MODELS AND APHORISMS

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We all know that great imaginative literature can be read on many different levels -- Shakespeare could simultaneously produce gripping plots, sensitive character delineations, Tudor propoganda, and philosophical reflections on fate and social responsibility. I am going to advance a similar claim for the scientific models we are producing here at Santa Fe. My basic message is that while each of these models is primarily directed at some particular world of experience -- which might be physical, chemical, biological, social or economic -- on another level they can lead to new insights about *other* worlds of experience, including those that we ourselves inhabit in our personal and professional lives. These insights, I believe, can be encapsulated in the form of aphorisms, whose meanings are shaped by an understanding of the modelled worlds, and from there can extend metaphorically, to help us reinterpret our own worlds of experience. Later in my talk, I'll illustrate this claim with four examples.

I want to begin by pointing out a feature that virtually all SFI modelling efforts share. It is actually a negative feature: they are not "simulations". I had better explain what I mean by that, since for many people -- including some here at SFI -- the vocabularies associated with "modelling" and "simulation" are interchangeable.

There is a very interesting, large-scale modelling effort going on at Los Alamos now. It is designed to artificially generate traffic patterns that are comparable in every respect to what you might find on the actual roads of Albuquerque. The words that the modellers use to describe the entities they build into their model are the same words that Albuquerque's residents and traffic managers use: there are households, vehicles, roads, gas stations, and so on. And the modelled relationships between these entities faithfully mirror the relationships between REAL households, vehicles, roads. Furthermore, the purpose of the model is to generate predictions for exactly the observables that traffic managers and drivers worry about, under a variety of more or less plausible scenarios. The Los Alamos traffic model, then, is a simulation.

Now most SFI models are not like that. The very entities and relationships that appear in SFI models are highly abstracted from any world of direct experience. The abstractions in turn are based on what I will call *theories* about what "worlds of experience" are like. These theories have to do with what kinds of objects populate a world, how these objects relate to one another, and what kinds of processes change objects and bring new ones into being.

Thus, the relevance of SFI models to "worlds of experience" is mediated through these theories. It turns out that these theories are far from the "common-sense" views of the Western European/American cultural tradition that most of us have inherited. In fact, it is extremely difficult, if not impossible, to express these theories in that tradition's ordinary language without a lot of ambiguity and confusion. Yet, if the intuitions of the SFI modellers and others who hold these theories are right, the theories allow us to construct interpretations of our own "worlds of experience" that open up new possibilities for effective action.

How can we gain access to these theories? I claim that the best entry point is through the models themselves, even though the very meanings of these model depend upon the theories we seek to understand.[1] How this works is simple. The models are designed to highlight exactly those elements of worlds that the theories point to as central. So it is relatively straightforward to identify these elements in the modelled world, and hence to appreciate their significance.

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[1] I know this sounds circular -- indeed it *is* circular; the circularity is characteristic of the logic on which the theories rely. I call this kind of circularity reciprocal causation. Here, the meaning of the theories and the meaning of the models reciprocally "cause" one another: the meaning of the models is derived from the theories, whose meaning is apprehended through the models.

Once we understood them in these contexts, we can begin to discover them in our own worlds of experience, through reinterpretation. Notice how, from this point of view, far from the models "simulating" worlds of experience, the worlds of experience, through our understandings of them, can be said to "simulate" the models.

Now I turn to some models and the aphorisms we can draw from them.

Aphorism 1: Chance as a cause

Brian Arthur and I developed the following simple model several years ago, designed to study a phenomenon we called information contagion [1]. Two new, competing products are launched. There is a certain amount of publicly available information about the products, but potential purchasers supplement this with information they obtain by sampling previous purchasers, from whom they find out which product the previous purchaser bought, and an estimate of how good that product turned out to be. On the basis of this information, the new purchasers buy one of the two products -- and thereby enter the pool of previous purchasers from which future purchasers will sample.

Brian and I were interested in what kind of market structure would develop from the informational dynamics I just described. We found that the dynamics would always lead to a stable market structure -- and, typically, only a few kinds of structure were possible. What these were depended on the actual performance characteristics of the two competing products and on how purchasers used the information they obtained to guide their product selections.

Here I want to focus my discussion on a particular situation, in which the products actually have the same performance characteristic (this fact is unknown, of course, to potential purchasers). In this situation, three possible market structures can result: the two products can end up sharing the market 50-50; or one or the other of the two products could end up completely dominating the market.

