell & Simon, 1976).

So far, we have seen that Simon's creativity was spread across three conventionally distinct and seemingly disparate arenas of empirical science: the social, behavioral, and computer sciences. But this is not the end of the story. Ever since his student days in Chicago in the late 1930s, Simon had been seriously interested in the philosophy of science. At the University of Chicago, he attended the classes of Rudolf Carnap (1891–1970), and drank deeply the waters of logical positivism. In the 1940s and 1950s, Simon challenged the writings of such formidable figures as Ernst Mach (1838–1916) and Alfred Tarski (1902–1983) on the foundations of Newtonian mechanics; he put forth his own contributions in (once more) major journals in physics and philosophy of science (Simon, 1947/1977, 1954/1977, 1959, 1977).

From the 1960s on, and more emphatically in the final decades of his life, Simon challenged yet another doctrine espoused by some philosophers and scientists most notably Karl Popper (1902–1994) and even Albert Einstein (1879–1955): that the thought process by which scientists discover laws, form concepts, and construct theories is not amenable to logical inquiry. And while thinkers such as Popper were obsessed with the question of how and why science differs from non-science, Simon pondered the *commonality* between scientific and other kinds of creative thinking that goes on in invention and design. Thus, Simon entered creativity studies (Klahr & Simon, 1999; Kulkarni & Simon, 1988; Langley, Simon, Bradshaw, & Zytkow, 1987; Newell, Shaw, & Simon, 1962; Simon, 1977).

Almost a year before his death, Simon commented that

> . . . the "Renaissance Mind is not broader than other intelligent minds but happens to cover a narrow swathe across the multi-dimensional space of knowledge that happens to cut across many disciplines which have divided up the space in other ways. My own narrow swathe happens to be the process of human problem solving and decision making, and almost everything I have done lies in that quite narrow band.[3]

This statement, while informal, offers the hint of a conjecture that is important to this paper. The conjecture is that to make sense of a multidisciplinary creative mind, we need to recognize that such a mind does not flit from one domain to another; nor is it a fragmented entity that harbors several distinct cultures in separate chambers of the mind. Rather, such a mind achieves its multidisciplinary creativity by assimilating its various distinct enterprises into a common, powerful *cognitive style*. In Simon's case, it is this cognitive style we wish to uncover.

4. What is cognitive style?

As Simon (1975) himself pointed out, a style is "one way of doing things chosen from a number of alternative ways" (p. 287). Thus, if there is only one way of doing something, then the matter of style is moot. The issue of style arises when one has to search through a space of alternative ways.

Generally speaking, in the case of *people* (in contrast to artifacts such as buildings) style designates certain features of a person's way of thinking reasoning or doing that are idiosyncratic to that person (Dasgupta, 1991, 1999; Davidson, 1999; Gaiger, 2002; Gombrich, 1969, pp. 3–32; Holmes, 1989; Simon, 1975; Wollheim, 1984, pp. 25–84). More specifically, a person's *cognitive style* is a compendium of one or more *identifiable patterns or regularities underpinning the goals, knowledge and/or reasoning he or she brings to bear in the course of cognitive processes*.

An individual's cognitive style is sometimes evident in the created product as in the case of a particular composer or painter. But scientists may also manifest cognitive styles, though they are more difficult to identify that those of the artist, since the products of scientific thought are usually couched in language and form that (deliberately) mask the scientist's persona. The problem is to penetrate the "objective mask" in order to reach the scientist's cognitive style (see, e.g., Dasgupta, 1999; Davidson, 1999; Holmes, 1989). In the sections that follow, we identify what we believe are the most significant elements of Simon's cognitive style. "Significant" here means that they afford an understanding of the nature of Simon's multidisciplinary creativity.

5. An ontological and methodological commitment to empiricism

Throughout Simon's long engagement with the social sciences, we observe an emphatic commitment to *empiricism*. He was, of course, wary of the important distinction between the empirical nature of the social sciences and that of the natural sciences. Unlike the case for "natural laws," "social laws" must take into account the "state of knowledge and experience of the person whose behavior the laws purport to describe" (Simon, 1947/1976, p. 251). Yet, as in the case of stating natural laws, the observer must be objective—*his* "knowledge and experience," *his* "desires, values and prejudices" must not interfere with his observations (Simon, 1947/1976, pp. 19–20). In *Public Administration*, he and his coauthors reminded the reader that the book was about

> administration as a science—not . . . in the sense of the exactness [of] . . . the physical sciences . . . but . . . in the sense of an objective understanding of the phenomenon without confusion between facts and values. (Simon, Smithburg, & Thompson, 1950, p. 20)

This "objective understanding" rested on the assumption that there is a reality to be described and understood, and it is the business of the empirical sciences to do so. In 2000, he reiterated this point:

> I consistently maintain that science is concerned with describing and explaining how the world is (including the world of human behavior). "How the world is" includes what preferences inhabitants of the world hold and apply to their choices. . . . [T]his description and explanation does not include the preferences or values of the observer . . . who is doing the science.[4]

Simon's commitment to empiricism in the social sciences extended to the possibility of performing *social experiments*. In *Administrative Behavior*, he toyed with the idea of "administrative experiments" in which the researcher would study one specific organizational phenomenon under conditions that isolated the issue of interest from all other factors impinging on organizations. Such stringent methodological conditions, he pointed out, scarcely ever prevailed in the "administrative experiments" reported in the literature (Simon, 1947/1976, pp. 42–43).

By the early 1950s, in the aftermath of such developments as game theory, communication theory, cybernetics, and computers, there were other influences that prompted the exploration of experiments in the social sciences. The empirical work of Homans (1950) and Festinger (1950) in sociology and of Bevalas in organizational communication theory (Simon, 1950) evidently struck a nerve in Simon. In 1952, he and a colleague, Harold Guetzkow, formulated a long-term research program on organizational behavior that would be based on "laboratory experiments" (Simon & Guetzkow, 1952).

From the early 1950s till the very end of his life, Simon railed against the anti-empiricism of mainstream (neoclassical) economics. The economic actor, according to neoclassical theory, was a maximizer of satisfaction, a perfectly rational, omniscient being who was wholly at odds with Simon's empirically grounded model of the decision maker with his subjective rationality.

