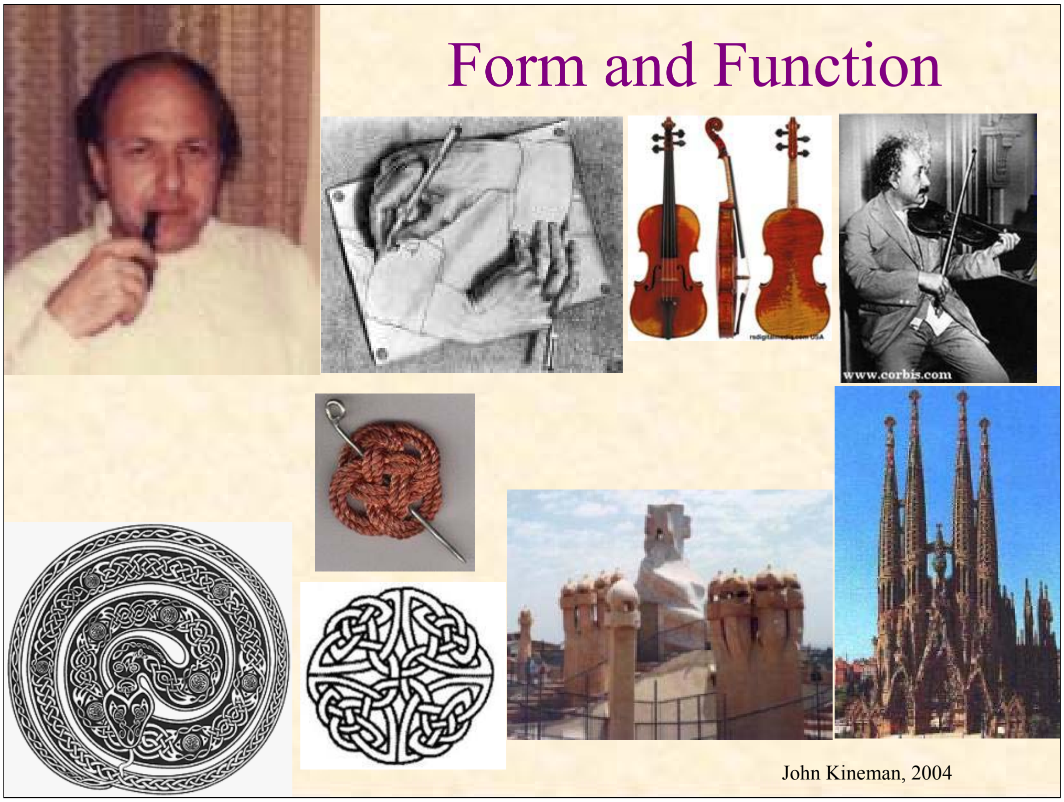
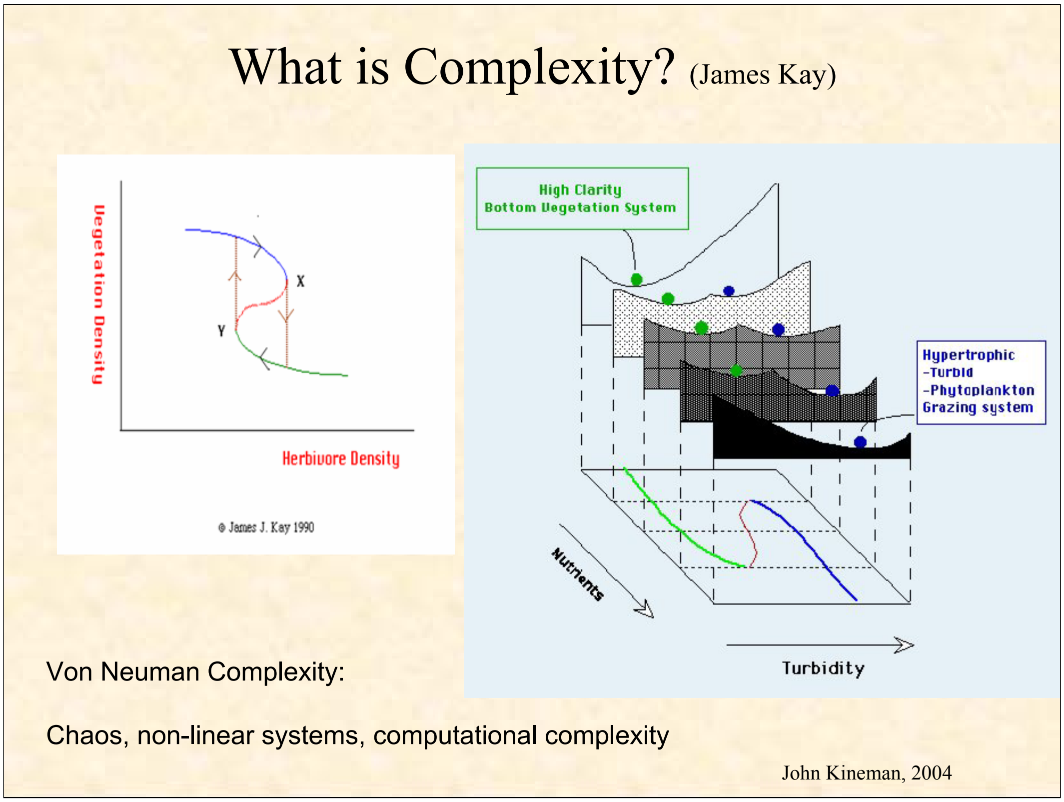


Dr. Robert Rosen was fascinated by the question “What is Life.” He considered that the central question of theoretical biology. As it turns out, he spent his entire life answering this question, and the results he got took him places he didn’t particularly want to go, i.e., to theories and worldviews that many others considered heretical. However, we are fortunate that he was not discouraged, for his contributions to biology, mathematics, physics, philosophy, and systems science are monumental.

His central idea was “function.” This is a word that is used for a lot of things, but he meant it in a very precise way, that eventually became defined by his system theory. Function involves “purpose” or Aristotle’s 4^{th} level of causation. It has traditionally been excluded from most of science, because of the goal to make all science “mechanistic.” Today we know that nature is not a pure mechanism, and its non-mechanistic aspects actually dominate in many aspects of living systems, including social and psychological systems.

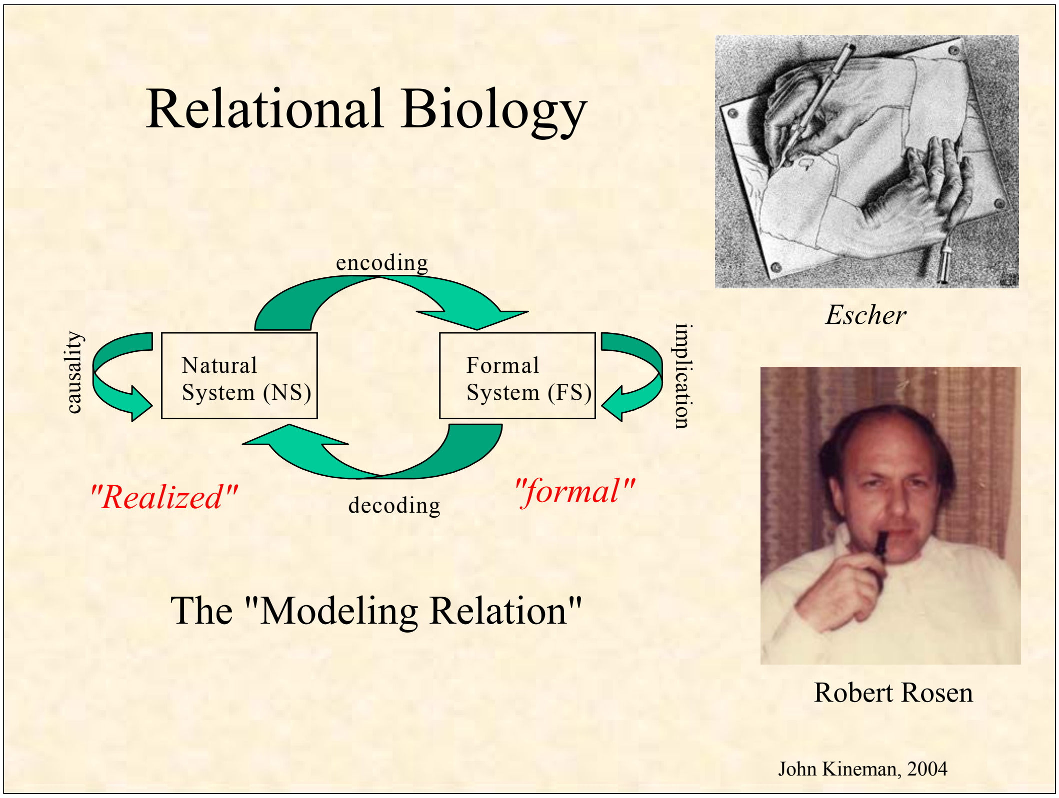
Rosen liked to use violins, Celtic knots, and organic architecture (Gaudi) to illustrate his idea of function. The violin, for example, produces music. This function would be not be detectable by any analysis of the violin alone. Only an analysis of the violin in its full context would reveal this function, assuming one’s scientific view allowed one to infer functions at all. But we can also say that the function itself produced the violin. Granted a human was involved (as the “efficient” cause and producer of “formal” cause), but the final cause of the violin, is music.



One aspect of complexity in the behavior of a system can be seen in the ecology of Lake Erie, which was discovered to have a non-linear "flip" behavior between stable system operating modes. In one mode, it can have clear water, but in the other the water is cloudy (turbid). It does not occupy the states between, but can be triggered to flip by raising or lowering nutrient inputs. This kind of "switching" behavior can be seen in many systems, and it can be very hard to detect and to model. In the extreme case, it represents "non-linear" behavior, meaning that a graph of the change will not be a smooth curve, but will have a catastrophic change that can't be predicted from the trend of the graph preceding it.

