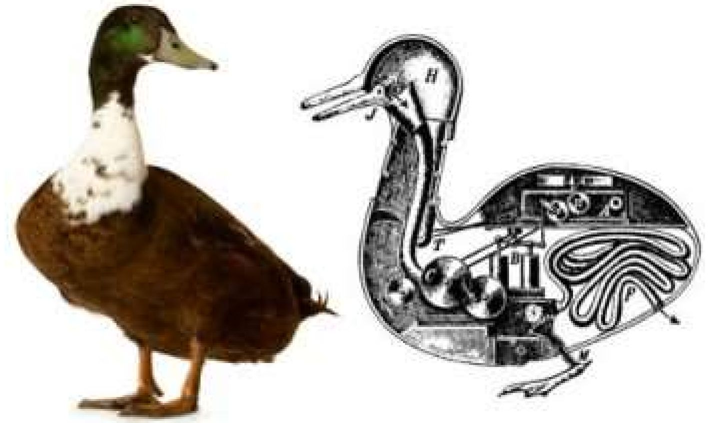
Complex Systems Science vs. Reductionist Science: A Clash of Paradigms

Karl North 2015



If systems thinking is simply a necessary way of addressing the problems of a reality that is by nature obviously complex and interconnected, why is its holistic worldview so revolutionary and seemingly new to us? And why are conventional habits of inquiry and problem solving proving so ineffective? Where did these habits come from? As I address these questions here it may be helpful to contrast the two paradigms by looking at the source of the conventional paradigm in the history of science.

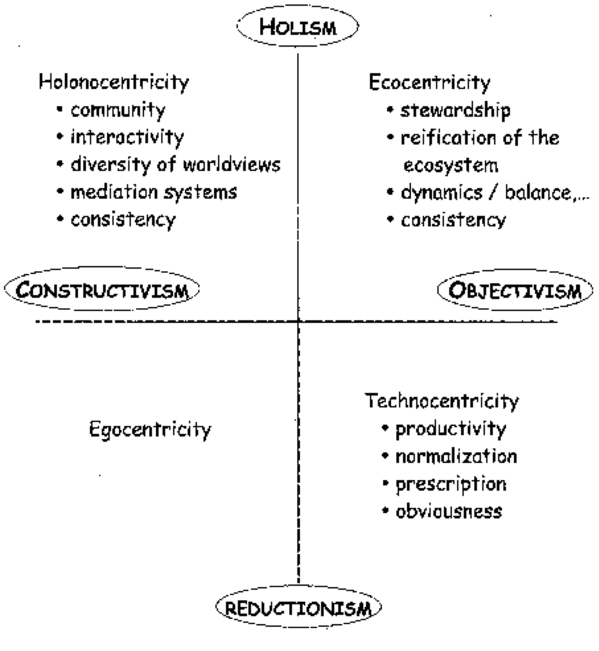
The way we do science today suffers from a view of the world that began in the 18th century, as the acquisition of knowledge began to rely more on disciplined observation of the world rather than interpretation of religious beliefs. By studying problems in isolation from their real-world systemic context, researchers found they could gain reliable, predictive results usable to invent powerful technologies. This became known as the reductive method because it reduces the focus of inquiry to the relationship of two or three variables. Experiments are performed under 'laboratory conditions' - all other variables that might be causally related are deliberately held constant.

As already mentioned, this approach yields predictable, replicable results, but only in the laboratory. The trouble is that when applied in the real world outside the laboratory, application of the discoveries of reductive science are reliable only in the short term. Other variables are set in motion and generate unexpected results - '**emergent properties'** that the reductive method was not designed to discover. However, emergent behaviors and other issues of complexity are central to the world's most pressing technological, economic, environmental and social challenges.