By the middle of the 1950s, he had embarked on reinventing *Homo economicus* to take into account how decision making is actually made in an organizational setting.[5] The outcome of this endeavor was, of course, his model of the boundedly rational, satisficing *H. economicus* whose behavior manifested the kind of empirical plausibility—social and cognitive—that had shaped his model of the Administrative Decision Maker. Along the way, Simon created a new research tradition in economics which is most accurately described as the *cognitive* tradition (Dasgupta, in press). It was this creation that was the reason for his Nobel Prize in 1978.

Simon's commitment to empiricism in economics prevailed till the very end: in 1999 he would write that

> main line economics has neglected its empirical chores. It has spent too much time spinning gossamer webs of mathematical theory that are attached to the world by hypothetical "facts" having little or no basis in observation. (Simon, 1999, p. xi)

By the time Simon (and Newell) had evolved their concept of "physical symbol systems," his commitment to empiricism had extended well beyond administrative, social and economic behavior to the realm of what he called the *artificial*—that is entities that exhibited purposive, adaptive behavior (Simon, 1996, p. 57). This *genre* of entities included, in particular, computers and computer programs.

"Computer science is an empirical discipline," according to Newell and Simon (1976). They were not suggesting that computer science is a *natural* science but rather that, like the empirical natural sciences, one gained knowledge by way of experiments. When computer scientists build computers and design computer programs, they are conducting experiments, because it only by way of building such artifacts and putting them into action can one discover new phenomenon and understand known phenomenon that would not be otherwise possible.

Twenty years after the Turing Award lecture, Simon reiterated this point explicitly in the context of artificial intelligence (AI), in an article which, in hindsight, must count as his most definitive statement about AI (Simon, 1995). Almost all that we have come to know about artificial intelligence, he wrote, was by way of building AI programs, running them, observing their behavior, changing them, rerunning them, and so on.

6. A commitment to *operationalism*

Our understanding of Simon's multidisciplinarity is greatly facilitated when we recognize the presence and role of *operationalism* as a component of his cognitive style. Indeed, we contend that this is one of the two most important ingredients of his style.

In general, operationalism refers to the notion that to know or understand something (such as a concept or an idea) one must know the operations (or procedures or rules) by which that something can be realized. More precisely, any proposition, hypothesis, theory or model concerning both natural and artificial systems must rest on operational concepts so that one may carry out procedures to confirm, corroborate or falsify such statements.

Simon's operationalism originated in the late 1930s in the influence of logical positivism through his encounter with Rudolf Carnap at the University of Chicago[6] and, in particular, his acquaintance with A.J. Ayer's *Language, Truth and Logic* originally published in 1936 (Ayer, 1936/1971). Ayer's influence was considerable as Simon acknowledged in *Administrative Behavior*, in which Ayer's distinction between ethical, "value laden"—and thus unverifiable—statements, and statements that are empirically verifiable entered his inquiry in the form of an extensive discussion of "Fact and Value in Decision Making" (Simon, 1947/1976, Chapter III). Five decades later, he recalled that

> My later reading of Ayer was, in fact, ... important in solidifying my ideas in these matters, and it was certainly his chapter on "is and ought" in LTL that I mostly relied upon in my sharp is-ought distinction in AB.[7]

The core idea of logical positivism is, of course, the verification theory of meaning, which asserts that something in the "real world" is meaningful if and only if the proposition it expresses is empirically verifiable. That is, a proposition (or "sentence") is only meaningful if one knows *how* to verify the truth of that sentence. The verification theory of meaning is one guise in which operationalism can be expressed, and it played a very concrete role in Simon's thinking about administrative decision making. But there is another, more direct, expression of operationalism, and this came from the *physicists*—beginning with the *Science of Mechanics* by Ernst Mach (1838–1916), the 9th (1942) edition of which Simon would read and reference in 1947 (Mach, 1942), and advocated most strongly by Percy Bridgeman in his *Logic of Modern Physics* 1927), a work which Simon referred to in *Administrative Behavior* (p. 46).

Granted that Simon was aware of operationalism through the influence of the logical positivists—or by way of the writings of such physicists as Bridgeman—what role did it play in Simon's creative thinking? The answer, in brief, is that operationalism was a *dictating* element in his approaches to administrative theory, economics, and classical mechanics. Consider the following evidence in support of this claim.

6.1. Demolishing a theory of administration and discovering a problem

In 1937, Simon posed to himself the question: "What is the logical structure of an administrative science?"[8] And the answer would emerge in the form of a doctoral thesis completed in 1942 which became the book *Administrative Behavior* first published in 1947 (Simon, 1947/1976). However, between the broad question and his answer to it, lay a stage of more precise *problem discovery*—which entailed a scathing criticism and virtual demolition (in Simon, 1947/1976, Chapter II) of the then current "principles of administration." Simon's main source of these principles was Gulick (1937).

Simon identified four principles of administration put forth by Gulick *each of which he rejected because it was not operational*. For example, the first of Gulick's principles, pertaining to specialization (division of work), asserted that "Whenever men ... are working together the best results are obtained when there is a division of work among these men" (Gulick, 1937, p. 3). Simon demolished this principle on operational grounds. Its very "simplicity" "conceals fundamental ambiguities" (Simon, 1947/1976, pp. 21–22). There are different ways in which specialization can be achieved. Gulick's principle does not serve well in choosing between alternative ways of dividing an organization's work. What Simon desired was a principle that allowed one to determine *in what manner* one should specialize—that is, the principle should enable the administrator to choose among alternative modes of specialization.

Simon made similar arguments for rejecting the other three principles. Each principle was demolished on operational grounds. Simon's "problem," thus, was to discover operational principles that would *enable* the administrator to make decisions between conflicting situations or criteria.

6.2. Envisioning a rule-based "anatomy" of organization

For Simon, the "logical structure" he sought for a *science* of administration—the issue he had raised in his 1937 memorandum—was predicated on the notion that

> . . . an administrative organization is simply a device for specializing and parceling out the process of decision[9]

Thus, an administrative theory must specify *how* such decisions are made. It is at this stage that Ayer's (1936/1971) distinction between "ought" statements and "is" statements enters the picture. Simon recognized that decision making entails as much the ethical ('ought') element as it does the factual ('is') element. Decisions refer to *goals* and the means to achieve such goals. But the choice of a goal is a matter of preference—a matter of values.

