CULTURE AS A SEMANTIC FRACTAL: Sociobiology and Thick Description

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Abstract: This report considers the problem of modeling culture as a *thick* symbolic system: a system of reference and association possessing multiple levels of meaning and interpretation. I suggest that *thickness*, in the sense intended by symbolic anthropologists like Geertz, can be treated mathematically by bringing together two lines of formal development, that of semantic networks, and that of fractal mathematics. The resulting *semantic fractals* offer many advantages for modeling human culture. The properties of semantic fractals as a class are described, and their role within sociobiology and symbolic anthropology considered. Provisional empirical evidence for the hypothesis of a semantic fractal organization for culture is discussed, together with the prospects for further testing of the fractal hypothesis. Keywords: culture, culturgen, meme, fractal, semantic network.

I. Introduction.

In the past decade the study of culture has become increasingly important to evolutionary biologists. This is because the development of new theories has made it possible to treat evolution in populations in which there is inheritance of both genetic and cultural information (Lumsden & Wilson, 1981, 1985; Cavalli-Sforza & Feldman, 1981; Boyd & Richerson, 1985; Lumsden, 1988; Findlay, Lumsden & Hansell, 1989). Considerable information about possible rates and directions of genetic evolution in models of such populations has now been obtained. For the most part, however, the accompanying treatments of culture have remained tightly focussed on the question of units of cultural inheritance, that is, on whether culture is made up of socially transmissible bits and pieces of information in a manner that allows distinct patterns of heritable variation to exist across generations. This issue quite properly has been regarded as essential in applying to cultural transmission the powerful models of classical population genetics. Tentative answers to the question of cultural units have generally affirmed the validity of units and indicated an array of possibilities, ranging from classes of observable behaviors and artifacts to categories of meaning and knowledge stored in individual brains. Lumsden & Wilson (1985) pointed out that mental development is very likely to create basic units of culture along the lines sought, just as the operation of the genetic code organizes an otherwise continuous molecular text into heritable units of variation. The most probable site of action for this process is long-term semantic memory, which stores the knowledge structures formed in the mind during enculturation (further discussion in section II, below). These and subsequent authors have suggested identifying the elemental units of semantic memory with the basic heritable unit of culture (Lumsden & Wilson, 1985; Stuart-Fox, 1986; Barkow, 1989) and shown that a hierarchy of more complex units follows readily from this basic association.

Despite the progress achieved on the question of cultural units, these studies generally have ignored other principal characteristics of culture. The picture of culture adopted by human ethology and sociobiology is, for the most part, that of a collection of distinct socially transmitted and learnable behaviors or ideas. This bare-bones characterization, emphasizing properties of culture that make it amenable to population-genetic metaphors, has understandably drawn criticism from social scientists and humanists (Sahlins, 1976; Bock, 1980; Hallpike, 1982, 1985; Lumsden & Wilson, 1991), who have pointed out repeatedly that culture is more than an unstructured set of heritable units: the associations among units carry meaning and significance too, and one is entitled to question the relevance of paradigms, however quantitative, that ignore them.

In this report I consider the problem of modeling culture in a way that respects the concept of (i) a culture unit (*culturgen* (Lumsden and Wilson, 1981), *meme* (Dawkins, 1976), etc.) and (ii) culture as a socially constructed network of interrelated meanings open to multiple levels of interpretation (the *locus classicus* is Geertz, 1973, 1984). The mathematical objects known as fractals provide a means of respecting both concepts while providing new ideas about how units of culture are organized into an overall information system.

My approach is a follows. In section II the concept of a semantic network is developed in a form applicable to fractal models of culture. Section III considers the question of the organization or structure of culture, including but going beyond the question of units. Particular attention is paid to the concept of culture as a symbolic system endowed with multiple levels of meaning. In section IV fractals are introduced to model complex semantic networks embodying multiple layers of meaning. The key problems of development, transmission and computation in such knowledge structures are considered together with the possibility of

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empirical tests of the fractal model. The discussion leads to the working hypothesis that human culture has, at least approximately, the properties of a semantic fractal. Prospects for testing the hypothesis are discussed. The final section identifies some of the principal limitations with the fractal concept and suggests that continued progress may require the formulation of more complex objects than now considered.