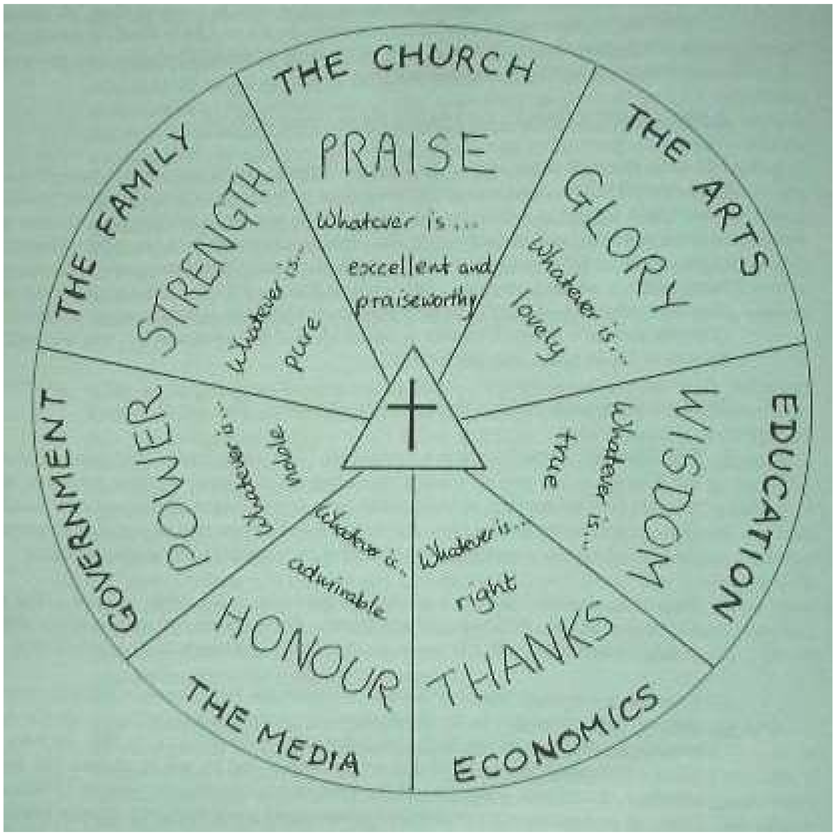
A simple example of emergence from chemistry is what happens when elements are combined in certain ways into compounds. One could not discover the emergent properties of water (H_20)from the study of the elements hydrogen or oxygen in isolation. This example is so obvious that anyone can understand. Examples later in this lesson will illustrate how emergent properties generated under more complex circumstances are anything but obvious without more holistic methods of inquiry.

The capitalist economic system, which developed at the same time, encouraged this method of inquiry because its short-term predictive power was congenial to the capitalist goal of maximizing short-term profit. Gradually the reductive method dominated scientific work, and the word ‘science’ became synonymous with the method. The reigning scientific worldview became ‘reductionist’; that is, only research using that method was accepted as science.

The reductive method of narrow inquiry led to increasing specialization and compartmentalization where scientists know ‘more and more about less and less’ and are ignorant outside of their fields. This approach actually replaced a more holistic one based on common observation that problems often have multiple causes that require understanding of many areas of knowledge. As late as the 19th century the best scholars sought multidisciplinary expertise. For example early social scientists often called themselves political economists because for them an understanding of economic behavior was impossible without knowing about political power. However, Enlightenment thinkers rejected the holistic paradigm because they associated it with the theocentric worldview of the medieval church and its insistence that all knowledge find a basis in scripture.



From R. Bawden (1997)



In time limitations of the reductive method became increasingly apparent. Applied to the complexity of the real world outside the laboratory, its piecemeal inquiry and results are intrinsically too narrow in scope to reveal emergent properties or ripple effects over space and time – often dismissed in the language of reductionism as ‘side effects’. A general pattern has emerged where technologies based on purely reductive science work for a while as expected, then start to produce unexpected and often unwanted results, outcomes that at least from a reductionist perspective are a surprise and are therefore labeled “counterintuitive”.

A Reductionist Science Morality Tale

Folktales often provide important lessons for living. Fantasia, an early Disney film, immortalizes a famous folktale, The Sorcerer’s Apprentice. This tale has been relevant enough to be reworked as novels, music, and poems from the time of ancient Greece to Faustian Europe.