Simon acknowledged that value terms cannot be reduced completely to factual terms, and he cited Ayer as providing justification for this conclusion (Simon, 1947/1976, pp. 45–46). But if decision making entails values and ethical judgments, and if such questions of value cannot be entirely reduced to empirical, verifiable statements of fact, how can decision making (and consequently, administrative theory) attain a scientific status? Simon's answer was that one *can* determine the correctness of decisions since "it is a purely factual question whether the measures . . . [one] has taken *in order* to accomplish . . . [one's] aim are appropriate measures" (Simon, 1947/1976, p. 48). One cannot assert whether or not the goal of a decision act is "correct," but one *can* judge empirically whether the *means* adopted to attain the end is correct. The means is correct if, in fact, it achieves the desired end.

Thus, the "science" in administrative decision making lies in this relationship between the goal sought and the action or means used to achieve it. The goals of administrative decisions concern values that lie outside empirical inquiry. However, *given* some goal or end, then whether some means achieves this end *is* empirically testable. It is the means–ends *combination* that has the potential of being a "scientific" proposition. This means–ends combination is an operational statement—for it stipulates a rule or procedure to achieve the end.

Just as Simon rejected Gulick's principles on operational grounds, so he rejected Stene's (1940) administrative theory because the latter was not willing to exclude value judgments:

> A more generalized theory will result if value elements are eliminated by stating all propositions in an "if-then" form . . . viz., "If attainment of objective *whatever they may be*, is to be maximized, then such and such must be the case." This is a purely factual proposition.[10]

This is about as direct and succinct a statement in Simon's writings, *circa* 1940, as to the nature and form of what a "scientific" theory of administration should be. It should be an operational theory, connecting means and ends in the form of "If-Then" rules.

Indeed, the text of *Administrative Behavior* specified operational principles *tacitly* as "If-Then" rules. For example, his response to his own criticism of Gulick's first principle (of specialization) couched in If-Then form reads (Simon, 1947/1976):

IF an organization has specialists and the organization is to benefit from their presence
THEN departmentalize the organization by (specialist) process

In 1947, Simon with two collaborators began writing a textbook on the topic of "public administration." The book (Simon, Smithburg, & Thompson, 1950) clearly bears the imprint of *Administrative Behavior*. In particular, the authors decided early in the planning stage that the propositions would be in "if this—then that" form.[11]

6.3. Inventing the boundedly rational decision maker

The core element of *Administrative Behavior* is an explicitly operational model of the human decision maker. It is operational because the model is built round the notion that at any moment of time, the decision maker is faced with several alternative means–ends strategies, each with its own consequences, such that the decision maker must select one strategy that is followed by the preferred set of consequences. If the strategy selected is indeed conducive to the achievement of the given end, the decision maker has behaved rationally.

Unfortunately, the decision maker must operate under the following constraints (Simon, 1947/1976, p. 79): (a) because of cognitive limitations, or limitations of knowledge or of imagination, it is impossible for the behavior of an individual to reach any high degree of rationality. (b) The decision maker lives in an "environment of givens," and his behavior is adapted within the limits set by these givens.

These two statements collectively constitute Simon's principle of bounded rationality (called "subjective rationality" in Simon (1947/1976)). The human decision maker circumvents his bounded rationality by appealing to certain cognitive aids such as teachability (or learnability or "docility"), memory, habit, attention, and "behavior persistence," by relying on certain social constraints that serve to guide decisions (e.g., organizational norms), and by constructing "substantive" and "procedural" plans.

Simon's bounded rationality principle is so well known it needs no further explanation here. But what *is* of interest in this discussion is that the model of the boundedly rational decision maker is strongly grounded in Simon's commitment to operationalism—his boundedly rational decision maker is a positivistic, operational being who draws on various aids to make decisions.

6.4. Becoming a meta-physicist

In the year in which *Administrative Behavior* was published, Simon also published a paper on "The Axioms of Newtonian Mechanics" (Simon, 1947/1977). The one evident connection between his work in these two quite distinct fields is the presence of operationalism in both.

He was drawn to a re-examination of the foundations of Newtonian mechanics because, he explained, the most influential treatment of the field fell "short of modern standards of 'operationalism'" (Simon, 1977, p. 349). Indeed, there is a marked resemblance between

Simon's general treatment of rationality in decision making and his approach to the problem of mass and force in mechanics. In the former case, he questioned the principle of perfect ('objective') rationality because he doubted that humans can meet this condition. In the realm of Newtonian mechanics, he questioned Mach's basic definitions and propositions because it was not clear (to him) how certain terms appearing in these could ever be determined. Perfect rationality and Machian axioms of mechanics both suffered from a similar shortcoming: they were non-operational, or had limited operational content. In the "Axioms" paper, Simon proposed a new model in which he paid particular attention to the operational definitions and postulates of such physical concepts as "unit of length," "simultaneity of events," and a postulate stating what is meant by an observer referring to a clock (Simon, 1947/1977).

Thus, Simon's model of human decision making and his model of Newtonian mechanics were both underscored by a commitment to operationalism. Yet, *Administrative Behavior* was a psychological study, and his theory of bounded rationality was grounded in cognitive notions. Could it also be that Simon's operationalism in the realm of physics was also rooted in *a psychological* concern with the nature of natural science?

We gain some insight into this question from a later paper, written in 1954 (Simon, 1954/1977) in which he compared his own work on the axiomatization of Newtonian mechanics (which he refers to as "NM") with another axiomatization (McKinsey, Sugar, & Suppes, 1953) (which he refers to as "CPM"):

> What distinguishes the two axiomatizations . . . is the difference in purpose . . . The authors of CPM state that 'Our sole aim has been to present an old subject in a mathematically rigorous way.' My aim in NM was to present an old subject in a mathematically rigorous and *operationally significant way*. (Simon, 1977, p. 371, Italics in the original)

Thus, it is not enough for theorists to formulate axiomatic treatments that are mathematically rigorous; such approaches must also signify how the mathematical "system" can actually be used by physicists to connect to "real" physical phenomena.

> *The viewpoint taken in NM is that in the axiomatization of a . . . physical theory we are concerned not only with the formal and analytical aspect of the axiom system but equally with the semantic relations between the system and the phenomenon it purports to denote*. (Simon, 1977, p. 371, Italics in the original)

Both the papers, separated by 7 years, suggest, one implicitly the other explicitly, that Simon's philosophical stance in the realm of physical science was influenced by operational concerns that were cognitive in nature: concepts in physical theory should be so framed that the physicists would *know how* they could be used.

