# CONFRONTING ECONOMIC PROFIT WITH HIERARCHY THEORY: THE CONCEPT OF GAIN IN ECOLOGY

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## ABSTRACT

Contemporary problems are often complicated by values intruding into the arena of physical systems. Economic notions of profit have values embedded in them in a way that generally does not occur in ecology and the other natural sciences. We generalize profit as gain in settings beyond strict economics in a way that encourages placing values properly in biological and historical social systems. Complications of elaborate control quickly enter the scene at this point and in this paper we invoke hierarchy theory to keep levels of analysis straight. Hierarchy theory often invokes dualities and a mix of process and structure that are fluid under changes in level of analysis. Notions of gain and profit are recursive as the system uses resources and must change strategies to deal with scarcity, which forces increases in efficiency in yet a new round of change. The transition from abundant resources used carelessly to scarce resources used efficiently changes controls in systems. Such changes over time amount to hierarchical restructuring, which in turn requires of the observer meticulous application of new levels of analysis as the system is redefined. The system bounded at a new hierarchical level encounters dualities embedded in the hierarchical concept of the holon, which offers a precision of definition of the new system as it exists as an autonomous whole while still being part of some larger system. We introduce these shifts and dualities using examples from nuclear energy, colonial insects and changes in complex societies such as Rome and the EU. In the end both ideas of profit and hierarchy theory are clarified in a two-way exchange.

Keywords: Ants, duality, EROEI, hierarchy, high gain, holon, level of analysis, low gain, resources, societal collapse, termites.

## INTRODUCTION

Economists are unusual in that they are trained to deal with values associated with their formal models. An issue in the contemporary world that extends outside economics per se is that humanity addresses new problems at a larger scale where values intrude whether we like it or not. One of the strengths of science has been its relatively dispassionate attitude to the material it studies such that values are excluded as far as possible. Storms may be bad for people caught in them, but the atmospheric processes have no interest in that fact one way or another. It is good to predict weather outcomes, but values are irrelevant to the calibration of atmospheric movement. One source of this dilemma of values versus valueless physicality arises when physical material is mixed in with biological and social entities. The critical complication in biological and social systems is that the scientists' models address entities that themselves have models for the world (Rosen 1979). The object of study has codes which more or less require values for the scientist to achieve a workable representation. For instance, a model for disease brings with it some preferred state from which there has been a departure, even if the molecules of the sick individuals care not about any one condition over another. The traditional dispassionate posture of science is open to confusion when values and coded information are part of the system under investigation. By using hierarchy theory as a general expression of the problem we attempt in this paper to generalize the role of values so that they are neither muddled nor overlooked across complex systems in the natural and social sciences.

Ahl and Allen (1996) assert that changing technology alerts science and society to new problems, which may be either new in themselves or new only in that they can now be detected. Either way, these issues cannot be adequately addressed with traditional disciplinary approaches. For instance, forest management is far more exacting these days, for it must meet demands for public participation as never before. Accordingly, Stoltman, Radeloff and Mladenoff (2004) have moved away from describing forests with tables and graphs, and they instead take up graphic forest visualization that anyone can interpret simply with the naked eye. Computer-based visualization moves to use the evolved human information processing abilities innate in us all. The public stops complaining that the science is arcane and technical, saying instead, "I get it!" GIS is now friendly to an intelligent general public. We forget how revolutionary were the early Apple computers. The inscrutable "cd\" needed to move between files in MS-DOS as late as the 1990s has now given way to icons, the mouse, and drag and drop that children use easily. The authors here draw from ecology and ecological economics, filling a tool box that can be valuable as society meets the complexity of biology and people mixed together in the context of new difficulties. This paper pulls together ideas from hierarchy theory and translates them for use across a range of contemporary issues invoking larger sized systems investigated with new technology.

To date hierarchy theory and ecological economics have not been set properly in each other's context. We find that while hierarchy theory and ecological economics are individually adept at dealing with particular issues, comparison between the two approaches lends richness and power to both sides. Hierarchy theory deals with complexity and duality very well. It deconstructs elaboration by using a special case of set theory where sets are recognized as having special asymmetric relationships and so become levels. The notion of gain comes straight out of economics. Applied to biological systems gain shows new possibilities in the relationships bound up in the simple but powerful notion of profit. The prefix "eco" refers to the home of the system in question. Its occurrence in both economics and ecology suggests a common concern for resources in the context. When things are placed explicitly a wider context, problems move upscale into regions of complexity. Ecology does address resources, but rarely goes on the use the economic concept of profit made from the system exploiting its environment. The ecologists' model is more one of organisms exploiting resource to get by, not to make a profit. The ideas arising in our fresh biological discussions of gain have then been turned around and applied to social systems that are more than simply economic. Aware of some parallels between hierarchy theory and notions economic gain, the authors here have engaged in a systematic treatment across the divide. We have been surprised at the rich cross-fertilization that has occurred and communicate that in this paper.

As a dialect of GST, hierarchy theory deals with complexity, focusing on issues of the observer and levels of analysis (Ahl and Allen, 1996). A useful application of hierarchy theory occurs as ecological economic theory addresses issues of return on effort, essentially investigating profit in biology. Ecologists generally do not deal with the economic concept of Energy Return on Energy Investment (EROEI). That idea is so important in economics that the acronym EROEI exists as common parlance in economic circles, but is still essentially absent in ecological discourses. In this paper we will use hierarchy theory to lay out the intellectual device of EROEI for ecologists, so that they can go further in embracing a sophisticated view of the economics of biological and ecological systems.

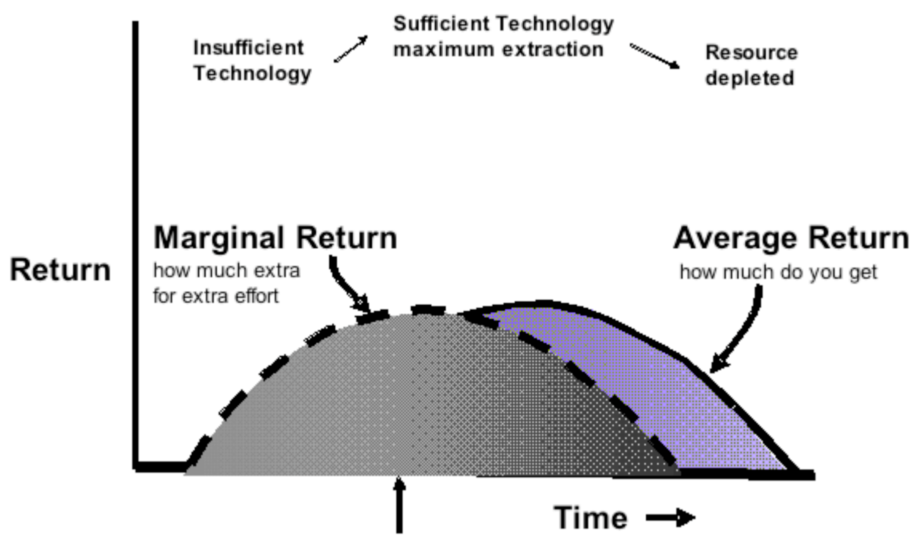


Figure 1. While average and marginal returns are a stock in trade in economics, economists do not generally plot them over time as Tainter (1988) does. Instead they plot return against effort as a production function, showing diminishing returns on hypothetical effort; the more work you put in, the less you get per unit effort. Here we see average and marginal returns over time. Marginal return more or less maps onto the benefits to societies of complexification over time