There are, however, ways to mathematically model non-linear switches, as suggested in the graph. Here the number of states are theoretically finite and once known can be modeled. The idea of complexity is that when enough of these kinds of behaviors are interacting with each other, to overall state of the systems cannot be predicted – its complexity increases.

It is tempting to suggest that all complexity can be explained by large networks of such switches. This led to the more traditional approach to complexity which can be attributed to Von Neuman. Von Neuman was involved at the foundations of computer science and his ideas led to development of the "Turing machine" and the first computers. Rosen, however, claims that Von Neuman complexity is not enough.

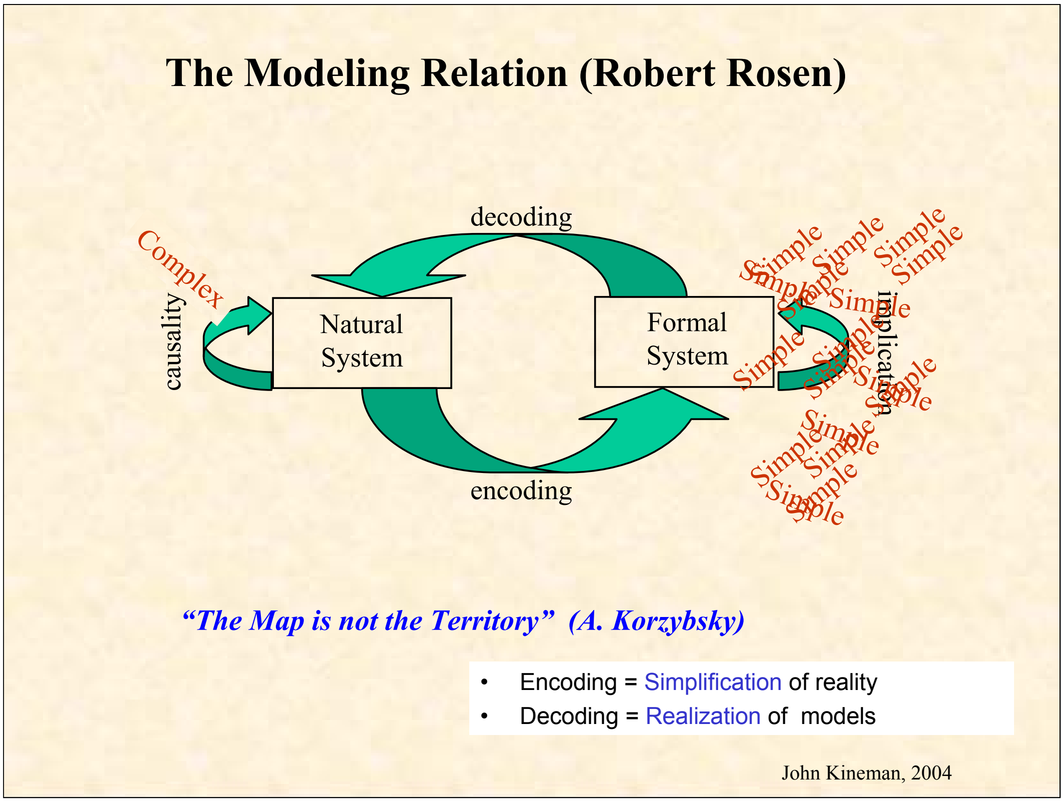


Robert Rosen proposed what is essentially a complementarity principle in his “modeling relation” between realized (tangible) systems and unrealized (formal) systems. Escher said as much in his famous work, "Hands." Such a model leads to multiple realization possibilities (not unlike quantum superposition).

This was first proposed as a model for epistemology – i.e., “knowing” and/or science itself. All science makes models of nature. But it quickly became a principle that might be applied to natural systems themselves, at least biological ones that could themselves have “internal predictive models.” He was eventually forced to generalize these ideas and suggest that all natural systems in fact contain formal, semantic (i.e., meaningful) entailments – some aspect of modeling relations. The theory is particularly applicable to quantum phenomena, for example.

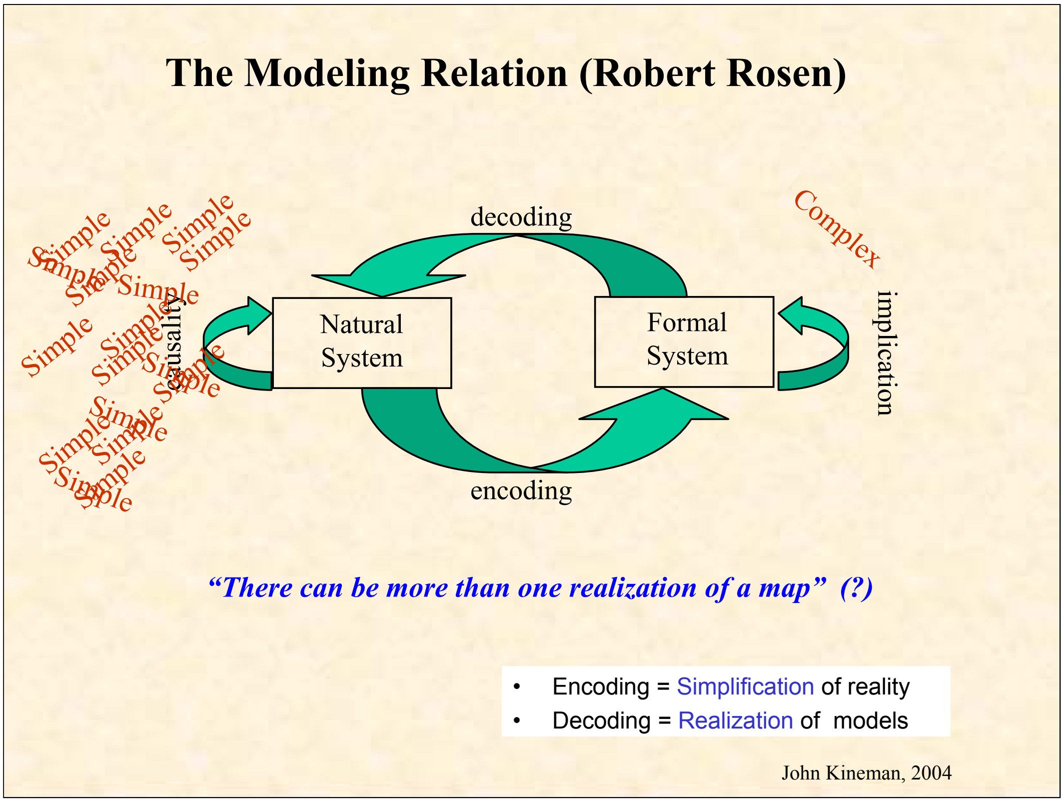
Example of form-function complementarity: A butter knife can be used for many functions besides spreading butter, for example removing screws. But if we specify a function, say removing screws, the realization of that function may not be a butter knife, it might be a screwdriver, which would not function well for spreading butter. Hence, form and function are independently real aspects of a greater relationship, and they cannot precisely define each other without uncertainty (i.e., they are not mutually reducible).

*Note that the “natural system” can also be represented by an identical diagram, hence leading to unlimited nesting of contexts. It is from that contextual nesting that semantic definitions may be obtained.



To dramatize the essence of complexity, and its implications, we can think in terms of a relational diagram (after Rosen, 1986, "Anticipatory Systems"), in which we represent a natural system on the left and a model or descriptive information system on the right. Science, of course, is about "encoding" such information from nature, and "decoding" it back to test theories and make predictions. If the decoding works, that is, if it commutes with the encoding, then we believe we have a good model because the model behaves like what we observe of the natural system.

As it turns out, this only occurs satisfactorily with "simple" systems, which are describable in mechanical terms -- primarily physical systems. Living systems are "complex" in the sense that no single description (FS) of them can capture all their important qualities (NS). Instead, we must recognize complexity and design for multiple descriptions, each tailored for different use, and remember that any one model is a partial description.

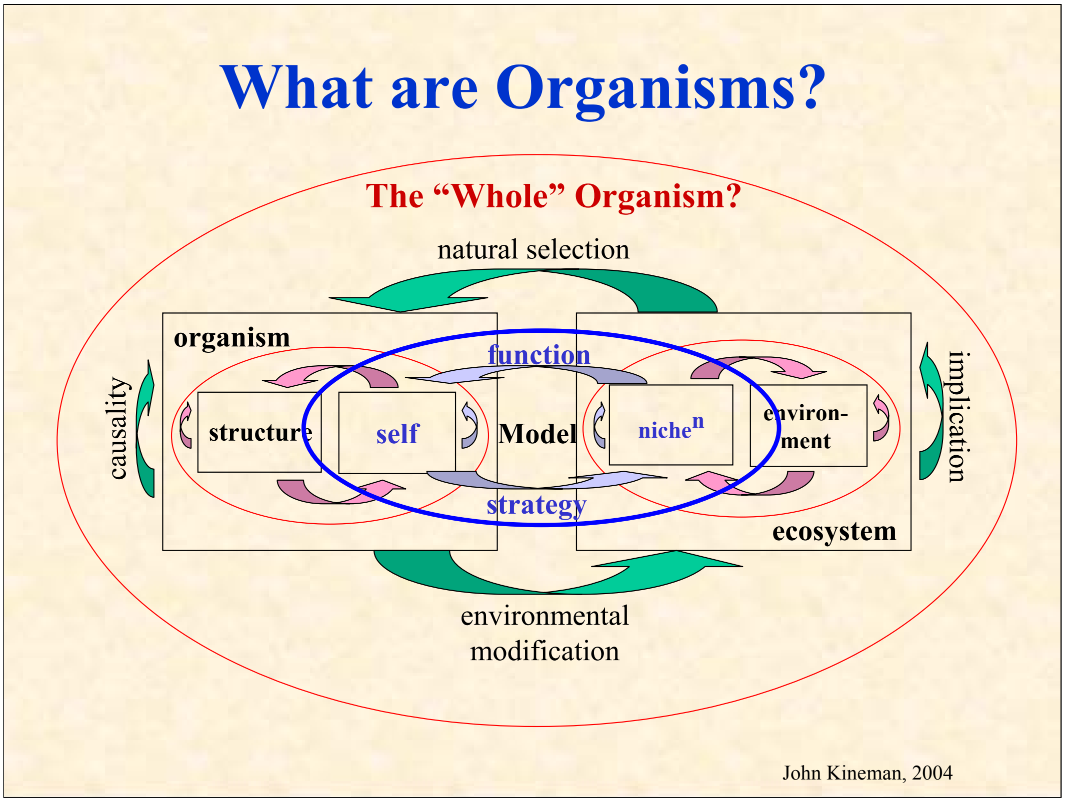


On the other hand, in the deeper view of this modeling relationship as an ontological (fundamental) explanation for complexity, the reverse situation can also be seen.