6.5. An operational research tradition in microeconomics

By the middle of 1950, Simon had embarked on a new scientific activity, the aim of which was to create a *H. economicus* whose behavior manifested the kind of empirical plausibility that had shaped his model of administrative man (Simon, 1950). He wished to investigate "how the processes of rational decision making [in the economic context] are influenced by the fact that decisions are made in an administrative context."[12] The outcome of this endeavor was a series of papers published between 1951 and 1957 wherein emerged a new *operational* model of *H. economicus* viewed as a decision maker. The manner in which this model came into being is described elsewhere (Dasgupta, in press). It suffices to state here that this model was essentially the origin of a new *research tradition* (in Laudan's, 1977 sense) in economics. Indeed, it was for the creation of this research tradition that Simon received the Nobel Prize (Carlson, 1979).

When Simon wrote to Koopmans that he wished to investigate "how the processes of rational decision making" in the economic world "are influenced by the fact that decisions are made in an administrative context," he had already decided the direction of his approach. He wanted to construct a bridge between the economist and the organization theorist (Simon, 1951). But this bridge was to be a one-way street; it must lead *from* administrative theory *to* economic theory. Moreover, it would be paved with psychological matter, for

> [A]s my work has progressed, it has carried me further into the psychology of decision making processes. I have on several previous occasions expressed my conviction that a real understanding of "rational choice" will require further investigation of these psychological problems.[13]

By "psychological," Simon meant, as his later work reveals, *cognitive*. At the core of Simon's new research tradition for microeconomics was a concern for cognitive *procedures* (or *processes*). As we have discussed elsewhere (Dasgupta, in press), this entailed a radical switch in perspective (a "paradigm shift" in Kuhn's (1970) language) from that underlying the existing neoclassical tradition in economics. Moreover, this change in perspective was fundamentally along operational lines as becomes clear from the book by Cyert and March (1963) both very close associates of Simon. This work, one of the seminal texts belonging to the new research tradition that Simon had created, had woven into it several ideas distilled from Simon's writings. We get an explicit sense of what their "behavioral" theory of the firm was when they stressed that their theory placed "an explicit emphasis on the actual *process* of organizational decision making as its basic research component" (Cyert & March, 1963, p. 125).

6.6. The computational stance

For Cyert and March, the "natural theoretical language" for specifying this process was "the language of a computer program" (Cyert & March, 1963, p. 125). Thus, this theory of the firm is not embedded in the form of the familiar declarative form in which the propositions of the neoclassical research tradition were (and still are) usually couched, but rather in the form of flowcharts, algorithms, computer programs. The *computational stance* is the ultimate, uncompromising expression of operationalism. In fact, well before the Cyert–March book was published, with the advent of the digital computer, Simon's operationalism had matured into an explicitly computational form (Newell, Shaw, & Simon, 1958).

7. Evolving a model of the human thinker

An important element in Simon's thinking was that over a period of some 35 years, he created and evolved a model of the thinking agent that served as a common representation onto which he mapped problem situations from different disciplines. The idea of mapping from different problem domains into a common representation is, of course, not unique to Simon. Mathematical modeling is the classic exemplar, reaching back to antiquity. Representing problem domains in the language of mathematics is particularly common to economics, physics and engineering theory. However, Simon differed in two important ways.

First, while economists, physicists and engineers are usually adept in mapping from just one problem domain (their particular field of specialization) into mathematical representation, Simon mapped from the domains of several disciplines onto his representational models. Second, in the process of mapping from different domains onto his representational model of the human thinker, Simon *evolved* his very model. Thus, when Simon recalled that his "narrow swathe across the multi-dimensional space of knowledge across many disciplines . . . happens to be the process of human problem solving and decision making,"[14] the *evolution* of the model itself constituted a core element of this "swathe." It was a key constituent of his cognitive style.

Space does not allow us to describe in any detail the manner in which the model evolved. Such details will be published elsewhere. Here, we present only the main characteristics of the three principal versions of the model.

7.1. The Administrative Decision Maker

The book *Administrative Behavior* (1947/1976) contained the first version of the model, which we call the "Administrative Decision Maker." According to this model, the decision maker has goals to meet. His task is to obtain means to achieve such goals. A goal, however, may itself be the means to achieve some other "higher level" goals. Thus, the goals form a hierarchy or, more accurately, a tangled, weakly connected web of means and ends.

If the means the decision maker selects is conducive to the achievement of goals, he has behaved "rationally." However, there are limits to his capacity to act rationally. This may happen for several reasons: because the connection between means and ends (goals) are obscure; because the decision maker fails to consider alternative goals; because of unintended consequences of the means employed; or because the decision maker's knowledge is flawed. In other words, he is *bounded* in his ability to make genuinely rational decisions. Yet, this does not make him *irrational*. He attempts to circumvent these limits by virtue of certain cognitive capacities—memory, habit, ability to plan, and so on—and by environmental cues: social constraints and expectations imposed by the organization of which he is a part.

7.2. The Universal Decision Maker

Simon challenged the conventional (neoclassical) wisdom of *H. economicus* as a perfectly rational being because of the latter's profound mismatch with the Administrative Decision Maker. He set out to investigate "how the processes of rational decision making [in the economic context of the firm] are influenced by the fact that decisions are made in an administrative context."[15] In doing this, the model of the human decision maker itself was *changed*. A newer, richer, more detailed model emerged, encompassing not only the administrator and the economic decision maker but also certain organisms and even automata. For this reason, we call this version the "Universal Decision Maker." The model consisted of three major components (Dasgupta, in press).

First, there was a *prescriptive* postulate about the fundamental nature of the model's domain, viz., that organizational behavior is a network of decision processes (Simon, 1947/1976, p. 220). Second, there were four *descriptive* propositions about decision making: (i) the principle of bounded rationality—that the capacity of the human mind for formulating and solving complex problems in a fully rational and objective manner is bounded (Simon, 1957, p. 198); (ii) the principle of satisficing—the decision maker establishes goals as aspirations ('satisficing' goals) and seeks means to meet such aspirations; (iii) the principle of heuristic search—the decision maker seeks a satisficing decision by sequentially searching the space of possible choices, and selects one that meets the satisficing goals; and (iv) the principle of adaptive behavior—organisms and organizations alike cope with the uncertainty of the future and their inability to predict the future with any degree of accuracy by means of adaptive behavior; that is, by continually adjusting actions or behaviors to changing environment so as to meet given goals according to information received from the environment. Finally, there are two basic postulates about what kind of theory any theory of decision making should be: they should be operational and empirical.

