LIMITS TO MEMORY IN ECOSYSTEMS AND SOCIETY

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Abstract

With the accelerating swarms of information in modern civilization, questions rise about the limits to information, its optimum use, and long range sustainability. Insights may be obtained from information in ecological systems using general systems models of energy hierarchy to aid comparisons. Analogs of memory are found within organisms, ecosystems, internet, and human culture. Short term and long term memory in various systems are hierarchically organized in energy transformation chains with increasing territorial scale. Abundant but short term information has small territory and impact. Derived from it, long term information is less in quantity but has increasing quality and scale. The biotic information in organisms of different sizes and scales found in nature appear analogous to the strength and scale of items of learned information in society. There are similarities in processes of succession, and in cultural evolution, and biotic evolution, each selecting information for long term storage. Simulation of a general systems minimodel suggests energy transformation mechanisms for memory maintenance. Information in different memory categories is rated on the scale of transformity (emergy/unit energy). Sharing on a global scale generates maximum potential for sustaining the most important information for civilization and environment.

Keywords: Memory, information, hierarchy, simulation, succession

1. Introduction

In the global frenzy about the marvels of information, people speak of unlimited information development and use. We recently asked a college president: what are the limits to information? The person said "none." Yet when we look to the real world of intelligent organisms and species variety, we find that ecosystems have information limits. The succession and evolution of natural systems is instructive in the way information is created, tested and maintained or rejected. Perhaps the natural systems are models that show how the information culture of the electronic age can mature and become more adaptive. Perhaps we can use general systems theory to find commonalities on memory of various kinds.

For the purpose of discussion we define information as something that is cheaper to copy than to generate anew. In Figure 1, the living units use information by reproductive copying, whereas the series of atmospheric units below are generated anew. Information is a pattern which is found with enough consistency to be predictable. Our knowledge of early human societies stems from our interpretation of their information stored as knots in string (Inca), cuneiform inscriptions in stone (Sumer), hieroglyphs (Egypt) and pictographs (China). The durability of these patterns allowed information to transcend a human life span. Humans manipulated patterns for informational purposes at coarser scales as well Rocks were piled to identify and reinforce pathways (cairns), and to interpret celestial event and identify seasonal transitions (Stonehenge).

