R. Rosen, "Life Itself" (Columbia UP, 1991)

Praeludium

"Hard" Science and "Soft" Science

p2. between quantitative and qualitative, between "exact" and "inexact" ... This duality is not to be removed by any kind of tactical accomodation, by any superficial effort of conciliation or ecumenicism. It is a matter more akin to religious conversion. ... This dichotomy rests on presupposition about the nature of material reality and on how we obtain knowledge about it.

Qualities and Quantities in the Sciences

p2-4. Rutherford: Qualitative is nothing but poor quantitative.
Hutchins: A social scientist is a person who counts telephone poles (anything we can count is trivial or irrelevant).
Rutherford's view, that every perceptual quality can, and must, be expressible in numerical terms, is associated with the viewpoint commonly called *reductionism*. In practice, reductionism actually asserts much, much more than this; in its most extreme form, it actually identifies a specific family of elementary numerical qualities (and the procedures for measuring them, at least in principle) and anchors them in *physics*. ... According to this view, there *is* no other science than physics; everything else we call science is ultimately a special case of physics.
p4. Hutchins is asserting that *quantitative is poor qualitative*.
There is nothing inherently illogical, or even unscientific, about either of these positions.
There are ways out of this impasse, but they are not palatable to either party. They involve a recongnition that mathematics has more to offer besides numbers and a corresponding recognition that perceptual qualities may be expressed in terms of them.

Syntax and Semantics

p5. The mathematical world is *embodied* in percepts but exists independent of them. ... These facts have indeed spawned another profound dualism, a dualism between idealism (which at root is an attempt to extend the reality of number to the rest of the perceptual universe) and materialism (which is an attempt to include "mathematical reality" inside conventional perceptual realms).
p7. The (formalist's) idea that all truth can be expressed as pure syntactic truth, which is the essence of the formalist position in mathematics, I claim to be analog of Rutherford's position in science, the formal analog of "hardness" and quantitation.
The formalist position is, first of all, an expression of a belief that all mathematical truth can be reduced to, or expressed in terms of, word processing or symbol manipulation. Hence the close association of formalization with the idea of "machines" (Turing machines) and with the idea of algorithms.
Second, the formalist position, that the universe of discourse needs to consist of nothing

more than meaningless symbols pushed around by definite rules of manipulation, is exactly parallel to the mechanical picture of the phenomenal world as consisting of nothing more than configurations of structureless particles, pushed around by impressed forces.

Gödel's Theorem

p7. Basically, he showed that, no matter how one tries to formalize a particular part of mathematics, syntactic truth in the formalization does not coincide with (is narrower than) the set of truths about numbers. ...

p8. For our purpose, we may regard it as follows: *one cannot forget that Number Theory is about numbers.* The fact that Number Theory is about numbers is essential, because there are percepts or qualities (theorems) pertaining to numbers that cannot be expressed in terms of a given, preassigned set of purely syntactic entailments. ... There is always a purely semantic residue, that cannot be accomodated by that syntactical scheme. ... Mathematics, like language itself, cannot be freed of all referents and remain mathematics. ... In other words, Number Theory is not a closable, finite system of inferential entailment. .. Formalization is not, as Hilbert thought, a *universal* strategy. If mathematics is a war against inconsistency, then that war is simply not as easily won as Hilbert believed.

CC Perhaps, there is an almost self-eveident example of Gödel's theorem, and in the future, just as non-Eudlidean geometry, the theorem would be almost trivial (self-evident). Is it possible to make such an example using atoms to demonstrate that the simple reductionism does not work?

Complex Systems

p9. In this light Gödel's theorem says that number theory is more *complex* than any of its formalizations, or equivalently, that formalizations, governed by syntactic inference alone, are *simpler* than Number Theory.

Rutherford's position, as articulated above, can be rephrased as asserting that *every material system is a simple system.* .. this position is just another form of Church's thesis, a direct assertion of the simulability of mathematical models of reality.

To a mathematical Rutherford, then, Number Theory would look *soft* relative to its formalism, precisely because there are more qualities, and hence more entailments, in Number Theory than could be accomodated in terms of "hard" (i.e., syntactic) entailments. This is exactly why biolgy looks soft to a physicst, for example.

Chapter 1 Prolegomena

1A. What is life?

p11. Ironically, the idea that life requires an explanation is a relatively new one.

P13. Why could it not be that the "universals" of physics are only so on a small and special (if inordinately prominent) class of material systems, a class to which organisms are too *general* to belong? What if physics is the particular, and biology the general, instead of the other way around?.

If this is so, then nothing in contemporary science will remain the same.
p14. Life is material, but the laws framed to describe the properties of matter give not purchase of life. Something is missing here, ... something is missing, something big, but it is hard to see even the biggest things when they are not there.

1B. Why the Problem is Hard

p15. One of the main reasons the fundamental question "What is life?" is so hard ... we are really asking, in physical terms, why a specific material system is an organism, and nothing else.
p 17. a fact or datum, by itself, is essentially meaningless; it is only the *interpretation* assigned to it that has significance. Thus, for example, one can literally see the rotation of the earth on any starry night; it has always been patently visible, but for millennia human beings did not know how to understand or interpret what they were seeing. ... in all these cases, it was the absence, not of data, but of imagination that created difficulty.
It may perhaps be true that the question "what is life" is hard because we do not yet know enough. But it is at least equally possible that we simply do not properly understand what we already know.
p18. We cannot thus study organisms by inorganic proxy, at least not experimentally. The best we can do is to *dismember* an organism, to break it apart and treat its parts in isolation as proxies for parts *in situ*.
Many people have tried very hard to produce such criteria for separating the quick from the dead. Put briefly, they have all failed. This fact is most significant in itself, but perhaps of even greater significance is the further fact that we can somehow *know*, with certainty, that they have indeed failed.
p19. The crux of the matter is that, when one tries to embody our recongnition criteria for organisms in an explicit list, we find nothing on that list that cannot be *mimicked* by, or embodied in, some patently inorganic system. ... Indeed, a whole approach to biology, which used to be called *biomimesis*, was based on this observation.

1C. The Machine Metaphor in Biology

p20. No one can say what an organism is. It is, however, all too easy to say what an organism is *like*. In itself, this is not a bad thing to do; trouble arises when one substitutes the latter for the former.
p21. Today, I dare say that the molecular biologist, above all regards this field as representing the ultimate incarnation of the Cartesian automaton.
But above all, the machine metaphor (supported, of course, by the groups of modern physics) is what ultimately drives, and justifies, the reductionism so characteristic of modern biology.
The belief in reductionism, butressed precisely by the machine metaphor, extrapolates these facts back to the entire universe; there is always a set of parts, into which any material system can be resolved, *without loss of information*.
p22 . One cannot, for instance, solve a three-body problem by breaking a three-body system

into three one-body systems or ...
CC This analogy is not good, because the equation of motion can be written precisely in terms of elements.
To sum up: the role of the machine metaphor in biology today is as follows. First, it assures biologists that their subject is an analytical one, ... Second, it assures them that the *same* set of parts will solve all problems of fabrication and of physiological simultaneously. Third, it assures them that nothing happens in biology that is outside the ken of the physical universals. ... if biology is hard, it is simply because there are so many parts to be separated and characterized.

Chapter 2. Strategic Consideration: The Special and the General

p29. Mathematics seeks the smallest set of conditions under which mathematical truth obtains, because this is the most elegant, the most parsimonious, the most illuminating, in short, the most beautiful.
p32. The repeated association of limiting processes with generalization of something, of which we have seen a number of instances so far, is itself a very general thing. Limiting processes are a gateway that can take us from a given world to a generally much larger world.

2E. On the Generality of Physics
p36. (Reductionism) is an assertion, or conjecture, or belief, pertaining to the generality of contemporary physics itself. And ideed, it is not a conjecture based on any *direct* evidence (as , say, Goldbach's conjecture is), but rather on indirect (circumstantial) evidence, insofar as evidence is adduced at all. In short, it rest on *faith*.
p37. With respect of biological phenomena, contemporary physics is in exactly the same situation that nineteenth-century physics faced in the atomic and cosmological realms: it either stands mute or it gives the wrong answers.

