Essays on the Nature of Causality

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Abstract

Empirical observations drawn from modern physics and chemistry are combined with evolutionary theory to obtain large scale patterns in the causal history of the universe. What emerges from this picture is a causal understanding of how complexity increases in closed historical systems. Such systems are characterized by a natural hierarchy of stable levels of spontaneously self-organizing forms of matter. In this hierarchy levels of older and smaller forms of matter are sequentially combined into more complex and larger configurations each of which displays new emergent properties.

Key Words

Causality, Evolutionary Theory, Complexity, Progress

Introduction

The four essays that are included in this paper portray how my thoughts on causal relationships have unfolded over the last decade. I first used a version of Appendix One on natural hierarchies in 1990. It reflects previous efforts to find a theoretical framework for integrating scientific knowledge. Essays One and Two are the product of theoretical work on complexity I began in 1992. Essays Three and Four are from my paper *The Third Culture: Exploring the Relationship between Biology and Philosophy* completed in July of 1995. Together these essays form the underlying theoretical framework of my attempts to synthesize scientific knowledge into a coherent worldview.

It would be an oversimplification, therefore, to say that the central issue of these essays is complexity. We observe increasing complexity in the history of life on Earth and we tend to confound it with our notions of progress. The collective goal of the four essays, however, is to show that complexity increases as the result of natural algorithms and has little to do with our concepts of progress. I do not see progress, therefore, as a major conceptual issue, in spite of the emphasis it has received by other authors (Ruse, 1996).

Essay Number One: Definitions & Assumptions

My starting point is to define what I mean by causality. In the past I have used an holistic definition of causality as the sum of all cause and effect in the history of the universe. But in these essays I also use the term in a more restricted sense to describe our common sense notion of causes producing effects in the everyday world.

What I do not accept is a necessary link between causality and determinism. My view is that all phenomena are the result of "causes", but it does not follow that these "causes" are deterministic. This view, instead, accepts that cause can arise stocastically from the conditions of the past.

This touches only lightly on the subject of determinism when compared to modern quantum mechanics and chaos theory. They have undermined the foundations of our notions of predictability and given us, instead, a view of reality that, at its very core, makes our world uncertain. This has only served to reinforce the unease many have with modern physics, which in the nineteenth century provided a rock of certainty, but in the twentieth century has become as uncertain as Heisenberg's famous principle.

All of these currents and events in the recent history of the physical sciences revolve around questions of causality. Therefore, this brief introduction to the term is offered only as a point of departure, and, as hopefully will be shown, to precisely define causality is the purpose of these essays.

The next task is to define the term "event". An event in causal theory is any change in the initial conditions of the moment of the present. Conversely, the present can be defined as the only point in the flow of time where events can take place. The thought experiment which illustrates "event" is to imagine reality as we know it suddenly frozen in time. All cause would cease, everything frozen in a changeless state. In this case, causality itself would cease. In this imaginary frozen universe what is missing is "event". Therefore, an event is any, in an absolute theoretical sense, change in the state of the universe.

Two things quickly become clear. One, because of this absolute sense of change, change in the universe must be continuous as space itself is continually expanding. Two, change and event are synonymous. In common usage, however, we still speak of an event, that is a single event, when we wish to identify a specific change in our world.

This definition of "event" points out one of my central assumptions, namely that causality is continuous in the universe. There are no gaps in the flow of cause and effect in the history of the universe. Our intuitive sense of the discreteness of events is caused not by gaps in causality but, rather, by the distance in either time or space between causes and their effects. This intuitive belief in discrete events collapses when time and space are reduced to the scale of the subatomic. But still, we "see" events that are separated in time or space as being causally disconnected. This intuitive sense results from our superficial awareness of the continuity of causality. As our awareness increases, the "gaps" between events shrink. What I have assumed is there can be no "gaps". Reality, in this case, is counter-intuitive. (Note that the concept of "coarse graining" also explains the apparent "gaps" in our perception, see Dennett, 1995.)

The notion that there is varying distance between causes and their effects is an important one. I have tried to articulate this concept in the past using the notion of "functional infinity". The concept is confusing in that it can have two different but related meanings. The first sense is that at some point the distance in time or space between causes and their effects becomes so great that it is of functionally infinite distance, and effectively renders, therefore, no intelligible causal connection. The second sense is the more important of the two. It is the notion that there are intermediate events between an initial cause and its ultimate effects, and when the number of these intermediate events becomes great enough, it renders a functionally infinite causal distance between the initial cause and ultimate effects.

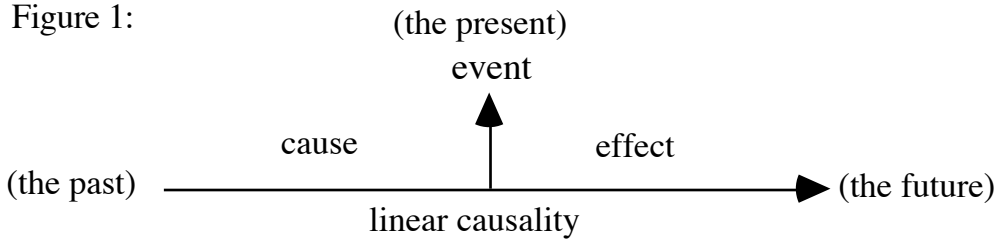
Both of these concepts of a functional infinity are useful in isolating a phenomenon of interest for study, and, indeed, the reductionist methodology is based on them. But it does point out a fallacy in our common sense use of the concept of infinity. The confusion is between a concept of absolute, mathematical infinity, and infinity as bound by our degree of awareness of reality. In the second sense, infinity is any number that is beyond our capacity to comprehend. This second sense of the word is what I define as functional infinity. The problem is that our capacity to comprehend is a changing capacity, one which, hopefully, will increase with time.

The point I wish to make is that just because there are functional limits to our perception of causal connections in nature, this by no means renders those causal connections nonexistent.

More Definitions

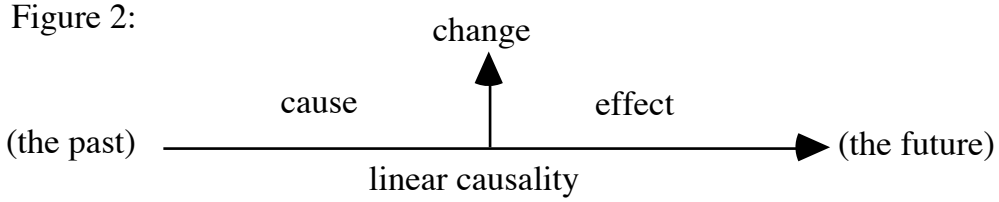
Cause: The notion of cause is temporally dependent, in that cause must always precede effect in time. Linear causality can be represented simply as a line.

