Hierarchic, *Near*-Decomposable, Causal, Evolutionary Dynamics
The Architecture of Complexity[1]

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[1] Prepared for the **OECD BLOG**. The final appearance, in the public domain, of the classic on *The Architecture of Complexity* (Simon, 1962 – henceforth referred to as *AoC* – no pun with the *Axiom of Choice* is intended), appeared (very slightly revised) as the last chapter of the 3rd edition of **The Sciences of the Artificial** (Simon, 1996), with the subtitle: *Hierarchic Systems*. The original paper was read on April 28, 1962 – which would have been Ludwig Wittgenstein's 73rd birthday. So, it is appropriate that Simon acknowledges allegiance, in Simon & Newell (1956), referred to in the lead footnote in Simon (1962), to that much quoted Gibbsian aphorism: *Mathematics is a **Language*** – whereas Wittgenstein (1953, §109), did his best to free Philosophy from the '*bewitchment of intelligence by **language***' (emphases added)! For my purposes here, *given the kind of scientist Simon was*, I assume the word **ARCHITECTURE** can be interpreted in any of its standard *design process* senses, whilst keeping in mind that it could also mean *the product* of the design process.

> "Herb had it all put together *at least 40 years ago* – and I've known him only for 35."
> Newell, 1989, p. 400; italics added.

And so it was, with *Hierarchy* in 1950 (Simon, 1977, p. 180 & chs. 4.1 & 4.4), *Near-Decomposability* from about 1949 (Hawkins & Simon, 1949, Simon, 1977, ch. 4.3, Simon, 1991, p. 377 and Goodwin, 1947) and *Causality* (Simon, 1952a and Simon, 1977, chs. Chs. 2.1 & 2.2), underpinning the reasonably rapid evolution of dynamical systems into a series of stable *complex structures*[2]. The *cybernetic* vision (Simon, 1952b) of an interregnum became the fully-fledged digital computer basis of boundedly rational *Human Problem Solvers* implementing *Heuristic Search Procedures* to prove, for example, axiomatic mathematical theorems (in the monumental **Principia Mathematica** of Russell & Whitehead) substantiating Newell's entirely reasonable claim that 'Herb had put it all together at least 40 years ago'.

In defining the notion of *complexity*, in *AoC* (pp. 467-8), Simon eschews formalisms and relies on a rough, working, concept of complex systems that would help identify examples of observable structures – predominantly in the behavioural sciences – that could lead to theories and, hence, theorems, of *evolving dynamical systems* that exhibit properties that are amenable to design and prediction using the *hilfenkonstruktion* of *hierarchy*, *near-decomposability* and *causality*. Thus, the *almost* informal definition[3] is (p. 468; italics added):

> "*Roughly*, by *a complex system* I mean one made up of a large number of parts that interact in a *nonsimple* way. In such systems, the whole is more than the sum of the parts, …, in the .. *pragmatic* sense that, given the properties of the parts and the laws of their interaction, it is not a trivial matter to *infer* the properties of the whole. In the face of *complexity*, an in-principle reductionist may be at the same time a *pragmatic holist*."

Simon was always a *pragmatic holist*, even while attempting the reduction of the behaviour of complex entities to *parsimonious* processes that would exhibit the properties of 'wholes', based on *nonsimply interacting* 'parts', that may themselves be *simple*. In many ways, *AoC* both summarised Simon's evolving (sic!) visions of a quantitative behavioural science, which provided the foundations of administering complex, hierarchically structured, causal organisations, by boundedly rational agents implanting – with the help of digital computers – procedures that were, in turn, reflections of human problem solving processes. But it *also presaged* the increasing precision of predictable reality – not amounting to non-pragmatic, non-empirical phenomena – requiring an *operational description*

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[2] It is not without significance that almost all of these pioneering articles are reprinted in Simon (1977) and, moreover, the hierarchy and near-decomposability classics appear in section 4 of this collection with the heading *COMPLEXITY*!

[3] It parallels the much-hyped, 'modern definition', subscribed to by *aficionados* of the *Santa Fe methodology*, in many ways – except that it does *not* extol the virtues of *disequilibrium emergence of wholes*, from the interaction of a large number of parts, with stable (in the sense of, say, De Finetti, 1975, § 8.4) statistical distributions.

of complex systems that were the observable in nature, resulting from the evolutionary dynamics of hierarchical structures. Thus, the final – fourth – section[4] of *AoC* (p. 477, ff) 'examines the relation between complex systems and their descriptions' – for which Simon returned to Solomonoff's pioneering definition of *algorithmic information theory* (Simon, 2004, p. 34)[5].

AoC was equally expository on the many issues with which we have come to associate Simon's boundedly rational agents (and Institutions) *satisficing* – instead of optimising, again for pragmatic, historically observable, realistic reasons – using *heuristic search processes* in *Human Problem Solving* contexts of behavioural decisions. The famous distinction between *substantive* and *procedural* rationality arose from the dichotomy of a state vs, process description of a world 'as sensed and .. as acted upon' (p.479, ff), in *AoC*[6].