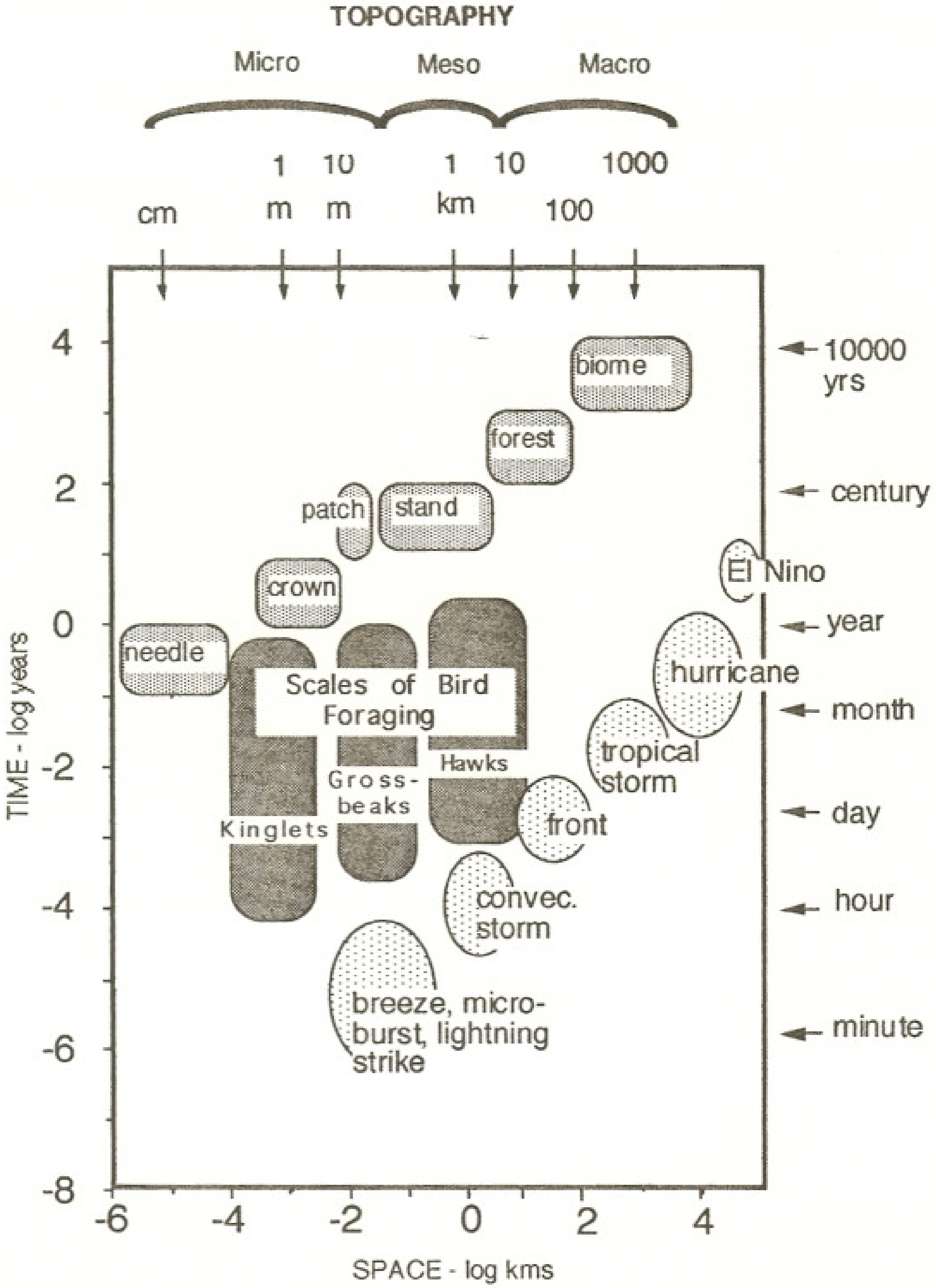


Figure 1. Discontinuous distribution of space/time dimensions of categorie of the biosphere. The left and right edges of each polygon represent th spatial grain (the largest pixel size which faithfully represents phenomenon) and spatial extent (the linear dimension of the area in whic the phenomenon's life history occurs). Bottom and top edges of eac polygon represent the time step and time horizon, respectively, in which th phenomenon's life history occurs (Sendzimir, 1998).

2.1 Technological Processing

Electronic technology is revolutionizing the processing of information both in kind and quantity. Analog video has greatly increased the volume of imagery broadcast for entertainment or education. Digitization promises to further amplify this flow along with that of the written word in electronic and paper media.

Unfortunately this torrent of data is often mistaken for an increase in information quality. While digital storage increases the possibility of obtaining information, the difficulty of finding useful information has not changed. It may be easier to replicate the needle, but a larger haystack hides the replicates. The blinding effect of all the extra hay (information of dubious quality) has been described as "data glare." The ambiguous nature of the central tool and icon of the Information Age revives the question as to what gives information its usefulness or quality.

The question of information quality is especially poignant in the face of current environmental challenges. For example, the potential consequences of global climate change demand attention. However, quality seems to be sacrificed because people are seduced by the speed at which information is processed and the density at which it can be stored. Terrabytes of images about these issues may slow rather than enhance our ability to digest difficult issues. The television solution of reducing the information torrent to "sound bites" rarely exposes the key issues and often trivializes dialogues about complex environmental problems.

Some believe the newspapers will withstand the video onslaught because the printed word represents higher quality information. The idea is that the usefulness of information resides in the quality of its processing. The intelligence and diligence employed in reducing a one megabyte image to a one kilobyte paragraph or line drawing is the quality investment which captures the useful data. We note such quality in the way literature or remarks become 'classical' as their profound insight makes them resonate through time. As people repeatedly find the information useful, it endures; it is worth copying.

2.2 Biotic Processing

Living organisms are information carriers. Like their ecosystems and their non-living components they are organized hierarchically with items of small scale information contributing to support fewer items of larger scale. (Figure 1).