Figure 1:



As my definition of event demonstrates, this image is synonymous with:

Figure 2:



Next is to resolve the dual nature of cause and effect. This arises as cause becomes effect which, in turn, becomes a cause.

Figure 3:

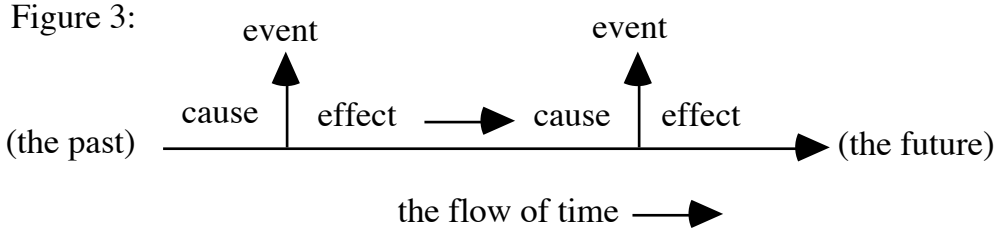
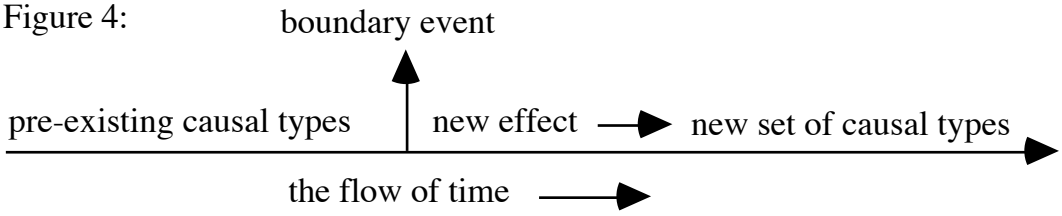


Figure 3, demonstrates that the term "cause" has meaning only by virtue of its temporal relationship to event. Cause precedes event. The obvious corollary is that the term "effect" only has meaning when it's understood that effect must follow event.

A cause can also be understood to be a phenomenon. Using the words as synonyms, it is easier to see that there are as many different types of causes as there are types of phenomena. This allows me to introduce a new concept, that in the history of the universe there have been changes in both the number of, and the types of causes / phenomena that, for any given moment in the present, produce events. From this concept follows the notion that new, novel types of phenomenon have appeared spontaneously at different points in the history of the universe. The cooling of the early universe made of a "quark soup" that led first to the formation of protons and neutrons and then to hydrogen and helium atoms is one example of new, novel phenomena, in this case atoms, arising out of pre-existing conditions. From these ideas we can see that in the history of the universe we can refer to pre-existing causal types and new effects. The events that give rise to these new effects represent "boundaries" between what effects were possible in the past and what new effects are now possible in the future.

Figure 4:



Using my example of the early universe, the new effect that was possible after the formation of atoms was the formation of the first stars.

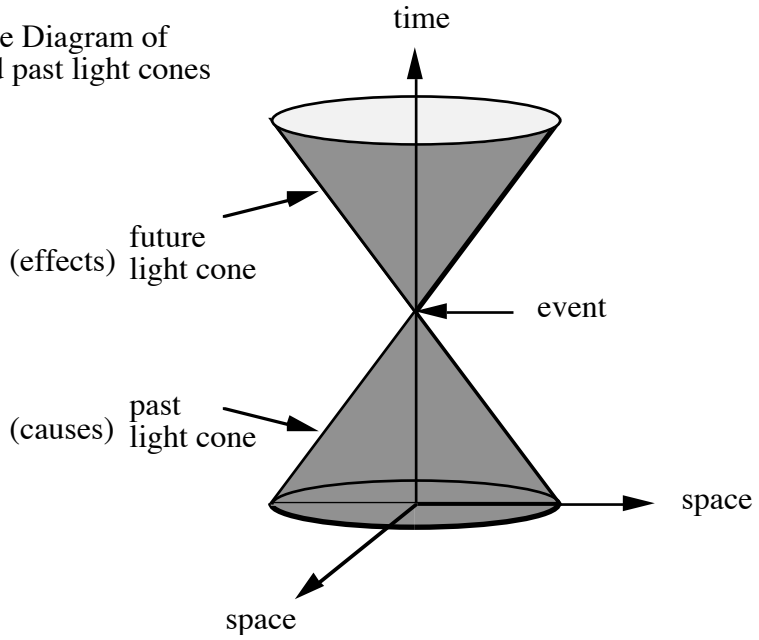
Obviously, the Big Bang at the beginning of the universe is the first boundary event. Pre-existing causal types can only be referenced from those effects produced immediately after this first event. These causal types are the first "pre-existing" causal types of interaction, and equally as obvious, they are not "pre-existing". But for my purpose the term, pre-existing types of causal interactions, is a useful one given this notable exception.

Cones of Causality

To discuss how causes, events, and effects interact through time it is useful to use "space-time" diagrams from Minkowskian geometry. The idea is to portray what happens to effects produced by an event as time flows forward and, conversely, how effects from the past affect events in the present. Figure 5, is from Steven Hawking's book *A Brief History of Time*, and shows both of these processes (Hawking, 1988, 26). The concept of a "light cone" is used because the speed of light is the upper limit for the propagation for any phenomena and, therefore, defines the physical limits of possible causal interactions.

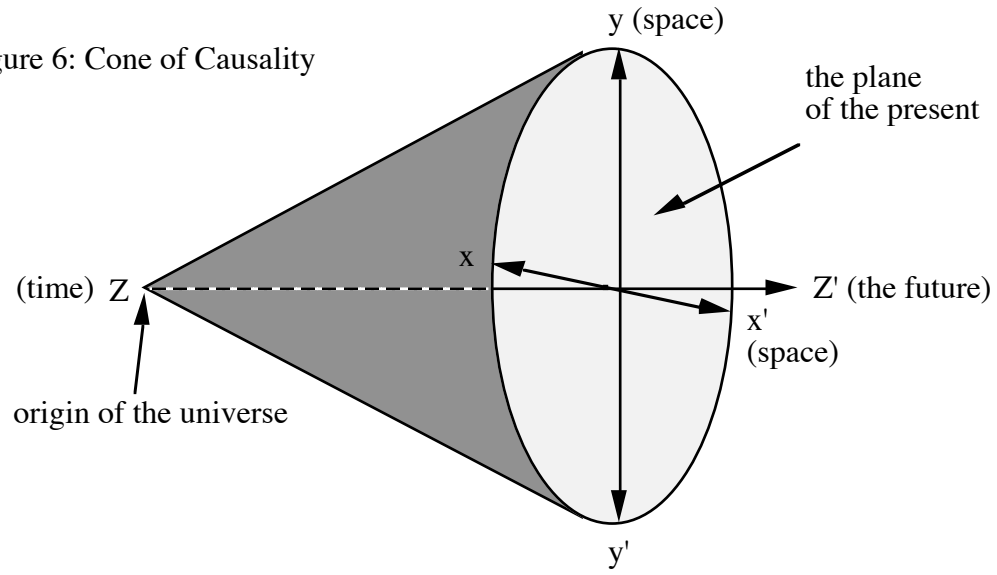
The future light cone, represented in Figure 5, describes the area of space where light from a single event can causally influence future events. Conversely, the past light cone represents all of the positions in space-time of past events that can influence an event in the present. In this figure, don't be confused by the fact that the future light cone representing one thing, and the past light cone representing another have been combined in a single representation.