The tale begins as an old sorcerer departs his workshop, leaving his apprentice with chores to perform. The apprentice (Mickey Mouse in the Disney version) tires of fetching water for a bath or tank, and enchants a broomstick to do the work for him, using magic he is not yet fully trained in. However, soon the floor is awash with water, and he realizes that he cannot stop the broom because he does not know the magic word to make it stop. Despairing, he splits the broom in two with an axe, but each of the pieces takes up a pail and continues fetching water, now faster than ever. When all seems lost in a massive flood, the old sorcerer returns, quickly breaks the spell and saves the day.

Similarly, modern science at the beck and call of high finance has created ever more powerful technologies. Trumpeted to the public as a cornucopia of progress, these technologies initially appear true to promise. But like apprentice magic, they often bring tragic consequences in time. And there is no sorcerer to return, break the spell, and return everything to normal. One source of these problems is in the exclusive use of the reductive method.

The scientific community - as it begins to acknowledge that specialized knowledge is useless and even misleading without a way to gauge the consequences of decisions across broad interconnected wholes and much later in time – is adopting the paradigm and methods of systems thinking.

Close Encounters with Reductionist Science

For several decades I operated an entirely grass-based sheep dairy within driving distance of a major university agricultural school. In the interest of maximizing sustainability I followed cues from natural systems to design a farming system that was as reliant as possible on its own inputs – those generated by the farm itself. A holistic plan for intensive grazing management was critical to the design because it needed to incorporate multiple interdependent goals: soil building - diversification of forage species - high forage production and health - high sheep production and health and quality milk for our on-farm cheese production. The farm had to work as an integrated agroecosystem.

To my disappointment I discovered little research at the university that could help me with my design effort, and virtually no one trained or interested in such a holistic design problem. The animal scientists were expert in high concentrate livestock diets and had little interest in the grass diets that ruminant digestive systems are built for. The plant scientists had a lot to say about forage monocultures but nothing about using grazing management to create a diverse and productive pasture. Veterinary science could offer drug treatments but nothing about pasture as a pharmacy of medicinal forages. The soil scientists had been trained to chemical fertilization and could not help me with building fertility by increasing soil organic matter with farm-composted manure bedding. Dairy scientists had no interest in dairy sheep or the relationship of pasture diversity to milk quality. My design problems demanded that the scientists step too far out of their disciplinary comfort zones.

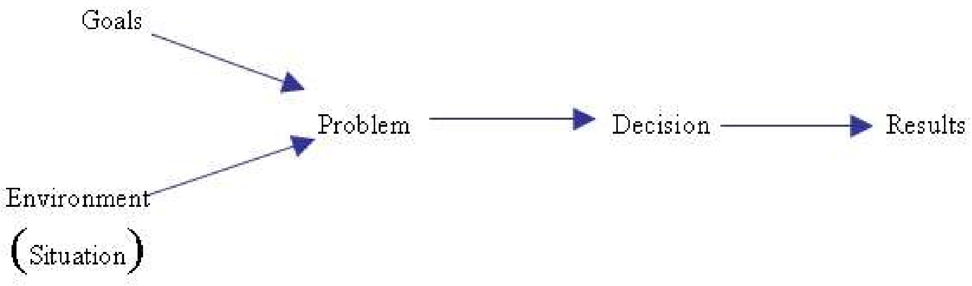
I finally found one university agricultural extension agent who shared my interest in the holistic potential of intensive grazing management. In his thesis research he had encountered the same problems with academia as I had - because it required a transdiscipinary effort of which his academic mentors in the different relevant disciplines were incapable. In the end both of us have had to rely heavily on experiential knowledge developed from our own trial and error, and in my case knowledge gratefully shared among practitioners in the organic farming movement.

Because the dominant worldview has existed for so long, it has spread from the scientific community to the whole culture of the West, and is therefore often unconscious in practice. People readily admit that we live in a universe where "everything is connected", and indeed, the evidence for this is all around us. Yet in practice, out of habit we narrow our vision to only a few of the variables that are relevant to the problem at hand.