7.3. *The Symbolic Problem Solver*

In constructing the model of the Administrative Decision Maker, Simon had been drawn into the psychology of decision making, as he made clear in a letter to Koopmans (see Note 13). By the end of the 1950s, he had entered the domain of cognitive psychology. Simon's third model, which we call the "Symbolic Problem Solver" was the outcome of this transition.[16] Yet, it was a subtle transition. Perhaps the fundamental distinction, as Simon would reflect much later, was that the two models were rooted in different research traditions—decision making in the social sciences in the case of the Administrative Decision Maker, and problem solving in the behavioral sciences in the case of the Symbolic Problem Solver (Simon, 1987).

The seminal work outlining the new model was the paper by Newell et al. (1958). Psychologists reading this paper would be hard pressed to guess that the intellectual origins of this work lay in Simon's earlier work on administrative and economic decision processes. Yet, the earlier versions were very much present in this model—in its quite explicit operational character; and in the more subtle, disguised presence of the four principles of bounded rationality, satisficing, heuristic search, and adaptive behavior. Its most distinctive feature, however, was that it was couched in the language of computation and information (symbolic) processes.

Finally, it is worth noting that while the Symbolic Problem Solver model became the theoretical backbone for Simon and his later collaborators' investigations into AI, cognitive psychology, the logic of design, and the logic of scientific discovery, the Universal Decision Maker was retained for explicating behavior and thought in the realm of social affairs—or (as Simon would later put it) in the realm of "reason in human affairs" (Simon, 1983). We see most clearly their interplay in *The Sciences of the Artificial*, which itself evolved through three editions (1969, 1981, 1996) in tandem with the development and application of the two models.

8. A rich and eclectic knowledge space

Many writers on creativity have observed that to be creative one has to be *knowledgeable*. The creative being's knowledge space is *rich* (Gardner, 1984, pp. 9–12, Weisberg, 1999; Dasgupta, 1996, pp. 180–181). If this is the case for creativity in one field or discipline, we may expect it even more accentuated in the case of a Renaissance mind. In Simon's case, the density, richness and eclecticism of his knowledge space were phenomenal. He was remarkably varied in his intellectual interests from a very early age, either by way of formal course work or through self-study. We learn from his autobiography that he kept "his own education entirely in his own hands" (Simon, 1991, p. 9). He studied and played chess. A few months before his death he recalled that

> my interest in chess began as a boy of 8 or 10, and I studied the game fairly seriously when I was in high school. I also, at the time, actually made a full game tree for the game of tic-tac-toe . . . .[17]

He studied, mostly on his own, mathematics and physics—including the "standard textbooks in mechanics, electricity and magnetism, quantum mechanics and mathematical methods of physics."[18] At 15, he had read Dante's *Inferno* and Milton's *Paradise Lost*, and had studied ethics. He observed his father—an engineer—at the workbench at home making radios or model sailboats. There were engineering books "around" at home, and so he had many opportunities to learn about the engineering enterprise.[19] In high school, he studied "deeply and widely," economics and the social sciences. He immersed himself in natural history, and collected plants and insects. He cultivated the local library and museum in his home town of Milwaukee (Simon, 1991, pp. 9, 11, 26).

By the end of his second year as an undergraduate, he had passed his "upper division" courses in the social sciences, had "read widely in the humanities," and "strengthened" his background in the physical and biological sciences; he had had a "good introduction to sociology and anthropology,' but "a rather inadequate one in psychology" (Simon, 1991, p. 53). And, as we have seen, through Carnap and Ayer, Simon was well informed in the philosophy of logical positivism.

The richness of Simon's knowledge space is not explicitly evident in *Administrative Behavior*. What *does* emerge from a close reading of the book is the *assimilation* of concepts and ideas from several, conventionally separate disciplines, and their *transformation* into forms that served his particular purpose. Thus, the psychologist Edward Tolman's discussion of purposive behavior, the philosopher Alfred Ayer's deliberations on fact and value, the executive Chester Barnard's insights into how administrators function, the philosopher–psychologists William James' and John Dewey's writings on the nature of habit and attention, the applied mathematicians John von Neumann's and Oscar Morgenstern's rigorous treatment of the strategies of games, the mathematician Jacques Hadamard's reflections on mathematical invention—these were not only elements of Simon's knowledge space, they were also transformed and integrated for the purpose of building his model of the Administrative Decision Maker.

In following Simon's excursions into the foundations of physics, we are again struck with the density of his knowledge of physics. This was not just textbook knowledge, but also procedural knowledge—knowledge of *how to use* concepts, facts, theories and other kinds of declarative knowledge elements, integrate them, and create new knowledge. Here is evidence of expertise.

In his study of "extraordinary minds," Gardner (1997) takes note of the '10-year rule': that it takes about 10 years of practice to become a "full fledged expert." One characteristic of expertise, according to this belief, is the acquisition of several thousand *chunks* of information, also called *schemata*, in the course of becoming experts. Simon himself has argued along these lines (Simon, 1996, pp. 89–92). Such expert knowledge develops in the course of apprenticeship and training. For a scientist working in a mature field such as mathematics or physics, such expertise accrues through the long years of undergraduate and graduate training.

Simon, as a (meta-)physicist seemed to refute this 10-year rule, since he had not gone through such a formal apprenticeship in physics or philosophy of physics. So where did this body of rich, integrated knowledge of physics come from in Simon's case? Partly through coursework in high school and as an undergraduate. And later, even as a young faculty member in the social sciences at the Illinois Institute of Technology, he continued his formal excursions into physics by attending courses offered by colleagues at the Institute and the University of Chicago on theoretical mechanics, topology, and mathematical methods in physics (Simon, 1991, p. 100). However, in physics, as in several of the other disciplines, Simon was fundamentally an autodidact—by way of "16 years into serious dabbling in physics."[20] As for the 10-year rule, Simon disclaimed that his own work on the foundations of mechanics refuted the rule: "the 10-year rule applies to world class experts," and he did not believe that he was a "world class expert" in physics. Rather, he regarded his papers on Newtonian mechanics as contributions to the philosophy of science.[21]

The eclecticism of Simon's knowledge space is repeatedly evident as we follow his research into decision making. The idea of setting satisfying aspirations as goals derived from his knowledge of the work of George Katona—one of the few people in the 1940s and 1950s who straddled both economics and psychology—and other psychologists. In challenging the neoclassical model of *H. economicus*, he was evidently intimate with neoclassical microeconomic theory. At one point he resorted to the theory of feedback mechanisms (Simon, 1952b). He was thoroughly familiar with the principle of feedback in servomechanisms, had read the classic book by Lotka (1959), the paper by Rosenblueth, Wiener, and Bigelow (1943), and Wiener's *Cybernetics* (1948).[22] By 1950, Simon was seriously contemplating the "study of organizations and other social servos" (Simon, 1950).