Fiqure 5: Space-time Diagram of future and past light cones



If you now take the future light cone and start with the first event of the universe, the Big Bang, you then have a cone of causality that encompasses all of the events that have happened in the history of the universe. This is my holistic definition of causality as the sum of all cause and effect in the universe.

Figure 6: Cone of Causality

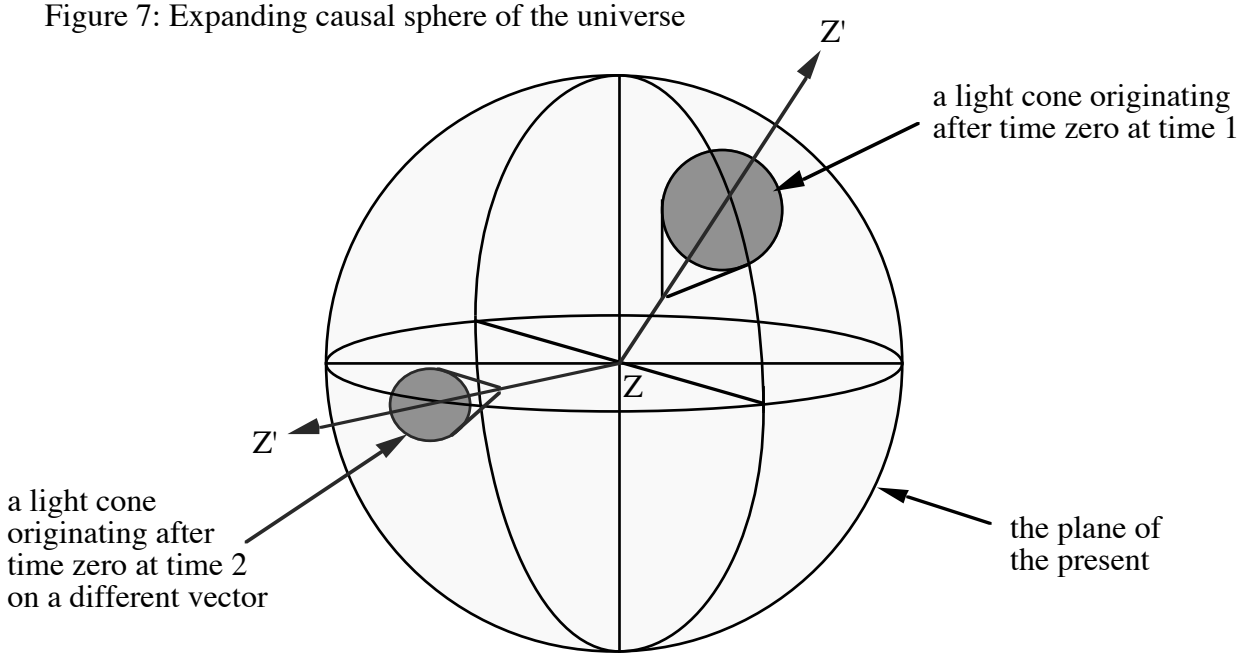


In Figure 6, the axis z-z' is the coordinate of time and the axes x-x' and y-y' are coordinates of space. In addition, the line z-z' represents a linear chain of causality. The plane which has the axes x-x' and y-y' represents the instantaneous moment of the present. Note there is a solid cone produced if you image all of the causal interactions that have occurred from point z, the origin of the universe, to the plane of the present. I have purposely represented the plane of the present as a circle to portray the expansion of the universe. The move I now wish to make is to introduce a new term that is defined by this representation.

At the causal plane of the present there exists a unique combination of causal types, causal inter-relationships, and the number of each of these. This total combination of causes creates at the plane of the present an *initial state of causality* for the next instant in time. The plane of the present is, of course, moving forward with the passage of time. And because of the fundamental fact of continuous change in the universe (remember, if nothing else the universe is continually expanding) the initial state of causality is also constantly and instantaneously changing as time flows forward. This is much like the dynamic wave-front that emanates from a bomb blast. Note that my “plane” of the present should not be a plane at all, that is, it should not be flat. It should be curved so that all points on its surface are of equal distance from the point of origin.

In Figure 7, I take this one step further and wrap the plane of the present into a sphere in an effort to show that a single cone of causality can encompass only a portion of the surface of the causal sphere of the universe. This sphere, like the universe itself, is constantly expanding as time moves forward.

Figure 7: Expanding causal sphere of the universe



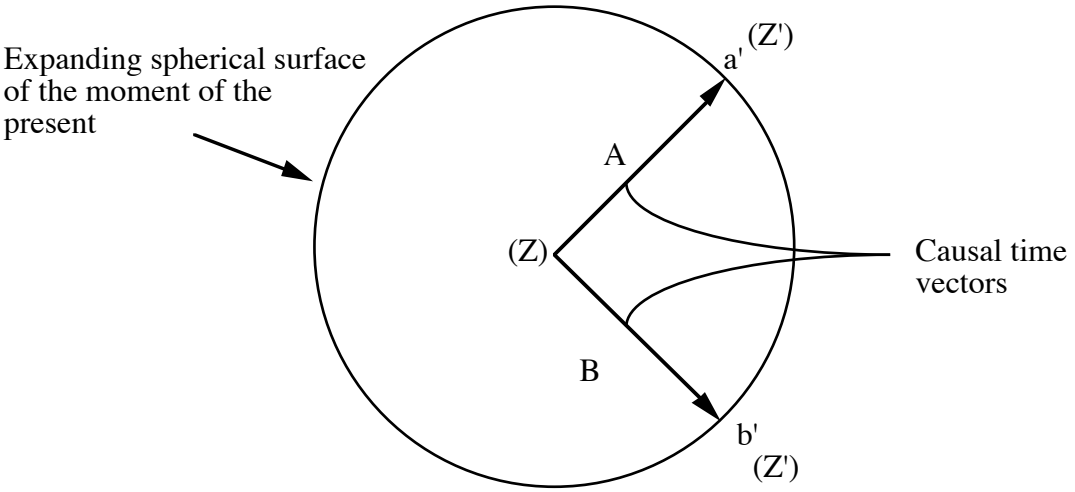
Lateral Causality

The next concept to introduced should be central to any theory of causality. This is the concept of lateral causality. I have used this concept elsewhere to describe different modes of thinking about our world as in the difference between lateral as opposed to linear thinking. It's important here to show that the concept is not unique to my work. Similar concepts have been developed for ecology and non-linear thermodynamics. Refer to J. Baird Callicott's *In Defense of the Land Ethic* page 107, and his reference to "this field theory of living nature." Baird also quotes Harold Morowitz as he sets out his "field-ontology" of organic being. Morowitz uses the language of non-linear thermodynamics in his description of this "field-ontology" with his use of "dissipative structure", "local perturbations", and "vortex". Baird then goes on to describe Arne Naess' "relational total field image [in which] organisms [are] knots in the biospherical net of intrinsic relations." The key notion to take from these examples is the concept of a field of causality. To place my concept of lateral causality in proper perspective, think of lateral causality as the process by which a causal "field" comes into being. But to properly develop my concept of lateral causality, I must introduce yet another concept, that of absolute causal time.