Chapter 3. Some Necessary Epistemological Considerations

p40-1. Strategic retreat

3B. The First Basic Dualism
As Descartes says, we know our *selves*, without even having to look, by an immediate kind of direct apprehension and with a knowledge that brooks no skepticism. Oddly, I have not been able to find a really good word that incorporates all of the activities of the self that we know with such immediate certainty.
At any rate, we know our self with ultimate certainty, even though this knowledge is *subjective*... at best it can be reported. .. This is the *inner world*. Everything else is *outside*. What else is there? Whatever it is, I shall call it the *ambience*.
That world (= external world) is important to us, because our bodies are in that world,

and to that extent at least, we must seriously care what goes on out there.
p41. Much more could be, and has been said about this fundamental dualism between the self and its ambience, but we shall need no more than the simple fact of its existence. Science, in fact, requires both; it required an external, objective world of phenomena, and the internal, subjective world of the self, which perceives, organizes, acts, and understands. Indeed, science itself is a way (perhaps not the only way) of bringing the ambience *inside*, in an important sense, a way of importing the external world of phenomena into the internal, subjective world that we apprehend so directly.
Indeed, as we shall see, the fact that inner, subjective models of objective phenomena *exist* connotes the most profound things about the self, about its ambience, and above all, the relations between them.

3C. The Second Basic Dualism
p41. For each of us, this separation is absolute, indubitable, and unequivocal, though it may be different for different selves.
It is the dualism between *systems and their environments*.
Roughly speaking, a system in the ambience is a collection of percepts that seem to us to belong together. ... The abstract concept of *systemhood* is indeed a very difficult one to grapple with, as is the reltated notion of *set-ness*.
p42. Set-ness is such a basic and familiar notion that it took two thousand years for it to be recognized explicitly;
The notion of systemhood is at that same level of generality and plays the same kind of role in our management of the ambience.
For once the distinction is made, attention forcuses on *system*.
The growth of science, as a tool for dealing with the ambience, can be seen as a search for special classes of systems into which the ambience may be partitioned, such that (1) the systems in that special class are more directly apprehensible than others, and (2) everything in the ambience, any othe way of partitioning it into systems, is generated by, or reducible to, what happens in that fundamental class. Newtonian mechanics, for instance, thought it had found such a class; so, today, does quantum theory. But it is, above all, a *special* class.

3D. Language
p43. An essential part of the inner world of any self is one's language.
p43-4. Just as nobody has been able to characterize an organism in terms of a discrete list of properties, no one has been able to characterize a "natural language" in terms of a list of production rules. Indeed, if it were possible to do this, it would be tantamount to saying that a (natural) language can be completely characterized by syntactic properties *alone*, i.e., made independent of any semantic referents whatever. There have indeed been deadly serious attempts to do precisely this. They have all failed, often rather dramatically, indicating that, in general, semantics cannot simply be replaced by more syntax. Nevertheless, the attempt to do so has served to extract various kinds of syntactical "sublanguages"; **these will play an analogous rule, in the external world of the self, to segregation of**

systems in one's external world or ambience.
p44. We shall understand by a formalism any such "sublanguage" of a natural language, defined by syntactic qualities alone.
I shall henceforth refer to a formalism as a *formal system*; to distinguish formal systems from systems in the ambience or external world, I shall call the latter *natural systems*.
p45. *natural language is not a formalization.*
The study of formal systems is what comprises the subject of mathematics.
I conclude this brief consideration of language by pointing out two aspects of natural language that will play key roles in what follows but that never end up as part of formalisms. These are (1) the use of the *interrogative*, to which I have already alluded, and (2) the use of the *imperative*. The latter, for example, is universally presupposed, even in mathematics; an algorithm, for example, is nothing but a strong of imperatives, ordering us to apply specific production rules to specific propositions, ...
p46. The entailment process embodied by algorithms or recipes is very different, than that governing their application. The difference, indeed, is precisely the difference between fabrication and physiology (mentioned already in 1C).
CC this does not seem to be identical to the distinction of making and understanding.
p47-8. There is no mechanism within the formalism for changing an axiom, or a production rule, or for applying a different algorithm. Furthermore, from the standpoint of the formalism, anything that happens outside is accordingly unentailed. ... from their standpoint everything important that affects them is itself unentailed.
p48. We have paralleled three of Aritotelian four categories of causation; specifically, if we call the theorem P an effect, we may identify his idea of material cause of P with the axioms of a formalism, his idea of efficient cause of P with its production rules, and his idea of formal cause of P with the specification of a particular sequence or algorithm of production rules, generating a corresponding trajectory of propositions from axioms to P.
p48-9. In any formalism, there is a kind of natural flow from axioms to theorems, very much like the familiar unidirectional flow of time. Indeed, the formal analog of "time" is embodied in the idea of sequence, the order of application of production rules or inferential operations in proofs and algorithms. This flow of "formal time" is irreversible just as real time is.
p49 . The rejection of finality in science is usually cast in this temporal context, in the form of an unspoken "Zeroth Commandment" permeating all of theoretical science: "Thou shalt not allow the future to affect the present." The upshot of this discussion of finality is the following: in purely formal terms, a concept of final causation requires modes of entailment that are simply not generally present in formalisms. ... Later I will argue that the incorporation of finality into our scheme of things, in the form of the additional modes of entailment it requires, is not only possible, it is crucial.

3F. On the Comparison of Formalisms

p54. The first matter of importance to note that, from the standpoint of the formalisms being compared, *encoding and decoding arrows in figure* 3F2 *are unentailed.* In fact, they

belong to neither formalism, and hence, cannot be entailed by anything in the formalisms. the comparison of two inferential structures thus inherently involves something outside the formalisms, in effect, a *creative act*, resulting in a new kind of formal object, namely, the modeling relation itself. It involves art.
p55. In short, the totality of formal models of something that is not itself a formalism to begin with is 1. indefinitely large, and 2. is not itself a formalism.

3G. Entailment in the Ambience: Causality

p56. All we perceive directly are ourselves, together with sensations and impressions that we normally interpret as coming from "outside", and that we merely impute, as properties and predicates, to things in that ambience.
What we do perceive is only a sample of what we could perceive and the problems of induction arising therefrom. ... To such a skeptic, indeed, there is little to distinguish science from paranoia (which is basically a search for, or a belief in, entailment that are in some sense not there).
Nevertheless, it is hard to believe, for instance, that we could use natural language, in its semantic role of bringing external referents inside, if there were not a great many phenomenal entailments.
p57. Entailment relations between phenomana are subsumed under the general framework of causality. ... entailment relations can exist between phenomena and that their study comprises causality; hence science and causality are to that extent synonymous.
Two entirely different mode of entailments (inferential and causal entailments) are themselves related. The assertion of this relation is embodied in the concept of Natural Law; the crucial instrument in establishing the relation is the concept of model.

3H. The Modeling Relation and Natural Law

p58. Natural Law makes two separate assertions about the self and its ambience: 1. The succession of events or phenomena that we perceive in the ambience is not entirely arbitrary or whimsical; 2. The relation between phenomena that we have just posited are, at least in part, capable of being perceived and grasped by the human mind. ... Science depends in equal parts on these separate prongs of Natural Law.
p 59. The art of bringing the two (causal and inferential entailments) into correspondence, through the establishment of definite modeling relation between them, is the articulation of the former within the latter; it is in effect science itself.
In physics, for example, a measurement process is precisely geared to associate a number with an event or phenomenon.
p60. It is in fact one of the basic beliefs of physics, made explicit in quantum mechanics, that every observation, i.e., every material interaction of the self with its ambience, can be equivalently expressed in terms of an appropriate family of numerical measurements.
Any measurement is an act of abstraction, an act of replacing the thing measured by a limited set of numbers.
p61.

p62 . The encoding and decoding arrows in this case are still unentailed, but it is no longer clear how they could be entailed. ... Thus these arrows, which play the central role in comparing causal and inferential entailment, and hence, in the operation of Natural Law itself, turn out to possess a new ambiguous status, equally within, and outside of, both the self and its ambience.
p63. Reduction to a common set of material constituents is not the only way, nor even a good way, of comparing natural systems.

3I. Metaphor

p65. This is the essence of metaphor: decoding without encoding, in a sense, only the top half of our modeling relation.
machine metaphor, open system metaphor
At root, such metaphors are pursued in the belief, or expectation, that they can in fact be turned into models.

Chapter 4. The Concept of State

4A. Systems and States

p67. Systems are described in terms of their possible states, while their environments are not.
There is indeed a profound parallel between Newtonian particle mechanics and the pure syntax of formalization; in each case, everything is supposed to be generated from structureless, meaningless elements.
p68. Hence the power of the belief in reductionism, the scientific equivalent of the formalist faith in syntax. ... And there has as yet been no Gödel in physics to challenge that credibility directly. But there is biology.