II. Semantic Networks and Culture.

Semantic memory, storing a person's understanding of the world (Lumsden & Wilson, 1981), tends to organize both continuous and discontinuous impressions into clusters. Experimental studies have shown that the clusters contain objects or abstractions that have the most attributes in common, and share the fewest attributes with other objects or abstractions. They appear to be a size that enhances efficiency in storage and transfer of information (Brunswick, 1956; Rosch et al., 1976). For each concept there tends to form a prototype that constitutes the standard, such as particular angles and lengths to form the "typical triangle" or body shape and size to form the "typical bird" (Posner & Keele, 1968, 1970; Rosch, 1975; Kagan, 1984; Medin & Smith, 1984; Gardner, 1985; Johnson, 1987). Given an array of similar variants, a standard near the average is inferred and used as the prototype, even when it is not perceived directly. An important result for work on units of culture is that divisions are created and labeled, and cluster centers identified, even when the stimuli being processed vary continuously.

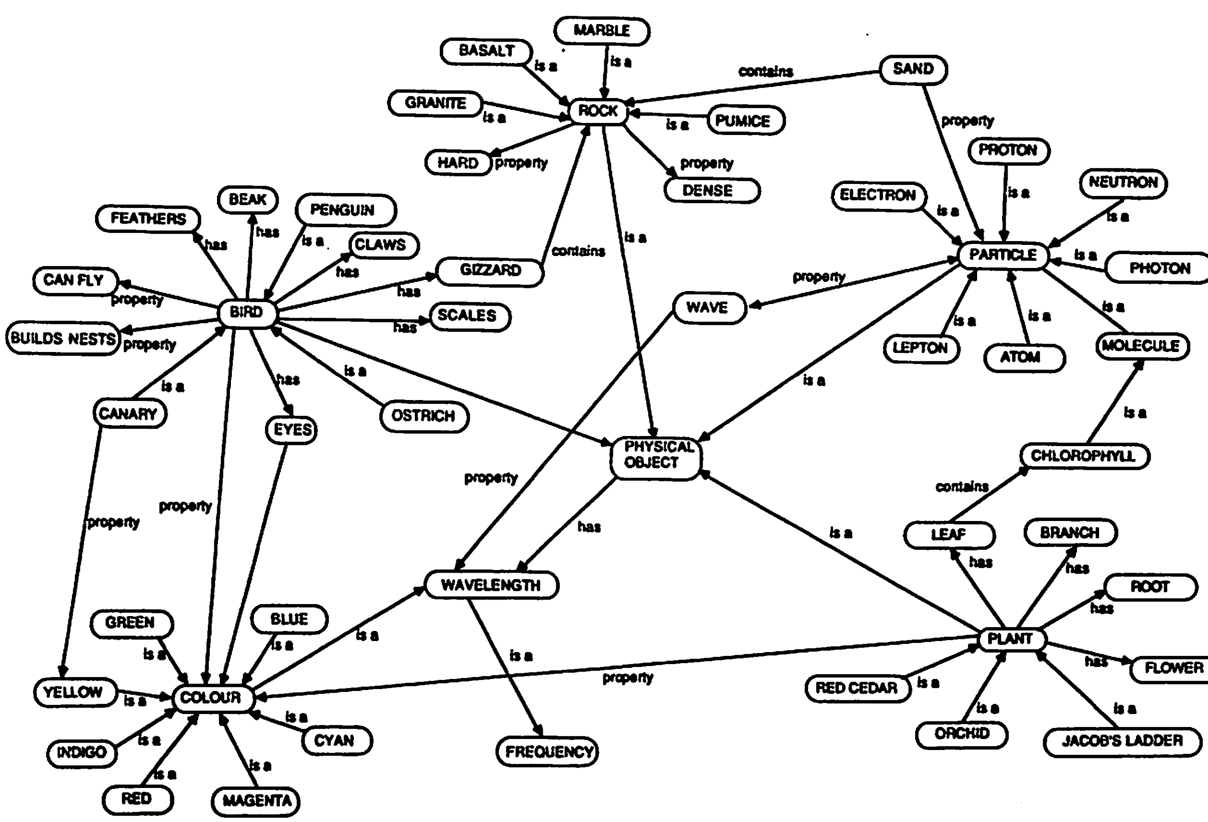

Figure 1. A semantic network, illustrating the complexity and connective irregularity of these cognitive objects.

