

Opinion

Robert Rosen's Anticipatory Systems Theory: The Science of Life and Mind

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Abstract: When I am at conferences, talking about the scientific work of my father (theoretical biologist Robert Rosen, 1934–1998), I am often asked which aspects of his work I think are most important. My answer is Anticipatory Systems Theory. It's about the entailment and characterization of both life and mind. It explains the fundamental nature of all life, showing how the human mind is an evolutionary concentration of the same peculiar behavior patterns manifested by all living organisms, regardless of species. How can we hope to fully understand ourselves or anything else in the biosphere of Earth without an accurate scientific comprehension of the entailment patterns underlying and generating all of it? The physics of orbital mechanics or atomic particles is insufficient for this. Therefore, I spend a lot of my time working to make the meaning of my father's scientific discoveries accessible to as many human minds as possible. I think humanity is going to need this work in the future, and already needs it now. This paper will examine the basic premises of Anticipatory Systems Theory and describe, using examples familiar to all of us from daily life, how we can recognize Anticipation at work in ourselves and in local ecosystems all over the planet. I will conclude with some important ramifications of this theory, including how Anticipation necessarily plays into evolutionary processes. I will also point out the vulnerabilities of Anticipatory Systems (i.e., living organisms) to *rapid* change in environment, potentially leading to extinction cascades.

Keywords: Anticipatory Systems; evolution



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1. The Importance of the Modeling Relation

It all begins with The Modeling Relation. Robert Rosen [1–3] created a diagram that is essentially a model of the modeling relation and he did so because he realized that this relation embodies something about the Laws of Nature in this universe. We could not use models to predict future behavior of systems like the weather if the universe did not carry the entailment to support such a practice. A constructed system of inferential entailment that accurately represents a particular natural system's causal entailment (as it pertains to some set of behaviors of that system we are interested in) is the definition of a model. If we encode it correctly and with enough detail in the area pertaining to behaviors we are interested in, the model will then be able to *accurately* predict future behaviors of the original, natural system.

The very fact that the universe does carry this entailment about encoded models is extremely important for understanding the organization of systems that are alive—because it is one aspect of the universe that has been incorporated into living organisms, at the organizational level. All living organisms are Anticipatory Systems. They are Anticipatory because an active form of the modeling relation is a fundamental component of all life. Putting that another way: The Modeling Relation is the source of the Anticipatory pattern of behavior that allows us to recognize a material system manifesting that pattern as being *alive*. Therefore, we can associate the Anticipatory organization of all living organisms with the very *signature of life*. Furthermore, because the human mind represents an evolutionary concentration of the behaviors and capacities of life, the model-based, model-guided nature

of Anticipatory Systems is the signature of a consciously aware, sapient mind as well. Please see Figure 1.

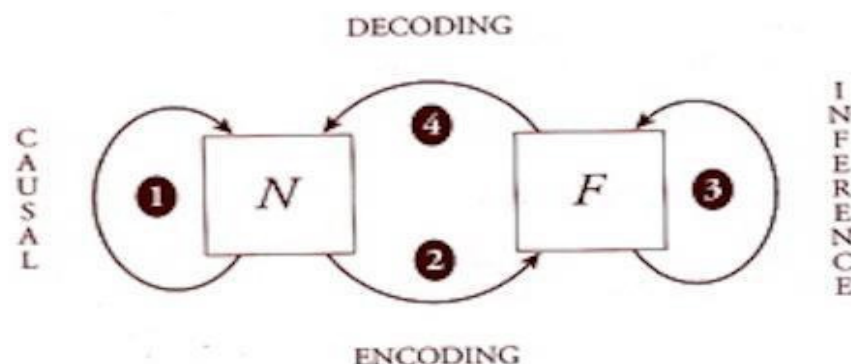


Figure 1. Robert Rosen's Modeling Relation Diagram.

From this standpoint, it is not very surprising that the human construct we call “Science” would be built upon the Modeling Relation, also. If an active form of The Modeling Relation is the foundation for life and mind, how could we fail to manifest this in our attempts to better understand the universe around us? So what is this Modeling Relation?