Many animals use information to control other parts of their system. There is growing evidence that spatial patterns constitutes information important to their survival. Spatial geometries at different scales provide opportunities for animals to forage, nest, mate and find shelter. Figure 1 illustrates the space/time dimensions of bird foraging in a hierarchically structured model of a boreal forest landscape. The fine textures of needles and tree branches in tree crowns are crucial to tiny birds, such as kinglets, which forage for individual insects. At coarser scales, the patch structure of forests, the areas of forest stands and the distances between them, are important to flocking foragers. For example, when entire tree stands are flooded with high densities of budworm during meso-scale outbreaks (a few hectares) grosbeaks will arrive in flocks to forage. Both kinglets and grosbeaks eat the same resource, but respond to spatial pattern at different scales. The manner in which moose browse or spruce budworm populations break out determines and reinforces the spatial patterns of patches in the boreal forest. The process of foraging for seeds and defecation of those seeds in concentrated areas (latrines) by tapirs determines the spatial patterns of Moracea palms in neotropical rainforests. Larger birds, such as hawks, orient on spatial distributions of macro-features such as forest ecotones, shorelines and mountains.

For other large animals, such as moose or cougars, the spatial distributions of macro-features such as shorelines and mountains have important consequences. Temporally repeatable patterns are also significant in entraining the behaviors of animals. Examples include the periodicities of tides, floods, fires and storms.

The usefulness of any object or pattern is repeatedly tested by organisms, and those patterns which confer advantage tend to persist. Organisms do not simply find useful patterns; they interact with them and can even modify them. Therefore, the usefulness of any pattern is not a given; it is tested repeatedly and can wax and wane in importance under different regimes of climate or resource availability. The reinforcement of spatial patterns by interaction with organisms is an example of self-organization of systems. The variety of patterns in the landscape represent a spectrum of utility, and as different patterns are worked and re-worked that spectrum can shift. In systems with a long history of testing (such as ecosystems), the constant which endures is the testing for utility, not the information itself. The information resides in a diversity of organisms and structures, and the system persists by maintaining the most competitive collection of interactions between pattern and process, or, the interactions between fixed and dynamic design. System resilience results from a diversity of patterns and processes working on each other at different time and space scales.

2. Ecological Succession and Memory Transfer

When a landscape or water body is recolonized, the species participating are often temporary, with a rapid turnover as they are replaced by others in successional processes. Patterns are locally different because the conditions are different and the histories of seeding and species access are different. Examined on a larger scale, there is a mosaic of short term inputs, species retention, and information distributed in the genetics of the scattered species and in the structure of relationships in soils and waters. Later some of these species may not reoccur. For example, early succession may have an abundance of different weeds, exotic species, and blooms, each one dominant locally. With unutilized resources of sunlight and materials, these local patches grow explosively, overgrowing others, resulting in a low species diversity locally. The pattern is analogous to the short term memory of the brain as it receives various fragments of information which are held locally for a time. Orrell (1997) estimated the number of species that can be supported on earth using estimates of global plant productivity and a relation of species to energy.

Some species are retained in the landscape where they participate in repair and recolonization wherever the opportunity may be provided by a pulse of destruction and restoration. Some of the successional species are well adapted to the physical and chemical climate so that they reoccur in later episodes. For example, the pines in the landscapes of the southern United States become widely distributed, standing ready to reseed when the canopy opens again. After hundreds of years of participation in efficient restoration cycles, these species spread and their distribution is then on a large scale, which makes the successional process more efficient. The genetic information is shared throughout the larger regional area. The genetic information of these species and the structural information in their architecture, soils, and biodiversity interplay is widespread. This information is more secure because of its widespread distribution, less vulnerable to local losses. The pattern is analogous to the long term memory of the brain in which information is shared by larger areas of the brain. Since such regional patterns correlate with the space/time dimensions of macro-scale processes such as glaciation or dought cycles, long term memory stores macro-scale data of time patterns.