If we define some specific function (purpose), such as "opening a can" it is true that we can "realize" that purpose by making a can opener. The can opener "realizes" the function of "opening the can", i.e., it provides an observable, material system that is capable of performing the function.

However, if we think of a complex function, which in essence introduces creativity (to imagine other ways to realize it), it is clear there are many realized systems that can perform the function to varying degrees of efficiency, a can opener, a screwdriver, a coin, etc.

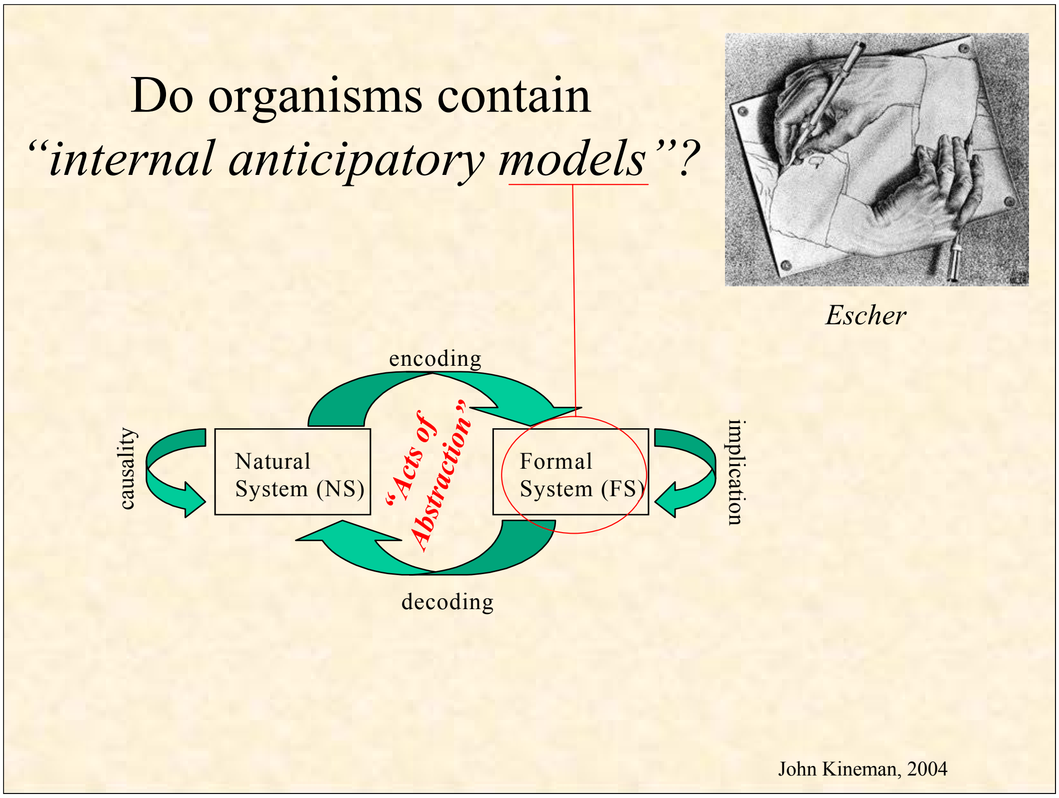
This is meant only to illustrate the principle of complementarity embodied in the modeling relation.



Are organisms contained entirely within their membrane? Do we not have to include the role of the environment in any definition of an organism? The role of evolution? Is the organism a species or an individual? This problem of defining the system boundary results from thinking in terms of objects – the habit inherited from the physical sciences. Rosen suggested thinking in terms of relationships. According to him, it is the relationship that is most real.\

This attempts to capture the idea of the organism existing in multiple contexts. The functional model of the organism includes self and niche. When we construct modeling relations for organism and ecosystem, we see that the functional component of each is part of the model of the organism.

Considering further, that as shown before, a complex hierarchy must be unbounded, we can infer that function extends fully throughout this hierarchy. This lends meaning to the concept that organisms cannot be separated from nature and remain organisms. It also gives a theoretical way to model the statement that "an organism is more than the sum of its parts" because there is always a higher level implicated above any set of observable components.

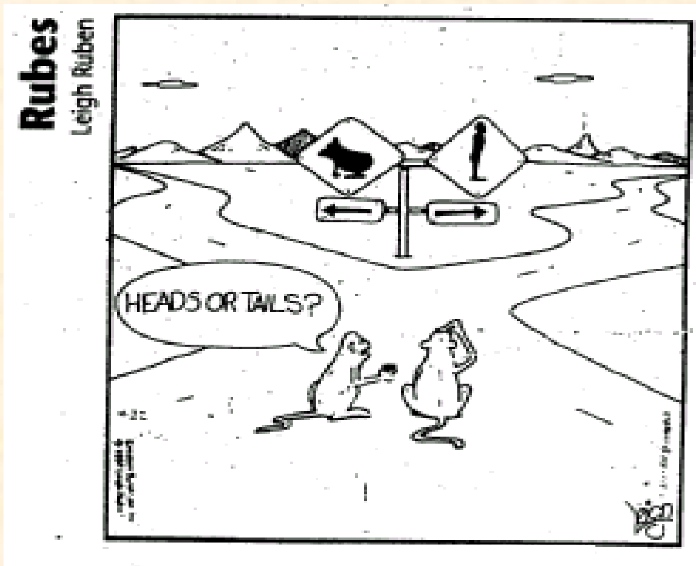


Once we decide to take this modeling relationship as an ontological description, that is, we use it as a theoretical way to analyze a system, we can learn different things about the system than we get from a purely mechanical analysis.

For one thing, it implies that all organisms, indeed all complex systems, contain some self-descriptive elements and that is one way to explain why they are complex.

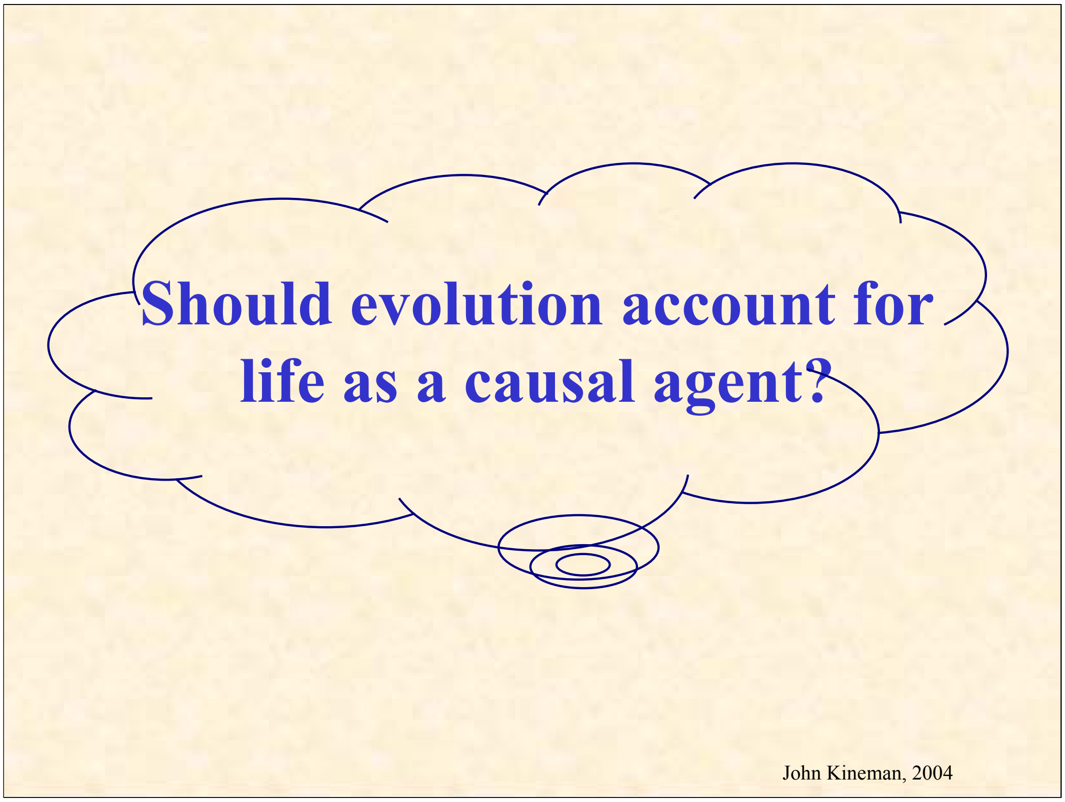
In biological organisms this descriptive element can reasonably be thought of as a model. The organism responds to its model, not the environment directly, while all the while continuing the process of checking it's model against the outside world.