A key feature of Simon's model of decision making was the idea of *search*. Here, he resorted to his considerable knowledge of the psychology of human chess and the logic of the then embryonic field of computer chess.[23] The emergence of a distinctly computational flavor to his Universal Decision Maker model was influenced in part by the ideas advanced by Shannon (1950) and John von Neumann on the problem of designing a chess computer.[24]

9. Bisociative analogizing

The remarkably eclectic nature of Simon's knowledge space was not sufficient to contribute to his multidisciplinary creativity. It was, rather, the use to which he put his knowledge, and the ways in which he drew upon his knowledge space that is significant. We are referring here to his cognitive *actions* or *reasoning strategies* at the knowledge level.

Of these strategies, the most important in our view was *analogizing*. Simon drew analogies between game playing and administrative decision making, engineering design and decision making (Simon, 1947/1976, pp. 66–67, 96, 99), modeling economic behavior and modeling physical reality (Simon, 1959), organizations and servomechanisms (Simon, 1950), decision making and laboratory experimentation (Simon, 1947/1976, p. 70).

It is has been widely documented that analogical reasoning plays an ubiquitous role in the creative process—especially in the realm of scientific discovery and technological invention (Finke, Ward, & Smith, 1992; Hallyn, 2000; Hesse, 1966; Holland et al., 1986; Holyoak & Thagard, 1995; Thagard, 1988). Thus, the observation that Simon employed analogical reasoning might seem unsurprising.

However, the point of interest in Simon's case is two-fold. First, the richness of his knowledge space allowed him to draw fruitful and surprising analogies—surprising because the domains that entered into the analogies were quite distant from each other. Koestler (1964) used the term *bisociation* to refer to the mechanism whereby two or more previously unconnected domains ('matrices of experience') are connected in the act of creation. Koestler "bisociation" is extremely vague; however, the drawing of surprising analogies between two seemingly unconnected and distant domains, and mapping concepts from one domain of the analogy to the other, or categorizing one aspect of the domain of the analogy as an instance of the other, are precise instances of Koestlerian bisociation. We will refer to such surprising analogizing as *bisociative analogizing*.

We find several interesting examples of surprising analogies between distant domains in Simon's reasoning. For lack of space, we present here just two instances, the first relatively less technical than the second.

9.1. Analogizing from laboratory experimentation to decision making

One of the ways in which the decision maker circumvents bounded rationality, according to Simon, is by appealing to the essential lawfulness of nature. In constructing the model of the Administrative Decision Maker, he pointed out that despite the virtual impossibility of achieving perfect rationality—which demands following the consequences of all possible alternative behaviors "through unlimited stretches of time, unlimited reaches of space and unlimited sets of values"—the decision maker can take comfort in the "regularities of nature" (Simon, 1947/1976, p. 69).

Behavior also manifests regularities in some sense, and so one may expect that alternative behaviors will differ in only a small number of ways. This makes decision making more manageable, since such behaviors share much in common and differ in only a few aspects. By simply varying these particular aspects, one can reduce the extent of having to search all the alternatives.

The scientist in the laboratory takes advantage of this: in her experiments she can study behavior by varying only a few variables with the assumption that other factors will remain the same across the spectrum of behaviors she is interested in (Simon, 1947/1976, p. 70).

Thus, Simon drew an analogy between the method of laboratory experimentation and decision making. The reasoning was along the following lines:

1. Despite the many different variables with which a natural environment is associated, the laboratory scientist does not have to deal with the interactions of all the variables in order to study a given phenomenon. Rather, only a few variables change within the

phenomenon's range, others remaining constant. So only those changing variables need to be considered in laboratory experimentation.

2. Likewise, in making decisions in the "real world," one does not have to consider all possible changes in the world as a result of the decision maker's change of behavior. Only a small number of parameters are affected by one's behavior in a given situation. So, only those consequences need to be considered, since the other conditions are expected to remain constant.

9.2. Bisociating models of economic behavior and models of physical reality

In a paper written in 1959, Simon addressed the problem of demarcating the formal part of an axiom system for an empirical theory from those terms and axioms that connect to observable entities (Simon, 1959, 1977). This problem was a fundamental issue for philosophers of science, logicians and (some) physicists. Simon was concerned with those sentences and terms used in a physical theory "that can be confronted more or less directly with evidence." In the language of the logical positivists, such sentences and terms are called "observation sentences" and "observables," respectively (Simon, 1977, p. 376).

In an axiomatic system describing an empirical universe, there must be (among other things) "primitive terms" that correspond to observables, and these need to be distinguished from "defined terms." Simon's concern was precisely this distinction and how to make it. In fact, Simon was challenging Tarski's (1956) definition of "definability" that could be used to distinguish between definable and primitive terms in an axiomatic system. Simon found that according to Tarski's definition, his (Simon's) earlier concepts of mass and force became primitive terms—whereas, according to Simon (1947/1977), masses of particles can, in general, be computed under certain conditions. Here lay a contradiction—for, according to "commonsense notions of definability," what can be computed cannot be primitive.

Simon suggested that if Tarski's definition of "definability" was weakened in a certain way, a better explanation of the "commonsense notion" would obtain (Simon, 1977, p. 378). His specific proposal was a new concept he termed "defined almost everywhere." Given a term to be defined (e.g., "mass" or "force"), if Tarski's original definition of definability "holds almost everywhere" (within a certain region of "space") then the term is said to be "defined almost everywhere."

Simon seems to have arrived at this concept by way of drawing an analogy between the problem of definability in the realm of physics and a problem known as the "identification problem" in econometrics.

Recall that the definability problem arose because Simon (and others before him) wanted to demarcate observables from non-observable ("theoretical") entities. It turns out that econometricians and statisticians have to deal with an analogous problem. For, in building their mathematical models of economic behavior, they distinguish between variables for which data can be gathered ("observables") and other variables that are "non-observable" or "latent" variables. In econometrics, the identification problem is the problem of determining the values of latent variables from the statistical data on the observables. Under certain conditions, the values of latent variables *cannot* be ascertained from the data, no matter how many observations are taken of the observed variables.