I define absolute causal time as a vector of time that has its origin at the beginning of the universe (point Z, Fig. 8) and extends outward as a single line of linear causality. Its leading point is a single, unique point in space on the expanding sphere of space-time, or as I describe it in Figure 7, the expanding spherical surface of the plane of the present. In Figure 8, there are two vectors of causal time shown, vectors A and B. The length of each vector is the elapsed time since the origin of the universe. The point of origin is the same for all such vectors, as it must be, but the points of termination are different points in space (points a' and b'). Think now of two events occurring simultaneously, one at

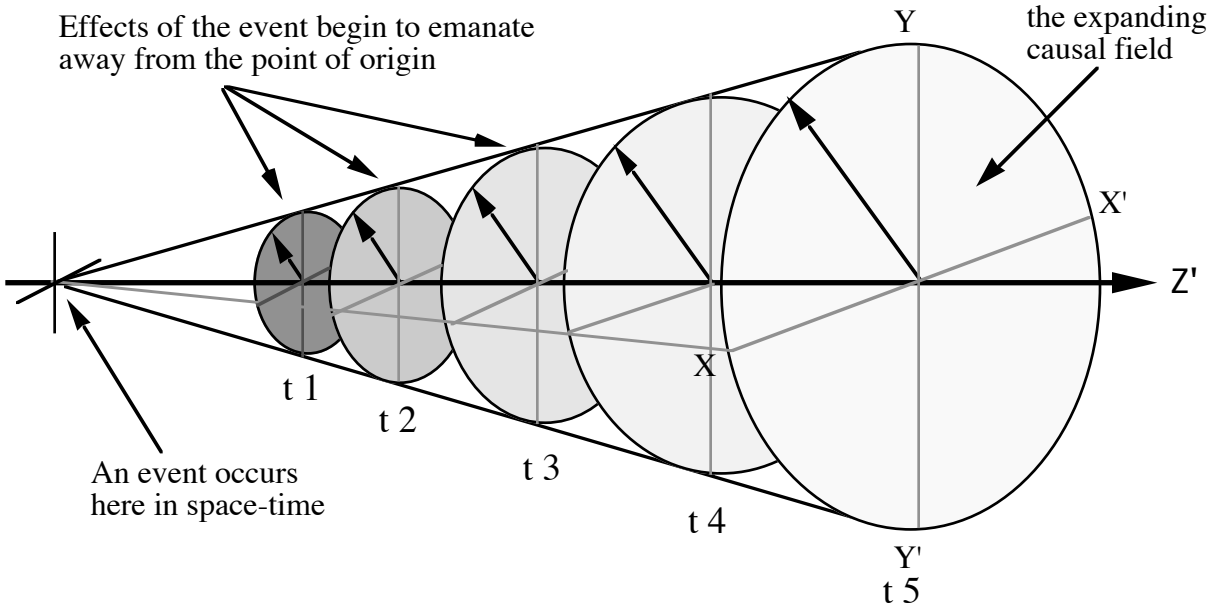
location a' the other at location b'. The two events have occurred simultaneously as measured in absolute causal time, that is, at the same distance in time from the origin of the universe, but they have occurred a finite distance in space from each other. As a result, any effect produced by event a' can not causally interact with effects produced by event b' until it travels the distance between locations (or at least half way, as in the case where the effects are traveling toward each other). Note also that any effects produced by events a' or b' can not travel at a rate faster than the speed of light. For the purpose of illustration, let us assume a second to be an instant in time. It follows that if a' is further from b' than twice the distance light can travel in one second (about 2 x 300,000 kilometers), then causal interactions between the effects of events a' and b' can not be instantaneous. Another way to say this is that an observer at b' would be unable to detect the effects of the event at a' until two seconds have elapsed. Given the distances we observe in space, one can imagine events which occurred simultaneously in absolute causal time having effects that do not causally interact until millions of years after the events that gave rise to them. And indeed, this is just what can happen when we look up into the night sky and see a star.

Figure 8: Vectors of absolute causal time



By referring back to Figure 6, you can see that what I have added in Figure 8, is the notion of multiple vectors of time (Figure 7, also shows multiple vectors). Note that I am not referencing absolute spatial coordinates when I refer to points a' and b'. There is no fixed point of reference in the universe by which to do so. Rather, what I am doing is referencing events at different locations in space to absolute causal time. By doing this, one can reference in space-time past effects that influence current events. This is easier to picture by imagining that on the linear time axis z-z' are causes, events, and effects that occur in the same location in space, and that all other effects resulting from these same events exist laterally in the field described by the x, y coordinate plane.

Figure 9:



Here, finally, is the critical point. Given that causality is continuous in nature, then any event produces an expanding field of effects that emanates outward on the x, y coordinate plane of the present from a single vector of causal time that represents a unique point in space.

In Figure 9, I portray "slices of time" (times t1 to t5) in order to show the progress of the dynamically expanding causal field that is produced by any event. I use arrows to show a specific effect (it has a directional vector) traveling away from the point of origin of the event. As you move forward in time, you can begin to imagine that this field of causality sweeps out a cone of possible causal interactions in relationship to other events on other time vectors that are themselves producing cones of potential causal interaction. Note that this "field of causality" grows *laterally* to the vector of absolute causal time (axis z-z'). As time flows forward, the plane of the present moves forward from the events of the instantaneous past. Effects that were produced in the past begin to move outward from their point of origin. Depending upon the type of effect (that is, the type of phenomenon produced by the event) the effect will travel away from the spatial origin of the event at some finite speed, the speed of light being the upper limit. For other effects, such as a massive particle, the effect may move away on a specific vector of direction and slower velocity (note the vector I've shown in Figure 9). Now imagine an effect produced by a given event that has no velocity. It would remain on the original time vector while all other effects, those with a velocity, would move laterally away from it. The effects without velocity can be thought of as linear effects, while those traveling laterally away can be thought of as lateral effects. Steven Hawking, when describing the effects of a pulse of light produced by an event, uses the metaphor of a stone striking the surface of a pond. The splash causes ripples to spread out in expanding circles as time

flows forward. Lateral causality travels away from its event of origin in much the same way.