There is a lot to discuss in the above Modeling Relation diagram. N represents the *Natural* system of interest. F represents the encoded model we build, based on the natural system—also known as the *Formalized* system. The numbered arrows are labeled as follows:

- (1) Causal (Entailment): This represents the underlying entailment that drives the ongoing behaviors and capabilities of the Natural system: Why it is the way it is and does the things it does.
- (2) Encoding: This represents the process of observing the Natural system, learning about the causal entailment that is generating what we observe, encoding that entailment into a form that we create but that logically follows the same pattern as the causal entailment of the Natural system, allowing us to build the Formal system—the model.
- (3) Inference (Inferential Entailment): This represents the encoded form of entailment as a similarly ongoing process that can be run forward or backward in time or interact with altered circumstances in various ways.
- (4) Decoding: This arrow represents taking the predictions generated by the model and comparing them with what the Natural system is actually doing. If they match, then we have achieved the modeling relation and our model is reliable. If the predictions do not match what the Natural system is doing, then we must figure out why. That means running through the four numbered arrows again to see what we missed, what was improperly encoded, or what else could be wrong.

Notice that the processes of observation and learning about the causal entailment of the Natural system are not specified by this diagram. Neither is the mode of encoding causal entailment to inferential entailment. Neither is anything specific about the passage of time. All of that is left to the model-builder to figure out. There is, however, a clear sequence specified by this diagram as well as the fact that it is a closed loop of entailment, itself.

Note also that time never stops, it is constantly flowing through the universe . . . which means that change is also constant—Furthermore, that fact generates a cautionary issue in modeling: The Natural system is constantly changing through time and will eventually be sufficiently different from what it was when we encoded an accurate model of it to make our model no longer accurate enough to generate reliable predictions. Robert Rosen called that process “temporal spanning”. The process of arrow #4 will warn us when that situation has been reached. So, just because it once showed us we had a reliable model, it is important to recognize that time will eventually take that reliability away from us. Notice also that nothing about the Formal system, by itself, tells us whether it is accurately encoded or carrying enough entailment from the Natural system to be able to predict

reliably what the Natural system will do. Again, the process of arrow #4, Decoding, is what can do that for us. This whole cycle is never finished. All models spit out predictions. There is no way to tell from the predictions themselves if they are reliable. Only by comparing the predictions with the actual behaviors of the Natural system can we be sure. Furthermore, time will eventually render all accurate, well-encoded models temporally spanned. Therefore, modeling in science requires skill and vigilance in equal measure.

2. Living Organisms as Anticipatory Systems

Robert Rosen described all living organisms as systems which are capable, from within their own organization, of both metabolism and repair. He said those two functional capabilities are non-fractionable from one another, and in fact are components of each other. What does it mean when he says that two distinct functional capabilities are components of each other?

Consider the human immune system and the way body cells have the capacity for “programmed cell death”, which the immune system handles in a particular way. The immune system of course requires energy to run so we can easily see how metabolism is a component of repair. However, the way the immune system handles programmed cell death is to send macrophages which engulf the cells signaling they are ready to self-destruct. It’s a form of digestion and recycling of nutrients that the macrophages perform, which is a metabolic function. These two functional capabilities of metabolism and repair occur within/inside body cells and between body cells, all through human life. The immune system also kills pathogens all the time, and then digests and absorbs the nutrients which are repurposed in the body. In that way, we can see the immune system as being simultaneously a component of metabolism just as metabolism is a component of immune system. However, both functional capabilities arise from our own systemic organization. In order for that to be true, how much informational manipulation is required for this? In order for the body to repair and maintain itself, how much information must be required and information processing capacity to extract meaning must also be required? Furthermore, then there is the issue of how much information is involved in gestation. . .

We know that DNA and RNA represent encoded information. We further know that along with the genetic information specifying how our bodies develop and grow from a single fertilized egg cell, there must also be encoded information specifying every process by which that is achieved and every process our bodies maintain themselves with once gestation is complete. Every baby that is born with a healthy body and normal functioning of metabolism and repair capabilities must necessarily have some innate models for “Self” and for “Health”—which is based entirely on what the model for “Self” is. So, we have a fundamental “Self” model and a “Health (of Self)” model encoded in every single cell of our body. The “Self” model in a human being is obviously a collective self; this must be so, because cancer is clearly a body cell that has developed a singular “Self” model, one which treats the rest of the body as “Environment”—a source for raw materials needed to maintain “Self”. The immune system in a healthy baby must necessarily have the ability to recognize “Self” proteins and leave them alone. Anything not “Self” is immediately attacked and killed. Any damage that occurs is immediately detected, assessed, and repairs attempted.