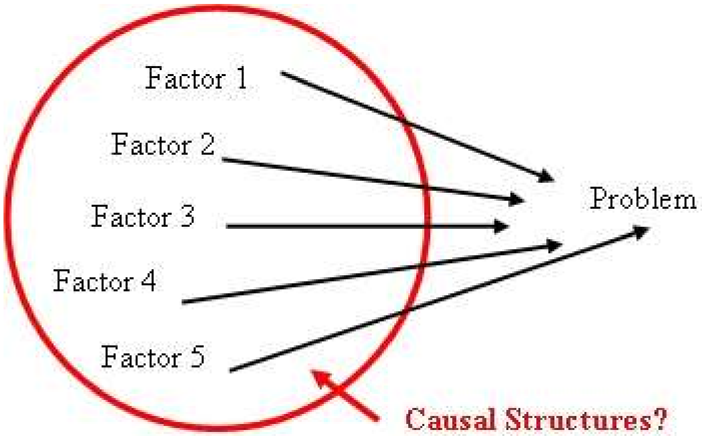
Circular vs. Linear Causality

There exists other ways of doing science that pose problems broadly enough to account for likely ripple effects and nonlinear change. Here I will discuss specific ways in which the systems thinking approach to inquiry contrasts with the dominant scientific paradigm.

A common way of approaching a problem is to react to an event by looking for a single cause. In this event-oriented worldview problem solving is a unidirectional, linear process in which a goal-driven reaction to a problem situation finds a cause in the immediate environment and then produces a decision and finally results. And there the process ends.



An improved version of the linear process is to look for multiple causes or factors. In this factorial approach, different factors are weighed as to their effect on the problem. If Johnny is doing poorly in school, we may look for causes in the home environment, the school environment and policies, the teaching and classroom environment, Johhny's aptitude and motivation or a combination of factors.



However, embedded in this 'laundry list' habit of thinking about causality are several potentially false assumptions:

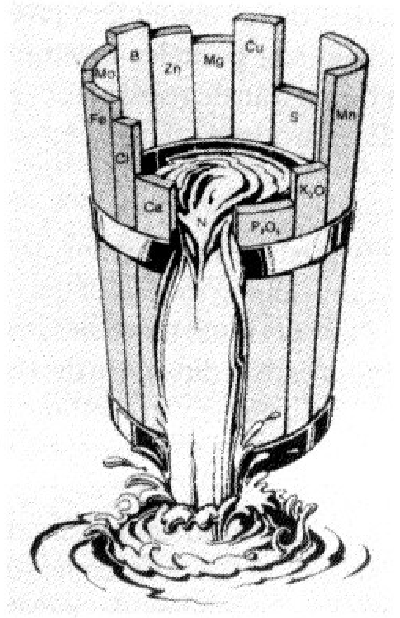
- Each factor operates independently of the others, or has a fixed, proportional effect on another.

- There is only one dependent variable - so causality runs only in one direction between two factors.

- Causality is instantaneous, or relatively quick.

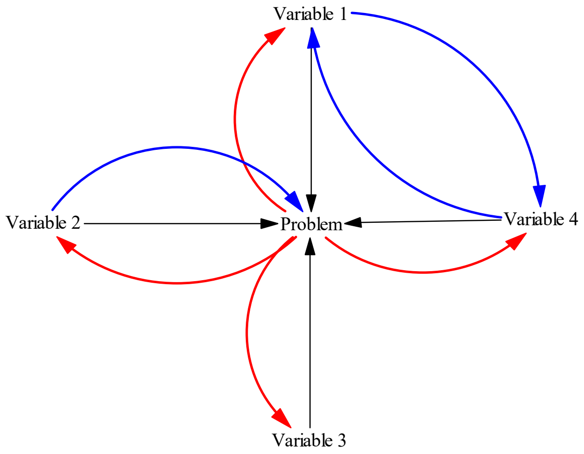
Factor interdependence, however, is common in our universe. For example, we know from the 19th century research of Justus von Liebig that plant growth is limited by the level of the least available soil mineral. Known as Liebig's Law of the Minimum, it has found application in many other multi-factor situations and has become a cardinal concept in systems thinking.