Is this how the entire course of human evolution was decided?



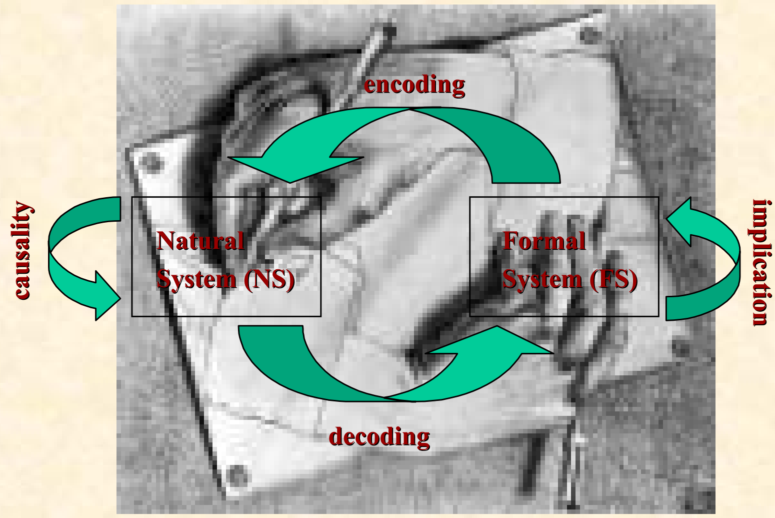
John Kineman, 2004

If we take this organismic explanation seriously, it then has implications for evolution, for the effect of "function" on evolution cannot be ignored. This idea was actually pointed out clearly by James Mark Baldwin (who was a Darwinist, not a Lamarckian) over 100 years ago, but it was not developed as part of our neo-Darwinian view of evolution. Today "the Baldwin effect" is gaining increased interest, primarily because of its applicability to learning systems and cybernetics.



We are led to this question, which is still considered somewhat heretical amongst evolutionary biologists. However, many inroads have been made in this direction beside Rosen’s ideas. Odling-Smee, for example, just published a comprehensive volume on “niche construction” based on his life’s work as a biologist studying “Niche constructing phenotypes.”

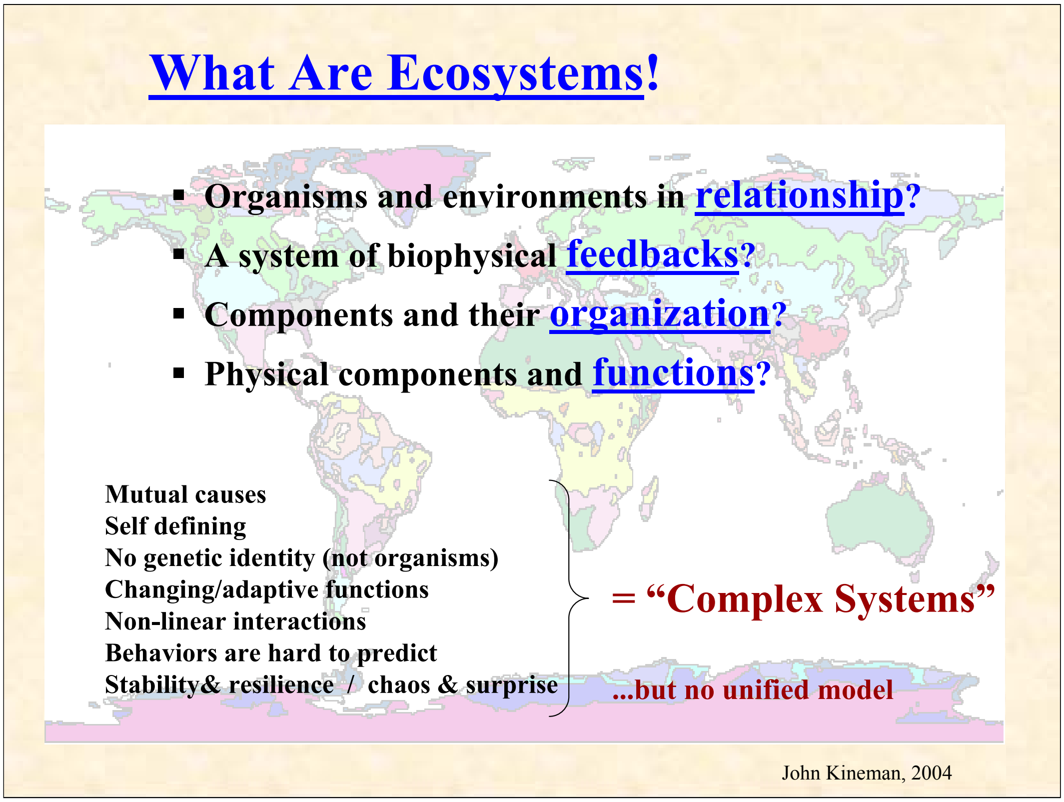
The Modeling Relation and Ontogeny



M.C. Escher / Robert Rosen

John Kineman, 2004

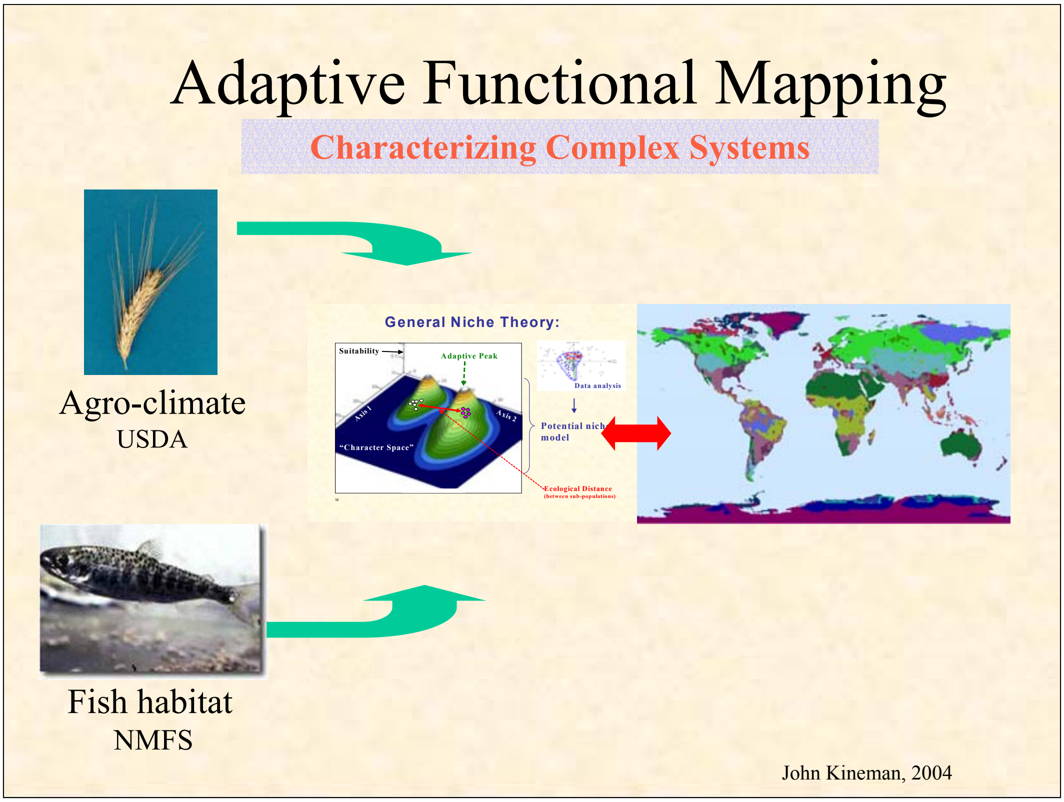
This illustrates the similarity between Escher's concept and Rosen's. The idea of such a complementarity, taken as an ontological case, is that it can exist inside or outside of time. The mutual drawings can be temporal, as in the cycle of generations in biology, or simultaneous as in quantum duality. In other words, the relationship may be more real than time itself, but whenever it is "realized" into a spatio-temporal system, it may then be realized with a temporal sequence.



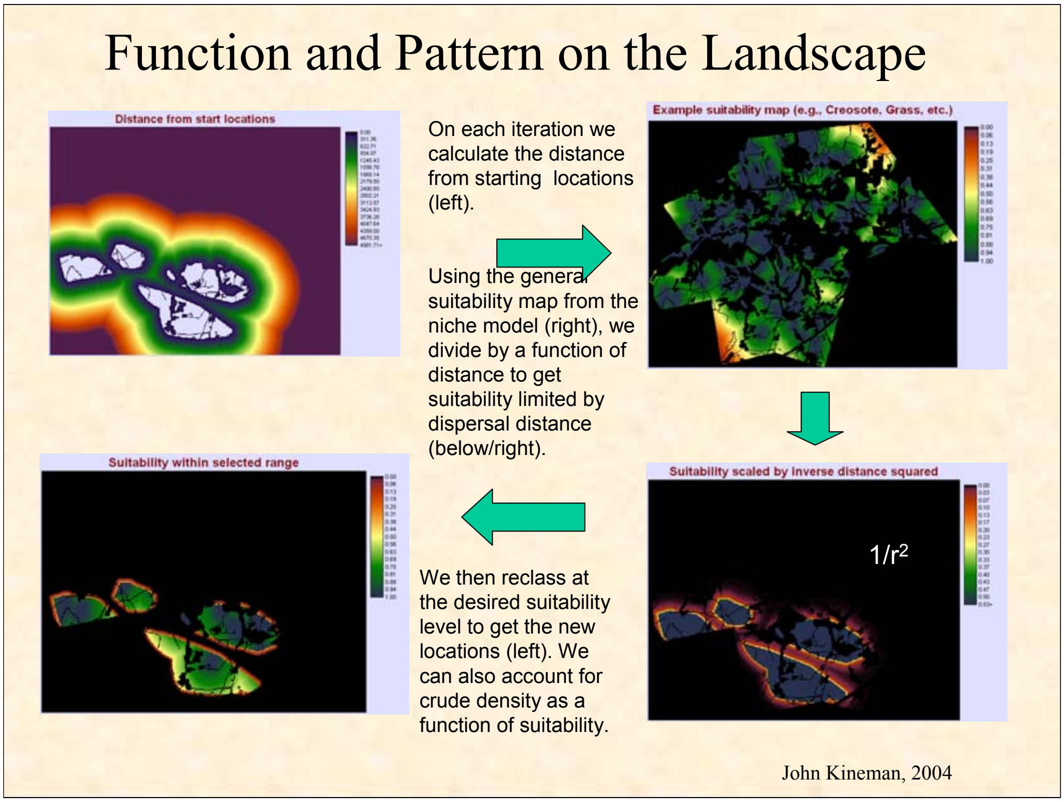
Ecosystems in general are not organisms, and they are not strictly physical systems either. They seem to be an intermediate category. Are they complex systems?? Certainly. Are they living systems? Yes by most definitions. But unlike organisms, they fit into a class of living systems that do not have an internal model of their own identity and function, but are instead unforced associations of their parts. While there is organization, perhaps a form of self-organization, they can also have multiple functional modes of their overall operating. As shown before, they can "flip" between different sets of functional definitions. Organisms, in this sense, seem more restricted on only one life strategy.