4B Chronicles

p69. All the self can see is a sequence of percepts, ordered by its subjective sense of time.
The result of the self looking at its ambience is only a tabulation; a list of what is seen, indexed by when it is seen. Such a list we shall call a chronicle.
p70. The problem of induction is generally hopeless, because arbitrary properties ... do not reveal themselves in samples. Stated otherwise, no sample entails anything about a nonsampled instance.

4C. Recursive Chronicles

p72. a list can never entail a formula.
p73. $f(n) = T^n(r)$ ... we say that the function f, defined in this manner, is *recursively defined*; its successive values are obtained, not by evaluating it at the successive numbers in its domain, but applying a fixed operation or mapping T to its *preceding value*. ... every value $f(n)$ entails the next value $f(n+1)$. ... This apparently trivial situation is the germ on which the state concept, and hence, contemporary theoretical science itself, rests.

CC Iteration may be a better word.

4D. Recursion: Some General Features

p74. recursive chronicles, generated by a mapping T and its iterates, are precisely the ones that can be induced from.

p77. Why is the n-th entry is a recursive chronicle given the particular value $f(n)$? As usual, there are three different answers we can give to this question: 1. Because the initial entry is the value r; 2. Because of the mapping T, which generates the chronicle; 3. Because of the exponent n, for which $f(n) = T^n(r)$. Each of these answers is associated with one of the Aristotelian causal categories; the initial condition with material cause of the effect $f(n)$, the mapping T with efficient cause, and the exponent n with formal cause.

4E. On Taylor's theorem

p78. The unfortunate fact is that most chronicles are not recursive. ... On the other hand, Natural Law suggests that recursiveness must play a key role in the scientific enterprise. How can these facts be reconciled?

Let us begin by observing that the heart of recursion is the conversion of the present to the future, or the entailment of the future by the present.

p79. Taylor's theorem provides a glimpse at how we can make a chronicle, which in itself is not recursive, act as if it were by embedding it in a larger set of chronicles. That larger set, in the case of Taylor's Theorem, consists of a velocity chronicle, an accelaration chronicle, and so on.

p81. There is indeed a deep relation between Taylor's theorem and recursion in general.

4F. Recursion and Constraints

4G. Coping with Nonrecursiveness: Recursion and Constraint in Sets of Chronicles

p89. When we encode chronicles constituting data into a formalism, we will see that recursion itself encodes something about the ambience. What it encodes is not data, but a property of data; the assumption we make about what recursion encodes, and how that encoding is accomplished, in fact constitutes a new facet of Natural Law itself.

4H. Newton's Laws

p89-90. the central concept of Newtonian mechanics, from which all others flow as corollaries or collaterals, is the concept of state, and with it, the effective introduction of recursion as the basic underpinning of science itself.

p90. The first observation is that, philosophically, the Principia belongs to the tradition of Greek atomism, going back at least to the fourth century B.C. The atomists were analysts, seeking to break reality into some kind of ultimate units. ... The structureless particle of the Principia are thus essentially the atoms posited by the Greek analysts. But the Principia did not concern itself with analysis; it was instead a book about synthesis. It tacitly accepted as given the fruits of analytic atomism and addressed rather the question:

what behavior can be manifested by such particles, individually or collectively?
The heart of the Newtonian synthetic theory is recursion.
p95. The upshot of Newton's second law is to effectively collapse the state of the particle, which is an infinite set of variables, down to only two of them, down to position and velocity alone.
Newton's laws serve to transmute the initial dualism between system and environment into a new dualism, that between phase and forces, or between states and dynamical laws.
p96. This purely reactive character of a single particle is very deeply embedded in the concept of state itself;

4I. On Entailment in Physics: Cause and Effect
p98. Any system is characterized by the entailments within it. Thus a formal system is characterized by its inferential structure, ... and a natural system is likewise characterized by its causal structure.
p99. Newton's idea had the virtue of giving everyone plenty to do, a universal framework for the theorist to play with, and at the same time, infinite room for the experimentalist, the observer, and the analyst. ... Only biology, to its chagrin, was forced to stand aside from this triumphant wave, at least until our own century; in deed, molecular biology can be thought of a retarded impact of that wave, which washed over the rest of the intellectual world three centuries ago.
p102. In the Newtonian picture, systems get states; environments do not (and cannot); environments rather become identified with dynamical laws, i.e., with the rule governing the diachronic succession of states.
We have automatically placed beyond the province of causality anything that does not encode directly into a state-transition sequence. Such things have become acausal, out of the reach of entailment in the formalism, and hence, in principle undecodable from the formalism.
p103. Every natural system possesses a largest model (particle model), from which every other model can be effectively extracted by purely formal means. Reductionism can be characterized as the search for this largest model. Furthermore, I repeat that this largest model is of an essentially syntactic nature, in that structureless, unanalyzable elements (the particles) are pushed around by mandated rules of entailment that are themselves beyond the reach of entailment.
I shall define a natural system to be a mechanism if it possesses the properties I have just articulated: namely, (1) it has a largest model, consisting of a set of states, and a recursion rule entailing subsequent state from present state; and (2) every other model of it can be obtained from the largest one by normal means.

4J. Quantum Mechanics, Open Systems, and Related Matters
p104. The heart of Newtonian causality (recursion) has passed intact from classical to quantum mechanics.
p105. No one is today sure what the formalism of quantum theory encodes, or even it

is encodes anything at all; in this latter view, advocated by Bohr under the rubric of complementarity, the only thing that matters is the decoding.
These formalisms serve to replace the vague word "event" with the apparent nor precise "state x of system N", and ultimately, to replace "system N" by "family of structureless particles." This last replacement, which as we have seen is at the heart of reductionism, basically constitutes a redefinition of the term "system".
p106. Open systems are not precisely "system"
p107. physics has always had serious difficulties with "open system" e.g., families of particles that can turn over. As we have seen, the difficulty is precisely in assigning to such a situation a notion of state that is recursive. The physicist has always tried to avoid dealing with such situation; where it could not be avoided, the strategy has generally been: (1) to close the system up again, obtaining thereby a set of states governed by recurs in rules, and then, either (2) impose enough hypotheses to make the "open system" governed by new recursion rules on that same set of states, or (3) cede autonomy altogether and superpose on the recursion rules governing the closed system some explicit but arbitrary function of time. In every case, the strategy is then to regard the "open system" as an underlying closed system plus something.

Chapter 5 Entailment Without States: Relational Biology

5A A New Direction

p108. Contemporary biology has concerned itself almost exclusively with the endlessly fascinating epiphenomena of life, but the secrets are not to be found there, no more than one can fathom the nature of the dynamical bond by staring at the periodic table.
p109. Thus contemporary biology simply is what these people (virtuosi in the manipulation of lab equipment, geared primarily to isolate, manipulate and characterize minute quantities of matter) do; it *is* precisely what they say it is.

5C. On the Concept of "Organization" in Physics

P114. "Organization" becomes an attribute of thermodynamic state. It is measured at that level by its distance from the equilibrium state. Insofar as thermodynamic state can be identified with a set of underlying phases, "organization" is measured by a single number, expressing how improbable that set is.

5D. The Concept of Function

p116. I shall now argue that what is missing from the thermodynamic images of organization, but which lies at the heart of our intuitive usage, is tied to a concept that biologists call *function.*
It is relatively easy to objectify the concept of function. ... We can ask a question like: *if we were to remove, or change, one of these distinguished parts, what would be the effect on that behavior?* This is a pregnant question. It involves a new element, not merely observation, but willful, active intervention. The result of that intervention is, in effect, the creation of

a new system. ... Any discrepancy between these behaviors defines function of the removed part. Indeed, as we shall see, *it provides us with another way of describing that part,* a new way of encoding that part into a formalism.
Any part of a system that can be assigned a function in the above sense will henceforth be called a *component* of the system.
From a formal point of view, the concept of function, and its embodiment in terms of components, is a part of stability theory. Namely, we are comparing two different situations: an original unperturbed one, and a second one, arising as a perturbation of the first. the discrepancy between the two systems defines the concept of component; the discrepancy between the two behaviors defines the function of the component.
p117. I shall say that any system is organized to the extent that it can be analyzed into or built out of constituent components. The characteristic relationships between such constituent components, and between the components and the system as a whole, comprise a new and different approach to science itself, which we call the *relational theory of systems.*