Already, here, we have vast amounts of information flowing and being interpreted, according to those fundamental models of “Self” and “Health (of Self)”. However, another aspect common to all living organisms is essential to life, essential to both metabolism and repair: and that is *sensory capacity*. Sensory capacity is all about information. In some sense, living organisms seek out and metabolize information every bit as much as we do food or other aspects of our environment that we require to maintain ourselves. In order for that to work, we would require a model of environment, of some sort. Every bit of sensory information that comes in is interpreted according to what is better or worse for “Health (of Self)”. I refer to that range of evaluation as *the optimality scale*.

Consider how much information processing has to be going on, even in single cellular organisms—species that lack a central nervous system or a brain. It does not require a

thought process at all. This same “mindless” information processing is being done in human physiology all the time, for example by our immune system. We are not aware of it, we are not consciously directing it; instead, it directs itself. How? Models. Encoded models are a natural part of life and life, itself, is based around the activities of model-building, model-using, and seeking information from environment for our models to interpret and predict meaning of. All life is guided by this internal activity. Some people have trouble accepting this idea as being true, but it decodes and I will show you.

As I worked to develop ways to describe and convey my father’s scientific work at conferences, I had the insight that one proof there are encoded models directing the behavior of all living organisms is the characteristic error signal that exists with all model-based guidance systems—including the ones humanity has created as extensions of ourselves through technology. The existence of error is a constant hazard in GPS use for navigating in cars, for one example. This is the classic “map versus territory” issue because the map is a model of the territory that can predict how to get from one point to another point using various forms of human transportation. However, the map has to constantly be updated according to changes that occur in the territory, or else it becomes dangerous to use for guidance in arriving at a chosen destination. Do an image search on the internet for “gps fails” and you will see what I mean! New roads are built all the time, which represents change to the territory but not dangerous change. However, all it takes is one rock slide that takes out a mountain highway to radically alter the safe route from A to B. If the GPS map is not updated, it will direct drivers onto a road that no longer exists. In the dark, in bad weather, it’s easy to imagine how that could be a fatal mistake.

3. The Existence of Error in Biological Systems

Model based error is rampant in life and in mind. So many examples exist (which most human beings have experienced without realizing what they are) that it’s hard to narrow things down to just a few examples. Allergies, for instance. An allergy is a recognition error made by our immune system. Certain types of pollen may be misidentified as a pathogen, provoking an inappropriate immune response with histamines produced and the accompanying symptoms arise in our bodies. When someone develops an allergy to peanuts, the error can actually become life threatening. Death by error! Similarly, when the immune system begins to misidentify self proteins as foreign, auto-immune syndromes begin to manifest themselves. That can also end in death by model-based error. One reason I feel medical science needs to build Anticipatory Systems Theory into their models of human physiology is because we need to learn how to interact with these models to remedy such errors. We have figured out how to teach our immune system to recognize new pathogens like COVID-19 with the use of vaccines, but all methods we currently use for treating auto-immune syndromes involve dampening the entire immune system. We do not know how to remove an error in the “Self” recognition protocols. Likewise, we do not know how to enlarge the “Self” model our immune system runs on, to include a donated organ. However, human physiology is not the only place that the model-based, model-guided nature of life is visible. If we know what to look for, we will begin to see it all around us. If we tune our vision to recognize the error signal, we will likewise be able to observe that it all around us!

If we take a look at organism species which are known for various forms of mimicry or camouflage, we will have a glimpse into how the existence of error in model-based, model-guided systems is deliberately utilized in interactions within ecosystems. Manipulating error, itself, has actually evolved within some species, because of interactions within native environments—sometimes to an astonishing degree. The ability to manipulate the models of other species to benefit “Self” is something that *fitness* can act upon. All forms of camouflage and mimicry are ways to defeat or confuse the sensory detection of other species, perhaps to avoid predation or to help with hunting. In the case of a group of flowering plants known as bee orchids, the flowers have evolved to resemble female bees of particular species that are the main pollinator of the plant species in their native

environment. The flowers cause a recognition error in the male bees, who try to mate with flower after flower, and thereby cross-pollinate more flowers than they otherwise might. The intricacy of the mimicry even extends in some species to emitting pheromones similar to what the female bees of their pollinator species emit when ready to mate, reinforcing the recognition error in the male bees through a second sensory pathway. Diabolical but effective!