In this image, the Colorado River delta in Mexico is toward the top, which is facing South, and the Imperial Valley of the US is at the bottom-right.

Here we can an example of how patterns and functions can be independent but related in landscape ecology. Administrative boundaries represent a socio-political function, but they aren’t visible in photographs or satellite images. We joke about finding the state line on the ground. It’s real, but it’s not physically real. Unlike State lines, the US-Mexico border is clearly visible by satellite in many places. Why is that? It is because a very real functional difference has written its signature on the landscape. The functional difference was there before the pattern emerged! Many biological and ecological entities are the same way. Their structures are in relationship with their own and other ecosystem functions. So perhaps we can say that structures cause functions to emerge and functions cause structures to emerge.?



An example from my own work (Kineman) is building a functional model of an organism, or taxon, or even sociological function, so that these concepts can themselves be mapped in somewhat standard ways. This is the complement to mapping observed and classified features of the landscape, and it represents a way to make our global information systems more relevant to issues involving complexity. An early stage of this idea, for species mapping, has recently been implemented in the Lifemapper project at the University of Kansas (see www.lifemapper.org)



Landscape complexity can involve the adaptive movement of organisms that alter their environment as they move. This can be modeled using “cellular automata” or “agent-based modeling” as developed at the Santa Fe Institute, NM initially by Chris Langdon. This idea is to actually implement a Rosennean modeling relation using maps that represent both the “Natural System” (NS) which is the realized and thus observable distribution on the landscape (actual locations) and the “Formal System” or function, represented by a map generated from a model of “potential” distribution or “suitability.” The point of this kind of implementation is to have each alter the other in succession – an iterative process that then models the likely dispersal of an organism and its incremental modification of the landscape. In other works, this is a way to model actual “niche construction” as theorized by Odling-Smee (book titled “Niche Construction”). The approach may even be capable of discovering unknown “attractor” modes that the whole system could possibly flip to, by allowing a number of such models to interact. This can be done in present software, such as SWARM.

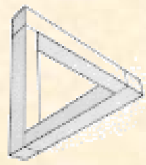
A Simple Dispersion Model: Niche Construction?

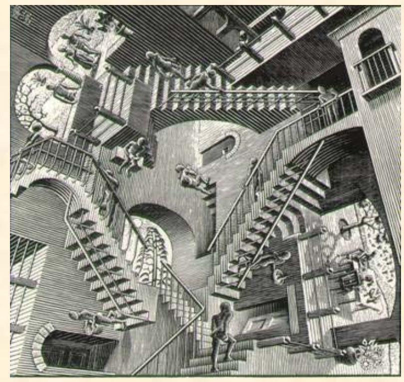
John Kineman, 2004

Here is a demonstration of the “niche construction” simulation.

These techniques all fall under the category of computational complexity. True complexity is indeed involved in niche construction, but this is a computational technique that can model only what can be reproduced in a computer. To Von Neuman, and Church/Turing, that may be all that is important. But to Rosen it still missed something more organic or “organizational” about the whole system, and each whole system that is a part of it – the organisms. When and where, i.e., for what questions, that missing aspect is important is a central question for management, because it determines the usefulness of such models for making decisions.

What about Physical Realities?





Is Space-Time itself complex?

M.C. Escher

John Kineman, 2004

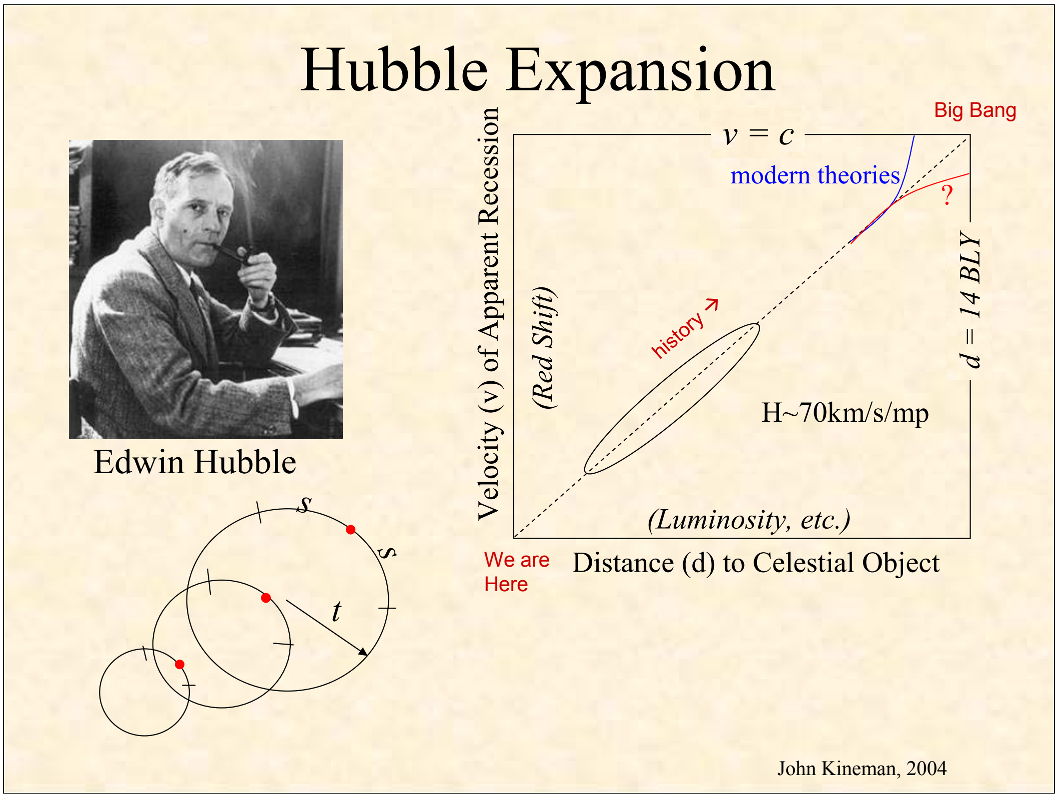
"Physical" traditionally means syntax (structure) devoid of semantics (functional meaning). It is based on measurable, computable structures that can be modeled as "mechanisms." This is achievable within, and only within, a defined space-time coordinate system, because that is what establishes our concept of physical "causality" and the uniqueness of objects (states) which underlies computability.

"Function" exists outside of a space-time domain, and thus can exist in complementary relationship to it, as an equally real, causal aspect of nature. This is hard for us to imagine because we are more familiar with what we see, than these aspects of what we are (i.e., functions).

If “complex" involves a fundamental complementarity between explicit realizations and implicit functions, then it must be involved in the very definition of space-time. Space-time itself must be complex.

Can we test these ideas?

The cosmos offers one possible laboratory.

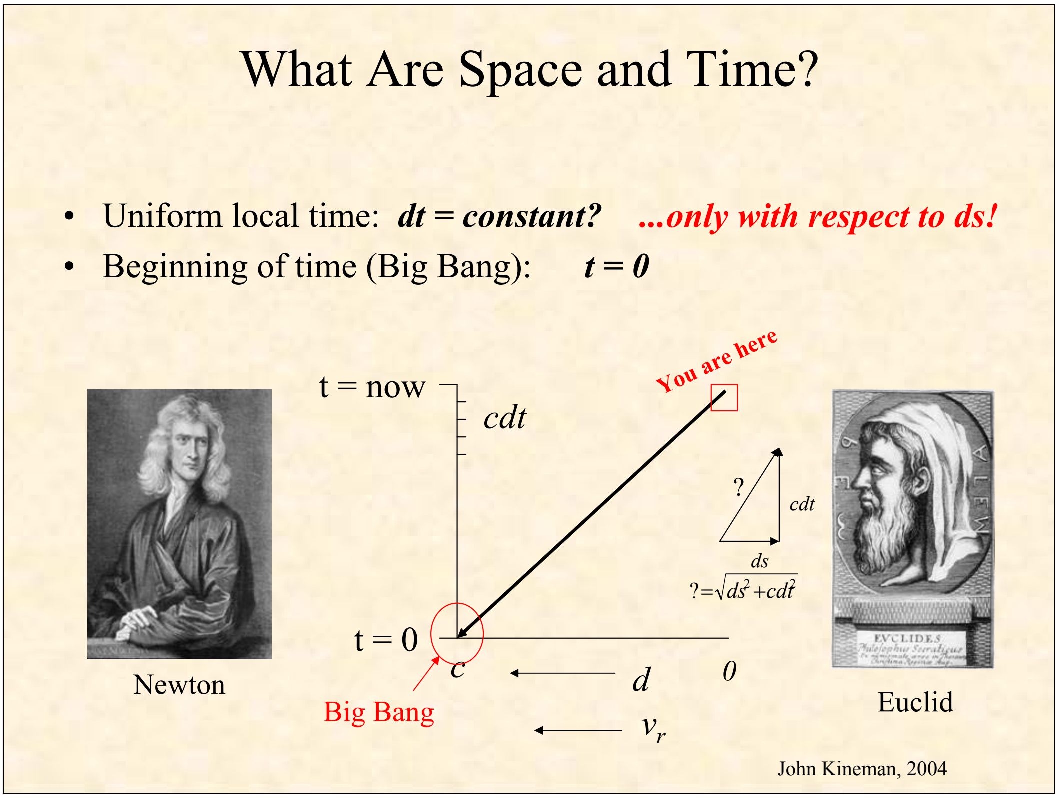


Most of us have heard of the Hubble expansion – the expanding universe and "red shift" of distant celestial objects due to their increasing recession velocity from us. Most of us also have a classical Cartesian/Newtonian view of this, as shown above. Projecting present space-time definitions backwards, we see an "origin" which must have been small by today's standards, and thus ... etc. implying the Big Bang.