Figure 1-9

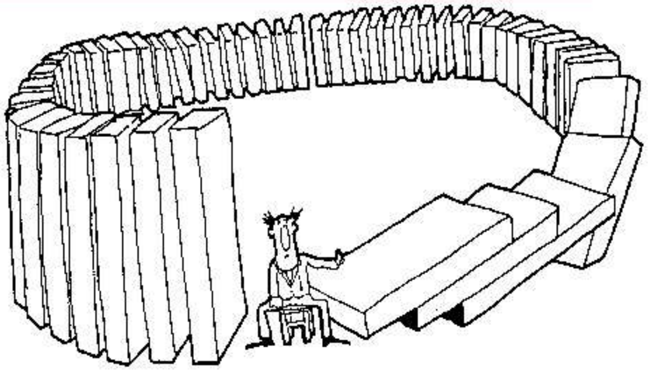


White 1982

Feedback effects are common drivers of behavior in many situations – but factorial causal structures do not consider the likelihood of circular causality that produces them. What if something in Johnny's home environment made it hard to finish homework assignments, which affected his classwork and ultimately his motivation, and what if the response of the system was reprimands at home and low grades at school, which lowered his motivation and success in school even more? What if different factors are really variables that can produce feedback effects on each other? For example, what if Johnny lives in a neighborhood where poverty produces crowded homes and underfunded schools?



Systems thinkers look for **feedback relationships** and include them in their mental models. This circular causality often involves **delays** that are responsible for consequences that are unexpected because they occur later in time. Also, circular causality is the only possible explanation of nonlinear behavior.

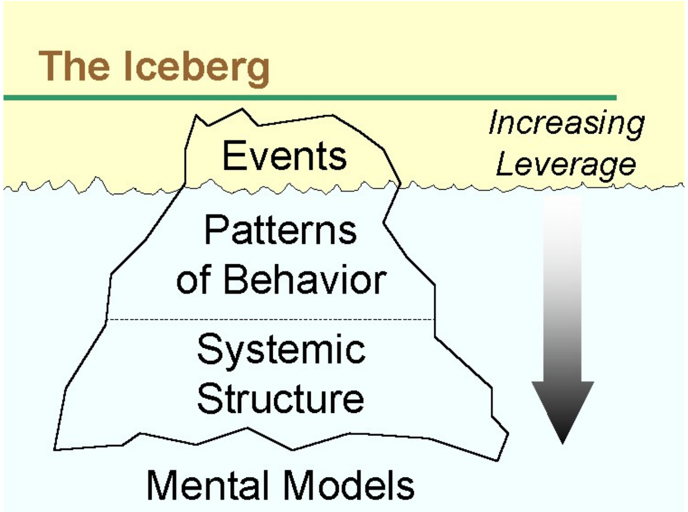


In complex systems, cause and effect are distant in time and space

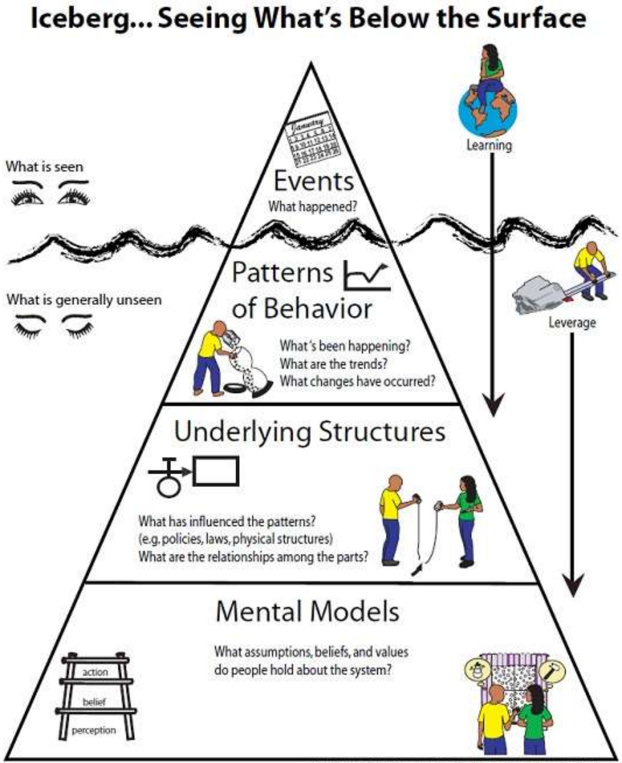
I once had a student in a high school class who started out the year well, but became more and more prone to fall asleep in class. He was the only student in this class who lived in a black inner city neighborhood. All of the students had been placed in this college-bound track after aptitude testing. No other students were falling asleep. Therefore I was hesitant to blame either the student or my teaching. One day after class I asked him why he was so tired. He said he had a night job because his family needed the money. One day my department head visited the class and saw the student had fallen asleep. Unaware of the changing pattern of the student's behavior over time, he blamed the student and reprimanded him harshly. After class I had to console the student, suggesting that he ignore what the other teacher had said.