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Much of the research interest in semantic memory concerns the manner in which its basic units - the denotata of objects or abstractions - are organized into larger-scale knowledge structures and meaningful arrangements of cognitive symbols. One major hypothesis is that the coding is propositional, with the units strung together as statements in a discrete discursive calculus (Pylyshyn, 1984). Operations on the contents of memory are then a "language of thought" analogous to the production of sentences from a lexicon and syntax. A principal alternative hypothesis is that the structure of knowledge is not closely tied to language or predicate calculus. It is coded more flexibly in the form of *semantic networks*, in which each unit is linked to a variety of others (Quillian, 1969; Lindsay & Norman, 1977; Anderson, 1983; Sowa, 1984; see also Brachman & Levesque, 1985). The links bear specific meanings such as "belongs-to", "has-as-a-property", and so on, but beyond that may amalgamate into a multiplicity of configurations.

Progress with clarifying the nature of these configurations has been gradual. As recently as the 1950s the classical association theory of learning and memory dealt almost entirely with simple pairwise connections between items of learned information. Subsequent work on serial learning tasks such as list memorization highlighted inadequacies with strictly pairwise linkage patterns. An extended model used directional associations between successive items to form the knowledge structure. It was thought that once these directional associations were established, seeing or hearing the name of one item on, for example, a word list would trigger recall of the next items on the list (Estes, 1982). The fact that the memory of list structures does not disintegrate completely if one item is omitted during recall led to the idea that at least weak associations exist among non-adjacent items. The fact that backward recall, the elicitation of a stimulus item as a cue, can occur necessitated the incorporation of the idea of inverse associations. However, the greatest single factor in favor of semantic memory structures more complex than chains came from the study of free association, which indicated that the structure of semantic memory is netlike (Figure 1; Quillian, 1969; Collins & Loftus, 1975; Sowa, 1984). In addition to nodes equivalent to concepts, such networks may include nodes pertaining to sensory information and motor control information.

Quillian (1969) suggested that such networks obey a principle of spreading activation: a node representing a given concept is activated when a person sees, hears, reads, or thinks about the concept. Activating one node activates the nodes linked to it, and these in turn activate other nodes. The activation decreases with both time and linkage distance and takes place as long as the activation level remains above some threshold. In this way, the activation eventually spreads through whole segments of the network. Links can vary in strength, i.e., in the ease with which activation spreads along them. Because the number (and kinds) of links to a node may vary widely, as may the activation distance travelled by a link to reach its target, semantic networks look complex and irregular when drawn as connected graphs (Figure 1). Since the information encoded in a semantic network is not innate, a theory of network formation is a theory of culture transmission. An important question therefore is how such networks are to be modeled if one is to treat their relationship to culture and its transmission from generation to generation.

III. Notions of Culture.

In anthropological and evolutionary studies the term "culture" has enjoyed several usages, each broadly different. I should make clear which is intended here. In sociology and social anthropology it often is used to refer to the lifeways of a people, that is, the pattern of behaviors that connect a social group to its environment. In archaeological studies culture generally is cast in terms of the artifacts produced by the lifeways, including the distribution of the worked materials through space and time. Although these definitions are heuristic and productive, they are limited by the fact that they do not cut below the surface of everyday life. Artifacts and behaviors are products of mental activity. Cultural transmission, in turn, is based on the formation of cognitive structures and processes, not the direct handing over of tools or overt behaviors. Ultimately, this ideative transfer creates the individual competencies for action and production, and endows these not only with utility but with significance and meaning (Geertz, 1973, 1984).

Cultural anthropology is the discipline that has led the treatment of culture as a system of shared understandings, interpretations, and symbolic representations, and which has been unrelenting in its critique of sociobiologies aimed only at the surface life of human cultures (Lumsden & Wilson, 1983: 23-50; 1991). In this respect at least, cultural anthropology closely parallels cognitive science in associating culture with the notion of a network of meaningful relations among ideas, including their realization in action. For some research strategies, such as ethnoscience and cognitive anthropology, these networks of meaning and significance reside in individual minds (e.g. Goodenough, 1964, 1969). Mapping the networks (Conklin, 1955; Metzger & Williams,1963 a,b, 1966; Berlin & Kay, 1969) highlights both the idiosyncrasies of individual learning and the central tendencies underlying the lifeways of a society.