3. Short and Long Term Memory in Evolution

Whenever and wherever there are new conditions and unutilized resources, there are opportunities for new biotic innovations. The variations generated by processes of mutation and selection fall on fertile ground, and some innovations can displace older species and structures. Microevolutionary changes can be recombined into emergent macroevolutionary progress capable of displacing previous species. For example, the salt marsh grass Spartina anglica, which developed new genetic combinations from hybridization of other marsh species, was innovative in replacing low productivity mud flats in temperate latitudes with highly productive vegetation and associated animal populations (Knox, Odum, Campbell, 1999).

In a time and place of new energy opportunities there are many species that appear in the fossil record for a short time and locally. Some of the innovations become more widely spread, becoming information that is broadly shared by the larger landscapes and waters. Evolution by this view has a short term memory that is small scale, local, and rapidly changing. Some of the products of the small scale genetic information are retained, made more secure and longer lasting by becoming widely shared with larger territory. All this follows the old evolution idea of area of taxonomic entities increasing with their age. Whereas the species are mostly local and transient, the common shared components of the basic mechanisms of life are global and represented by the widespread distribution of the higher taxonomic levels (Orders, Classes, and Phyla).

4. Short and Long Term Memory in Information of Society

The processing of information by society also has aspects of short term and long term memory. The frantic development of the computer industry and its uses has rapid and local developments of hardware and software, much of it with short lifetime and local uses analogous to short term memory. Those innovations that get a broader distribution become more secure by being shared over a larger scale, developing an inertia and the value and high emergy of being shared. The prevalence of internationally dominant operating systems raises fears of competition-stifling inertia and has generated anti-trust actions by government.

On the other hand, the internet provides a new mechanism by which some of the small scale, local innovations are adopted by the larger realm, even worldwide.

Whereas the short-term processing of information is made efficient by miniaturizing, as observed in development of computer chips and in the nerve cells of organisms, the long term memory of society is on the larger scale of sharing information in forms that last. So far the sharing of genes, religious elements, and cultures globally are the long term memories on the same scale as stone tablets and inscriptions on monuments that last through thousands of years.

5. A General Model of Short Term and Long Term Memory

A general systems minimodel of information processing is given in Figure 2, for which long and short term memory, succession, evolution, and processing of information by society are examples. As usual with energy systems diagrams, scale of time, space, and transformity increase to the right. The unit on the left represents short-term, local and different innovations, whereas the unit on the right collects and stores long term, large territory, and high transformity shared information.

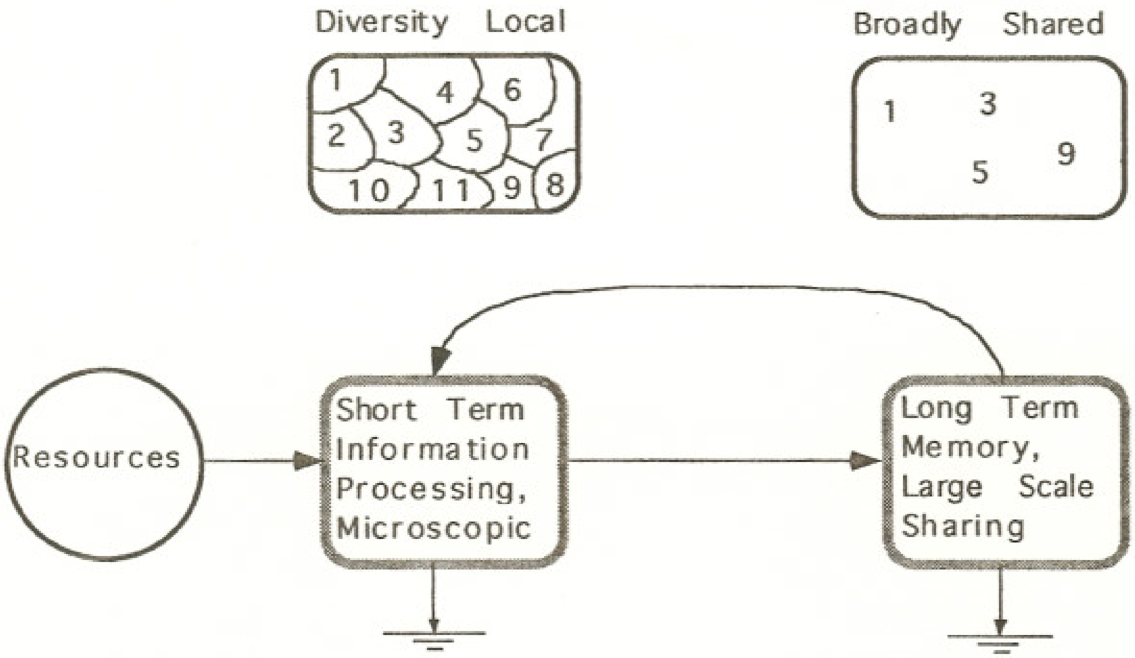


Figure 2. General systems model of memory processing.