5E. In the Strategy of Relational Modeling.
p118. A Newtonian approach ... the behaviors of our original system are recaptured in terms of the state transition sequences imposed by the general recursion rules on the special set of states that represent our original organized system. The only thing remaining is to mandate the initial conditions; we must specify one of those special states; otherwise, we will find ourselves studying some other disposition of those same particles but one that is artifactual as far as our original system was concerned.
In empirical terms, then the very first step in the analysis of an organized system is to destroy that organization. That is, we kill the cell, sonicate it, ... We must do it to liberate the constitutent particles, which are then to be further fractionated. In the Newtonian picture, this procedure has only taken us from the limited, special set of states that cell originally occupied into a larger set of states, where we have more room and can see more clearly.
p119. I can epitomize a reductionistic approach to organization in general, and to life in particular, as follows: *throw away the organization and keep the underlying matter.*
The relational alternative to this says the exact opposite, namely: when studying an organied material system, *throw away the matter and keep the underlying organization.*

5F. The Component
p120. The component may be thought of as the particle of function; it plays the same kind of role in relational modeling that particles play in reductionistic or Newtonian modeling.
p121. But the notion of component is tied to that of function, and this in turn is dependent upon the larger system of which the component is a part.
A particle, or any unit of structural analysis, does not (indeed, cannot) acquire new properties by being associated with a larger family of such units; on the contrary, the larger family is itself endowed with precisely those attributes that are contributed individually by its members. Thus, a thoroughgoing reductionistic, structural approach to the natural world

must deny reality to such concepts as novelty or emergence at any fundamental level. These become mere epiphenomena, new ways of collecting the same old particles. The collection may look new, but the particles themselves, unaffected by that fact, continue to impart their attributes to the new collection in the same old ways.
The situation is quite different with a functional unit or component. As we have seen, such unit can by its very nature have no completely inherent, invariant description that entails its function; on the contrary, its description changes as the system to which it belongs changes. It can thus acquire new properties from the larger systems with which it is associated.
what we call a component must be endowed with the following properties: (1) it must possess enough "identity" to be considered a thing in itself, and (2) there must be enough room for it to acquire properties from larger systems to which it may belong. ... It is this latter part that specifically pertains to the function of the component.
p123. A component possesses an inherent polarity or asymmetry, ... specifically, there is an input side or afferent side, reflecting the collective influence of the rest of the system, and of its environment, ... likewise, there is an output side, or efferent side, reflecting the influence of the component.
The formal image of a component must be a mapping: $f : A \to B$.

5G. Systems from Components

p126. *Organization is that attribute of a natural system which codes into the form of an abstract block diagram.*
Organization itself is a rather complicated concept; it invoves a family of sets, a corresponding family of mappings defined on these sets, and above all, the abstract block diagram that interrelates them, that give them functions.

5H. Entailments in Relational Systems

p127-8. An individual mapping in a category,

$$f : A \to B, \tag{0.1}$$

is in itself already a vehicle of entailment. It says specifically that, for any element a in its domain A

$$f Rightarrow(a \Rightarrow f(a)). \tag{0.2}$$

The mapping f and the specific value a on which it acts, are each required to entail the image $f(a)$, ...
p128. Only elements of sets can be entailed within a category as an image; this entailment is called the inner entailment.
In the above picture f is the efficient cause, and a is the material cause.
p129-30. Outer entailment: structure that comes from the defining properties of categories themselves.
composition of mapping: gf is entailed from f and g by a binary operation $F(f, g)$. it is crucial to keep in mind that F is not in the category, however.

Finalistic Entailment: Function and Finality

p131. two kinds of entailment; inner entailment and outer entailment. The former were embodied in individual mappings the formal images of components), while the latter came from the global inferential rules governing the totality elements; the outer entailments allow us, in a limited sense, to entail mappings and sets as well.

p132. The Darwinian argument is that the produce of an evolutionary process gives the appearance of design but without any of the finalistic implications of design.

As such, the explanation of function then devolves upon the evolutionary process itself, and not upon the particular relation of part to whole that process has generated. It thus remains illegal to explain the funtion by referring to its role. This is only a facon de parler, and never be taken literally.

The bulk of biology itself is not at all concerned with elucidation of evolutionay chronicles, but rather with trying to understand organisms as individual natural systems in their own right.

Any exclusion of finality from evolution does not thereby exclude it from physiology, or conversely.

p134. A component is entailed by its function, in any particular abstract block diagram in which it appears. functional entailment.

There is nothing unphysical about functional entailment. What is true is that functional entailment has no encoding into any formalism of contemporary physics. ... On the other hand, it reflects basic features of material orgnization per se.

Augmented Abstract Block Diagrams

p135. In Category theory, there is nothing that mandates this absolute distinction between sets and mappings. In this way a mapping can be entailed as an image of a map.

p137. The map entailing a map can also be entailed by another map, and so forth. This can be iterated indefinitely.

Finality in Augmented Abstract Block Diagrams

p139. The causal correlates of the simple diagram $f : A \to B$ we have the following:

1. If we treat the image $f(a)$ as effect, then $f(a)$ has material and efficient cause but not final cause;
2. If we try to treat the map f and its argument a as effect, then they have only final cause, identified with what they entail (namely, with $f(a)$).

p139-40. Note explicitly that final cause is not a unique mode of entailment, in the same sense that the other causal categories are. ... Thus, it is that finality is allied to the notion of possiblity, while the other causal categories involve necessity.

p140. There is nothing in the components that mandates that particular organization, nor anything in the organization that mandates those particular components. It is only after an organization has been specified, by means of positing a definite abstract block diagram, that its components acquire specific functions, and the resulting entailments within that organization can be analyzed and explored. All the rest lies in the specific character of

particular realizations, whose particularities are not entailed relationaly.
Of course, such ideas do not sit well with those who analyze only individual material realizations of particular modes of organization. In such particular situation, the organization is "wired in" to the physics of the system, impression that the physics is entailing the wiring, rather than (in a precise sense) the reverse. This impression encourages them to look for entailments from material structure to functional organization, entailments that are not in fact there. Nevertheless, the temptation is strong to attempt to argue "from material structure to function", to posit unique relationships between the two, and to dismiss denials of such relationships as "holism". to them, what they call "holism" is sterile, precisely because it denies these entailments, on which their activities depend.
p142. the function of f is the entailment of f.

5L. The Theory of Categories
p149. Category theory can talk about itself, or describe itself, in ways more nearly akin to natural languages than to the formal systems that normally constitute mathematics.

Chapter 6 Analytic and Synthetic Models
6A. Modeling Relations
p154. The difference between direct sum and direct product, between synthetic and analytic models, is also closely allied to the difference between syntactic and semantic.

6C. Analysis and Cartesian Products
p164. Every family of observables gives rise to an analysis, a representation of the set on which the elements of the system are characterized in terms of the Cartesian product of the spectra of those observables.
p165. The analytic model of this type should look familiar; it looks like a state space; the observables that define its constituent quotient set are state variables. By making such models, we pull questions about S itself into corresponding questions pertaining to the ranges of these state variables; ...
p166. The essence of analytic models is that every element s of S gets encoded into something; in fact it gets encoded into the values $\{f_\alpha(s)\}$ of the observables $\{f_\alpha$ we have chosen to define the model.

6D. Direct Sum
p167. We learned about S by looking at the ranges of mappings defined on S, and inputing back from range to domain. The strategy now will be: to learn about S by injecting things into it; to consider S as range rather than a domain.
p170. we will now assign a model $M(S)$ to the direct union or direct sum

$$S = \sum_{\alpha} U\ _{alpha}.$$

Intuitively, a state of S will be determined by assigning a state to each summand U_α. that is, $M(S)$ consists of all α-tuples (u_α), where $u_\alpha \in M(U_\alpha)$.

CC that is, analytic model is specified by the common set of all the models with specified observable values, while synthetic model is specified by specifying its component values.

Analytic and Synthetic: Comparison and Contrast

p174. Synthetic models are an embodiment of pure syntactics, whereas analytic models are inherently semantic.
p176. Every synthetic model is an analytic model. ... There generally exist analytic models that are not synthetic models.
p177. There exist analytic models that possess no synthetic refinements.
We can require of our formal world that synthetic and analytic do coincide. This is a very special world, in which the system itself is already linear in some sense. It is tantamount to mandating that the system is an inherently syntactic structure. ... Presuming anything like this about S is tantamount to placing the most severe restrictions on causality itself.