Which will actually happen? Obviously, this question is critical for the companies that make and distribute these products. The answer is that the question is completely unanswerable a priori. The aggregate, market-level pattern that comes into being cannot be determined in advance; it is *constructed from* the many individual-level acts of sampling (and the consequent choosing). Since the sampling is completely random in our model, it is appropriate to say that chance, operating at the individual level, determines which market structure emerges at the aggregate level. **Chance, then, is the cause of the aggregate order in this system.** But chance as a cause does *not* mean that anything can happen: chance is constrained by the micro-structure of this system, so that it can "choose" only amongst three particular kinds of aggregate order.

We are all by now familiar with the idea that decision-makers have to take their uncertainty into account when they make their decisions -- and with the procedures economists recommend for how the decision-makers should do this. The issue raised by this model is very different: the question is not what we don't know, but what *can't be* known -- and how phenomena that operate below our analytic powers of resolution can nevertheless generate structure at the levels in which our own actions take place.

Our "common-sense" view of causality does not handle this interaction between experiential levels at all well. For example, if we want to explain a phenomenon like the decline of IBM, we seem to oscillate between two modes of explanation. The first (and most common) is to presume that if something is going wrong, somebody did something wrong -- and the appropriate remedy is to find out who it was and get rid of him. Thus, the "cause" is at the level of individual action. The second mode is to find some "law" operating at the aggregate, market-level, like: it's inevitable that well-established, successful firms, locked into the behaviors that led them to success, will eventually succumb to changing competitive conditions for which these behaviors are inappropriate. Neither of these interpretative modes search for cause in the relation between the structure of interactions at the individual level and emergent patterns at the aggregate level; and so, in particular, neither can incorporate a causal role for chance.

Aphorism 2: Winning isn't necessarily winning

The next model I want to discuss was created by Kristian Lindgren, who calls it the Evolutionary Prisoner's Dilemma [2,3]. Evolutionary Prisoner's Dilemma is an example of an Artificial World model [4]. That is, it consists of a population of micro-level agents; the agents interact with one another; and as a result of their interactions, the population of agents changes. In Evolutionary Prisoner's Dilemma, each "agent" is a strategy for repeatedly playing a fixed game against other agents (the game is NOT zero-sum). The agents interact with one another by engaging in a round-robin tournament of the repeated game. Each "generation", agents reproduce proportionally to their success in the round robin tournament. Then the new population plays its round robin tournament, and so it goes, generation after generation. Occasionally, new kinds of agents come into being, through "genetic" errors in reproduction. Thus, Lindgren's Artificial World is an open system, capable of generating what John Holland calls "perpetual novelty".

What happens in Evolutionary Prisoner's Dilemma? When it is started with an initial population of relatively simple strategies, meta-stable "ecologies" develop, which dominate the system for many generations. These ecologies consist of a (generally small) set of strategy types, represented in some fixed proportion to one another. Other strategy types besides the dominant ones come into and out of the system, but none attains signficant "market share". There may be a variety of reasons why the particular mix of strategy types making up an ecology "reproduces" itself from generation to generation. For example, there may be predation cycles, (type A plays well against B who plays well against C who plays well against A); or mutualism (types A and B tend both to get high scores when they play against each other). In addition, of course, the dominant types must be able to protect themselves against new arrivals.

Sooner or later (and it is generally later), an ecology fails to respond to some new challenge. New strategy types gain a foothold, stability is lost, a period of rapid change ensues, until the ecology is sooner or later (generally sooner) replaced by a new meta-stable ecology; and so on. That is, Lindgren's model manifests what evolutionary biologists call Punctuated Equilibrium.

Now I want to call attention to the phenomenon to which the aphorism "winning isn't necessarily winning" refers. Typically (virtually universally) the new strategy type that successfully invades an ecology, setting in motion the process that leads to its dissolution, disappears in the ruins of that ecology and does not reappear as a dominant type in the successor ecology. It usually succeeds in invading, because it is particularly effective in playing with (at least) one of the current dominant types; but when the frequency of this type changes sufficiently, the ecology loses its ability to reproduce itself -- and the invader may (and generally does) find its way of playing ill-adapted to the new ascendent types.

Note that this phenomenon is quite different than that to which the old adage "he won the battle but lost the war" apply. That adage implies that a temporary advantage over a particular adversary may cost more to the victor than the vanquished -- at any rate, it may not be sustainable, and the adversary can rally and eventually triumph. In Lindgren's world, the whole notion of "adversary" may be meaningless, since the relations with a given co-participant can range from predator to ally to prey (indeed, to neutrality), and any given relationship only takes on its meaning for survivability in the context of all the other relationships between current system participants.