Tainter (1988) has investigated returns to investment in complexity in problem solving in various historical societies. Tainter's book, *The Collapse of Complex Societies*, is part of the conceptual basis of this paper. Tainter argues that societies are problem-solving systems that become more complex to solve increasingly difficult problems. The benefits of complexity at first increase, but eventually decline as simpler solutions are progressively exhausted. Increasing efforts based on constant or declining resources burdened the infrastructure of these societies to the point of diminishing returns to problem solving. Economic weakness then made such societies vulnerable to collapse. In conventional economic terms, investments in complexity can be cast in the framework of marginal returns, the extra returns from extra units of investment. Ecologists are aware of average returns, but seldom go on to appreciate the derivative of average returns embodied in marginal returns (Figure 1).

## HIGH GAIN, LOW GAIN, AND LEVEL OF ANALYSIS

Allen et al. (2001) introduced the notion of gain in ecological and human systems as offering a duality: high gain and low gain. Both types of gain pass through the cycle of increase and decline found in figure 1. The decline of high or low gain cycles leads to either extinction of some sort or a switch to the other type of gain. High gain systems use ready made resources, and are so called because the return on effort of gathering the resource is high. Under a high gain regime, something other than the system at hand previously concentrated the resource. Therefore in the right situation the resource is ready for the taking without much need for refining what is gathered. But that right situation does not last because, once the hot spots of resource are dissipated, high gain systems either disappear or they must become low gain. Low gain systems use lower quality resource. Under low gain the resource is so low quality as to require the system to gather extensively much raw material and then refine it. The process of refinement increases the quality of what has been captured so that it becomes high enough quality to be ready for use. High and low gain systems both require fuel of high quality: high gain systems just take it, while low gain systems must make it.

All this might seem straightforward enough, but there are complications that make hierarchy theory likely tool to separate meanings clearly. The complications arise from a necessity that applies to both types of gain. For high and low gain there is an ultimate need for quality fuel to be burned. All animals need food that must be of sufficient quality to sustain them, it is just a matter of what they have to do to get it. If in the end both types of system need quality fuel to get the job done, then we can question that the difference is a material issue. In fact the duality of the resource as high or low depends not on the materiality of the situation, but upon how the system boundary is defined. A system is high gain if it is bounded so that refining the resource may be taken for granted because material exists already refined in the environment. But a high gain system redefined to be bounded as something larger may show low gain processes. In the larger conception the redefined system cannot take a high quality resource as a given and so must instead itself perform the refining of the resource as an active internal process. High and low gain thus become a matter of level of analysis. Hierarchy theory operates on questions of level of analysis, and so should be a useful framework here.

Concrete examples will help to highlight the distinctions made by hierarchy theory as it treats resource issues as a matter of levels of analysis. At the outset, a situation may appear straightforward while still being rife with ambiguity. That is where hierarchy theory steps in to straighten things out. One might note that nuclear energy is plentiful and of very high quality. But this self-evident verity is not independent of level of analysis. The truth of high gain nuclear energy necessarily depends on taking a position that bounds the system so as not to include uranium ore inside the system. A high gain specification of nuclear energy does not even include uranium fuel rods inside the system, in that the enriched fuel is the resource in the environment that the high gain power plant takes as input. There is only a lot of energy readily available if the resource appears as something ready-made, something concentrated by an external force that created the fuel rods. Seeing fuel rods as made for the power plant by a part of the social system that is external to energy generation per se, is not an unreasonable position to take. Managers of nuclear energy power plants hold exactly that frame of reference. Someone else will make the fuel; my job is to generate electricity. In a parallel fashion the prospector thinks not one moment about the processes that make his nuggets, all he cares about is that his environment has lumps of gold in it for him to gather in high gain mode. A high gain characterization of nuclear power bounds the system as one that simply uses the energy offered by nuclear power plants. The fuel is external to that system.

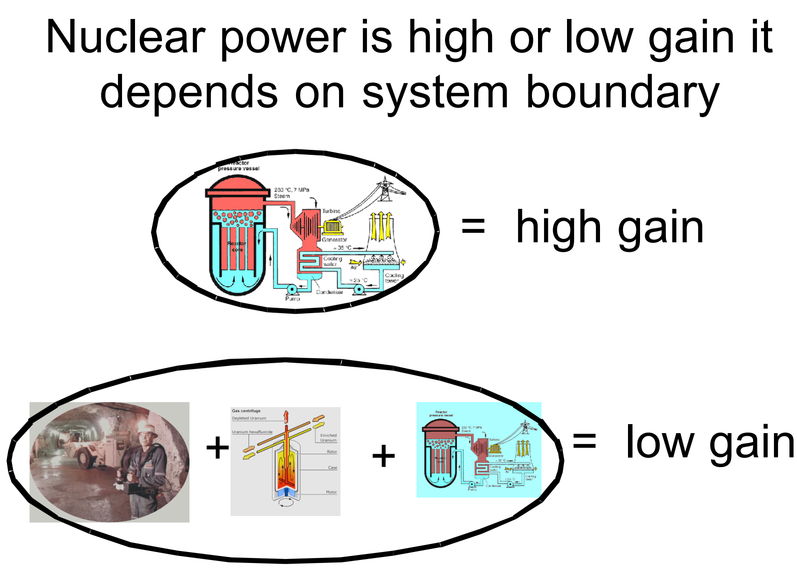


Figure 2. High and low gain are distinguished not as material issues, but as a matter of level of analysis. If the system is defined as simply taking in resources ready to use, such as fuel rods, then the system is high gain. But that same material system may be bounded larger so as to include the mining operations and the refinement processes to make the fuel. At that point the redefined system takes in low quality material and processes it into fuel for ready use, whereupon the system becomes low gain. High gain versus low gain is not a material issue, but is one of level of analysis.