An important alternate view takes culture to be a rather more public good, one that expresses a society's central symbolic tendencies and interpersonally distributed acts of polysemy (Geertz, 1973; Rosaldo, 1984; Bruner, 1986). A helpful example of this view, whose repeated enunciations over the years have tended to exhibit the semantic exfoliation and ramified polysemy of its proposed subject, is provided by Geertz's case (1973: 11-12) of the Beethoven quartet. It is surely the case, the argument runs, that the quartet is not the sheet music itself (which is an imprint of the score of the quartet), or what musicians do with the score (which are, at least sometimes, performances of the quartet), or what we hear (which are aesthetic perceptions of the quartet), or some other post-Beethoven part or product of human doing. Instead, the quartet is a tonal structure *sensu stricto*, a meaningful and significant piece of music, known and instantiated in varying degrees through scores, performances, or listenings. But as the *quartet*, there is an existence apart from all of these, a symbolic and semantic independence. And, similarly, for the rest of culture. A luxuriant complexity of possible significances and meanings, constituting the semantic *thickness* of these symbolic forms (Geertz, 1973), makes the individual's relation to culture (or some fragment of it) one of continuing interpretation rather than one-shot determination: culture ties its symbolic constituents into a multiplicity of referents, forming a "stratified hierarchy" (Geertz, 1973: 11). Within any one rite, ceremony, norm or artifact there

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is, in context, always more to encounter just beneath the current layer of meaning. And it is just this remarkable thickness, the critique runs, realized in terms of both coherence of reference and richness of interpretation, that is among the principal notions missing from sociobiological thinking about culture (Lumsden & Wilson, 1983; Lumsden & Wilson, 1991).

We have recognized the validity of such assessments and shown that, with the aid of semantic network techniques, quantitative evolutionary models can begin to accommodate the semantic nature of culture and cultural transmission (Lumsden & Wilson, 1981, 1985, 1991; Lumsden, 1987; Findlay & Lumsden, 1988). To date, however, most sociobiological attention has been directed at the question of coherence as realized through specific netlike assemblages of conceptual nodes (culture units). Much less attention has been paid to interpretive richness. In one sense, of course, this is trivial given a semantic network approach: in a rich interpretation there are many linkage pathways extending from one node to other; there are, in fact, as many as one needs, and they may vary in number and distribution with time, and extend as far through the network as required to set up meaningful relations among the remote associates. This applies both to culture as an embodiment of the semantic networks of individual memories (a la Goodenough) and as the ideational architecture of public, symbolic action (a la Geertz).

By itself, however, this capacity of semantic networks to incorporate indefinitely extended sequences of new nodes and links is not sufficient to meet the requirements on culture set forth by the idea of thickness. As meaningful parts of culture, rites, ceremonies, and other embodied collective activities have a certain semantic compactness rather than infinite extension. This makes them identifiable in the first place, in a manner that allows sufficiently rapid distinction of them from other things going on. Yet, they admit a very large (possibly infinite) number of interpretations (think of *Macbeth, Clockwork Orange,* or *Sea of Love*). It is as if such units of culture pack a very large (possibly infinite) amount of interpretive structure within a reasonably small spreading activation distance around a semantic locus. Inside the perimeter defined by that distance, network structure is such that there is almost no end to discoverable meaning and interpretations. These units are thick.

What sort of representations, if any, can encode thickness? While the formidable complexity of culture warns against a simple, all-encompassing paradigm, I wish to suggest that the mathematical objects called *fractals* may provide a partial answer. The property of fractals that recommends them here is their hierarchical richness of structure. They are, in the terminology introduced just above, thick objects: An infinity of levels of connective organization, nested one within the other, is locked within each one.

IV. Thick Culture: A Semantic Fractal Model.

Fractals, their mathematical properties, and their extensive range of applications have been the subjects of detailed reviews. The classic sources are Mandelbrot (1977, 1983), but see also Gardner (1978), Peterson (1984), Coniglio (1986), and Peitgen & Richter (1986). The classification of fractal structures has introduced a number of challenging and counterintuitive concepts, such as that of a fractional number of dimensions occupied by a geometric object. The semantic fractal model can, however, be described without a lot of mathematical derivation.