Essentially *AoC* is suffused with pragmatic definitions and human procedures of realistic implementations, even in the utilising of digital computers. Computability theory assumes the Church-Turing Thesis in defining algorithms. The notion of computational complexity is predicated upon the assumption of the validity of the Church-Turing Thesis. Simon's algorithms for *human problem solvers* are *heuristic search processes*, where no such assumption is made. Hence it is not surprising that a feeling of *ennui* engulfed him in his later years (Simon, 2004, p.47; italics added)[7]:

> "The field of computer science has been much occupied with questions of *computational complexity*, the obverse of computational simplicity. But in the literature of the field, 'complexity' usually means something quite different from my meaning of it in the present context. Largely for reasons of mathematical attainability, and *at the expense of relevance*, theorems of computational complexity have mainly addressed worst-case behaviour of computational algorithms as the size of the data set grows larger. In the limit, they have even focused on computability in the sense of Gödel, and Turing and the *halting problem*. I must confess that these concerns *produce in me a great feeling of ennui*."

[4] The first section of *AoC* 'offers some comments on the frequency with which *complexity* takes the form of *hierarchy*', the second 'theorizes about the relation between the structure of a complex system and the time required for it to *emerge* through *evolutionary processes* and the third 'explores the the dynamic properties of hierarchically organized systems and shows how they can be *decomposed into subsystems* in order to analyse their behavior' (p. 468, all the italics are added).

[5] Solomonoff (1964) was first presented at the celebrated *Dartmouth* conference of 1956, where Simon was also present, which initiated the field of *artificial intelligence*.

[6] Anyone who studies the example of *Hora* and *Tempus* (pp. 470-1) may, justifiably, wonder whether it is not (yet another) instance of the famous first three chapters of Book I of the *Wealth of Nations*! However, Simon's example is in the context of hierarchical systems – but, then, why does *Tempus* not hire a telephonist to 'answer the phone' and avoid the falling 'into pieces' of partly assembled watches? Because such a hiring increases the degree of hierarchy, which, thereby, increases the number of interacting subsystems, leading to 'higher' descriptive complexities.

[7] This is, in more stark and explicit ways, the same reflections expressed by Simon in the appended letter to me (written after reading my book on **Computable Economics**, a first draft of which was completed in 1991 when I was 'only' 43 years of age. Perhaps he was being 'kinder and gentler' to me!).

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[8] Simon died on 8th February, 2001; this may have been his last *written* paper before death intervened, I think unexpectedly (see the attached letter from Simon, dated 25th May, 2000.

Appendix

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25 May 2000

Professors Axel Leijonhufvud
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Dear Friends,

I want to share some first impressions on my reading of “Computable Economics.” (I confess that “reading” did not include going through all the proofs.) I was delighted and impressed by the mileage you could make with Turing Computability in showing how nonsensical the Arrow/Debreu formulation, and others like it, are as bases for notions of human rationality. Perhaps this will persuade some of the formalists, where empirical evidence has not persuaded them, of what kinds of thinking humans can and can’t do – especially when dealing with the normative aspects of rationality.

As the book makes clear, my own journey through bounded rationality has taken a somewhat different path. Let me put it this way. There are many levels of complexity in problems, and corresponding boundaries between them. Turing computability is an outer boundary, and as you show, any theory that requires more power than that surely is irrelevant to any useful definition of human rationality. A slightly stricter boundary is posed by computational complexity, especially in its common “worst case” form. We cannot expect people (and/or computers) to find exact solutions for large problems in computationally complex domains. This still leaves us far beyond what people and computers actually CAN do. The next boundary, but one for which we have few results except some of Rabin’s work, is computational complexity for the “average case”, sometimes with an “almost everywhere” loophole. That begins to bring us closer to the realities of real-world and real-time computation. Finally, we get to the empirical boundary, measured by laboratory experiments on humans and by observation, of the level of complexity that humans actually can handle, with and without their computers, and - perhaps more important – what they actually do to solve problems that lie beyond this strict boundary even though they are within some of the broader limits.

The latter is an important point for economics, because we humans spend most of our lives making decisions that are far beyond any of the levels of complexity we can handle exactly; and this is where satisficing, floating aspiration levels, recognition and heuristic search, and similar devices for arriving at good-enough decisions take over. A parsimonious economic theory, and an empirically verifiable one, shows how human beings, using very simple procedures, reach decisions that lie far beyond their capacity for finding exact solutions by the usual maximizing criteria.A recent example that I like is the work of Shyam Sunder (now at Yale, alas)
and his colleagues on the equilibrium of markets with “stupid” traders, and the near indistinguishability of such markets from those with optimising traders. When we have remade economic theory on that model, we will be able to write honest textbooks.

So I think we will continue to proceed on parallel, but somewhat distinct, paths for examining the implications of computational limits for rationality – you the path of mathematical theories of computation, I the path of learning how people in fact cope with their computational limits. I will not be disappointed however if, in the part of your lives that you devote to experimental economics, you observe phenomena that seduce you into incorporating in your theories some of these less general but very real departures from the rationality of computational theory. This seems to me especially important if we are to deal with the mutual outguessing phenomena (shall we call them the Cournot effects?) that are the core of game theory.

I am sure that you will be able to interpret these very sketchy remarks, and I hope you will find reflected in them my pleasure in your book. While I am fighting on a somewhat different front, I find it greatly comforting that these outer ramparts of Turing computability are strongly manned, greatly cushioning the assault on the inner lines of empirical computability.

Once again, thank you very much for sending your fine book. Please continue to keep me in touch with your work. I'll send along some recent reprints of mine.

Cordially,

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and Psychology