Both of these have pulsing, rapid on the left and long interval but extremely accentuated on the right. On the left the build-up of available resources is followed by the pulse of local, short term information innovation. On the right, the accumulation of innovations from the short term process acts as a build-up for the pulse of emergent changes that have world-wide application. Examples are the development of life, of human species, and the computer.

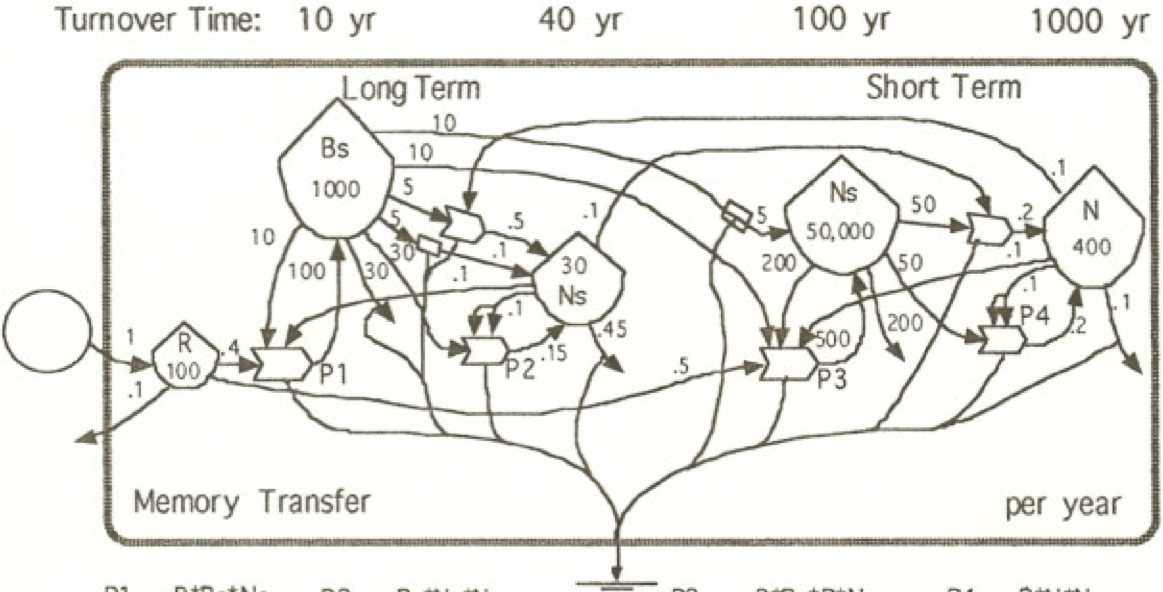
Biodiversity exists at both ends of the information processing hierarchy. On the left the biodiversity of small scale differences (example: species) is large when considered over the entire area, but tends to be small locally. Locally, each species well adapted to local conditions and underutilized resources can overgrow others there. On the right the biodiversity is high but limited by the large emergy required to maintain the essentials that are globally shared. Maintaining shared information requires a continual cycle of duplication, reapplication testing, and selection by reinforcement.

6. A Simulation Minimodel of Memory Transfer

The two level system in Figure 2 is drawn in more detail in Figure 3 in energy systems language. Values of flows and storages were assumed so that turnover time of each unit increases from left to right. Longer turnover time means items that are fewer and larger. The configurations are those of general systems hierarchies that maximize function by feedback reinforcement. Theories long discussed in ecology suggest that the usability and ability to maintain information decreases with the square of the amount of information. The model has a quadratic demand for information (Bs and N) support drawing on both carrier storages (Bs and Ns).