This story is an example of the need to look beyond events for the causes of behavior, to look for patterns over time, and then for the causes of the patterns that we find. To build these habits of systems thinking, a powerful conceptual tool is the Iceberg View of reality.

Invisible Cause: the Iceberg



Most people search for understanding mainly in events. The iceberg directs our focus below the surface of events to ask whether events are recurring in historical patterns, and then look for the causes of those patterns in a systemic structure.

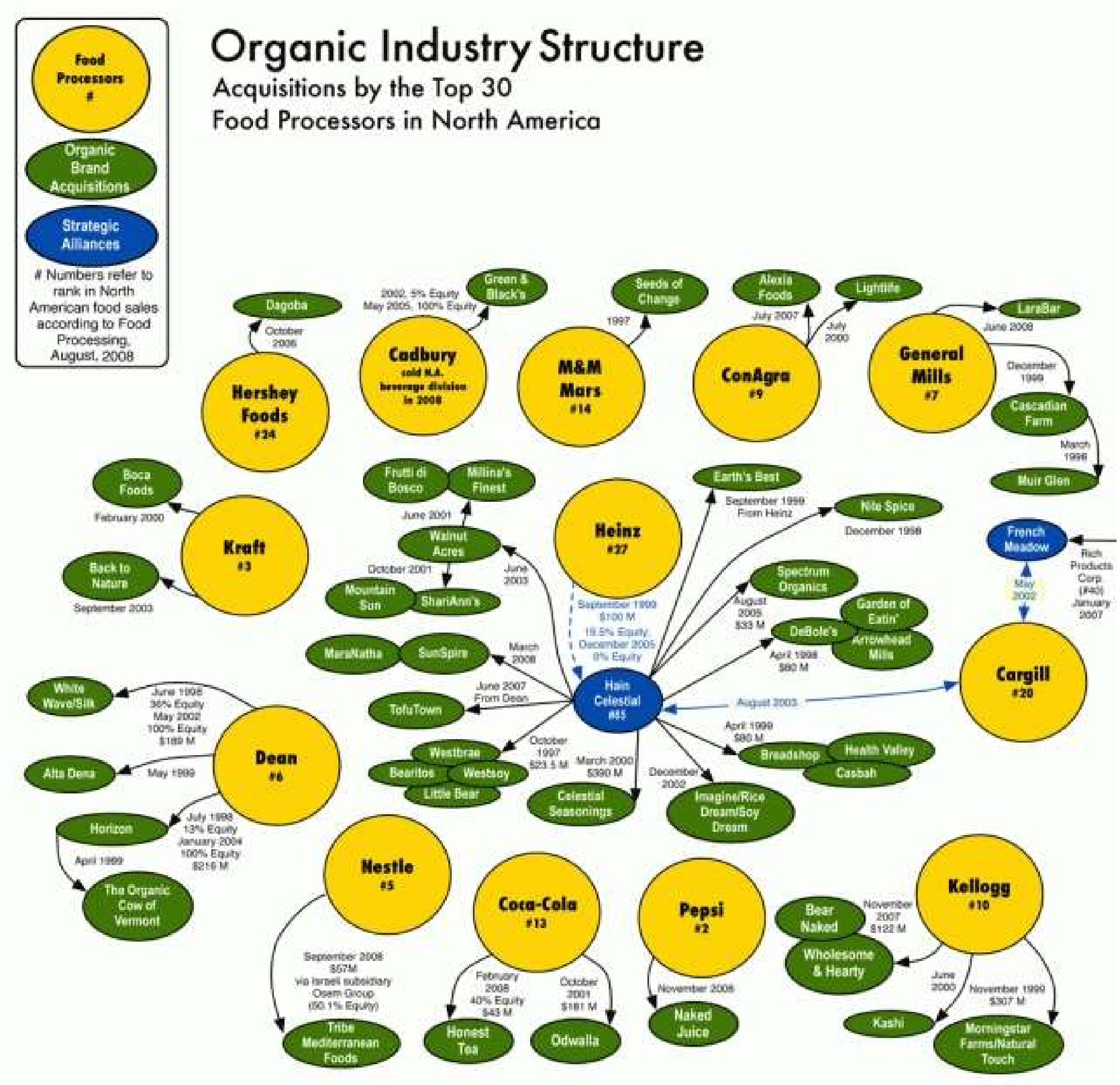