6F. The Category of All Models of S

p177-8. One analytic model is called better than another if it is a refinement, if it discriminates better between the elements of S. On the other hand, a synthetic model is called better than another if it "sees" more summands. This idea of "better" was reflected formally in the ordering relations we found on the totality of analytic and synthetic models of S.
p178. As our preceding discussion shows, these two ideas of resolution do not in general coincide.
The esssential feature of a model S is that it encodes something about S. In an analytic model, we encode an element s of S into a set of observable values

$$s \to \{f_{\alpha(s)}\}$$

and thereby encode S itself into a Cartesian product

$$s \to \prod_{\alpha} f_\alpha(s) = \prod_{\alpha} S/\cap_\alpha R_{f_\alpha}.$$

In a synthetic model, on the other hand, an element s of S is encoded into a cross-section of a direct sum:

$$s \to \{u_\beta\} \in U_\beta.$$

The essential fact about such encodings is that they are in general many-to-one; that is many elements of S generally get encoded into the same name or label in the model.
CC Here the word model is more like expression. This is why encoding is used.
p179. To refine analytic models is easy; simply expand the observable set. To refine synthetic models, the base space is expanded; that is, the model is made from finer components (refined components).

Chapter 7 On Simulation

7A. The Machine Concept

p183. In the Newtonian mechanism, the distinction between animate and inanimate idsappeared; indeed , life is now to be explained in terms of the same mechanics that had previously explained the motion of the comets, the planets, and the stars, for there now was no other accepted mode of explanation. Here the allure of the machine metaphor.

7B. Some General Heuristic Remarks

p184. It took a very long time for anyone to recognize that recursiveness and program, were formal concepts that could be studied entirely in the abstract, divorced from any particular material embodiment. It did not in fact occur until 1936, when Turing published his famous paper.
p185. The Turing machines are in fact the forma counterparts of the clockwork, although they were not constructed as such.
Simulation is what machines do, and a system (formal or material) is a machine if it simulates, or can simulate, something else.
p186. I shall show, EVERY MODEL SIMULABLE IMPLIES ANALYTIC = SYNTHETIC, and to a sufficiently large extent, conversely.

The Algorithm

p188-9. Three mappings (rules) F, G, and H designating recursiveness is what I shall call an algorithm. Here

$$k' = F(k, w, \sigma), \;\; w' = G((k, w, \sigma), \;\; \sigma' = H(k, w, \sigma),$$

where k is the coordinate (k-th letter) in the word w (thus (k, w) is the elementary configuration), and σ corresponds to the velocity (i.e., the rule to give the immediate future). (k, w, σ) is the set of elementary phase space.
p189. What I have called an algorithm is essentially a Turing machine.
p190. The reading head is the seat of entailment, all the inferential structure, all the mappings. I shall call it hardware. On the other hand, the tapes, and anything that can be inscribed on them, contain no entailment at all; I shall call them software. This distinction between hardware and software has no Newtonian counterpart; the closest we can get to it is to think of particle configurations as “software” and environment (the seat of forces) as “hardware”. This is clearly an unnatural and most unattractive way of trying to talk about physics.
CC of course only the input symbols on the tape are the software.

7D. Simulation and Programming

p191. The assertion that formalizations suffice in the expression of Natural Law, and hence, that causal entailment is to be reflected entirely in algorithms, is a form of Church’s thesis. ... For good or ill, it is not true, not even in mathematics itself.
p192. The word “simulable” becomes synonimous with “evaluable by a Turing machine.”
p193. In causal terms, simulation involves the conversion of efficient cause, the hardware of

that being simulated, into material cause in the simulator. In essence, this means that one can learn nothing about entailment by looking at a simulation.
Note the following significant fact. Namely, it is obvious that any machine can simulate itself. Its program for doing so happens to be the empty word. ... any machine can have only a trivial description of itself.

7E. Simulation anbd Programming continued

7F. Simulations and Models
p199. In the case of modeling, the relation between the model and the system (encoding and decoding) do not affect the formalisms in the two systems being compared. At the level of the formalisms themslves, the inferential structures that define them are themselves unentailed. They are simply presumed to be given at the outset. All the entailment relations within the formalisms are preserved by the modeling relation between them; that is precisely why we can learn about one of them by studying the other.
p199-200. As with modeling, there must be an encoding and decoding. It is precisely here, however, lthat the basic difference arises.
p200. Namely, in simulation, the map to be simulated is pulled inside the simulator by the encoding itself. Simulation is not a congruence between inferential structures.
p201. Insofar as the distinction between "hardware" and "software" is intrinsically meaningful, it is always preserved by modeling relations. It is never preserved by simulations.

Chapter 8 Machines and Mechanisms
8A. Review
p202. Intuitively, analytic models are based on the notion of observables and led to encodings of N into Cartesian or direst products of spectra of obervables. Synthetic models, on the other hand, were based on the idea of direct sums of disjoint summands.
p203. Roughly speaking, I showed that a formalism can be simulated if this inferential structure could be expressed as software to a mathematical machine, in particular, as program. As I suggested this places severe restrictions on that inferential structure; simulability of a formalism is a strong condition to be mandated of it.
8B. Machines and Mechanisms
p203. We shall say that a natural system N is a mechanism if and only if all of its models are simulable. We shall further say that a natural system N is a machine if and only if it is a mechanism, such that at least one of its models is already a mathematical machine.
My characterization of mechanism will be seen to be nothing but Church's Thesis, explicitly and fully manifested in its true material garb. As I noted earlier, the intent of Church's thesis was initially to characterize vague notions of "effective" calculability and algorithm, and hence programmability in Turing machines. But because it is so easy to equivocate on the word "machine" and because everything that happens in the material world must certainly be considered "effective", Church's thesis has always been tacitly supposed to have a physical content as well.

p204. My definition of mechanism above merely charaterizes the world in which this equivocation is legitimate (i.e., within which Church's thesis becomes elevated to a Law of Nature) and investigate the consequences.
In any case this characterization of mechanisms and machines will be seen to be completely intrinsic and unrelated to any questions of history, or of fabrication, by which material machines are usually characterized.
"every natural system is a mechanism", or "every organism is a machine" are, of course, part of the very fabric of which contemporary science is composed.
p204-5. Some of the conclusions that will be established in the remainder of the present chapter are:
Conclusion 1: If a natural system N is a mechanism, then it has a uniqe largest model M^{max}. That is, the category of all the models of N ($\mathbf{C}(N)$) contains a unique maximal element, with respect to its natural partial ordering. Epistemologically, this model contains everything knowable about N, according to Natural Law.
Conclusion 2: If a natural system N is a mechanism, then there is a (necessarily finite) set of minimal model M^{min}.
Concusion 3: The maximal model is equivalent to the direct sum of the minimal ones;

$$M^{max} = \sum_i M_i^{min}$$

and is therefore a synthetic model.
These conclusions will allow us to define states for the maximal model, in terms of the minimal ones, in a completely intrinsic way, so that change of state is necessarily recursive in M^{max} if they are in the M_i^{min}. On the basis of this, we can conclude further:
Conclusion 4: If N is a mechanism, then analytic and synthetic coincide in $\mathbf{C}(N)$; direct sum = direct product.
Finally, I shall introduce a notion of fractionability, relating properties of N to corresponding properties of its synthetic models. We will then have
Conclusion 5: Every property of N is fractionable.

8C. On the Largest Model of a Mechanism

p205. To show that a mechanism must have a unique largest model is very easy.
Mechanism implies simulable, i.e., there is a program for a TM. The intersection of all the models in $C(N)$ which is the most refined model must be in $C(N)$ and must be simulable. Hence, its program size must be finite. Hence, the largest model is in $C(N)$. This must be unique trivially.
p206. if N is a mechanism, ther are only a finite number of refinements between any model and the unique max model.

8D. On the Smallest Models of a Mechanism

p206. totality of mimal models of N must constitute only a finite set, and the elements of this set are all mutually incompatible.

8E. Maximum Model from Minimal Models

p206. if the max model is not the direct sum of the totality of the minimal models, then there is a model P whose direct sum with $\sum M^{min}$ gives the max model. This is, however, contradictory to the assumption that M^{min} exhausts all the minimal models. Hence, max model must be the direct sum of minimal models.

p209. the relation between the largest model and the smallest ones is a purely syntactic relation; ie, it says that all we can know about N inheres already in (1) its spectrum of smallest mdoels and (2) the purely syntactic rules, independent of N, for generating direct sums in $C(N)$.

8F. On States and Recursivity in Mechanisms

p209. One corollary of the purely syntactic relation that exists between max and min models is the following: if the latter have states, then we can use these to assign states to max model in a unique way. This fact is indeed inherent in the very idea of a direct sum; see 6D; or once we have encoded N into the min models, a corresponding encoding of max model is thereby entailed.