What this illustrates is that the Anticipatory nature of life is clearly active in evolutionary entailment. The ability to encode accurate models of self and environment is something evolutionary forces can act upon. The ability to detect error in one's models is also something evolution has favored, which is how I interpret the evolution of intelligence. Intelligence allows an organism to recognize error in its own predictions and either re-encode a better model or build a workaround for models that cannot be re-encoded within a single lifetime. Some somatic models are so *built in to the flesh* that they cannot be changed, such as gills predicting an aquatic environment. The way species within an established ecosystem mirror the qualities and parameters of their native environment is quite pronounced and is what led Charles Darwin to develop his Theory of the Evolution of Species in the first place. One of the things that Anticipatory Systems Theory says is that organisms build their environment into themselves. Sometimes, it's material aspects of the environment, like carbon, water, salts, oxygen, etc., but that is only one aspect of environment. It may be behavioral aspects of environment that are built in, like day/night cycles caused by rotation of the planet. It may be lunar cycles manifested by tides. It may be seasonal cycles in environments that experience winter and summer as caused by the orbit of Earth around the sun. It may be electricity and polarity . . . Whatever the native environment manifests over evolutionary timeframes can be encoded into the organisms which are evolving there. It may be some aspect of behavior of other species within the same environment—some effect of the presence of another species, the way coral reefs require nitrogen which is usually provided by the urine of so many species of fish that live in or near the reef. Or the way certain parasites depend on the body heat of warm-blooded hosts to survive winter.

However, notice that once some aspect of environment becomes encoded into a species, it is de-facto predicted to continue. Aquatic species that evolve in fresh water environments usually cannot survive in marine environments, or out of water. If their environment changes too radically, too quickly for evolution to re-encode such models, the result is error and dysfunction. If the error is critical enough, it can be fatal. Furthermore, each species that goes extinct from a given ecosystem accelerates the rate and magnitude of change for all remaining species. Eventually, even species that were not harmed by the initial insult to environment and also did not depend on any of the initial extinct species in a direct way will probably be impacted as the process of accelerating rate and magnitude of change continues. Each species that is extirpated from the environment ramps it up that much more. This brings us face to face with the singular danger that exists for all Anticipatory systems: rapid change in environments cause error to arise from the guidance models of the species which evolved in those environments. The faster the changes, the greater the magnitude of change, the more perilous it will be for life. Eventually, the level of error will be fatal, increasing the rate and magnitude of change/error for remaining species. Extinction cascades are made of this.

Every mass extinction event in the fossil record of Earth has been linked with triggering events that generated rapid change—far outside the normal cyclical changes of ecosystems across the planet. From the vantage point of Anticipatory Systems Theory, we can see why. Model-based guidance systems have an Achilles Heel: rapid change in the environment causes *error* in the models that interpret and predict what incoming sensory information *means*. Most species, like single cellular organisms and plants, have no ability for detecting error in their own models, much less doing anything about it. When the model-based guidance is no longer reliable, organisms are left with pure reaction to radical change in environmental conditions. That often translates into dying. Wild swings in temperature

are the kind of thing that can kill a lot of plants, especially when they happen in ways that are counter to normal seasonal temperature ranges. Freezing temperatures in summer will even kill plants that have evolved to survive winter. This is a sobering situation to contemplate, given that human activity on Earth has now changed the composition of Earth's atmosphere in a radical way, in just a few hundred years. We are pushing a period of rapid and radical change, globally, that is bound to have serious consequences in local ecosystems all over the planet. The danger becomes much clearer when viewed from the model-guided nature of life and the knowledge of how error arises in Anticipatory Systems.

4. Human Nature as Dual Anticipatory Systems, and Anticipatory Dysfunction

As described earlier, I have come to view the consciously aware mind, as experienced by human beings, as a second Anticipatory System which has evolved within and emerged from the living physiology of the human soma. The reason I see the mind as a second Anticipatory System is because there is overwhelming evidence that the human mind has an encoded model for "Self" and for "Health (of Self)" which are independent of the somatic values, as well as its own optimality scale for evaluating sensory information.

The models for "Self" carried by the mind and the body are independent of one another. This means that they may not match and when they do not, then dysfunction ensues. I consider Gender Dysphoria to be an example of exactly this situation. The human mind has evolved to such a degree that it supersedes the somatic models of many kinds. The mental model of "Self" is more powerful than the genetic gender. Being transgendered is not a choice one makes; the mental model for gender is part of a fundamental definition for "Self" that everything else is based upon. It's born in. I have a sibling who is transgendered and have done extensive research into this, from an Anticipatory perspective. In fact, I have concluded that *only* from an Anticipatory Systems perspective does it really make sense.