This is shown in the simple graph of expanding space above. The common way of visualizing this is an expanding "balloon" (lower left). As the temporal balloon expands, space, represented by the surface of the balloon, stretches, and more distant objects all recede from each other at velocities that are proportional to their distance. That proportion is the "Hubble Constant" (H) which is estimated at about 70km/s/megaparsec at telescopic distances. From that we can estimate the age of the universe as about 12-14 billion years (or a "size" of 12-14 billion light years).

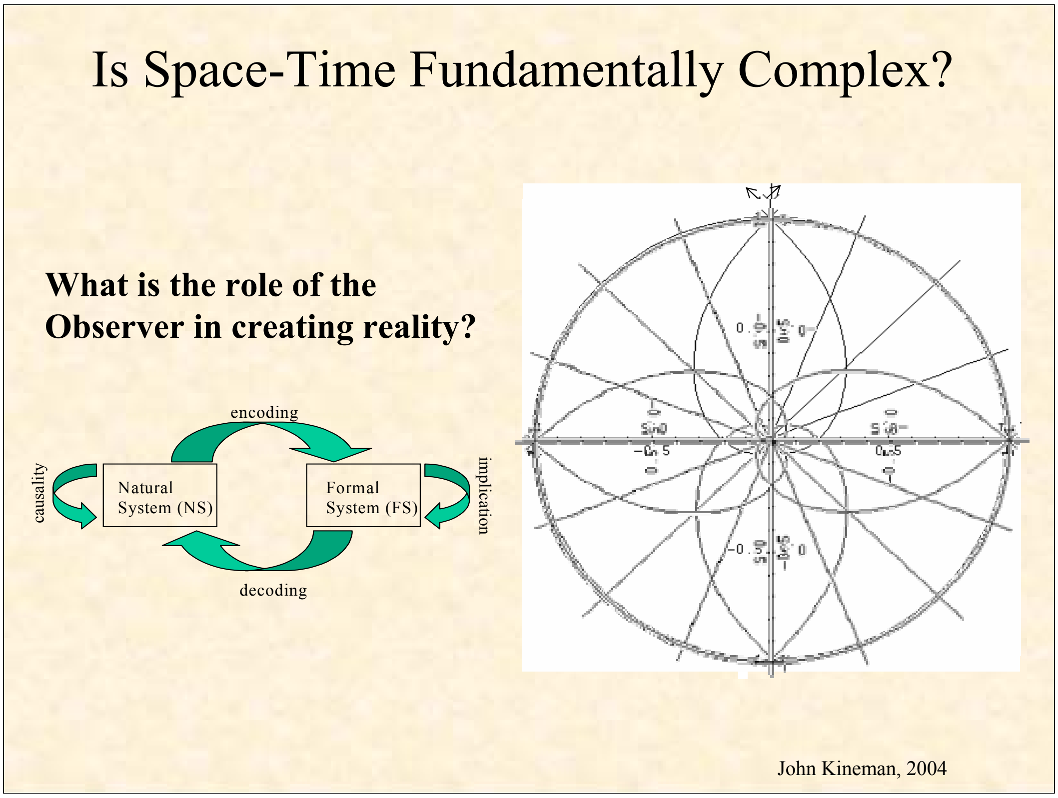
Today we know that H is not a constant. Most theories had it curving upwards toward the origin (upper-right in this case) , and so this simple geometry is too simple, but capture at least that aspect of the problem.

What if we model the variations from this picture as a change in rate of expansion, or scale of the whole model? This means going to what is called a "non-Euclidean" geometry.



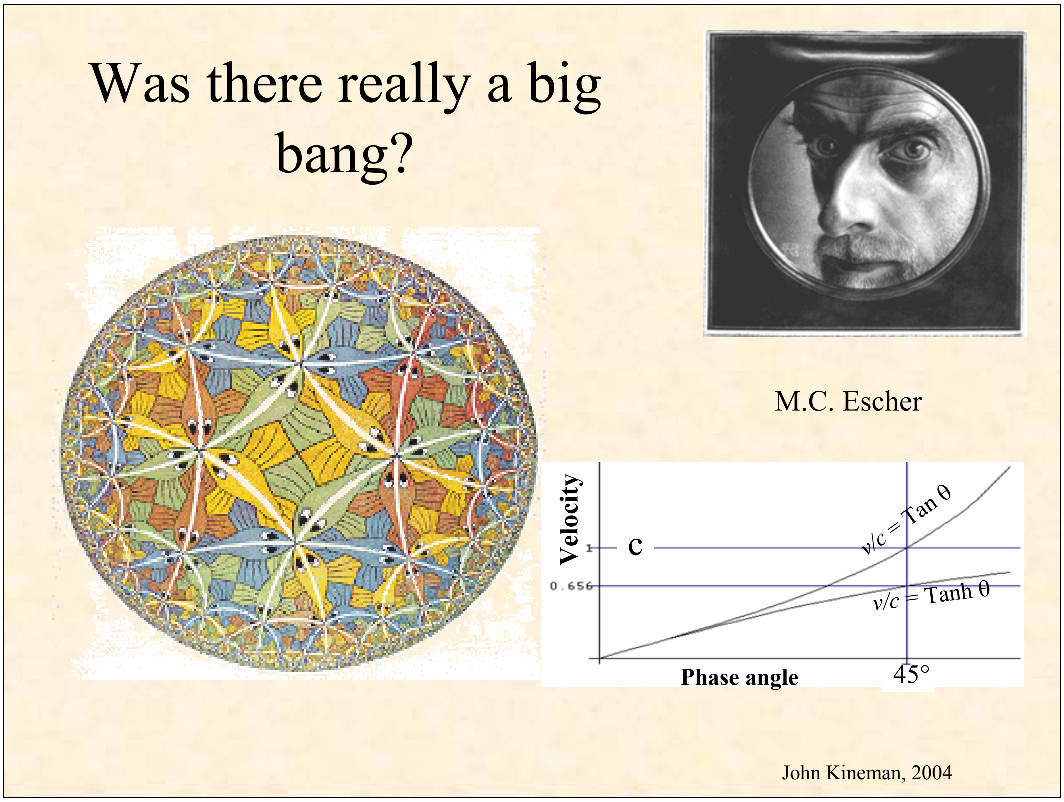
Looking at it now as a "space-time" diagram (same as before, just inverted) we see that Euclid doesn't like the classical Newtonian result very much. This is because the space-time domain itself is not Euclidean, which can be seen by the fact that the Pythagorean theorem doesn't work when we use time as one of the axes. To "Euclideanize it" or think in a space that is more natural to our thinking, where any arrow drawn has the same meaning, i.e., a space-time "distance" we have to make the time axis (or the space axis) imaginary, not real. This is the definition of Einstein-Minkowski space. We may continue to look at the diagram the same way, but by writing "ict" instead of "ct" the mathematics works and distances are now space-time distances.

But, as such this model still has an origin problem. It turns out that one can construct a cosmic geometry based on this idea that eliminates the singularity for the whole, but retains it for each "local" perspective. In other words we would see a finite origin, but globally it would not exist.