A low gain characterization of the same situation is equally tenable, and it too depends on level of analysis. A low gain specification of nuclear energy bounds the system not as an energy user, but one that includes the miners who must obtain the ore. Once mined, uranium ore is diffuse, and cannot be used for power plants until it has been hugely refined. Not even chemical refining will do the job, since the isotopes of uranium are chemically the same. It takes huge cascading filters, centrifuges, or massive electromagnets to concentrate the useful isotope. The issue is that society uses radioactive uranium, but its use may be characterized as either low gain, starting in the mining of low grade uranium, or it may be seen equally well as high gain in the direct use of fuel rods after refinement (Figure 2). Thus whether nuclear power is high gain or low gain is entirely a matter of level of analysis. This is exactly a situation where hierarchy theory can help keep tabs on which level is in effect in the description of a given situation.

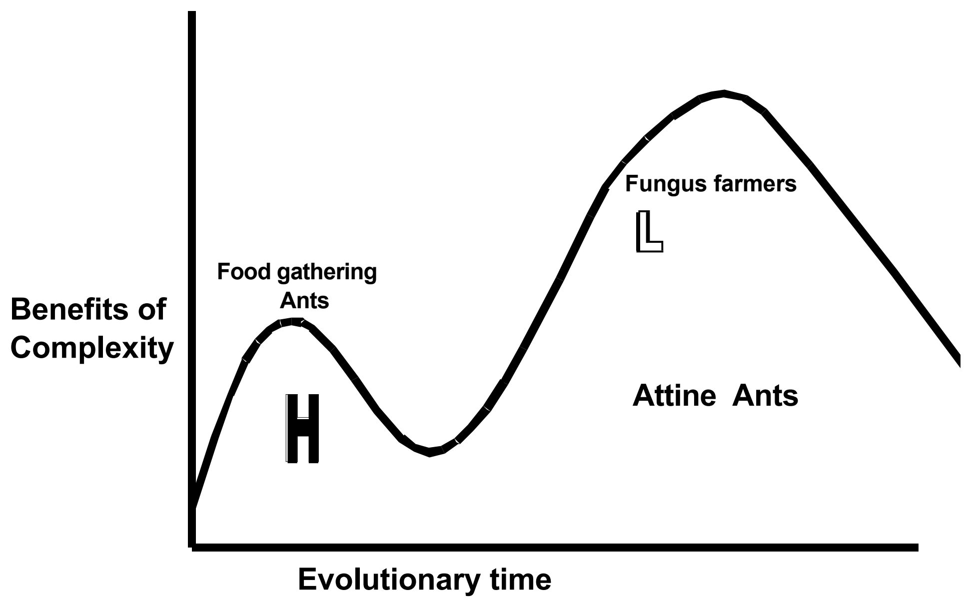


Figure 3. Most ants simply gather food directly and this might be characterized as high gain. The material that is used as fuel is simply gathered in a form that is ready to eat: high gain. But then there are the Attine ants, a complex of 12 related genera that gather some non-food resource, and then grow fungus upon it. Attine ants then eat the fungus in a low gain system of nutrition. Gathering food invites competition for quality resources but fungus farming side-steps that competition for food. The transition to fungus farming will have started as eating fungus in the environment, but as farming fungi emerged there was an abandonment of high gain harvesting of wild fungus, as a new cycle of low gain emerged as fungus farming. This figure shows the transition as one cycle of gain declines and is abandoned when a new cycle of resource refinement and gain appears. H indicates high gain, while L indicates low gain. Low gain systems characteristically capture more usable energy than the respective low gain system, which is why the low gain mode is higher and the area under it is larger.

## HIGH AND LOW GAIN IN BIOLOGY AND SOCIETY

Let us now move into biology, and see the same distinctions between high and low gain at work there. Allen et al. (2001) and Tainter et al. (2003) use the examples of ants and beavers to explain the differences between the two systems of return on effort. Most ant species gather food, and then simply eat it. There is of course competition for food, and various ant species have different strategies for capturing it (Levins, Pressick and Heatwole, 1973). But what if ants could avoid this competition by gathering some other resource, and then converting that into food? Indeed, the Attoid ants do exactly that, as they gather substrate, grow fungus upon it, and finally eat the fungus they have farmed. The Attoid ants belong to 12 genera and 180-200 species with a range across primitive to vary specialized advanced species (Wetterer *et al.* 1998). This would appear to be a low gain activity, relative to strategies of ants that simply gather food (Figure 3).

So far so good but there are the same complications that intruded into the nuclear energy example. The primitive lower Attine genera gather grasshopper feces, a low gain activity relative to gathering food (Leal and Oliveira, 2000). But species of the advanced fungus farming genus, Atta, gather leaves for the same purposes. The species of Atta ant are therefore called leaf cutting ants (Lofgren and Vander Meer, 1986). Atta colonies are much larger than feces gathering ants and are enormously more efficient in raising fungi (Anderson and McShea, 2001). While grasshopper feces would seem to be a low quality resource, for fungus farming it is like jet fuel. Leaves, on the other hand, are quite unsuitable as a substrate, and demand special strains of fungus that are exquisitely maintained. The advantage is that leaves are everywhere. So long as ants can achieve fungus farming on leaves, the critical advantage is that leaves are much more abundant than grasshopper feces. Leaves are lower quality than feces, and so farming fungus on them is a deeply low gain activity. Thus, speaking relatively, fungus farming on feces becomes a high gain activity compared to farming on leaves. Note the change in level of analysis here as the universe wherein comparisons are made has shifted. The arena of all fungus farmers excludes food gathering ants and in that smaller discourse, feces farming ants switch their appearance from low gain to high gain, once the comparisons are only to other more deeply low gain fungus farmers.

In figure 4 we see the ambiguity of the grasshopper feces gathers. Inside the low gain arena of farming fungus is the first (primitive) way of fungus farming that, relative to advance fungus farming, is high gain. Feces gathers are taking the energetically easy way out in farming fungus. Even in the super low gain leaf cutters, there is an early establishment phase where colonies are small and gather easy leaves. Young colonies of leaf cutters resemble the feces gathering colonies of primitive Attines, although they do not gather feces, only easy to gather leaves and petals. In other words there is a high gain phase at the ecological beginnings of the super low gain leaf cutters.

As we turn to the elaborations of human societies, levels of analysis again play a crucial role, and so hierarchy theory continues to be useful and relevant. Ecology is commonly historic in its intellectual posture, whereas economics is generally not a historical science. Tainter, being an archeologist, is a social scientist who keeps an eye on the history of the situations he studies (Tainter 1988). Unlike the classic position of economists, Tainter runs marginal returns over time (figure 1) and goes on to more or less equate marginal returns with the costs and benefits of becoming more elaborate. As effort is increased, the system gets less extra benefit for that extra effort. Tainter is explicit in saying that complexity is a device used by societies to solve problems, and they ratchet up effort and sophistication until the marginal return slopes down over time.