In more widely experienced examples of the mismatch of fundamental models for "Self" and "Health (of Self)", the human body still uses pain to discourage certain behaviors that are predicted to cause injury, but that the mind overrides because we can see how it is that the momentary or short-term pain of some action is in service to a greater good of longer duration or value. Putting that another way: The mental models predict that the activity which causes pain is still worth doing in order to achieve benefits to health that somatic models are unable to perceive or interpret. Hip replacement surgery, for example.

There are times when the interacting mind and body can generate dysfunction that I think is specific to being a dual Anticipatory System. Panic attacks are one example. Post Traumatic Stress Disorder (PTSD) is another. There are also behaviors we recognize are real phenomena, but have so far failed to find any explanations for. The Placebo Effect and Nocebo Effect, for instance. Expectation seems to play a critical role in all of these phenomena, both somatically and mentally. Expectation somatically can provoke expectation in the mind, and vice, versa. However, in all cases, *prediction is required for expectation to ensue*.

5. The Concept of Expectation

It is clear that the concept of "expectation" could not exist in a purely reactive framework because it refers to some future occurrence. Therefore, we must allow that it is an Anticipatory concept. It's based on a prediction about the way things are *going to be* and, like all predictions, an expectation is ultimately generated by a model of some kind. There are both somatic expectations and mental expectations, and they interact—which is part of what Pavlov was demonstrating in his experiments with dogs. I daresay that most adult human beings have memories of what expectation feels like, and even what finding out our expectation was incorrect feels like. The memory of an experience is an encoded model of that experience. Some experiences can drive epigenetic changes which turn out to be heritable. Traumatic experiences, for example, can generate patterns of expectation and response that lead to limbic, reflex-driven behaviors. The characteristic exaggerated startle of PTSD is a perfect example of a somatic model built out of mental models and patterns

of expectation, thereof. The hormonal profile and mind/body interactions of PTSD are something I have experienced myself, after my third child was born with multiple physical handicaps requiring a great deal of medical intervention over years of time. I mention this in order to give context for the following: Even recognizing the Anticipatory aspects of PTSD and going through enough counseling to learn that the syndrome is a self-created, somatic model-based malady does not lead to a cure. Somatic models are beyond the reach of the conscious mind. One cannot just decide to stop startling over unexpected noises like the phone suddenly ringing or sights like a family member coming around a corner in the house when you did not realize they were home. The adrenalin-laced exaggerated startle of PTSD happens all day long, over nothing. In my own case, it was only a ten day course in Vipassana meditation that was able to get rid of it. That was in October of 2008 and I have been meditating—and studying how this technique of meditation can possibly achieve that outcome—ever since. I suspect that it is the fact that Vipassana is a technique that involves body/mind interaction at the sensory level that makes it so effective in somehow resetting models in both.

Buddha called the mind “the sixth sense door”, and said it was on equal footing with our five main senses of touch, taste, smell, sight, and hearing. What he was talking about was the body’s response to incoming sensory information through the “sense doors”. He further described a part of the body/mind he called (in Pali language) the *sañña*, whose job it is to evaluate all incoming sensory information according to some sort of optimality scale: whether it’s “good” or “bad”. The body then generates sensations/biochemistry according to that evaluation. One example I use to illustrate this is to consider what it feels like to have someone honk at you in traffic when you’re pretty sure you have not done anything to deserve it. Then, you realize that the person was honking at the driver of the car behind you, not at you. The change in how that feels is a body/mind interaction based on how differently those two scenarios are evaluated by the *sañña*. One is a purely somatic reaction, the other is based on further information by the mind—but with somatic effects. The first is based on what feels like a public accusation by a stranger about your driving. The second is based on realizing it’s not directed at you! You are not being accused/attacked in public. It’s somebody else’s drama. It can feel very different in the body.

This explains perfectly what the Placebo Effect is: It’s a somatic expectation—an expectation in the body—based on the mind’s belief/prediction that some effect will be forthcoming. This is why I have concluded that the human body and mind are both distinct Anticipatory systems, but they are also components of one another, in the same way that metabolism and repair are components of each other. So much of human experience that is otherwise inexplicable begins to make far more sense when viewed through this Anticipatory Systems lens. Thus I assert that disciplines like Psychology, Psychiatry, Cognitive Theory, and the Social Sciences could make productive use of Anticipatory Systems Theory if it were integrated into current scientific models of body and mind.