Adapted by Systems Thinking in Schools, Waters Foundation, from Innovation Associates, Inc. August 2010.

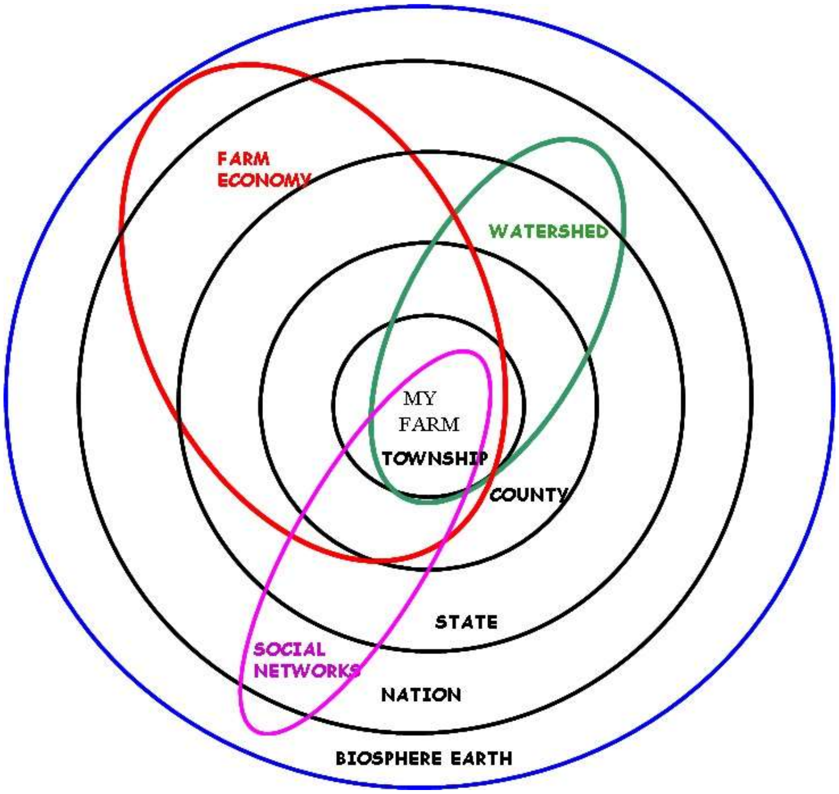
A simple example of an iceberg analysis of a physical event is a movement of the human body, say a footstep. To drill down toward root causes, we ask, Is it part of a pattern? We discover the pattern, ‘walking’, and ask, what in the structure of the body causes our ability to walk? We may trace it to habits stored in our memory when we learned how to walk. Then we are prompted to ask, What governs our ability to memorize? - and seek the answer in our genetic inheritance, the rules coded in our DNA.