Simulability and recursion (i.e., simple Markov type time evolution) need not be coextensive. Record all the time data. If it is not recursive, take derivatives or record tha pst informations until the sequence gives a recursive relation. Since, the system is a mechanism, there must be a finite max model, so the sequence cannot be indefinitely long. Hene, recursion relation exists.

p210. We conclude, then, that simulability actually entals recursion in max model. the constraints mandated by simulability are manifested in the form of differential equaitons.

In the case of QM to same recursiveness, encoding scheme wa changed.

8G. Synthesis and Antisynthesis: Fractionability

p211. If N is a mechanism, then any model is equivalent to a synthetic model. Hence, in particular, any analytic model must be a synthetic model.

p212. If N is a mechanism, any mode of analysis whatsoever is equivalent to a process of antisynthesis.

reductionsim and antisynthesis are essentially the same.

8H. Mechanisms and Contemporary Physics

p213. It is my contention that contemporary physics has actually locked itself into this world (= world of mechanisms). this has of course enabled it to say much about the (very special) systems in that world, and nothing at all about what is outside. Indeed, the claim that there is nothing outside is the sole support of contemporary physics' claim to universality.

The minimal models come equipped with states; it does not matter whether we call them phases or wave functions or whatever else we care to call them.

In short, we see the full form of contemporary physics flowing solely and entirely out of the hypothesis of mechanism. The only things that do not follow from that hypothesis are (1) that there is a universal fininite family of minimal models, corresponding to a fixed finite number of different kinds of “elementary particles” which suffice for any natural system N, and (2) the assignment of states to such “elementary particles”.

Chapter 9 Relational Theory of Machines

9A. Machines

p215. Machines in general admit relational descriptions.
p216. the functional units will be called components; their specific action on software will be expressed in terms of inputs to these components, and the entailment of corresponfing outputs.
The result will be to express the overall behavior of the machine as a family of ternary relations between inputs, outputs, and components.
Our main result is concerned with the kinds of interlocking graphs, or relational descriptions, that can arise from machines in this way. This result can be elegantly phrased as follows. It is possible to define a generalized notion of paths through these interlocked graphs. Our result is: in a relational description of a machine, there can be no closed paths. As we shall see, it is this result that dooms the Cartesian metaphor, and much more than this, that exposes the inadequacy of contemporary physics itself as a vehicle for encompassing biology, and hence, material nature.

9B. The Basic Idea

p216-7. For a machine: natural system such that (1) all models are simulable, (2) there is a model of the system that is a mathematical machine. I will use only one feature of this hypothesis, namely, that we can make a distinction between software and hardware.
p217. Intuitively, we think of the hardware of a mathematical machine as a processor of software. As such, this hardware has aninherent polarity; it has an inut or afferent side, and an output, or efferent side.
p217-8. The distinction between hardware and software means that we can decompose the largest model into two big direct summands. Every state of the machine can thus be split into two blocks, one block pertaining to what we called hardware alone, the other pertaining to what we called software alone.
Since by hypothesis we can write a state of the system in terms of the states of the consitutent particulate models, we can partition such a state into two blocks: hardware and software.
p218. The hardware of the system imposes a further classification upon software, namely, a classification into input, output, and “everything else.”
p220. We have seen that, in general, if a mechanism is a machine, then its state can be segregated into blocks or direct summands, i.e., put into the form: state = ((hardware), (input), (other), (outputs)). Since these blocks are direct summands, they are unlinked and can be selected ad lib.
p221-2. The map $f : A \to B$ can be interpreted as: A = inputs, B = outputs, and f = hardware, and $\to$ = flow induced by hardware f..
p222. $\to$ can be identified with “other” in the software. ... It cannot be stressed too

strongly that, in these considerations, the hardware f and the flows it induces on software are fundamentally different things; they encode entirely different aspects of the natural system they model.
p223. One of the features of such diagrams is that they are open-ended; domains in a diagram can be ranges of other things.

9C. The Second Step
p228. Henceforth, I shall call a diagram of mappings, such a relational model, an abstract diagram of the machine with which it is associated.

9D. Entailment in Machine Models
p230. Once we say that a natural system possesses a model that is a mathematical machine, we have placed what will turn out to be devastating limitations on the operations of causality in that system (or at least, on what is encoded into the machine model). Specifically, we have segregated the causal categories into disjoint structures.
The main feature here is the absence of certain kinds of paths in this graph. Specifically:
If a vertex in this graph originates a solid-head arrow, it cannot terminate a hollow-headed arrow.
p230-1. The solid head arrows, and the inferential rules they represent, are themselves unentailed in the machine.

9E. The Third Step
p232. This (= tidy situation in which everything in the system is already entailed by something else in the system) is precisely what cannot happen within the confines of machines, or even of general mechanisms. From this, we will conclude that, if it does happen, then what makes it happen cannot be a machine. ... It happens in biology.
p233-4.

$$\Phi \to X \Rightarrow f; f \to A \Rightarrow B, \quad 9E.1$$

where $\Phi \to X$ means that Φ changes as a hardware X which is an input. $\Rightarrow$ means the input-output relation. This diagram could be, as a formalism, be interpreted as a mathematical machine of the form

$$\Phi \to X \Rightarrow B,$$

if we interpret the composite

$$X \Rightarrow f \to A \Rightarrow B \quad 9E.5$$

as a single software flow with f as program. (i.e., Φ is hardware which executes the program f). But clearly, such an interpretation would profoundly obscure the causal features of the original diagram. (Why f? . Why $f(a)$?).
p234. ... This clearly arises because the hardware.software distinctions implicit in (9E.5) are not compatible (indeed, are inconsistent) with those arising from 9E.1.
Indeed, under this interpertation (9E.5) describes a simulation of f by Φ, rather than an

entailment of f by Φ. Nothing could more starkly illustrate the anomalous character of simulation and the mischief that can arise through its confusion of causal categories. I remark parenthetically that the confounding of simulation (computation) with construction, which lies at the heart of, e.g., von Neumann's well-known discussion of "self-reproducing automata," arises precisely here and rests entirely on the equivocal and inconsistent hardware.software distinction to which I have just called attention.

The distinction between hardware and software, then, is a completely meaningful and legitimate one, but it must be maintained consistently when decoded back to a natural system.

9F. The Central Argument: The Limitations of Entailment in Machine and Mechanisms

p237. To entail Φ we must graft a diagram before Φ to entail it. Only in the limit of infinite regression could we talk about every component being efficiently entailed, i.e., in which every question of the form "why Ψ ?" would have an answer in the system. But this limit obviously cannot be a mechanism; a mechanism must have a largest (simulable) model, and the limit does not.

It may be that we already have enough states, that Φ is already efficiently entailed in the diagram (9E.1). This possibility means that we can entail Φ, not by adding more states as we did above, but rather by drastically constraining the ones we already have.

p238. I am saying that the more constrained a mechanism is, the more programmable, the more like an organism it appears.

9G. Conclusions

p241. There can be no closed path of efficient causation in a mechanism; in terms of graphs, there is no cycle that contains all $\rightarrow$.

A mechanism is a system in which syntactics and semantics coincide.

By elevating them (mechanisms) to Laws of Nature, we guarantee that we shall never leave this world. This is, essentially, what contemporary physics has done; it has thereby become the science of mechanisms.

p242. Indeed, it there should be material system that is not a mechanism, all that contemporary physics can do about it is to tell us what properties it cannot have. .. For instance, such a system cannot have a state set, built up synthetically from the states of minimal models and fixed once and for all.

A system that is not a mechanism must have nonsimulable models. What then becomes of prediction, of verification, of falsification, and all the other such ideas that have (mistakenly, in my view) become touchstones for science itself?

What ever happens to mechanism, Natural Law remains; hence the concept of model remains. It is this to which we must retreat and venture forth again in a new direction.

These remarks provide an essential clue to how we may yet keep some of our mechanistic cake. The failure of a natural system to be a mechanism does not at all mean that it has no mechanistic models; ... If we are lucky, the closure of the subcategory of mechanical models will be precisely the whole category of all models.

Chapter 10. Life Itself: The Preliminary Steps

10A. The Answer

p244. The answer we propose is now this: a material system is an organism if, and only if, it is closed to efficient causation. That is, if f is any component of such a system, the question "why f?" has an answer within the system, which corresponds to the category of efficient cause of f.

Theoretical biology is the study of the category of all models of such systems.

p245. Biology becomes identified with the class of material realization of a certain kind of relational organization, and hence, to that extent divorced from the structural details of any particular kind of realization.

Biology becomes in fact a creative endeavor; to fabricate any realization of the essential relational organization is to create a new organism.