There is, however, one effect that all events produce. Remember, by definition an event is any change in the initial conditions of the universe. Given that the universe is the object we call space-time that is created by the distribution of energy and matter, and that all events produce changes in the energy-matter distribution of the universe, then all events, no matter how trivial, produce changes in the very fabric of the universe. In Hawking's words: "Space and time are now dynamic quantities: when a body moves, or a force acts, it affects the curvature of space and time - and in turn the structure of space-time affects the way in which bodies move and forces act. Space and time not only affect but also are affected by everything that happens in the universe." (Hawking, 1988, 33). This awareness of a dynamic space-time reinforces two of the key concepts I've introduced, the concept of the continuity of causality, and the concept of lateral causality or in boarder terms, a field of causality. What's important now is to go back to Figure 5, and examine what happens to Hawking's past light cone as time flows ever forward.

Essay Number Two: The Sources of Complexity

In my first essay I introduced the notion of pre-existing causal types that give rise to new, novel types of phenomenon at boundary events. I must now expand on these ideas.

Novel effects are produced by the increasingly complex interactions of pre-existing causal types. This increasingly complex interaction of types of phenomena may ultimately result from the expansion of the universe as the source of fundamental change. The key, however, is the notion that new, novel effects are produced in nature by pre-existing phenomena. This, in turn, sets the stage for a new round of increasingly complex causal interactions that were not possible before. These create, still again, new initial conditions of greater causal complexity, and so on. Put another way, the complex interactions of pre-existing causal types is the pre-condition for the spontaneous appearance of new effects. These new effects become simultaneously new causal types. The process is irreversible in, what is now believed to be, an infinitely expanding universe.

In this description is the notion that there are two classes of effects: pre-existing effects and new, novel effects. The emission of a photon of light must rank as one of the earliest and most fundamental of "pre-existing" effects of an event. While, in one local part of the universe, the evolution of *Homo sapiens* may be one of the more recent "effects" of complex causal interactions. We are the novel or new phenomenon relative to the release of a photon which has been occurring since the beginning of the universe and occurs still today. This notion of two types of effects leads to the concept that causal complexity in the universe has increased by two different means.

The first mechanism by which causal complexity increases is by the sheer increase in the number of events that have occurred since the beginning of time. The second means is by the spontaneous appearance of new types of phenomena. Therefore, causal complexity increases by both the increasing number of causal interactions, possible as the result of the growing number of past events, and the number of types of causes interacting. This can be understood in two different ways. The first is by realizing that causal complexity results from an increase in the number of possible causal interactions produced directly by the changing dimensions of an expanding universe, as the expansion itself results in an increase in the number of possible *temporal* combinations of causes. Distance itself changes, and with it the number of different temporal combinations of causes. As a result, with a fixed number of types of phenomena the number of different types of events is still able to increase due to the increasing number of possible temporal combinations. What results from this process is the appearance of the second class of effects—new, novel phenomena.

The second way to understand how the causal complexity of pre-existing causal types of phenomena can increase (that is, without new phenomena appearing) is by using Steven Hawking's space-time diagrams. Refer back to Figure 5, and imagine now only the past light cone. What is important here is to understand that the cone of past light includes the positions in space-time of all the possible events that can contribute effects, and therefore causes, to an event at a specific point in space. The critical question to ask is what happens to this past cone of light as time flows forward.

Figure 10: Past Light Cone

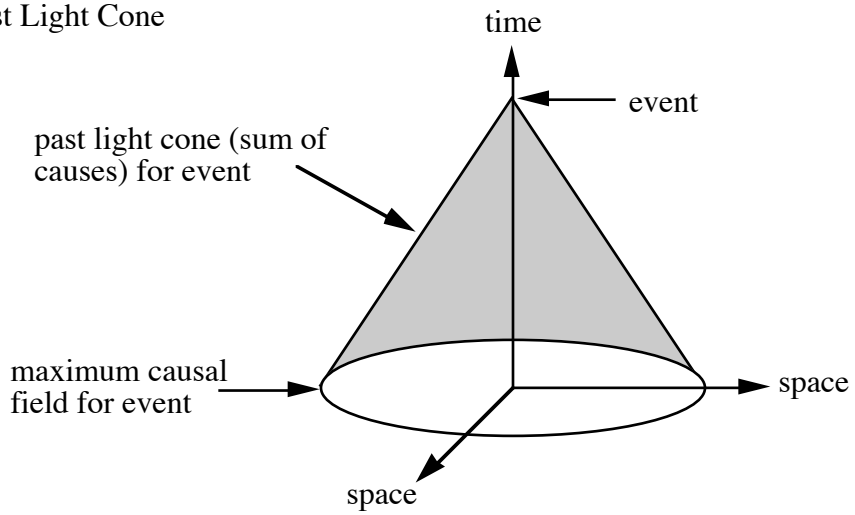
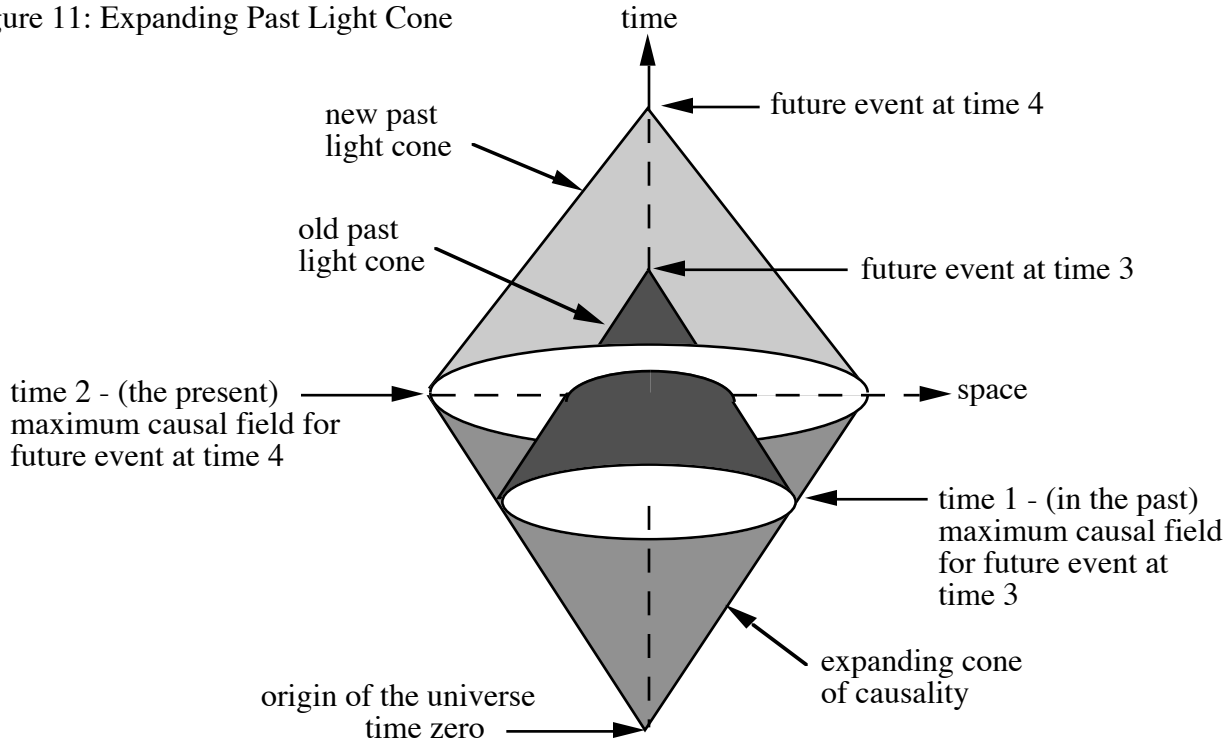