6. Conclusions and Food for Thought

I assert that the need to understand biological systems like ourselves is reason enough—all by itself, despite the fact that other reasons (as mentioned, above) exist—for the further support and development of the systems sciences. The systems approach offers the alternative direction of approach from purely reductionistic science and the potential to study system organization as a thing in itself. We need both avenues of approach in science. We know already what reductionistic scientific approaches are very good at. However, we will never be able to understand ourselves in a comprehensive way using only reductionistic science, based on an assumption of a purely reactive universe. Whats more, the fact that science relies on the Modeling Relation cannot be ignored. Because it does, it proves conclusively (every time we use it successfully) that the entailment embodied in that relation not only exists but can be used, and IS used, in science, to accurately predict future behavior of systems around us all the time. The fact that the entailment pattern

exists within the natural laws of the universe means it can be incorporated into system organization just as any other aspects of the universe can be.

It's also worth pointing out that if we accept the above is true, then we also have a proof that life is generated by organizational entailments, NOT accretion of material components. In other words, there is no way to add ingredients together to spontaneously generate life just as there is no way to add one more to some incredibly huge finite number and generate *infinity*. Infinity in some sense predicts the existence of a future, just as living organization does. Given those facts, we can even assert that life arose when that happened: The first Anticipatory system that spontaneously self-organized was model-based and model-guided. That is about the only supported conclusion we can make about the origin of life. All others are unable to be "decoded".

I have suggested, above, that the human mind is a second Anticipatory system—that evolved within and emerges from somatic life. I view human *mind* as an evolutionary concentration of the same model-based, model-guided, information-seeking and information-metabolizing system that *life* also emerges from. That model-based, information sifting/evaluating nature is what being an Anticipatory System *means*.

It's almost a fractal thing; the reality that our science needs to build a better scientific model of the model-based nature of life and mind if we are to have even a hope of fully understanding ourselves physiologically, mentally, and socially. Science is a human construct, formalizing natural systems in the universe into models, in a process that mirrors exactly the pattern that happens in the human body and mind, naturally.

Currently, I have observed that there seem to be two main approaches to the efforts in science to understand life and mind: One assumes life is all in the particles and, likewise, the human mind is all in the brain "wiring"—this is the mechanistic/reductionist approach and worldview. The other assumes that life and mind comes from some mystical force that pervades the entire universe, similar perhaps to the "weak force" and the "strong force" in physics, and is somehow mysteriously concentrated in living organisms, as the "strong force" is in atoms— and the imputed mind-like nature of the universe is somehow further concentrated in, or transduced by, the human mind. I view both of those worldviews as different variations on "the stardust theory" (that we are made of star dust and therefore stars and human beings are extensions of one another). The main flaw in both hypotheses is that they both ignore system organization as a causal aspect of the universe. It's not about the dust nor is it about the fact that both systems are components of the universe. To realize that something about local context can change outcomes of interactions is to admit that system organization can impact causal flow. To recognize that something as simple as molecular organization can radically alter the expressed behavior of atomic elements, as the compound sodium chloride does to the pure elements of chlorine and sodium. . . is to admit that organization can change observable, measurable phenomena and create patterns of behavior of systems that only exist and continue while the system is intact. It also admits the reality that relations between interacting material particles are essential components of the interaction/context/organization. Relations of time, of proximity, of motion, of sequence, and so on are causally active—in and of themselves—and therefore these aspects of system organization require scientific study and scientific understanding. We must develop some new methods in science for studying them without destroying them.

Once you've arrived at that point, then recognizing that a system incorporating the entailment embodied in The Modeling Relation is not only possible but essential for the peculiar Anticipatory behavior patterns of life and mind. . . In fact, I assert that this realization becomes inevitable. Modeling is the only reliable method for accurately predicting future events. Furthermore, even then, only when a model is within the relation diagrammed: with enough of the causal entailment of the system that pertains to what we want to predict encoded into the model in such a way that the pattern of entailment carries over. Error is an ever-present potential with the activity of modeling, and that is as true in life and mind as it is in science—or anything else we human beings use our minds for.

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