Memory Limits

General systems concepts expressed in energy systems language (Figure 3) automatically generate a set of rate equations for computer simulation (Odum, 1983, 1993), which are shown beneath the diagram.



$$P1 = R*Bs*Ns \qquad P2 = Bs*Ns*Ns \qquad P3 = R*Bs*B*N \qquad P4 = B*N*N$$

$$dR/dt = If - k1*R - k2*P1 - k3*P3$$

$$dBs/dt = k4*P1 - k5*P1 - k6*Bs - k7*P2 - k8*Bs - k9*Bs*N - k10*P3 - k28*Bs$$

$$dNs/dt = k11*P2 - k13*P2 - k12*Ns - k14*P1 + k15*Bs + k16 * Bs*N - k17 *B*Ns$$

$$dB/dt = k18*P3 - k19*p3 - k20*B - k21\ P4 - k22\ Ns*B + k29*Bs$$

$$dN/dt = k23*P4 - k24*P4 - k25*P3 + k26*Ns*B - k27*Bs*N$$

Figure 3. General systems minimodel for memory transfer.

Simulation of this design and these calibrations shows pulsing as is observed in all systems Certainly, pulsing is characteristic of human information storms. Margalef (1958) showec that ecosystems have pulsing in their biodiversity information storages (Figure 4).

7. Evaluation of Information

As demonstrated with these models, information requires resources. Information specialist continually sift and dump (forget) less important information. To maintain a species or useful block of learned information requires maintaining a whole population to generat choices and selection. All this requires energy resources. Stress energies affect th information that can be maintained, although there is controversy about whether the effec increases or decreases information. Small, fast-turnover components are maintained by fas processing, whereas large components may require more redundancy for sustainin information where processing is slower. Emergy measures the inputs required fo information on a common basis. For example, the old species-area curves provide data fc evaluating emergy requirements where resources are supplied on an area basis. Informatio and diversity indices are being made at many scales from microbes to GIS defined landscap

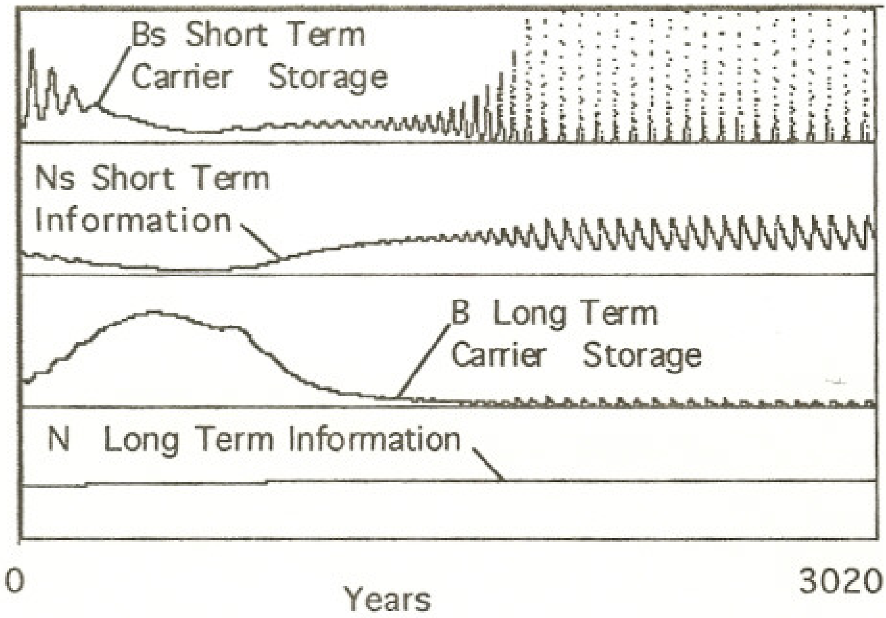


Figure 4. A simulation showing the pulses of short term information and the stability of long term information derived by selection.

patterns. Transformity measures the quality of information and its position in the hierarchy of size, time, and energy (Odum, 1996, chap. 12). The items in Figure 1 range from 1000 to 10 E6, increasing from left to right.

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