Figure 11: Expanding Past Light Cone



The answer is that it grows constantly larger as time passes. In Figure 11, I show two past light cones, one whose origin is at time 1, and another whose origin in the present at time 2. I have also combined the cone of causality from Figure 6, with the past light cones to establish the correct orientation. Notice that the older light cone at time 1, is smaller than the new light cone at time 2. This seems counter-intuitive for how is older less than the new. But if you remember that there was very little history which could contribute causes during the first seconds of the universe as compared to what there is now, around 14 billion years worth, then an expanding cone of past light makes sense.

The implications of this are that the set of events which can contribute causes to events in the present grows ever larger with the passage of time. In essence, history, itself, is this growing accumulation of events. These two explanations can now be put together to show the dynamics of increasing causal complexity.

Imagine that as the light cone of the past grows, and with it the number of past events, that these events have affected each other through the spread of lateral causal effects. In other words, within this cone of the past there were linear and lateral causal interactions which constantly increased in number as time passed. This process occurs whether or not new, novel effects are produced. As novel effects do occur they add to the number of causal types that can produce causal interactions, thereby escalating both the number and the types of causal interactions. This can be seen by looking at the state of initial conditions at the causal plane of the present. What is occurring is that the initial conditions of the moment of the present constantly becoming more complex as each moment of time passes. This growth in causal complexity can now be seen as an inherent property of our expanding universe.

Essay Number Three: Historical Systems

Causality, as I have defined it, is the study of the relationships between causes and their effects. But I must add that what I am defining is a naturalistic causality. The important distinction is that the relationships between causes and effects that we observe in nature have no purpose.

Causality as a part of philosophy goes back to Aristotle's four categories of cause —material cause, efficient cause, formal cause and final cause. (see Gould, 1995, for a biologist's description of Aristotle's analysis). But if you are not familiar with classical philosophy, as I am not, you will still appreciate that the language of causality is familiar. The terms random, deterministic, probability, historically contingent, and chaos all define different types of causal relationships. In evolutionary theory such terms as proximate and ultimate cause are used by evolutionary biologists such as Ernst Mayr (Mayr, 1982, 67). And Stephen Jay Gould's entire position on historical contingency is one long causal argument (see Gould, 1989). I will add here that an algorithm, either natural or constructed, is yet another type of causal relationship, which leads me quickly to the point I wish to make.

My reason for introducing these concepts of causality is that I believe viewing natural phenomena from the perspective of the causal relationships that produce them is the correct perspective that will lead to a greater understanding of evolutionary theory. I will go even further than this and propose a new conceptual framework that can be used to integrate the causal perspective into evolutionary theory—historical systems.

An historical system is one whose past will shape the course of its future. Such systems are characterized by a unique chronological sequence of events that gives rise to unique initial conditions in the present. System, as used here, is a set of integrated,

interacting parts. Integrated implies that a system forms from a series of events in the past into a stable entity in the present. Integrated, also, implies that unordered entities are acted upon by a process that then forms a new and stable entity from these parts. A process, in turn, is a sequenced set of changes that transforms something from one state to another.

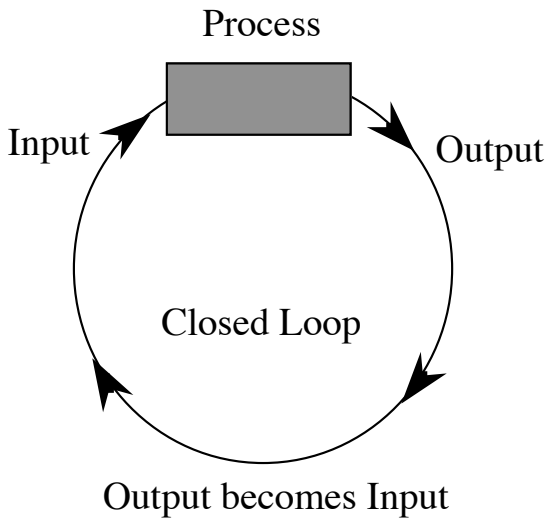
Historical systems have the following characteristics.

1) Change is inherent in historical systems. The expansion of the universe is the fundamental source of change for all historical systems.

2) Historical systems are closed systems where the output of the processes of the system become the only input to the system. In this respect historical systems are self-referential systems (see Sigmund, 1993, 2).

Closed versus Open systems—An open system is one where the output of the system is causally disconnected from the input of the system. Think then of a closed system where a sequenced set of changes transforms the input of the system to the "output" of the system. The output then becomes the input for a second round of the processes of the system. A closed system is a closed causal loop. A feed-back loop is similar, but usually refers to only one parameter of a system being fed back to an earlier point in the system as a control mechanism. A closed system on the other hand can be thought of as having its final output as the only input to the system.

Cause and Effect in a Closed System



This definition of a closed system can be modified by saying that it is possible to define a system as historical if it is in some way "effectively" closed. In this way it can be seen that life on Earth is a closed system, while at the same time acknowledging that

there is external input to the system in the form of energy from the Sun and an occasional meteorite. The point is: There is only one truly closed system and that is the universe itself. And, indeed, the universe is the only truly historical system by my definition. But life on Earth is a "closed" system in one very important sense—after its origin, life can only come from life. The process of life that is closed is reproduction. The germ-line of life on Earth is an unbroken physical chain and in this sense it is a closed system.

3) Novel phenomena arise in the system from the time dependent interactions of pre-existing types of phenomena.

4) The generation of novel phenomena occurs in a unique causal and temporal sequence that produces the directionality of time—time's arrow (see Bronowski, 1977, 192).