Tjalling Koopmans was among those who had discussed the identification problem between 1947 and 1953 (Koopmans, 1949, 1953), and Simon referred to Koopmans in his own writings, even before 1959:

> The problem of whether certain numbers that are not directly observable . . . are uniquely determined by observations of the direct observables has turned out to be one of the central problems of modern statistical theory. In the statistical literature it is known as the 'identification problem.' The axiomatization [of Newtonian mechanics] . . . illustrates that the identification problem is present in physics. (Simon, 1954/1977, p. 372)

In Simon (1959) he returned to this connection in the specific context of definability:

> . . . the problem of definability of non-observables in axiomatizations of empirical theories is identical with . . . the 'identification problem' in the literature of mathematical statistics. (Simon, 1977, p. 382)

Simon then gave examples of identification problems in purely mathematical terms. One of these was a system of equations in which, Simon pointed out, the non-observable parameters can be determined uniquely provided certain conditions were met—viz., the parameters were *identified almost everywhere* in the space of values of the observable variables. Here then was the source of the analogy. For Simon, the identifiability concept in econometrics was equivalent to Torski's definability concept. By analogy, the notion of "almost-everywhere-identifiable" in econometrics led to the "almost-everywhere-definable" concept in the axiomatic system (Simon, 1977, p. 385n). As he acknowledged half-a-century later,

> in its mathematical meaning . . . the identification and definition case[s] . . . are the same thing.[25]

This particular example illustrates quite clearly the nature of bisociative analogizing. We should not speculate whether this particular analogy would have occurred to anyone else. What does seem very clear is that (a) the analogy was quite surprising; (b) it was enabled by the richness and connectedness of Simon's knowledge space—including knowledge of Tarski's definition of "definability," the connection between this definition and his own axiomatization of Newtonian mechanics, and the identification problem in econometrics; and (c) the analogy afforded him the possibility of mapping the definability problem onto the identification problem, and then drawing on the concept of almost-everywhere-identifiable from the identifiability problem to arrive at his concept of almost-everywhere-definable.

10. A network of interacting, time-shared, goal-driven processes

Consider the following facts. In 1937, Simon's dissertation outline indicated an interest in both the logic of administrative decision making and the logic of Newtonian physics.[26] In the period 1937 to mid-1940s, he wrote *Administrative Behavior*, first as a Ph.D. dissertation (completed in 1942) then as a book (published in 1947). From 1942 on, when he accepted a faculty position at the Illinois Institute of Technology, he "continued . . . [his] mathematical and science education," studying textbooks, working out exercises, and sitting in on courses in physics and mathematics at both the Illinois Institute of Technology and Chicago University. With colleagues, he even conducted a seminar in the philosophy of science (Simon, 1991, pp. 100–101). And in 1947, he published his first paper on the foundation of Newtonian mechanics. Thereafter, Simon continued to publish intermittently on the foundations of physics. These forays overlapped with a stream of publications in administrative theory (including two major co-authored books, *Public Administration* (1950) and *Organizations* (1958)).

By the middle of the 1950s, he had also embarked on a new scientific activity, the aim of which was to create a model of *H. economicus* whose behavior manifested the kind of empirical plausibility that had shaped his model of the Administrative Decision Maker. Between 1952 and 1956, he published his seminal papers on economic rationality, work that led to his formulation of the Universal Decision Maker (Simon, 1955, 1956a)—and, eventually, to a Nobel Prize. By 1950, Simon was also pondering the implications of the computer for organization theory (Simon, 1950). And in 1953, he was writing to von Neumann on computer chess,[27] and to the British cybernetician, W. Ross Ashby about the latter's book *Design for a Brain*.[28]

In the summer of 1955, Allen Newell was reporting to Simon of his and Cliff Shaw's chess program, then in progress,[29] and in 1958, the seminal paper by Newell et al. (1958) on their information processing theory of human problem solving was published. The next year, Simon's "Definable" paper appeared (Simon, 1959).

Thus, if we take 1937–1959 as an interval of interest, we conclude with no uncertainty that in this period, Simon was working productively and creatively in *at least four different intellectual fields*—administrative theory, economics, physics, and cognitive psychology—and *had initiated a fifth field*, artificial intelligence (AI). Interspersed with these five fields were original contributions to sociology, econometrics, and statistics, as the collections of papers published as *Models of Man* (Simon, 1957) and *Models of Discovery* (Simon, 1977) clearly reveal.

Gruber (1989) suggested that a creative person's "pattern of work" over a lifetime can be described in terms of a *network of enterprise*—where, by "enterprise," he meant

> a group of related projects and activities broadly enough defined so that (1) the enterprise may continue when the creative person finds one path blocked but another open toward the same goal and (2) when success is achieved the enterprise does not come to an end but generates new tasks and projects that continue it. (Gruber, 1989, p.11)

Simon's work in the interval under review coheres well with this concept of a "network of enterprise(s)." As we have just related, it was not the case that Simon worked for a period in one of the fields, took it to an appropriate level, then abandoned it and moved on to another field. Rather, he worked in a *time-shared* mode in the various disciplines. But "time-sharing," taken in the precise sense the term was used in computer systems design (Wilkes, 1975) is misleading—for in a time-shared system the processes themselves on which the processor works need have no connection with one another at all. The constituents of Simon's network of enterprise were not mutually isolated. They interacted and communicated with one another at times. For instance, Simon's concern with the logic of decision making and the logic of physics originated in a common set of goals documented in his 1937 dissertation outline.[30] Later, there was an interaction between Simon's thinking about administrative decision making and his model of the boundedly rational economic man. The first writings on computer chess stimulated his thoughts on both the logic of decision making in organizations and the logic of problem solving. His concerns with decision making and problem solving merged into one.

His ruminations on mathematical economics and econometrics strongly influenced his ideation in the foundations of physics.

11. A focus on the ill-structured domain

Recently, Esther–Mirjam Sent suggested that Simon's creative work shows distinct transitions.

> From one . . . science to another, from organization theory to cognitive science, from negative evidence to positive simulation, from well-structured to ill-structured problems, from programmed decisions to non-programmed decisions . . . from algorithmic decisions to heuristic solutions . . . in other words from decision making to problem solving. (Sent, 2000, p. 388)

In fact, the evidence suggests quite otherwise. Simon's corpus of work was almost entirely in the realm of ill-structured problems (in the sense he himself has defined this concept, Simon, 1973): administrative decision making, economic decision making, human problem solving, scientific discovery, and design are all examples *par excellence* of the ill-structured. His domain *was* the ill-structured. He made the understanding of this domain his very own, and this facet can also be said to be an element of Simon's cognitive style.