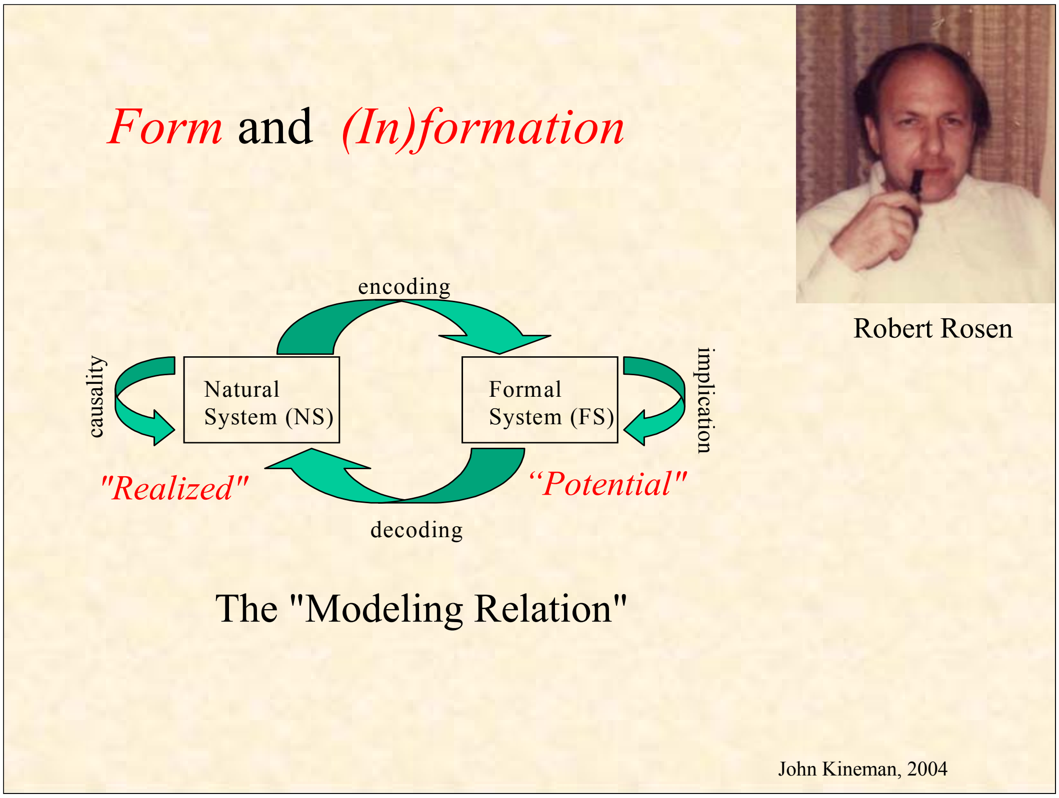


This is the result. It is a geometry where local space-time exists along any circumference and can be drawn as a regular Cartesian graph as we did before. That defines a local observer, who then sees a universe along the pear-shaped lines, which are the pathways of light in this model. Interestingly these pathways never reach the origin – they spiral inward infinitely and at any scale the whole diagram would look the same. It is a self-similarity, like a fractal. The model is fully consistent with the observations of the Hubble expansion, special relativity, and an accelerating early universe. Something like this was first proposed by E.A. Milne in the 1950. It was considered clever but it was neither rejected nor extensively used in modern theories.

This model is like one of Zeno's paradoxes, where two “realities” are both equally represented. One is the fixed Cartesian measuring system we see projecting our current standards into history, the other is an intrinsic time defined by the path of light. We thus have a graphic representation of a complementarity between observed reality and some kind of intrinsic reality. Could the intrinsic time be interpreted as the Formal System in a Rosen diagram? If so, then we have a model for the origin of “realized” space-time from some universal space-time. This dual nature of time has been noted by various authors regarding the “intrinsic time of natural systems” vs their external time. It could also be applied to our understanding of quantum phenomena and the nature of perception (or observership).



The concept expressed above by mathematical statements is easy to visualize in Escher's hyperbolic world. Here we see an infinite internal domain, defined by the hyperbolic curves that intersect as increasingly smaller scale, packed into a finite boundary. If the little fish in the diagram could only measure their "local" space using rulers that scaled the same way, they would experience an infinite domain.

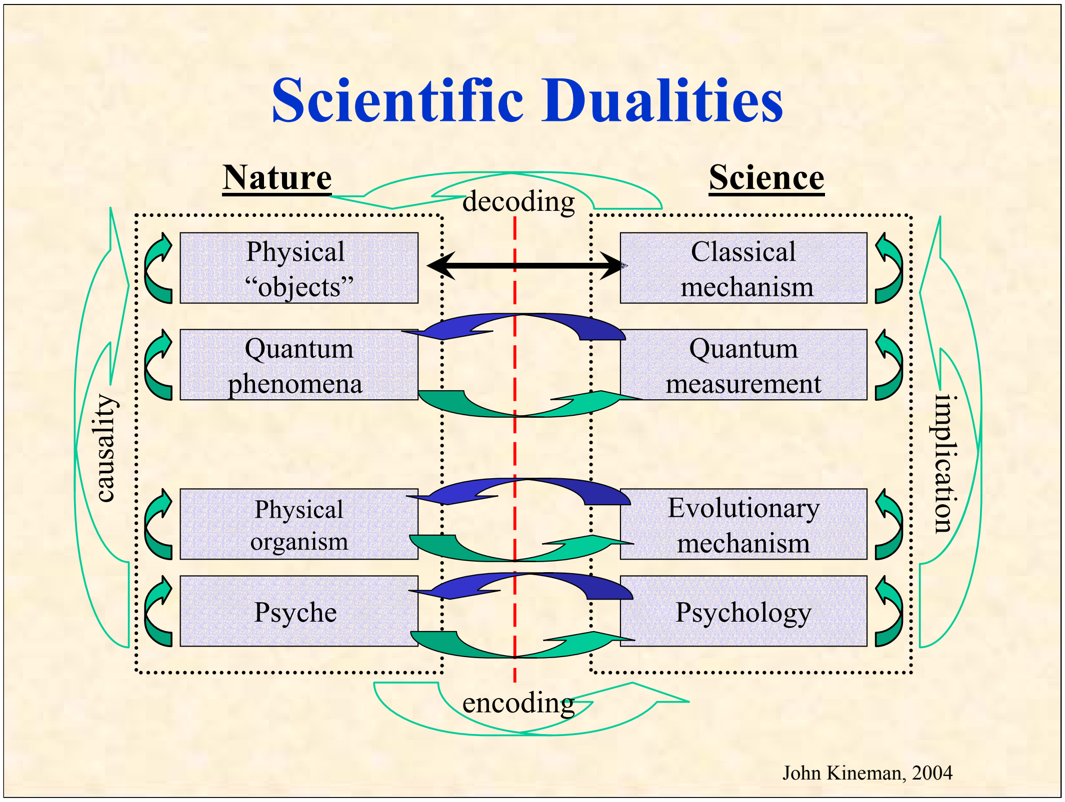


Does Rosen’s model give us a concept of information in the natural world? I haven’t said anything about the “encoding” and “decoding” arrows yet, but notice that these do not reside in any natural or formal system. They are outside of both halves of the complementarity. So where are they? How can they be considered real if they are neither realized nor part of a model? According to Rosen they reside in a domain of “abstraction” – they are the processes of abstraction, which is essentially measurement, or simplification of one system into a sub-set of quantities taken from it (“ab”).

If we only talk about using this model for science itself, i.e., the “epistemological” interpretation of the modeling relation, then we can safely say that the encoding and decoding processes are things we mysteriously do as intelligent beings. They are part of the mystery of the mind. They represent the modeler.

But when we apply this picture to nature itself, the implications are indeed quite heretical. If there are models in nature, there must be modelers. Is that vitalism?? Rosen did not think so, but it certainly is getting close to “the ghost in the machine.”

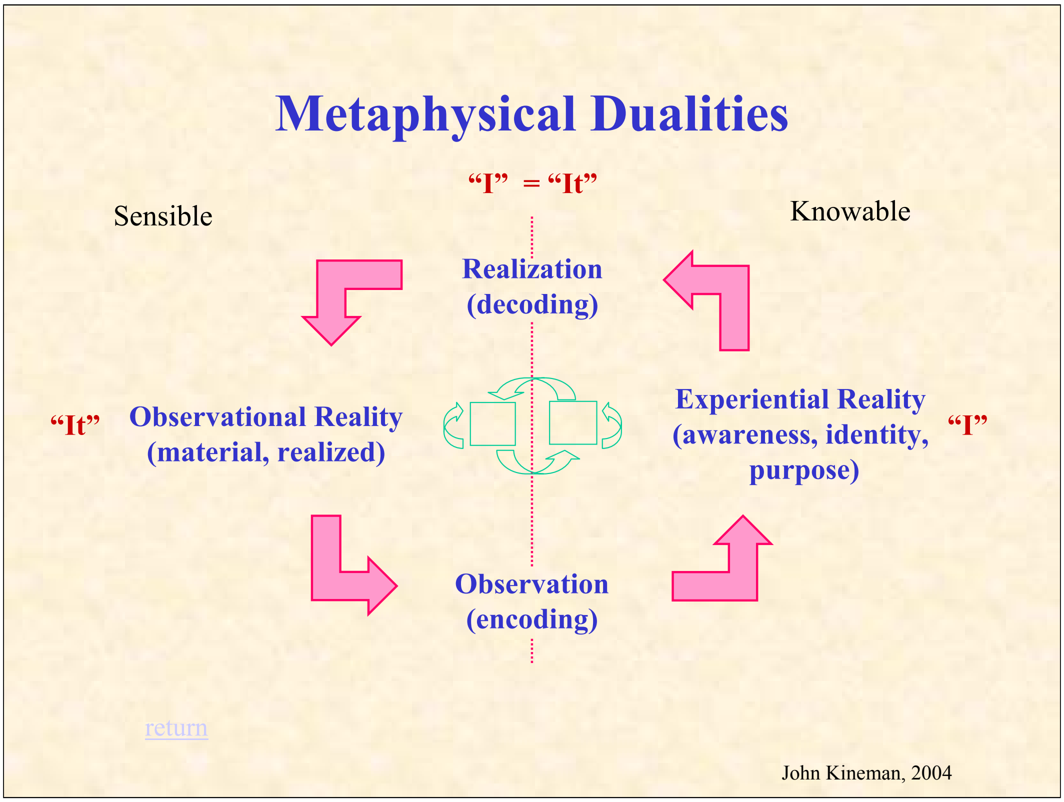
One possible *scientific* way to escape vitalism in this model is implicit in the construction itself. It is that it nests with larger modeling relations. So while at this level encoding and decoding appear to be outside any system, they are actually entailments in a larger system which can be studied in exactly the same way.



This shows the epistemological use of Rosen's modeling relation. This is its most accepted use and meaning. It is a meta-model of science – i.e., how scientific theories relate to the phenomena they study.

A mechanism is defined as when the relationship commutes, i.e., when encoding produces the same result as decoding. This is diagrammed as a solid black arrow in the first relationship at the top. Rosen calls this kind of system a "simple" system. However, simple systems can be quite "complicated" and even incalculable as a practical matter, but they are theoretically calculable.