5) Historical systems are characterized by increasing causal complexity as the result of a combination of increasingly complex temporal interactions of pre-existing types of phenomena, and the generation of new, novel phenomena.

6) The production of new, novel phenomena is cumulative and, therefore, through time increases the total number of interacting types of phenomena in the system.

This is not to say that some types of phenomena are not lost in the process. It simply means that the total number of phenomena increases through time even though some phenomena must be lost in the process of creating new phenomena. e.g. 1) There are no free quarks in the universe today. e.g. 2) The origin of the first cellular life on Earth precluded the possibility of a second origin of life from prebiotic macromolecules. e.g. 3) The evolution of cyanobacteria lead to increased atmospheric oxygen and forced the anaerobic bacteria from most of the Earth's surface thereby foreclosing many evolutionary possibilities. The so called "forced moves" in "design space" create many of these replacement events in the types of phenomena that are possible together at any given moment in history (Dennett 1995, Chapters 4, 5, and 6). The formation of protons from free quarks as the result of the cooling of the universe is one such "forced move" in design space. These forced moves are as Bronowski puts it "the barb which evolution gives to time" (Bronowski, 1977, 192).

7) Natural hierarchical levels of organization or "levels of stability" are inherent in historical systems. A natural hierarchical level is defined by the occurrence of a new, novel and stable phenomenon that increases the level of causal complexity of the system enough to give rise to a new level of spontaneous self-organization. These levels are characterized by their stability in design space.

8) As a result of these characteristics, all historical systems evolve.

The universe is a closed, historical system. The fundamental process that produces change in our universe is its expansion, and, indeed, the universe has evolved through time. The history of life on Earth is but a small part of that evolution, and the processes that produced life on Earth are one and the same as those for the universe itself. What I am suggesting is that biological complexity increases as the product of a natural algorithm. And that this natural algorithm is responsible not only for the increase in complexity that we observe in biological evolution but in the evolution of the universe itself.

Essay Number Four: A Natural Hierarchy of Causal Complexity

There are few ideas that are completely original, and so it is with my concept of natural hierarchical levels. Jacob Bronowski came to a similar idea with his concept of "*stratified stability*". The following quotes are from his essay *New Concepts in the Evolution of Complexity* (Bronowski, 1977, 190-195). "It is evident that we cannot discuss the variability of organisms and species without also examining their stability, as the second of the two balanced mechanisms that are needed to complete our understanding of evolution. I call this [mechanism for stability] *stratified stability*." "Here, then, is a physical model which shows how simple units come together to make more complex configurations; how these configurations, if they are stable, serve as units to make higher configurations; how these higher configurations again, provided they are stable, serve as units to build still more complex ones; and so on." "... the building up of stable configurations does have a direction, the more complex stratum built on the next lower, which cannot be reversed in general." "The total potential of stability that is hidden in matter can only be evoked in steps, each higher layer resting on the layer below it. The stable units that compose one layer are the raw material for random encounters [time dependent interactions of pre-existing types of phenomena] which will produce higher configurations [new, novel phenomena], some of which will chance to be stable." Bronowski speaks of "more complex configurations" and "higher configurations", but in what sense do we mean "more complex?

Defining Complexity

1) Norman Packard in Roger Lewin's *Complexity: Life at the Edge of Chaos*, (Lewin, 1992, 130-149).

"Biological complexity has to do with the ability to process information."

2) Murry Gell-Mann in *The Quark and the Jaguar*, (Gell-Mann, 1994, 227-231).

> "Recall that effective complexity is the length of a concise description of the regularities of a system."

3) Maynard Smith and Szathmary in *The Major Transitions in Evolution*, (Maynard Smith & Szathmary, 1995, 5-6).

> "A possible answer [to how to measure biological complexity] is in terms of the DNA content of the genome, which can be thought of as instructions for making the organism: more complex organisms require lengthier instructions."

A Causal Definition of Complexity

The key to understanding complexity is to ask what parameter it is that complexity measures. The definitions above have in common that it is information in some form that complexity measures. I submit instead that complexity is a measure of the number of types and the number of each type of causal interactions that are necessary to produce a given phenomenon. The greater either of the number of types or the number of each type of causal interaction that is necessary to produce a given phenomenon, the greater the complexity of that phenomenon. But how is this complexity produced?

I submit that increasing complexity is the result of a natural algorithm.

Defining an Algorithm

By Dennett's definition (Dennett, 1995, 50-51) an algorithm has:

"1) *substrate neutrality*: The power of the procedure is due to its *logical* structure, not the causal powers of the materials used in the instantiation.

2) *underlying mindlessness*: Although the overall design of the procedure may be brilliant, or yield brilliant results, each constituent step, as well as the transition between steps, is utterly simple.

3) *guaranteed results*: Whatever it is that an algorithm does, it always does it, if it is executed without misstep. An algorithm is a foolproof recipe."

What Dennett does not clarify until later in his book is that, as it concerns evolution by natural selection (or as I have tried to show—all evolutionary processes), we are talking about *natural* algorithms—algorithmic processes in nature that have the above characteristics but do not have an end directed goal. They exist and operate but they are not algorithms for producing particular outcomes. They have no teleological purpose, no "final cause".

The clearest example of the workings of this algorithm in producing stratified stability and increasing complexity is the nucleosynthesis of the elements. Using this example, all of the algorithmic processes that lead to greater causal complexity can be described. To build the necessary image start chronologically after the formation of the first elements at ~ 4 x 10^5 years after the origin of the universe. Through the causal interactions of gravity and these elements, the first stars coalesced and ignited. This step is the formation of a new, novel phenomena—stars—from the time dependent interactions of pre-existing types of phenomena—gravity and the first elements. With the first stars the process of nucleosynthesis began forming the heavier elements, which are themselves new phenomena. And if you continue through the chronological history of the universe, what emerges is a picture of one natural hierarchical level of stability being built on another, then another and so on. Until, finally, we reach the history of our own solar system and on to the history of life on Earth.

It is clear from this picture that Bronowski's "levels of stability" are one and the same as my natural hierarchical levels. And it should also be clear that understanding that these natural levels of stable phenomena are achieved by the workings of a natural algorithm—a mechanistic process that is mindless and without direction—should put to rest the notion of progress in the natural world.

Appendix One: Natural Hierarchical Levels of Stable Phenomena

Natural hierarchical levels of organization or "levels of stability" (Bronowski, 1977) are inherent in historical systems. A natural hierarchical level is defined by the occurrence of a new, novel and stable phenomenon that increases the level of causal complexity of the system enough to give rise to a new level of spontaneous self-organization. These levels are characterized by their stability through time and can be identified by the following features:

1. a unique scale in size—"on being the right size"

2. a new spontaneous organization of matter or "self-organization"

3. new emergent properties or processes—"more than the sum of the parts"

The following is a partial list of stable hierarchical levels of organization in nature, admittedly, as seen from a biologist's point of view.