By the same token, Simon did not undergo a "seachange" (as Sent, 2000, p. 388) has suggested from "programmed to non-programmed decisions" or from "algorithmic decisions to heuristic solutions." From 1938 when he began his inquiries into the nature of administrative decision making, he was concerned with what he would later call "non-programmed" decisions. Ill-structuredness entails the non-programmed, and "non-programmed decision" is synonymous with "heuristic solution."

As for changing from organization theory to cognitive science, here too, we have seen that Simon *expanded* his domain from organizations to microeconomic entities and thence into the realm of human problem solving, but the transitions were not "sharp," not "seachange"-like at all but *evolutionary* (though in a non-Darwinian fashion, Dasgupta, 2002). The model of the Administrative Decision Maker evolved into the Universal Decision Maker which evolved into the Symbolic Problem Solver. The transitions were by no means dramatic, as strongly delineated as the word "seachange" suggests.

12. Conclusions

Simon himself suggests that the Renaissance mind cuts a "narrow swathe" across the many disciplines. In his own case, he suggested that the swathe happens to be the process of human problem solving and decision making—that "almost everything I have done lies in that quite narrow band."[31] Augier (2000) refers to this trait more picturesquely as Simon's pursuit of a "monomania." Augier presumably uses this term metaphorically and not in its technical, psychopathological sense. Yet, to speak even metaphorically of Simon's monomania, his single-minded pursuit of a central idea, tells us very little of the nature of his multidisciplinary creativity. Many scientists, artists, writers devote large parts of their creative life to the pursuit and elaboration of a single theme, a single theory, but that does not make them polymaths. Moreover, to ascribe to Simon a monomania does not explain his forays into entirely unexpected domains such as the axiomatic foundations of classical physics.

In Section 3, we suggested that the Renaissance mind achieves its multidisciplinary by assimilating its various distinctive enterprises into a common cognitive style. In this paper we have proposed, by way of a close examination of Simon's historical record, the main ingredients of his cognitive style. To summarize:

(a) An ontological and methodological commitment to empiricism.
(b) An epistemological commitment to operationalism.
(c) A rich, connected and highly eclectic knowledge space.
(d) A model of the human thinker onto which Simon mapped problems from his various domains of interest and which, in turn, itself evolved in the course of his creative work.
(e) The use of analogical reasoning which, in conjunction with his extensive knowledge space, enabled surprising (bisociative) analogies to be drawn.
(f) The active presence of a network of interacting, time-shared, goal-driven enterprises (processes).
(g) A focus on the domain of ill-structured problems.

Some of these ingredients, in isolation, are not unique to Simon. Analogical reasoning is widely used in problem solving, and many are committed to empiricism and operationalism. And highly creative people are known to pursue networks of enterprises.

What is unique to Simon was the richness of his knowledge space and the way in which his knowledge interacted with the other ingredients. It was his cognitive style *as a whole* that characterized his particular Renaissance mind and enabled him to achieve his particular multidisciplinary creativity.

There are other details of Simon's cognitive style that cannot be presented within the compass of a single paper. For instance, Simon himself, no doubt, would have been interested in the nature of his representational schemes. We may also ask whether a plausible computational model (theory) of "Simonian creativity" can be constructed. These are important and fascinating questions that remain to be investigated. We hope that our investigation is an appropriate cognitive starting point for what might be called "Simon Studies."

Notes

1. Our approach was to elicit from Simon responses to certain questions and/or comments on issues that arose in the course of the investigation. We have endeavored to quote from, and interpret, Simon's responses in the proper contexts in which they were communicated. The contexts and the issues they relate to will (we hope) be evident from the text itself.
2. All citations of this work refer to the 1976 edition.
3. H.A. Simon, personal communication, email, February 21, 2000.
4. H.A. Simon, personal communication, email, May 26, 2000.

5. H.A. Simon to T.C. Koopmans, September 29, 1952. Herbert Simon Papers, Carnegie Mellon University (CMU) Archives.
6. H.A. Simon to R. Carnap, August 2, 1937, Herbert Simon Papers, CMU Archives.
7. H.A. Simon, personal communication, email, December 1, 1999.
8. H.A. Simon, “The Logical Structure of a Science of Administration Memorandum,” July 28, 1937. Herbert Simon Papers, CMU Archives.
9. H.A. Simon to H. Guetzkow, March 24, 1942. Herbert Simon Papers, CMU Archives.
10. H.A. Simon, “Comments on Stene’s Paper,” undated. Simon Papers, CMU Archives.
11. “Textbook Meeting,” Memorandum, November 8, 1947.
12. H.A. Simon to T.C. Koopmans, September 29, 1952. Herbert Simon Papers, CMU Archives.
13. Simon to Koopmans, September 29, 1952.
14. H.A. Simon, personal communication, email, February 21, 2000.
15. H.A. Simon to T.C. Koopmans, September 29, 1952. Herbert Simon Papers, CMU Archives.
16. This model is at the level of abstraction that Newell (1980) and Pylyshyn (1989) called the “symbol level.” Hence, the choice of this name.
17. H.A. Simon, personal communication, email, November 7, 2000.
18. H.A. Simon, personal communication, email, April 1, 2000.
19. H.A. Simon, personal communication, email, February 16, 2000.
20. H.A. Simon, personal communication, email, April 1, 2000.
21. H.A. Simon, personal communication, email, April 1, 2000.
22. H.A. Simon, personal communication, email, February 25, 2000.
23. H.A. Simon, personal communication, email, November 4, 2000.
24. H.A. Simon to J. von Neumann, June 24, 1953. Herbert Simon Papers, CMU Archives.
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27. H.A. Simon to J. von Neumann, June 24, 1953. Herbert Simon Papers, CMU Archives.
28. H.A. Simon to W.R. Ashby, June 15, 1953. Herbert Simon Papers, CMU Archives.
29. A. Newell to H.A. Simon, July 12, 1955. Herbert Simon Papers, CMU Archives.
30. H.A. Simon, “The Logical Structure of a Science of Administration,” Memorandum, July 28, 1937. Herbert Simon Papers, CMU Archives.
31. H.A. Simon, personal communication, email, February 1, 2000.

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