Allen, Havlicek and Norman (2001) address complexity in hierarchical systems. They experiment with plants in wind tunnels to show how complexity works. They demonstrate that complexity, as Tainter (1988) uses the term, amounts to some part of the system dealing with some problem at a certain expense. In their experiments Allen, Havlicek and Norman (2001) investigate plants grown in wind so the plants had to deal with that stress. The benefit to the complex system in nature is that plants grown out of the wind can grow faster because they are shielded from the wind by the taller plants. Cost is covered, in successful deployment of complexity, by increased functioning of other protected parts of the system, so that the whole has greater functionality. If the cost of complexity is greater than the increase in functionality of the whole, then complexity is a losing proposition. In that light, Tainter sees the collapse of complex societies as turning on decreasing value in increasing complexification. He identifies that the difficulty societies ultimately must face is that problem solving itself becomes impotent in that increasing complexity becomes self-defeating. The cost of increased complexity comes from a burgeoning infrastructure, which arrives along with the benefits of complexification. When we look at ecological entities, we see similar patterns, as ever more elaborate biotic arrangements become fragile, and the system stalls in death, speciation or extinction.

It appears that high gain is the mode most apparent when a new resource type is available. For a short time the system gears up to capture what is easily available. The capital accumulated is significant but not large. Soon the resource in its high quality phase is largely used up. Failure to respond to resource depletion leads to system collapse via death or some form of extinction. By contrast, dealing with resource depletion leads to the system entering a low gain phase.

## GAIN SEEN AS HIERARCHIES CHANGING OVER TIME

In psychoanalysis, Gustafson and Cooper (1990) make the distinction between vertical versus horizontal relationships in hierarchies, originally presented in Allen and Starr (1982). Gustafson complained, in a personal communication to Allen, that the original distinction between horizontal and vertical communication mentions the horizontal, but then barely uses the idea. Gustafson and Cooper (1990) distil down the distinction helpfully by suggesting that vertical relationships are essentially issues of greater inclusiveness in bounding the system, whereas horizontal communication in a hierarchy looks at relationships over time. Not only do we have to face the complications of hierarchical structure, but we must also expect that structure to change over time. Vertical hierarchical relationship is the device used in setting or changing the level of analysis. We need both vertical and horizontal hierarchical relationships because the change over time has ambiguities embedded in it that must be teased apart by moving up or down the hierarchy to find the adept level of analysis. Over time a hierarchy changes, and this is directly addressed by high gain giving way to low gain, and vice versa. Thus not only can hierarchy theory help keep things straight in issues of changing resource, but the matter of gain itself makes a helpful distinction in the nature of hierarchy elaborated over time. Gustafson and Cooper (1990) insist on bringing in hierarchies changing over time and that insistence invokes high and low gain in other discourses (e.g. Allen et al 2001). Thus the intellectual fertilization between hierarchy theory and high and low gain distinctions goes both ways.

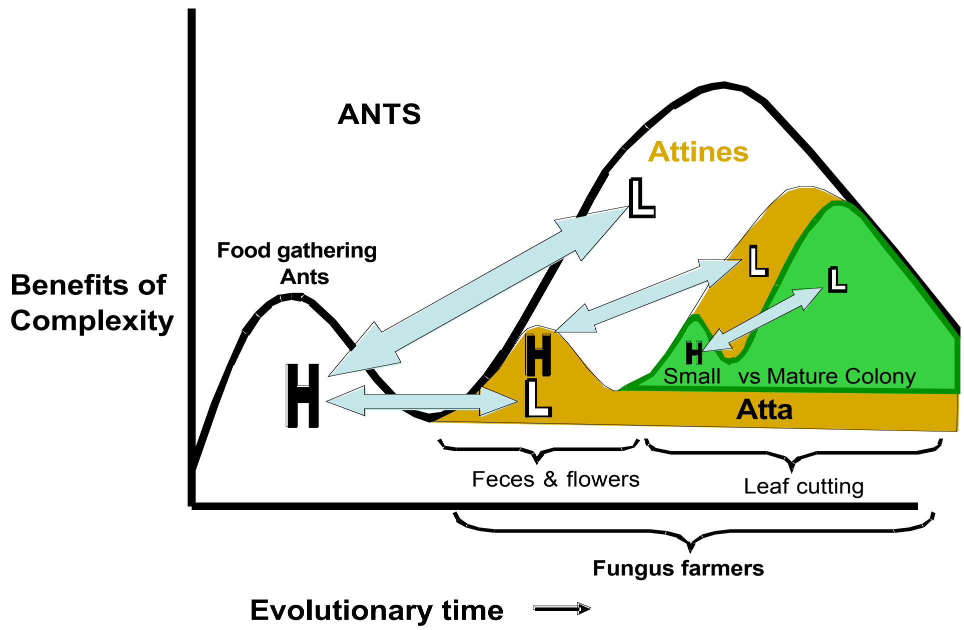


Figure 4. Here we see an elaboration of figure 3 so as to expose the several levels of analysis. While in figure 3 the benefits of complexity may be read directly they cannot be read so here. Benefits of complexity depicted here are relative within each mode of resource production. The patterns here are in some sense fractal inside successive levels of analysis. If we exclude the non-fungus farmers, then a new pair of high and low gain phases appear at a lower level of analysis. In that smaller universe where they are contrasted only with leaf cutters, primitive fungus farmers are now high not low gain. Even in the very small universe of just leaf cutters the young colonies are relatively high gain as opposed to mature Atta colonies that are deep low gain. H indicates high gain, while L indicates low gain. The arrows connect the respective high and low gain phases in the successively smaller universes of comparison, with the exception of the lowest arrow that shows feces farmers as low gain relative to food gathering ants. Thus feces farming ants are both high and low gain, it depends.

We see the progressive achievement of ever lower gain over time. But we also see that inside each low gain phase is a leading edge (figure 4), where the easy early part of the new low gain situation is exploited in a high gain fashion relative to the more low gain exploitation in the later parts of that phase. The first systems to go low gain have an easy time of it, and in that context take a high posture. At the upper level of analysis, such leading edge high gaining is still low gain, but at a lower level inside that discourse, the system starts off in high gain mode. For instance, the City of Madison is moving away from high gain manufacturing dependent on fossil fuel. It is moving to a low gain phase of information technology in the biology of cloning. But the University of Wisconsin, in Madison, is the world leader in this field, owning most of the cell lines of cloned human germ cells. UW is therefore high gaining the front end of the new biotechnology, waiting for competition and commoditization to come along. When that happens commoditization will drive Wisconsin researchers into a deeply low gain version of what they are doing now.