Many events are part of recurrent patterns governed by structures in social or ecological systems. Let’s say that the event is: a man takes a drink. Looking deeper we find this to be part of a drinking pattern of an alcoholic. Then we ask, Is the pattern due to a genetic predisposition in this man for alcoholism? Much of the time the quest for the system of influence governing this man’s alcoholism stops there, or only includes possibilities like the man’s family history. But what if we find a pattern of alcoholism that is more prevalent in one society than in another? The iceberg tool directs us to look for causes in the social, economic and political structures of the social system itself.

Another example is the industrialization of organic agriculture that surprised so many in that movement. What in the laws governing our economic system factilitated that takeover?



The iceberg tool helps us expand our mental model of the **system of influence** that governs events. This brings up again the critical question of boundaries. The systems thinking maxim - **'All boundaries are wrong; some boundaries are useful'** - is partly a reminder that we live in a universe of nested systems in which our search for causes cannot respect boundaries that are apparent because of the way our senses work, making some things visible and others invisible to the naked eye. Here is a diagram of some of the nested systems in which my farm is embedded. Others might be visible if I learned to look for them.

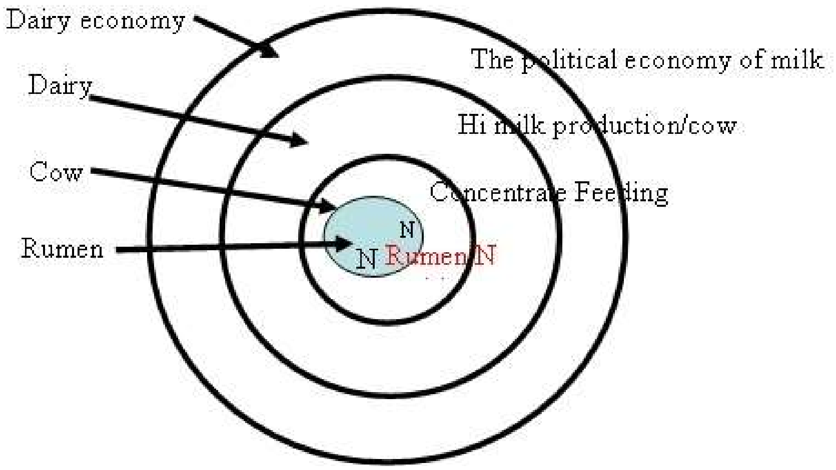


Conclusion

To summarize the systems thinking paradigm, we develop an understanding of a problem by constructing a hypothetical system of influence – the appropriate systemic context. It is a model of causal relations, an operational model of how things change over time. Two procedures are unique to this method:

- Continually question the boundaries of the model. Usually that involves transdisciplinary inquiry. Systems thinker Peter Senge labelled this process "The Five Whys" because it requires us to keep asking "And why is that?" to get to the root causes of a problem, which often are deep within the system structure, as Pogo told us.

Scientists sometimes use systems modeling methods without following this essential rule of the paradigm. A research project at a prestigious agricultural school built a system dynamics simulation model to solve the problem of excess rumen nitrogen - common in high production dairy cows – that was excreted and therefore wasted. Because the problem was narrowly formulated as confined to the rumen, the research focused on simulating various bio-chemical rumen environments that would absorb the nitrogen. An application of Senge's Five Whys would start by asking why there is excess nitrogen. Answer: because of the cow's high concentrate diet. And why is that? Because dairy cows designed for high milk production would die without that diet. Why do farmers need high production dairy cows? Because given the monopoly structure of the dairy economy, it is the only way farmers can make a living. Hence the real reason for the nitrogen problem might better be sought by modeling the political economy of the dairy industry.



- Discover how causal relations connected in circular **feedback loops** might explain nonlinearity and delays in the behavior(s) we are trying to understand. As we will see, there exist two kinds of feedback. As one or the other becomes dominant our model of the system of influence, problem behaviors can radically change direction – as in this global model of limits to growth.