10B. The "Machine Metaphor" Revisited

p245-6. In a machine, the components themselves are direct summands of disjoint states, and the whole machine can itself be described as a direct sum of such summands. In an organism, we can make no such identification; components are not in general direct summands of anything; indeed, the concept of direct sum is not even available any more.

p246. Suppose that f represents a component; let us ask the question "why f?" and seek an answer in terms of efficient causation: becasue Φ. As we have seen, if we are dealing with a machine, we cannot generally provide such an answer within the system, something outside. In effect, we are thereby ascribing a function to the environment, namely, to answer "why Φ" in terms of a category of final causation: "because Φ entails f." We thereby put not only efficient cause (of f) but also final cause (of Φ) into the environment.

In short, efficient causation of something inside the system is tied to final cause of something outside the system. As Voltaire once succinctly put it, " a clock argues a clockmaker," from which he then went on to conclude, by extrapolation, "therefore a universe argues a God." This kind of dialectic is in fact, as we have seen, inherent in the concept of machine; once one puts efficient causation of a system component into the environment, one thereby also puts final causation outside the environment. And as I pointed out before, one of the main intentions of the machine metaphor itself was to dispense with final causation entirely. Instead, it inevitably reappears in a worse form than before.

p247. organisms generally have many different machine models. But the organism itself is not in any sense a direct sum of such models; it can only be considered as a kind of limit of them.

These same considerations also allow us to conclude that biomimesis is not an effective strategy for producing organisms.

For the same reasons, I would hazard that "artificial intelligence" systems could never be intelligent.

p248. On balance, the Cartesian metaphor of organism as machine has proved to be a good idea. Ideas do not have to be correct in order to be good; it is only necessary that, if they fail, they to so in an interesting way.

10C. Relational Models of Organisms
p249. Organisms' abstract block diagrams manifest maxmal entailment; why f has an answer within the system (in terms of efficient causation). Unfortunately, this is simply not compatible with the idea of mechanism; therefore it can no longer be interpreted or understood in purely syntactic terms. Organisms then must manifest an inherently semantic character when viewed from the standpoint of mechanisms. As with the parallel situation of formalization in mathematics, this fact only gives trouble if we insist on believing tht syntax exhausts the world.

Chapter 11. Relational Biology and Biology
11A. What is Biology?
p255. To me, it is easy to conceive of life, and hence biology, wiothout evolution. But not of evolution without life. Thus evolution is a corollary of the living, the concequence of specialized somatic activities, and not the other way around. Indeed, it may very well be more a property of particular realization of life, rather than of life itself.
11B. The Paradoxes of Evolution
p255. Evolution has, as we have seen, come to do for biology today what vitalism did for it previously. Vitalism, in its most general form, simply asserted that whatever made organisms alive was forever out of the reach of what governed inanimate nature. Some additional principle, some vital force, had to be invoked; it was precisely this additional principle, missing from the rest of nature, which made organism in principle inexplicable via inanimate nature alone.
In the past, the only perceptible alternative to this vitalism was mechanism;
The converse claim that there is nothing in biology wich cannot be understood in precisely the same terms in which anything else in nature is understood.
p256. Mechanism offers a secure place for biologists in science ... respectability through the adoption of a common shared tradition and shared principles.
Biologists today have come to see in Darwinian evolution a way of distinguishing themselves again, of making themselves separate, without the vitalistic traps. Basically, the argument is now that it is evolution which is unpredictable, non-mechanical, immune to the entailments, the causality, the determinism which mechanism made them espouse. By the single, simple act of redefining biology, to assert that it is about evolution rather than about organism, we can in effect have our mechanistic cake, and eat our vitalistic one, too. To avoid making evolution subject to mechanism is therefore essential. But it is also essential to avoid asserting anything vitalistic. The only way to do this is to deny any vestige of entailment in evolutionary processes at all. By doing so, we turn evolution, and hence biology, into a collection of pure historical chronicles, like tables of random numbers, or stock exchange quotation.
p256-7. This absolute denial of entailment in evolutionary processes is thus a central, perhaps, the central pillar, of the current biology weltanschauung. If we did admit entailment into the evolutionary realm, then only two alternatives seem visible: (1) these entailments are tehmselves mechanistic, in which case biology disappears back into mechanism again,

and loses forever its distinguished character, or (2) these entailments are not mechanistic, which seems to mean they must be Vitalistic again. Both of these, for different reasons, are quite unacceptable. Hence we are driven to expunge entailment from evolution entirely, not on any intrinsic scientific grounds, but because of the psychological requirements of biologists.

11C. Mendel, Heredity, and Genetics

p259. Phenotypes cannot be fractionated into "atoms" as a constituent molecules can.
p261. Fitness can only be defined operationally and retrospectively as far as individual organisms are concerned. In particular it cannot be fractionated from anything. It is in fact a very mysterious concept.

11D. Biochemistry, Genetics, and Molecular Biology

11E. Chemistry and Sequence

11F. Protein Folding and Morphogenesis

Tertiary structure: protein structures could be considered as scaffolds to maintain reaction centers. hence,
p274. any larger structure that maintains their configuration would create the sequence; its exact nature, its chemistry, if you will, is otherwise irrelvant.
Hence these scaffolded entities do not have a symbolic representation in terms of that structure at all; they are precisely the intersymbol hybrids mentioned ealier.

11G. A Word on Entailment in Evolution

p275. Perhaps the earliest biologically respectable (ie, nontelic) assertion of entailment in evolutionary processes is found in E. Haeckel's idea of recapitulation. ... What it really asserts is that ontogeny, the morphogenetic processes which culminate in a particular organism, and phylogeny, the presumed evolutionary processes which culminated in that same organism, are in some sense similar. That is, they are intertransformable; alternate realization of a common model.
p276. Tacit in Haeckelian recapitualtion is the idea that, if ontognetic processes are subject to entailment, so are phylogenetic ones. It was not asserted that either phylogenetic process entailed ontogentic ones or vice versa. But that is how people tried to interpret recapitulation.
p277. This (D'Arcy Thompson's idea) is precisely the sort of thing which Haeckel was claiming; i.e., that somatic entialments themselves entail evolutionary ones. But that is precisely what is forbidden in contemporary views about evolution.
It is only here (=bifurcation) that we have even the appearance of "historical accident", becasue we place the source of the perturbation outside the entailment in the system.
p278 Elsasser's biotonic law is analogized with Maxwell's rule at first order phase trans.

11H. Relational Biology and Its Realizations

p279. Contemporary biology gives two kinds of answers to the question "what is life?". In somatic terms, the answer is: life is machine, a purely syntactic device, a gadget, to which a reductionsitic strategy may be universally applied. In evolutionary terms, on the other

hand, life is what evolves; the evolutionary process itself, which takes us from gadget to gadget, is devoid of entailment, the province of history and not of science at all.
to me neither of these answers, either separately nor together, serves to answer the question. Evolution, entailed or not, has from the beginning concerned itself only with origin of species of life; it does not bear on life itself.
Syntax itself has become confounded with what is objective, and this objectivity is what makes science a democratic activity, something which anybody can do, by simply following an algorithm. And, of course, reductionism carries with it the lure of unification; of having to know ulitmately only one thing, one principle, from which everything else syntactically follows.
p280. Complex systems cannot be exhausted by reductionistic fractionation either. Just as we cannot concatenate syntactic models to obtain an organism, we cannot, for the same reason, concatenate reductionistic fractions to get an organism.
But complexity is not itself life. Something else is needed to characterize what is alive from what is complex. Rashevsky provided this too, in his idea that biology was relational, and that relational meant throwing away the physics and keeping the organization. A rough analogue would be: throwing away the polypeptide and keeping the active sites. Organization in its turn inherently involves functions and their interrelations.

Second, the formalist position, that the universe of discourse needs to consist of nothing more than meaningless symbols pushed around by definite rules of manipulation, is exactly parallel to the mechanical picture of the phenomenal world as consisting of nothing more than configurations of structureless particles, pushed around by impressed forces.