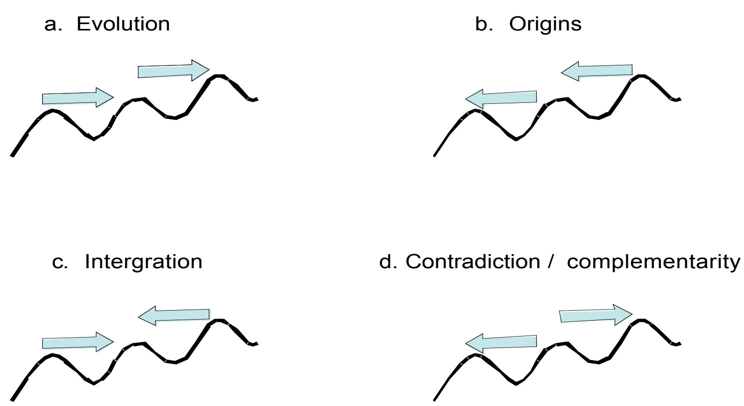


Figure 5. In this figure the humpback of benefits of complexity in figure 4 is abstracted further. The switches between high and low gain are reduced to directions of comparison. This approach looks for the general patterns in the relationships between successive high and low gain. a) The pattern in ants is the successive evolutionary pattern compared to each other. b) The origin of each type of gain is emphasized. c) The integration inside a single type of ant ecology is found in comparisons to both more advance and more primitive species. d) A reverse comparison to c) shows the contradiction as any given type of ant ecology can be high and low gain at the same time.

## DUALITY AND DIRECTIONALITY OF RELATIONSHIPS BETWEEN HIGH AND LOW GAIN

As we look at the relationships between ant species and their use of resources we see several patterns that enlighten the changing relationships in general terms. Feces-gathering ants that farm fungus may be seen as high gaining or low gaining, depending on the comparison made. This leads to ambiguity as to the status of feces gathering ants. Are they high or low gain? The answer is, “It depends.” Figure 4 shows the sequence of cycles of benefit of complexification across ants as a whole. If the comparisons on Figure 4 are always to the right, then we address successively each new low gain phase arising over time. In effect, comparisons always to the right are addressing the evolution of new relationships as each new low gain phase makes the previous low gain appear high gain. Thus in fungus farming we see increasing efficiency of resource exploitation. Alternatively, if the relationships are seen in comparisons to the left on Figure 4 as occurs in the lowest arrow there, then we are addressing a different issue of origins, a valid but different point of view. If we abstract figure 4 further and only look at the arrows as a general consideration we achieve figure 5. Evolution is generally characterized as "Modification through descent" where adaptive changes occur but always in the context of origins in primitive species. Figure 4 has two directions, the leftward direction capturing the tyranny of descent (figure 5a) while the rightward direction (figure 5b) identifies creation through modification.

But we can look at relationships in both directions at the same time. Relative to any given ant genus, there are two sets of arrows possible indicating two sorts of relationship (figure 5c, 5d). The relationships may be captured in arrows that point either to or from the ant genus in question. If both arrows point toward the particular stage, then the relationships that emerge are somehow the opposite of the situation described with arrows both pointing away. With both arrows pointing to the ant genus, say feces gatherers, then we see a certain unity in being an ant that uses the strategy in question. Feces gatherers both need to eat, and must of necessity gather feces as an unlikely "food" resource. There is an integrity achieved by evolution, and that is captured in the arrows pointing toward the genus in question (figure 5c). A given stage in evolution is indeed the result of modification through descent, and each stage shows a certain integrity of function at that evolutionary stage.

If we address arrows that point away from the genus in question in opposite directions then a new idea appears that is the opposite of the integrity discussed in the previous paragraph. When the arrows of figure 5d point away from feces farmers to both non-fungus farmers and efficient Atta colonies, we see a duality and a contradiction embodied in high and low gain. The contradiction is in the question, "How can a given genus be high and low gain at the same time?" The answer is through a duality that contrasts energetic flow of thermodynamics with coded plans for efficiency and some preferred outcome.

The research on high and low gain heretofore has shown the importance of distinguishing between the thermodynamics of functioning, as opposed to the functionality of efficiency. Efficiency imposes limits on raw thermodynamic possibilities. Thermodynamics as a discourse observes flux and change in processes. It measures rates, and it balances processes with the amount inside as opposed to outside an entity at a given time. If one views a flux properly, then one cannot see the limit on that flux because at the limit the flux reaches stasis. A clear view of the limits and constraints denies access to measurements on the flux that is so constrained. Thus there are processes in biosocial systems that are in contradiction, or at least appear at odds in some way: flux and stasis. The way to deal with contradiction in the Western tradition is to invoke a duality and that concept is captured in the arrows pointing away from the feces gathering fungus farmers (figure 5d).

The distinction highlighted in the duality raised above is between stocks and flows, an idea championed by the Resilience Alliance (2008). The tension in stocks and flows is between renewable and non-renewable resources. Non-renewables are usually best dealt with via stocks as the critical matter is how much stuff you have left. This is a question that is important to high gain systems. By contrast, renewables are more a matter of flux. The question here asks if the inputs balance with the outputs, a classic low gain concern. The problem is that stocks are, in a sense merely, slow fluxes captured as static amounts. All biosocial systems have stocks and flows, and which is which simply depends on the level of analysis.

Thermodynamics versus efficiency, and the stock versus flow idea, as well as the distinction in evolution between natural selection and adaptation have one underlying characterization. All pivot on the duality we find in Heisenberg's Uncertainty Principal, manifested in the wave particle duality. The particle is the rate-independent structure that exists at a point in space and an instance in time. It requires that the observer has found something that meets a definition. It is a structure and all structures are an assertion of the observer. Meanwhile, the wave is the dynamic process smeared over time and space, an expression of velocity. One cannot know the position and the velocity of a particle at the same time. An expression of the one denies the existence of the other in the model, and yet both are needed to account for the full phenomenon. Pattee (1978) shows how there are complementarities and contradictions of this sort in biology as well as physics. Many of these points of tension turn on the distinction between rate-dependence versus rate-independence.