The Quantum Level (origin ~ 1 x 10^{-32} second after time zero)

1) Scale in size—1 x 10^{-35} meter (Planck's length) to 1 x 10^{-16} meter
2) Self Organization—by ~ 1 x 10^{-12} second after the Big Bang radiation had cooled enough to form quarks (this is the "Quark Soup")
3) Emergent Properties & Processes—matter forms from energy

The Sub-Atomic Level (origin ~ 1 second after time zero)

1) Scale in size—1 x 10^{-15} to 1 x 10^{-10} meter
2) Self Organization—at ~ 1 second after the Big Bang the universe had cooled enough for quarks to form protons; electrons to form from radiation; and protons and electrons to interact to form neutrons
3) Emergent Properties & Processes—formation of the first atomic nuclei

The Atomic Level (origin ~ 400,000 years after time zero)

1) Scale in size—one ten billionth of human scale or 1 x 10^{-10} meter
2) Self Organization—protons capture electrons and form the light elements hydrogen and helium
3) Emergent Properties & Processes—primary or Big Bang nucleosynthesis; the properties of the elements hydrogen and helium; decoupling of matter and radiation; and the origin of the cosmic microwave background radiation

The Molecular (origin ~ 200 million years after time zero)

1) Scale in size—one billionth of human scale or 1 x 10^{-9} meter
2) Self Organization—formation of first stars, formation of the heavy elements; formation of molecules by electromagnetic forces
3) Emergent Properties & Processes—production of heavy elements in stars—secondary or stellar nucleosynthesis; all the properties of molecules as opposed to elements—complex chemistry is now possible.

The Prokaryotic (origin ~ 4000 million years ago)

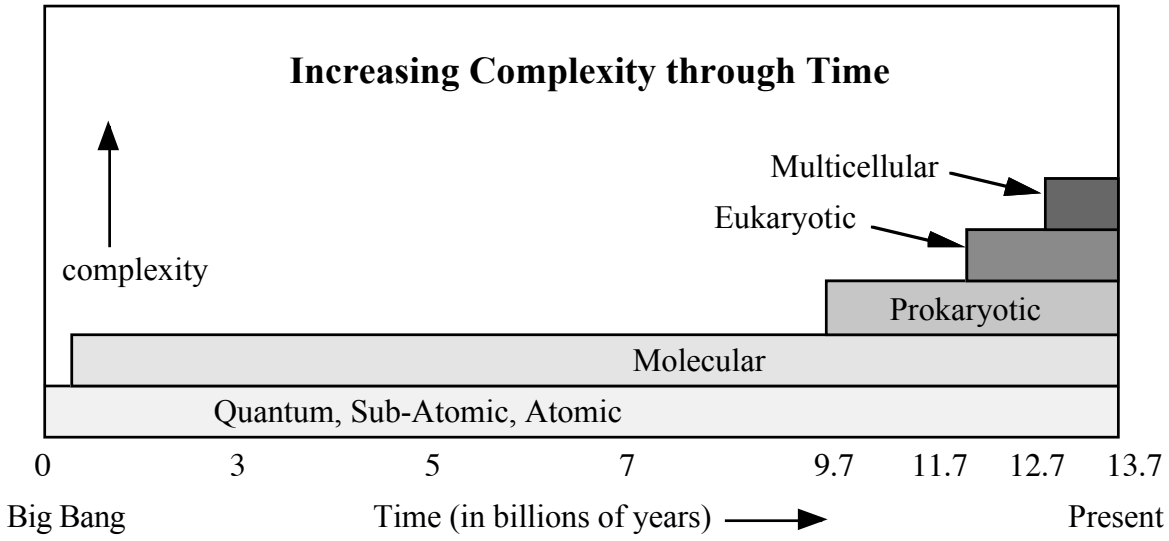
1) Scale in size—one millionth of human scale or 1 x 10^{-6} meter
2) Self Organization—organization of complex macro-molecules into a self-reproducing unit, the cell
3) Emergent Properties & Processes—the origin of life—Archaebacteria & Eubacteria; natural selection; speciation; self-reproduction by binary fission; anaerobic and aerobic respiration; photosynthesis

The Eukaryotic (origin ~ 2000 million years ago)

1) Scale in size—1 x 10^{-5} to 1 x 10^{-4} meter or ten to a hundred times larger than the prokaryotic
2) Self Organization—endosymbiotic mutualism of primitive eukaryotes and prokaryotic bacteria to form true eukaryotic cells
3) Emergent Properties & Processes—endosymbiotic mutualism; origin of Kingdom Protista; evolution of sexual reproduction (origin ~ 1100 million years ago)

The Multicellular (origin ~1000 to 600 million years ago)

1) Scale in size—one thousandth of human scale to human scale or 1 x 10^{-3} to 1 meter
2) Self Organization—multicellular organization by cell types into tissues and organs, to whole organisms; reproductive groups (demes); social organization (societies)
3) Emergent Properties & Processes—cell specialization; emergence of large life forms; origin of Kingdoms Fungi, Plantae, and Animalia; social behavior; language



References

Alles, D. L. (1995). *The Third Culture: Exploring the Relationship between Biology and Philosophy*. (Seminars presented to the Department of Biology, Western Washington University, Bellingham, Washington)

Bronowski, J. (1977). *A Sense of the Future*. Cambridge, MA: MIT Press.

Callicott, J. B. (1989). *In Defense of the Land Ethic*. State University of New York Press.

Dennett, D. C. (1995). *Darwin's Dangerous Idea: Evolution and the Meanings of Life*. New York: Simon & Schuster.

Ferris, T. (1988). *Coming of Age in the Milky Way*. New York: William Morrow.

Gell-Mann, M. (1994). *The Quark and the Jaguar*. New York: Freeman.

Gould, S. J. (1989). *Wonderful Life: The Burgess Shale and the Nature of History*. Cambridge, MA: Norton.

_____ , (1995). Boyle's Law and Darwin's Details. *Natural History*, August, p. 8-11 & 68-71.

Hawking, S. W. (1988). *A Brief History of Time*. New York: Bantam Books.

Lewin, R. (1992). *Complexity: Life at the Edge of Chaos*. New York: Macmillan.

Maynard Smith, J., & Szathmary, E. (1995). *The Major Transitions in Evolution*. Oxford: Freeman.

Mayr, E. (1982). *The Growth of Biological Thought: Diversity, Evolution, and Inheritance*. Cambridge, MA: Harvard University Press.

Ruse, M. (1996). *Monad to Man: The concept of Progress in Evolutionary Biology*. Cambridge, MA: Harvard University Press.

Sigmund, K. (1993). *Games of Life: Explorations in Ecology, Evolution and Behavior*. Oxford: Oxford University Press.

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