An agent in a coevolutionary world like Lindgren's that defines its success by "winning" against a currently dominant rival may find itself the victim of its own success. It is interesting to think what it would mean for such an agent, unlike Lindgrens', to *have* a strategy (instead of being a strategy). How might it predict the onset of "destabilizing" periods -- and recognize when a new ecology was beginning to form? What kinds of actions could it take that would help guarantee that it became part of a stable network of relationships with other agents? And what kinds of configurations amongst such networks could lead to a metastable ecology? These are not the kinds of questions that current "strategic management" practice addresses. But I would be very surprised if they were not very interesting questions to the players in the telecommunications industry poised to enter the new age of multimedia.

Aphorism 3. Organization as structure and process

Most of us think of organizations as defined by their *structure*. It is also possible to think about them in terms of their functionality, as a collection of *processes* for doing things. It is not so easy to think about the relation between an organization's structure and functionality -- and, in particular, how they mutually determine one another.

The next model I am going to describe leads to a particular definition of organization in which structure and process are inextricably bound together [5,6]. This new conception of organization is difficult to transfer from the model to other worlds of experience, although Walter Fontana, who developed the model, and Leo Buss have used it to construct a fascinating new theory of biological organization. I am still struggling to frame aphorisms that encapsulate the insights the model seems to provide into social and economic organization. In the meantime, "organization as structure and process", and a description of the model, will have to do.

Walter started with the idea of generating an abstract version of chemistry. The basic concept in chemistry is the idea of a reaction: thing A acts on thing B to produce thing C (and the structure of reaction product C is completely determined by the structure of reactants A and B). Moreover, there is an equivalence notion: thing D may act on thing E to produce thing C as well (so "A acting on B" is equivalent to "D acting on E").

These two properties are shared by a set of mathematical objects, called lambda objects (the rules for determining reaction products and equivalence for lambda objects are called lambda calculus). Walter's model takes a bunch of lambda objects and has them react with one another via random collisions. After a lot of collisions, he looks to see what lambda objects he ends up with.

Walter's first experiments were not very interesting. No matter how he started, he ended up with a collection of self-copiers -- that is, lambda objects that react to produce copies of themselves. Self-copiers "selfishly" and "individualistically" went about producing copies of themselves and crowded all other lambda objects out. The resulting collections did not manifest any interesting structure.

Then, Walter began to ban copy reactions: if a reaction produced one of the reactants, it was just declared null and void. Now some interesting structure began to appear. At the end of an experiment, all the lambda objects would belong to one or more large sets with a property Walter called self-maintenance: that is, every lambda object in the set was the end product of at least one reaction among other objects in the set, so that the set itself could continually "reproduce" itself even if its individual members could not. Moreover, these sets exhibited structure on two levels: syntactically (that is, there were identifying patterns to the symbol strings of which their members were composed) and semantically (that is, the transformation relations amongst the members of the set formed an algebra). Gradually, Walter developed a whole library of possible structures for self-maintaining sets -- each discovered by examining what lambda objects were left at the end of one of his experiments.

Walter and Leo began to think of these self-maintaining sets as organizations. They also investigated what happened when the lambda objects in two different self-maintaining sets were combined in an experiment. They found that in some circumstances one would drive out the other -- but in other circumstances, the two combined into a higher-level organization, which typically required additional lambda objects, generated by cross-reactions between the two component organizations, to stabilize the higher-level structure.

In my opinion, the Buss-Fontana theory does not translate in a straight-forward way into a theory of the social or economic organizations in which much of our own activities take place. Yet it raises some very interesting challenges to our conceptions about these organizations. Most important, according to their view, we must regard organizations in terms of the transformation processes they carry out. In addition, their theory suggests that persistent transformation processes require -- indeed generate -- structures that carry them. Hence the aphorism: organization as structure and process.

Aphorism 4. Rationality isn't necessarily intelligent

Experimental biologists use the word "model" in a very different sense from the examples I've presented so far. A "model" for them is a particular strain of experimental animal -- it's a *model* because it is standing in for the other kinds of creatures we are primarily interested in (like when mice stand in for human beings in pharmacological research). My last example is this kind of model: it is a physical, not a symbolic representation. This "model" consists of a huge data base assembled by John Padgett at the University of Chicago [7,8]. What John is doing with this model is an important component of the research initiative in organization that has been building up over the past few years here at SFI.