Duality is encountered regularly in hierarchy theory such that a central idea at the foundations of hierarchy theory is the holon, a dualistic concept developed by Koestler (1968). Hierarchies are populated by entities at different levels. The special type of relationship in a hierarchy, lower versus higher level entities, encourages a view of structures in hierarchies that recognizes that two way relationship. The entities in hierarchies are best seen as looking up and down at the same time. A holon is an entity at a level in a hierarchy. Because the holon must also deal with relationships upward in the hierarchy, it is not like a regular structure, which would often be seen simply as an integration of the parts to make the whole. The holon does not simply occupy a level in a general way but rather is poised right at the interface between up and down, between content and context. The holon itself is the skin, the boundary that surrounds that of which it is made. Inward captures down in the hierarchy, while outward captures upward. The skin integrates both inward and outward. Indeed, Koestler refers to the holons as Janus-faced. Janus is a god whose name gives rise to January, the doorway to the year, and "janitor," meaning originally he who acts as a doorman. Janus is the god of portals and openings. He is two-faced because he looks out and in at the same time. For the parts of a holon, the skin integrates in one direction the complications of the environment into a single signal. In the other direction, the parts are made to appear to the context as a whole integrated also by the skin that is the holon . The duality in the holon addresses the way that an entity in a hierarchy may be both an autonomous whole and a part of some larger whole both at the same time. The combination of the two arrows pointing inward in Figure 5c is a holonic expression of high and low gain. The species of ant in question sits poised between its orgins and its possibilities. The integration of forward and backward in time offers a certain unity in the manifestation of that species at that time in the development of fungus farming efficiency. The part/whole tension in the holon captures contradiction similar to that found in the questions about the feces farming ants being high gain or low gain. The concept of the holon asserts they are both high and low gain at the same time.

Hierarchy theory has a set of classic points of tension, and these arise in parallel in evolution and in the distinction between high and low gain. In evolution the tension is between natural selection and adaptation. Natural selection explicitly does not have a planned outcome, while the meaningful outcome of adaptation apparently turns on purpose in the present with an eye on utility in the future. For natural selection, the data explicitly come from a protocol that does not know the eventual outcome. Meanwhile, adaptation becomes clear only once the outcome is known and one can see how the history of a given evolution makes sense in terms of increasing functionality. The point of tension is that one cannot know and not know the outcome at a given instance in time. This is the same tension between ants being both high gain and low gain at the same time. It is another instance of the tension between rate-dependence and rate-independence. All this arises in hierarchy theory, and so its appearance in high and low gain, which is simply the description of hierarchies over time, is to be entirely expected.

## RATE-DEPENDENCE, RATE-INDEPENDENCE AND SYSTEM MEMORY

Hierarchy theory recognizes several sorts of hierarchy. In ecosystems the hierarchy is often process upon process upon process, with slower processes being the context of those that are faster and more localized. The order comes from relative rates, so these are rate-dependent hierarchies. The classification of types of organisms, among other fields in biology, often uses structure-based hierarchies, where upper levels are occupied by larger and more inclusive structures. Here species do not exist at a rate, nor do they fill a genus at a rate, and so this sort of hierarchy is of relationships between rate-independent structures. Then there are the structure process hierarchies, where there is an interleafing of process and structure. As individual structure gives way to multiple structures, the collections may take on a new dynamic. This dynamic leads to the behavior of a new structure. For instance, the level of a single cell can lead to cell multiplication, a dynamic at a higher level. Cell multiplication leads to an upper level structure, a tissue. This sort of hierarchy receives much attention in Allen, O'Neill and Hoekstra (1984). The change from high to low gain leads to this last sort of hierarchy in that high gain rests on pure rates of consumption whereas low gain rests on efficiencies and rate-independent preferred states.

In low gain systems rate-independence arises in the coded plans for efficiency. Plans exist independent of rate, even if they control rates. High gain systems show much more rate-dependence in that they take the form they do by virtue of the patterns that emerge from rapid rates of consumption and crude degradation of inputs. But even under high gain there is rate-independence, in that the rapid flux characteristic of the gradients, upon which high gain depends, generates new structure by a process of self-organized emergence. Such emergent structures exist independent of rate. Emergence arises as a result of some steep gradient that generates positive feedbacks that keep running faster until some limit is encountered. That limit is not planned, but is rather some sort of negative feedback arising from physical necessities. While one can cast such things in terms of rate-dependence, a reasonable alternative is to view the feedback loop as a structure. Negative feedbacks as structures offer correction that maintains stasis, not dynamics.

A concrete example of tension between rate-dependence and rate-independence will help here. Temperature regulation in animals can be viewed as balancing rates of heat input against heat output (Porter and Gates 1969). However as an independent consideration it can also be addressed as the working of a control system. The actual changes in the physicality of body temperature are effected by changing the balance of heat generation and input to heat output, a dynamical consideration. For instance sweating increases the loss of heat that is used to evaporate water. Shivering also changes the balance as the muscles generate heat, but shivering is invoked by a negative feedback control system, which has a set point independent of rate. A cold neck is taken by the animal to mean the animal is cold, and meaning has no rate. That is why a scarf makes one feel more comfortable in the cold. The signal for temperature is sufficiently separate from the dynamic balance of heat itself for it to be possible to set sweating and shivering at odds with each other. One can make an animal shiver and sweat at the same time by putting it in a warm context, but with an ice pack on the back of its neck. The coldness of the neck is a signal that the animal is cold, but it is only the signal and it is not the actual physical temperature. The feedback exists and works independent of rate even if in the end it causes a change in rates of heat generation and heat loss. The tension is between the physicality of heat flux on the one hand, as opposed to the rate-independent meaning taken from the signals of sensors on the other hand.

A complication of biological and social systems is that they manifest memory, and the tension between rate-dependence and rate-independence above arises in two sorts of memory, one dynamic and the other coded in symbols. An example of rate-dependence in memory arises in whirlpools. They remember which way they going by dissipating energy and maintaining inertia, and that is what keeps them turning in one direction as opposed to the other. Alternatively, there can be a coded memory whose basis is rate-independent. Meaning and symbols do not have a rate. Thus patterns of behavior may have a rate-dependent or a rate-independent basis. Interleafing these two sorts of memories leads to a sort of structure/process hierarchy. Creation and demise of these two sorts of memory follows high gain and low gain switching. High gain is thermodynamically held in place by fluxes maintaining passages. Meanwhile, low gain is maintained by some coded model for efficiency. Let us see some examples of this phenomenon for it explains a lot in biology and social systems.

During the last two centuries B.C., the Roman Republic was in a high-gain phase, as each conquered nation underwrote the cost of further expansion. When expansion ceased, the empire entered a phase in which it had to be supported by taxation on low-gain peasant agriculture, so that the empire's budget was essentially limited to annual solar energy. As taxes were raised to respond to problems (mainly foreign and civil wars), the peasant population fell and productive lands were abandoned. In the end, diminishing returns to complexity in problem solving induced economic weakness and made the empire vulnerable to collapse. Yet underneath the high-level drama of empire the day-to-day life of the Roman population resembled memory held in inertia derived from flux. What happens tomorrow simply follows from what happened today, in the manner that a whirlpool keeps turning in the same direction. After the collapse of the Western Empire, people in Italy and elsewhere for some time considered themselves still to be Romans. The Senate in Rome issued coins with the inscription "Invincible Rome," long after the slogan had become ironic. The memories persisted long after their material basis had ended. When circumstances allowed the emergence of the Italian Renaissance, many of these memories were deliberately recreated, albeit in altered form. Today's European Union is in some ways the realization of the idea of a unified Europe, which never died even after the end of the Western Roman Empire. Neither evolution nor history can ever precisely repeat, in part because each carries its history inside.