Gödel's Theorem

p7. Basically, he showed that, no matter how one tries to formalize a particular part of mathematics, syntactic truth in the formalization does not coincide with (is narrower than) the set of truths about numbers. ...
p8. For our purpose, we may regard it as follows: *one cannot forget that Number Theory is about numbers*. The fact that Number Theory is about numbers is essential, because there are percepts or qualities (theorems) pertaining to numbers that cannot be expressed in terms of a given, preassigned set of purely syntactic entailments. ... There is always a purely semantic residue, that cannot be accomodated by that syntactical scheme. ... Mathematics, like language itself, cannot be freed of all referents and remain mathematics.
p9. Rutherford's position, as articulated above, can be rephrased as asserting that *every material system is a simple system*. .. this position is just another form of Church's thesis, a direct assertion of the simulability of mathematical models of reality..
p18. Many people have tried very hard to produce such criteria for separating the quick from the dead. Put briefly, they have all failed. This fact is most significant in itself, but perhaps of even greater significance is the further fact that we can somehow *know*, with certainty, that they have indeed failed.
p19. The crux of the matter is that, when one tries to embody our recongnition criteria for organisms in an explicit list, we find nothing on that list that cannot be *mimicked* by, or embodied in, some patently inorganic system.

p36. (Reductionism) is an assertion, or conjecture, or belief, pertaining to the generality of contemporary physics itself. And ideed, itis not a conjecture based on any *direct* evidence (as , say, Goldbach's conjecture is), but rather on indirect (circumstantial) evidence, insofar as evidence is adduced at all. In short, it rest on *faith*.
p43-4. Just as nobody has been able to characterize an organism in terms of a discrete list of properties, no one has been able to characterize a "natural language" in terms of a list of production rules. Indeed, if it were possible to do this, it would be tantamount to saying that a (natural) language can be completely characterized by syntactic properties *alone*, i.e., made independent of any semantic referents whatever. There have indeed been deadly serious attempts to do precisely this. They have all failed, often rather dramatically, indicating that, in general, semantics cannot simply be replaced by more syntax.
p 59. The art of bringing the two (causal and inferential entailments) into correspondence, through the establishment of definite modeling relation between them, is the articulation of the former within the latter; it is in effect science itself.
p65. This is the essence of metaphor: decoding without encoding, in a sense, only the top half of our modeling relation.
p67. Systems are described in terms of their possible states, while their environments are not.
There is indeed a profound parallel between Newtonian particle mechanics and the pure syntax of formalization; in each case, everything is supposed to be generated from structureless, meaningless elements.
p68. Hence the power of the belief in reductionism, the scientific equivalent of the formalist faith in syntax. ... And there has as yet been no Gödel in physics to challenge that credibility directly. But there is biology.
p70. no sample entails anything about a nonsampled instance.
p72. a list can never entail a formula.
p102 . We have automatically placed beyond the province of causality anything that does not encode directly into a state-transition sequence. Such things have become acausal, out of the reach of entailment in the formalism, and hence, in principle undecodable from the formalism.
p103. I shall define a natural system to be a mechanism if it possesses the properties I have just articulated: namely, (1) it has a largest model, consisting of a set of states, and a recursion rule entailing subsequent state from present state; and (2) every other model of it can be obtained from the largest one by normal means.
p108. Contemporary biology has concerned itself almost exclusively with the endlessly fascinating epiphenomena of life, but the secrets are not to be found there, no more than one can fathom the nature of the dynamical bond by staring at the periodic table.
p109. Thus contemporary biology simply is what these people (virtuosi in the manipulation of lab equipment, geared primarily to isolate, manipulate and characterize minute quantities of matter) do; it *is* precisely what they say it is.
p119. I can epitomize a reductionistic approach to organization in general, and to life in particular, as follows: *throw away the organization and keep the underlying matter.*

The relational alternative to this says the exact opposite, namely: when studying an organied material system, *throw away the matter and keep the underlying organization.*

p132. The bulk of biology itself is not at all concerned with elucidation of evolutionay chronicles, but rather with trying to understand organisms as individual natural systems in their own right.

Any exclusion of finality from evolution does not thereby exclude it from physiology, or conversely.

p140. There is nothing in the components that mandates that particular organization, nor anything in the organization that mandates those particular components. It is only after an organization has been specified, by means of positing a definite abstract block diagram, that its components acquire specific functions, and the resulting entailments within that organization can be analyzed and explored. All the rest lies in the specific character of particular realizations, whose particularities are not entailed relationaly.

Of course, such ideas do not sit well with those who analyze only individual material realizations of particular modes of organization. In such particular situation, the organization is "wired in" to the physics of the system, impression that the physics is entailing the wiring, rather than (in a precise sense) the reverse. This impression encourages them to look for entailments from material structure to functional organization, entailments that are not in fact there. Nevertheless, the temptation is strong to attempt to argue "from material structure to function", to posit unique relationships between the two, and to dismiss denials of such relationships as "holism". to them, what they call "holism" is sterile, precisely because it denies these entailments, on which their activities depend.

p184. It took a very long time for anyone to recognize that recursiveness and program, were formal concepts that could be studied entirely in the abstract, divorced from any particular material embodiment. It did not in fact occur until 1936, when Turing published his famous paper.

p190. The reading head is the seat of entailment, all the inferential structure, all the mappings. I shall call it hardware. On the other hand, the tapes, and anything that can be inscribed on them, contain no entailment at all; I shall call them software.

p199. In the case of modeling, the relation between the model and the system (encoding and decoding) do not affect the formalisms in the two systems being compared.

p200. Namely, in simulation, the map to be simulated is pulled inside the simulator by the encoding itself. Simulation is not a congruence between inferential structures.

p201. Insofar as the distinction between "hardware" and "software" is intrinsically meaningful, it is always preserved by modeling relations. It is never preserved by simulations.

p203. Roughly speaking, I showed that a formalism can be simulated if this inferential structure could be expressed as software to a mathematical machine, in particular, as program. As I suggested this places severe restrictions on that inferential structure; simulability of a formalism is a strong condition to be mandated of it.

We shall say that a natural system N is a mechanism if and only if all of its models are simulable. We shall further say that a natural system N is a machine if and only if it is a mechanism, such that at least one of its models is already a mathematical machine.

My characterization of mechanism will be seen to be nothing but Church's Thesis, explicitly and fully manifested in its true material garb. As I noted earlier, the intent of Church's thesis was initially to characterize vague notions of "effective" calculability and algorithm, and hence programmability in Turing machines. But because it is so easy to equivocate on the word "machine" and because everything that happens in the material world must certainly be considered "effective", Church's thesis has always been tacitly supposed to have a physical content as well.
p213. It is my contention that contemporary physics has actually locked itself into this world (= world of mechanisms). this has of course enabled it to say much about the (very special) systems in that world, and nothing at all about what is outside. Indeed, the claim that there is nothing outside is the sole support of contemporary physics' claim to universality.
p234. ... This clearly arises because the hardware.software distinctions implicit in (9E.5) are not compatible (indeed, are inconsistent) with those arising from 9E.1.
Indeed , under this interpertation (9E.5) describes a simulation of f by Φ, rather than an entailment of f by Φ. Nothing could more starkly illustrate the anomalous character of simulation and the mischief that can arise through its confusion of causal categories. I remark parenthetically that the confounding of simulation (computation) with construction, which lies at the heart of, e.g., von Neumann's well-known discussion of "self-reproducing automata," arises precisely here and rests entirely on the equivocal and inconsistent hardware.software distinction to which I have just called attention.
p241. A mechanism is a system in which syntactics and semantics coincide.
A system that is not a mechanism must have nonsimulable models. What then becomes of prediction, of verification, of falsification, and all the other such ideas that have (mistakenly, in my view) become touchstones for science itself?
What ever happens to mechanism, Natural Law remains; hence the concept of model remains. It is this to which we must retreat and venture forth again in a new direction.
p244. The answer we propose is now this: a material system is an organism if, and only if, it is closed to efficient causation. That is, if f is any component of such a system, the question "why f?" has an answer within the system, which corresponds to the category of efficient cause of f.
Theoretical biology is the study of the category of all models of such systems.
p246. In short, efficient causation of something inside the system is tied to final cause of something outside the system.
p255. To me, it is easy to conceive of life, and hence biology, wiothout evolution. But not of evolution without life. Thus evolution is a corollary of the living, the concequence of specialized somatic activities, and not the other way around.
p256-7. This absolute denial of entailment in evolutionary processes is thus a central, perhaps, the central pillar, of the current biology weltanschauung.
p275. Perhaps the earliest biologically respectable (ie, nontelic) assertion of entailment in evolutionary processes is found in E. Haeckel's idea of recapitulation. ... What it really asserts is that ontogeny, the morphogenetic processes which culminate in a particular

organism, and phylogeny, the presumed evolutionary processes which culminated in that same organism, are in some sense similar. That is, they are intertransformable; alternate realization of a common model.
p279. Syntax itself has become confounded with what is objective, and this objectivity is what makes science a democratic activity, something which anybody can do, by simply following an algorithm. And, of course, reductionism carries with it the lure of unification; of having to know ulitmately only one thing, one principle, from which everything else syntactically follows.