John's data describe what families had and what they did in Florence between about 1282 and 1494. For example, it includes records of marriages, wealth, taxes, business partnerships, political offices. From this data, John constructs social networks that describe the patterns of interaction between the different families, and he studies how the structure of Florentine society, as described by these networks, changes over time. He is interested in how patterns of local interaction -- business dealings, marriage ties, neighborhood relationships -- can lead to the formation of large-scale "organizations" like the Medicean party, and how the structure of these organizations in turn constrains the kinds of local interactions that take place within them. And he wants to understand the relation between the categories with which Florentines describe their society -- their cultural attributions -- and the structure that underlies that society. But for John, and the other SFI researchers who have been drawn into the world of his model, the real focus of interest is not Renaissance Florence, as rich and interesting as that world might be. Rather, it is the general problem of the relation between structure, attribution and power in human society, and in particular the reciprocal causation between patterns of "local interaction" and aggregate-level organization.

The aphorism "rationality is not necessarily intelligent" derives from John's account of Cosimo di Medici. Cosimo was acknowledged by everybody -- contemporaries and historians alike -- as the head of the political faction that took power in 1434 and controlled Florentine politics for the next 60 years. Yet Cosimo never held any major political office and delivered few public addresses; those he did were most noteworthy for their nearly total lack of content. Every extant account of Cosimo's private audiences confirm that he rarely gave advice or orders, or commented on plans presented to him by associates, beyond a noncommittal but encouraging "Yes, my son". Cosimo seems to have existed mainly in the eyes of his beholders: the so-called New Men (whose families had only recently attained wealth and with it access to power) regarded him as the champion of the New Men; while the old aristocrats (to which class he belonged by birth) regarded him as the great bulwark of their threatened hegemony. This picture raises two principle puzzles: what was Cosimo *doing* that enabled him to control Florentine politics as no one had succeeded in doing before; and how could such contradictory attributions of who he was be sustained over the whole period of his ascendancy?

The key to John's explanation of these puzzles is his findings about the structures of the interaction network that became the Medicean party. Briefly, the Medici network had a star-like configuration, with the Medici's at the center: the other families in the network connected to one another only through the Medici's. The Medici's married into other aristocratic families, and they did business with New Men. The New Men with whom they did business had no ties of any kind with the aristocratic families the Medici's married. All Cosimo's associates were free to interpret him as they pleased, without risk of contradiction from the others. And any plans for concerted Medici action had to flow through Cosimo; his merest encouragement was necessary and nearly sufficient to initiate concerted action.

John's historical analysis makes clear that neither Cosimo nor anyone else *designed* the structure of the Medicean interaction network. It came about through the concatenation of a series of what can best be described as historical accidents. Moreover, it requires quite a bit of analysis to make visible the network's structure, from the myriad of local interactions of which it is composed. John can "see" the network's structure, but I am fairly certain that Cosimo could not have done so.

On the other hand, Cosimo was, in John's suggestive terminology, a robust actor. He could feel the advantages his structural positioning in the network offered him, and he learned how to exploit the stream of opportunities that this positioning kept flowing in his direction. Cosimo reacted -- or better, he let things from which he benefited happen.

There is no evidence that Cosimo engaged in rational planning, based on an assessment of his goals and available options. Indeed, rationality requires that an individual construct for himself a coherent identity, based on a consistent set of goals and values. It is unlikely that a Cosimo so constructed could have maintained the contradictory set of attributions that others held about him; actions coming from rational planning would exhibit a coherence that would have given these others a window looking into the "real" Cosimo inside. There just is not a "real" person -- that is, a coherent identity -- inside the robust actor. Yet Cosimo's style, and the structural position in which he found himself, were mutually supporting, and led to more "intelligent" action than could possibly have resulted had he followed the injunctions of rational choice theory.

I conclude with a brief remark about the "theories" from which the aphorisms I have discussed derive. The theories are primarily concerned with the interaction between entities at one "experiential" level and the patterns and structures that emerge at a higher, aggregate level. The central insight of the point of view underlying SFI models is that these two things -- micro-level interactions and aggregate-level pattern and structure -- reciprocally cause one another. Teasing out the logic of this reciprocal causation may be the primary unifying thread in SFI research -- and, if we can understand it, the key contribution we can make to making sense of our own worlds of experience.

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