We have a parallel biological example here in termites, well treated in chapters in the edited volume by Abe, Bignell and Higashi (2000). Primitive termites live in nests inside pieces of good wood. When the good material is gone, a move to some new home is necessary (Eggleton and Tayasu, 2001) . These are high gain termites, and their moving home is a classic high gain collapse. Low gain termites eat poor quality wood fragments, which are gathered by workers and soldiers over a wide area. Wet rotting wood still has about 40% goodness in it from a termite's point of view. As is characteristic of low gain systems, these colonies using lower quality wood are able to take advantage of economies of scale. These termites are the low gain species inhabiting iconic large termite mounds with millions of colony members (Noirot and Darlington, 2000; Eggleton and Tayasu, 2001). So we have high and low gain termites, but there is yet third sort of termite colony. Even when the wood has rotted into the soil, there is still 5% goodness in those remains, and some termites actually eat soil. These soil eaters are all tropical, and colonies are always small with as few as 20 members (Brauman, Bignell, and Tayasu, 2000). Not even all the members actually live in the colony, since only the brood and the royals are there, with all others surviving outside. The reason that termites are colonial is the need to maintain a gut flora that can digest wood. It works on the same principle of the gut flora in a cow's rumen, but being small termites could not maintain that flora if they existed alone. Thus colony life and feeding each other feces is central to termite ecology, in that it is the way to maintain a gut flora essential for digesting wood. The critical point here is that the soil eaters are very large as individual termites go. Food passes through them slowly, and the gut flora is significantly maintained by each individual as an individual. In these colonies of the most recently evolved termites (Donovan, et al. 2000) the nest is small to the point that it is essentially defunct; it exists only as a means of reproduction. As the thermodynamics of the colony declines, the point of being a termite with its memory of being colonial has moved down a level to that of the individual. This is akin to the memory of Rome existing, not as large scale flux and process, but in the memory of individuals. As thermodynamic emergence loses sufficient energy to continue, a structure-based memory carries forward the coded information, albeit biased and minimized. The next phase of expansion uses that information as a template for the new pattern.

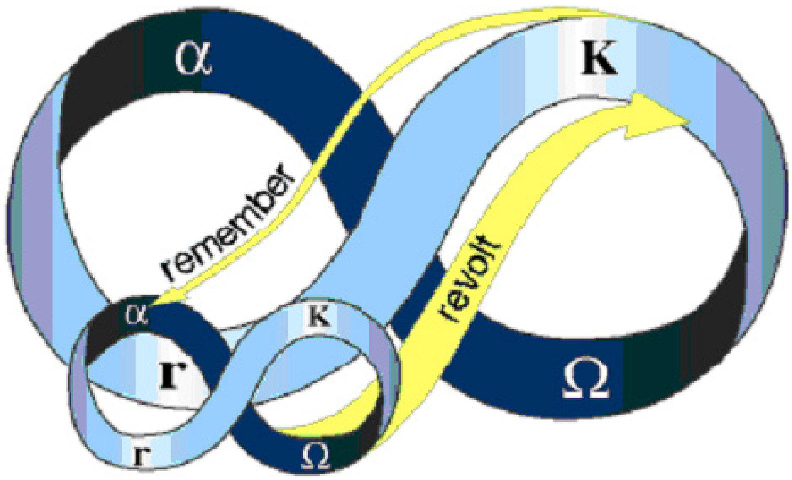


Figure 6. Taken from advertising material for Gunderson and Holling (2001) this figure shows the lazy 8 figure that Holling has been publishing elsewhere for a quarter century. The horizontal orientation captures increasing organization. The vertical orientation records increase in capital. Starting at r the system matures as it increases organization and capital until the highly organized K phase persists. In the end the K phase is overburdened with infrastructure and represents an accident waiting happen. When the accident does happen it takes the system to _ in a process of creative destruction. This is the end of a low gain K phase. The old capital reappears in the _ phase where at a lower level a coded memory tracks the system back to the r phase again.

The phenomenon of switching between memory embodied in patterns of flux occurs in other intellectual frameworks, notably in Holling's notions of panarchy (Gunderson and Holling, 2001). Holling's lazy 8 figures found there relate to high and low gain (Figure 6). Passage from bottom left to top right is a process of low gain expansion. The passage from bottom right to top left and then down to bottom left is the track of a high gain phase (Allen 2002). As capital and organization increase together, the system enters the K phase, which is distinctly low gain. In the spirit of Tainter's ideas on systems becoming overburdened with infrastructure leading to collapse, the K phase loses its capital in a process called creative destruction. The destruction is creative in that the system is released from elaborate low gain constraints. Soon the capital that was destroyed re-emerges in a disorganized state, perhaps in the form of dead as opposed to living trees after a pestilence has killed them. It is in this reset phase that information passes on to the next cycle. Being disorganized the capital cannot be protected and so is dissipated in a high gain phase as the system returns to the r phase of low capital and low organization. Note here that the loss of organization in creative destruction at phase _ causes the loss of the thermodynamic memory embodied in flux, and only coded structural memory survives. The coded memory in the _ phase is the information that takes the system to its new beginnings. When New England forests are clear cut or burned to the ground the system loses minerals for a few years until pin cherry comes in to seal the losses of nitrogen and other minerals. The pin cherry resets the forest system and allows its return. Pin cherry represents system memory that tracks the system back into recovery. Note the dynamic inertial memory is lost in the destruction of the old forest, but the memory in pin cherry is coded in the genes of the tree and is not associated with any rate. It is no accident that the memory in pin cherry belongs not to the upper level of the dynamic forest but to the lower level in which the individual pin cherry species resides. In *Panarchy*, Gunderson and Holling (2001) make explicit reference to memory associated with a change in level (figure 6). This fits exactly with the discussion of termites above, where colony thermodynamics is remembered to a degree by codes in the individuals not in the inertia of living in a nest.

The sequence in panarchy is robust. Only after a long low gain phase does the K system collapse into a new high gain phase. The high gain phase is persistent, even though it might be prudent for reasons of sustainability to switch to a new low gain. Any increase in efficiency introduced into a high gain system with resources will simply be folded into a continuation of reckless consumption of high quality resources. Increases in engine efficiency in automobiles as OPEC put a squeeze on United States' oil supplies in the 1970s did not lead to less consumption of petroleum. Rather, engine efficiency simply allowed American drivers to keep driving large cars despite high gasoline prices. The automobile industry even went on to invent the Sports Utility Vehicle (SUV). Only now at the time of writing this paper a quarter of a century later is General Motors planning to shut down its SUV factory in Janesville. The stubborn persistence of a high gain pattern of resource is otherwise known as Jevon's paradox (Polimeni et al, 2008). High gain will not change to low gain until the resource gradient becomes shallow.