But for complex relationships these arrows differ, and hence there is an imprecise complementarity between the two sides, and uncertainties.



We can perhaps apply this thinking to philosophical questions of existence as well, between all presumed reality "out there" and knowability. Is this what Descartes was referring to when he said that all we can really know is our own experience, all else being subject to doubt>? The philosophical notion exists, certainly, that all of reality may be a projection of our own mind. In "transpersonal" psychology and increasingly in popular/cultural psychology, this idea is prevalent. It was discussed, for example, in the movie "What the <bleep> do we know?," which was showing in Boulder last week. How can science comprehend such ideas? Does Rosen's modeling relation help?

This diagram contrasts the reality we can observe ("it") with the reality we experience ("I") and models the translation between them. Perhaps experience can be associated with the "acts of abstraction" which are encodings and decodings in Rosen's model that connect the two sides. Such acts are perhaps a kind of identity between "I" and "it" – Rosen refers to them as induction or influence between these two systems, whereas what we retain as knowledge establishes a fundamental separation between observer and observed.

In other words, the pure act of being, both expressing and learning, represented by the red line and Rosen's inductions between natural and formal systems may be easiest to call real.

Can Complexity theory be applied to understand Religious and Spiritual Matters?

- Is “final cause” outside of science? Can some forms teleology be handled scientifically?
- Does Eastern thought tend to emphasize similar ideas of holism and organic concepts of nature?
- Can there be an ultimate synthesis?

John Kineman, 2004

As one digs deeper into systems thinking, including Rosen’s formulation, it seems we come closer and closer to holistic and organic views of nature that are most characteristic of Eastern thought. The oldest spiritual beliefs in the world come from the East, particularly India and Nepal, and there have been many contrasts between Eastern and Western thought. There is, for example, a group of Western physicists who regularly meet with the Dhali Lama to discuss the nature of the universe and light. Arthur Jajonc, one of the physicists in this group, tell the story that Einstein sain in his early career, that light was the greatest mystery in physics and that he would devote his life to studying it. He was quoted toward the end of his life as saying that anyone who thinks he understands what light it is fooling himself.

Can system ideas help us bring Eastern and Western thought together?

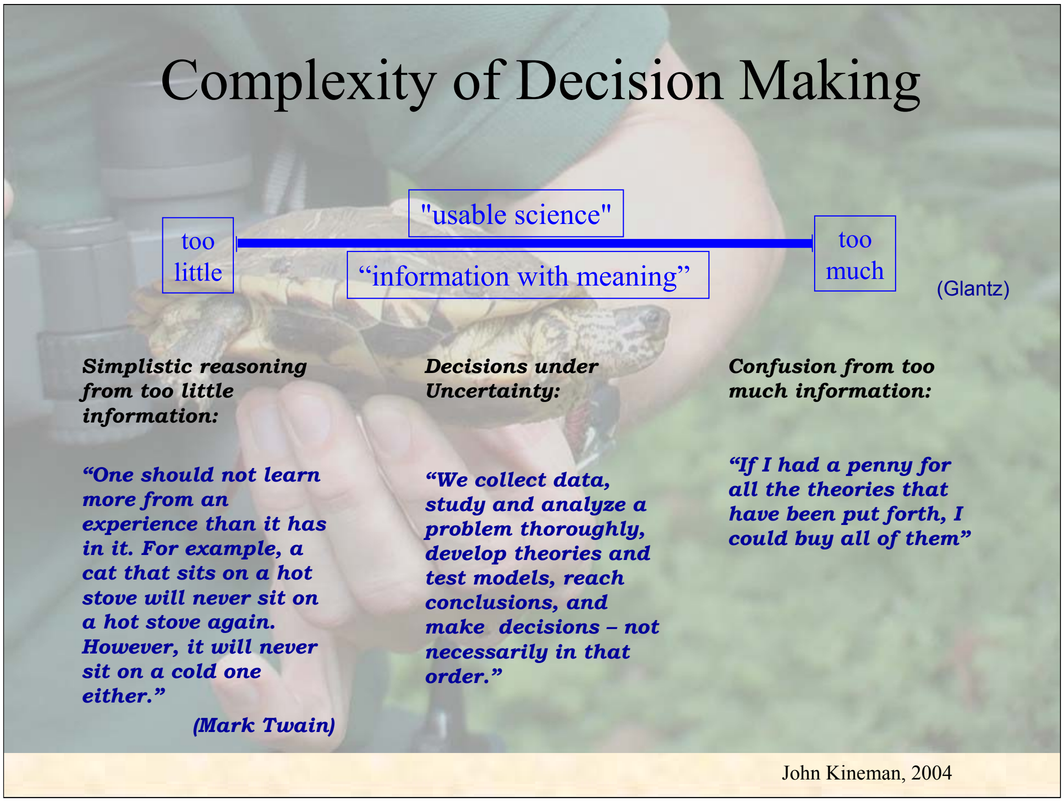
Humanity:
Will a better theory help?

- What is <u>our</u> functional model, as a society?
- How do we affect our ecological, sociological, and evolutionary future?
- What do we think about the values of life?

John Kineman, 2004

On the policy level, we may be aware of the sometimes frustrating and seemingly unproductive flurry of human opinions and activity. Parts of policy theory, if that is an acceptable term, disavows any fundamental way of judging correct policy. It is an outcome of social process without universal values. As such it is very much the output of a complex system.

Could it be useful, then, to think about policy with respect to the various internal models that make it complex? Perhaps this is too obvious and already the case, as we analyze what various groups “believe” and think of them as advocates for this and that. But do we also consider how those beliefs are encoded and decoded? Do we recognize that as an ongoing process that not only applies to the interplay of opinions, but also to continual testing against other realities? In other words, can we really consider policy to exist in a closed system, or, as Rosen claims for all complex systems, does it have larger system inducements? If so, there may be an argument for how nature can ultimately provide a testing ground for its variable results – a natural selection and evolution of cultural beliefs and values. “Cultural evolution” is a term that has emerged relatively recently from work in the systems sciences, for example from people like Bela H. Banathy. It represents a rich field for theory development.



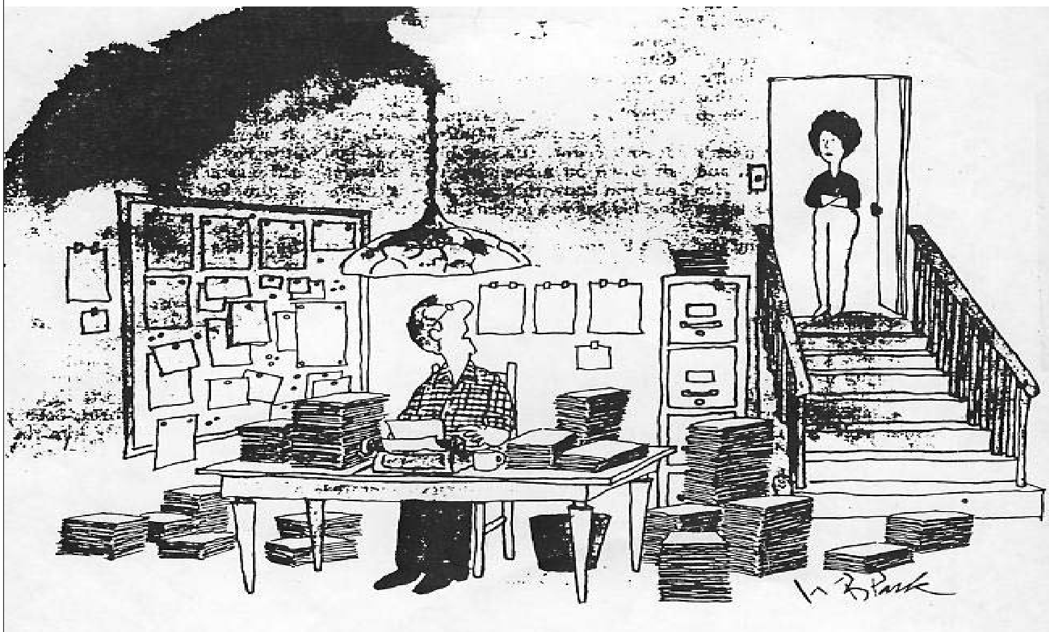
On the practical side of decision making, one can ask how much knowledge is really needed? This has become a hot issue in recent years regarding global change and other environmental issues. Do we understand the results of research? Is it so ambiguous that its value is neutral in a political debate? Will more help? Is more research a way of delaying decisions?

Functional complexity and systems theory, from at least Rosen's perspective, tell us that facts and their meaning are different things. To have meaningful facts, which one might presume policy needs, we must understand context. If we are swamped with facts and lose their contextual meanings, there is no value conferred to decision making.

Furthermore, if Rosen is correct, there is an infinite number of perspectives and potential bits of information that could be acquired about anything. Unless we introduce some concept of relevance, who is to decide the ideal amount of information to use?

Dr. Michael Glantz suggested the scale in this slide, between too little and too much information, and that we really need to be thinking about where we should fit in the middle on any issue, and how to get there – what he called "usable science" and what I add involves "information with meaning."

Complexity vs. Practicality



Finish it? Why would I want to finish it?

Finally, if all this has been overwhelming, don't feel alone. One of the biggest problems with studying complexity is that it is SO complex! Like anything, the key will be to find useful ways to "simplify complexity." This is what we always do in models, as Rosen says, and there is no alternative other than to stop thinking. But might there be a shift from striving for perfect models, or claims of perfection, to striving for appropriate ones and evidence that they fit the context?

In the end the true paradox might be that complexity theory should give us a new way to understand reality much more simply and usefully than trying to construct it from the parts. Despite the word "complex" for many problems applying complex systems theory is the most parsimonious approach.