It is telling that the termites fall into three categories, moderate sized high gain, massive low gain, and greatly diminished low gain starved of resources. High gain termites collapse in a move to some new site via reproduction. Massive low gain termite colonies are persistent, as is characteristic of low gain. The lower quality resource of low gain is more abundant, in that most material in general is relatively diffuse with concentrations of high quality being the exception. But in the end, efficiency backs the system into a corner where the termite system is so efficient that it reaches the ultimate limit in resources in food in soil. The resource is so low quality and so diffuse, that it forces a reduction in size of the nest, because there is simply not enough material resource to maintain full function. These three arrangements of high gain, low gain and super low gain all have the potential for disappearing and dissolving the social hierarchy.

Figure 7 shows the track of an ever poorer resource base with three points where collapse is likely. High gain can simply run out of quality resource. Low gain can over-develop, into a system that demands too much of its large resource base. Finally, super low gain can disappear from lack of resource of any sort. Economists say that social systems do not run out of resources, they just get more expensive. Economists are right on that point but the tropical soil eating termites present a counter example that ecologists would expect. The soil based system is fragile, as is evidenced by them existing only in the tropics where conditions are constantly favorable because soil eaters do not have the capital to survive a winter (Brauman, Bignell, and Tayasu, 2000). The pattern of termite colonies tells us that evolution has the potential to pass through all these phases. The largest biomass of termites on the planet exists in the massive low gain colonies but the largest number of species, indeed 60% of all termite species, are tropical soil eaters. Termite evolution appears to have the capacity to drive even low gain systems, until the resource base eventually disappears.

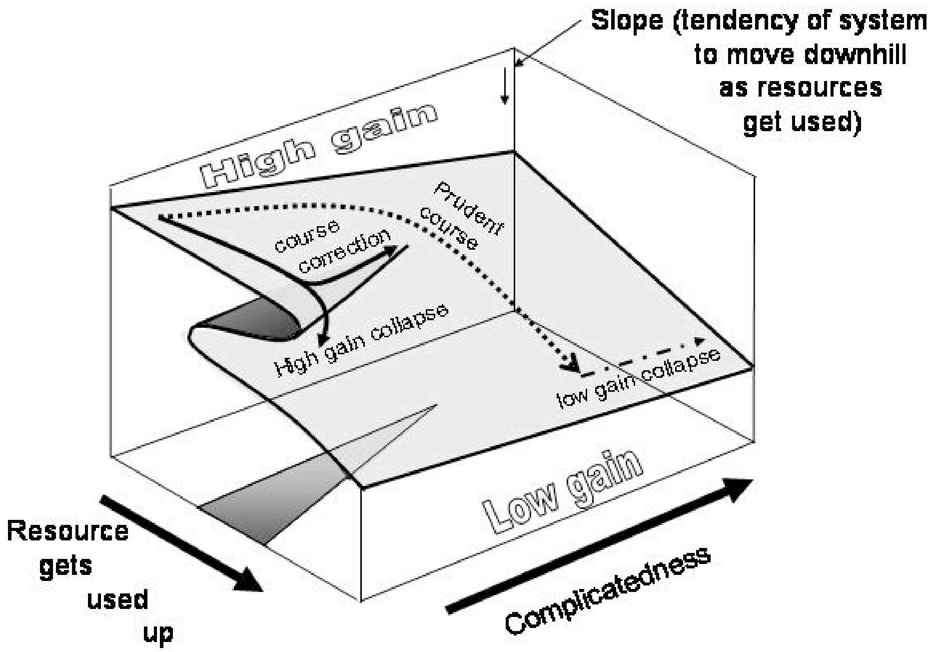


Figure 7. A representation of the tracks that lead from high to low to super low gain patterns. There are three points on the track where there is either a move to the next type of gain or collapse. The prudent course is never taken, since high gain keeps on using resources until it is under pressure to change course. Resistance to join the prudent track is the phenomenon of Jevon's paradox (Polimeni et al, 2008), where increases in efficiency are simply rolled into the high gain degradation of the resource gradient. If it does not change course the high gain system falls over the catastrophe cusp. When its existence is under threat the high gain system may change course at the last minute. As an alternative to collapse the system may turn to squeak past the base of the fold in a transition to low gain. That move to low gain efficiency never happens until the high gain steep resource gradient is almost gone. The track to low gain continues but may itself fall over a cliff, the front edge of the figure, as the system becomes too large and elaborate for its large resource base. In a final transition to super low gain the track turns right toward extremely limited resources. In that reduced resource phase the system becomes very fragile, such that the slightest further decrease in the very limited resource causes extinction as the system falls over the right hand end of the diagram.

## CONCLUSION

The notion of high and low gain is readily translated into hierarchy theoretic terms and that translation gives insights in both directions. The dualities that appear in hierarchical thinking with the concept of holon also appear in the tension between high and low gain. The duality in high and low gain gives a nice example of the how the deep abstractions of hierarchy theory can be expressed in more concrete terms. The dependence of high and low gain on level of analysis raises the same issues as arise in the discussion of the holon, but in alternative terms. High and low gain are manifestations of holons changing over time.

Notions of rate-dependence versus rate-independence are crucial to hierarchical thinking, and have served as anchors in Pattee's (1979) hierarchy theory through the 1970s and 1980s. That tension was central to moving hierarchy theory forward. As these ideas appear in discourse surrounding high and low gain, new subtleties arise, and new generalities too. The general condition of all biosocial systems having both thermodynamic elements as well as coded linguistic elements is so basic that many biologists would claim to have already known about it. And at one level they are right, they did. There must be energy involved and there must be codes for building biological systems. This is clear in the distinction between genotype (code) and phenotype (energetically maintained form) as one of the cornerstones of biology. But to cleave meaning and dynamics as cleanly as in the discourse of high and low gain is probably new. Yes, we need both elements to discuss biological and social systems, but the generic separation of them as distinct causes is helpful. Biology usually expresses the tension between rate-dependence and rate-independence as well as thermodynamic flux versus coded instructions as a series of special cases. Each instance has a place in the large vocabulary of biology, as when the term genotype is set juxtaposed to phenotype. The generality of hierarchy theory raises such discourses to a higher level, wherein genotype, hormones and ritual mating are all seen as rate-independent coding. High and low gain as a discourse brings those generalities into more concrete terms. Once we have seen the relationship between high gain and low gain and hierarchy theory it suddenly becomes more obvious how hierarchy theory can clarify biosocial issues as it has over recent decades. We knew hierarchy theory was powerful and effective, but until we wrote this paper, the authors here were not as clear as they might have been on why hierarchy theory works.

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