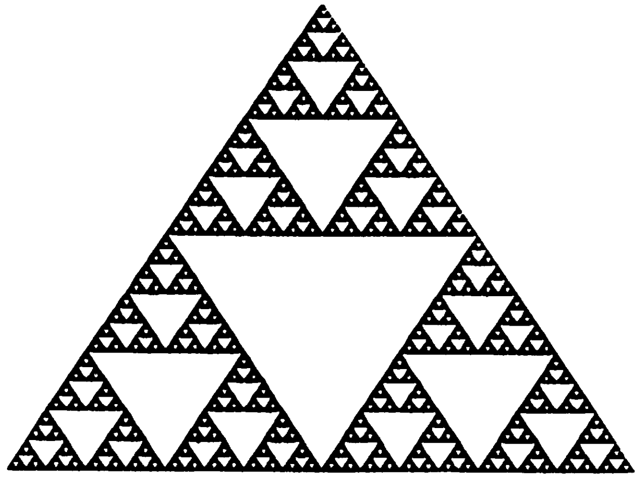

Figure 2. A regular fractal pattern based on the Sierpinski gasket.

Figure 2 shows a fractal pattern of the kind pertinent here. It possesses novel properties. The pattern, which is one of the prototypical regular fractal forms (too regular by far to serve as more than an expedient illustration of the general notion of thickness) is called a Sierpinski gasket (Mandelbrot, 1977, 1983). The gasket is regular in the sense that on each level of construction one applies the same rules for dividing up the pre-existing pattern. In examining the Figure we see that, relative to any convenient scale L of length, the mass M of ink used to fill the gasket*s opaque regions (assuming uniform density of ink spread) scales as $M(2L) = 3M(L) = 2^{d_f}M(L)$, where $d_f = \ln 3/\ln 2 = \log_2 3$ is the fractal dimension of the gasket. Fractal patterns generally obey scaling laws of the form $M(\lambda L) = \lambda^{d_f}M(L)$ with $d_f < d$, the Euclidean dimension of the system. The Euclidean dimension for the system illustrated in Figure 2 is $d = 2$.

Mandelbrot (1983: 135) points out that, in standard geometry, lattices are built up as regular network forms using arrays of parallel lines that bound the edges of unit cells. A fractal lattice is defined in a similar manner, as a regular fractal in which any two points can be linked by at least two paths that do not otherwise overlap. If the fractal is not regular (possessing stochastic properties of connectivity, for example) the structure is termed a *fractal net*. Fractal lattices and nets are themselves quite different from the lattices of standard geometric conception. Standard lattices are invariant under translations but not scalings. In fractal lattices the invariances hold with respect to scalings, not translations. When a standard spatial lattice can be interpolated (say by adding parallel lines midway between those already present), the interpolation is the whole space containing the original graph. Such a limit does not itself form a lattice. In contrast, the analogous limit of an approximate fractal lattice is a fractal lattice.

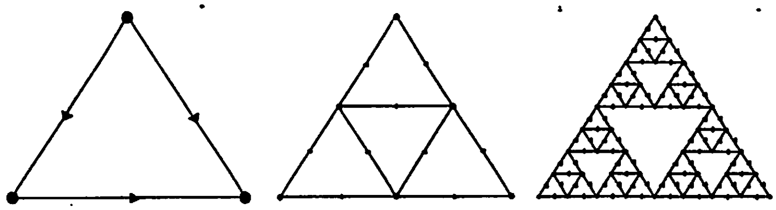

Figure 3. Iterative construction of a semantic fractal. For clarity of depiction the regular fractal pattern of the Sierpinski gasket has been used as the associated backbone along which referential links join semantic nodes within the network.

There is at least one way to make culture units like memes and culturgens thick: arrange them so that they form a fractal net. The process is shown in Figure 3 for a semantic network modeled for simplicity on the connectivity structure of the Sierpinski gasket. Connectivities are two or four links per semantic node on vertex, edge, and interior positions in the network, respectively. The longer the depicted length of a link joining two nodes, the weaker the implied strength of association between the two concept nodes. Now consider a cognitive process, working on the contents of this net, that either generates or interprets levels of meaning. At the first level (Figure 3a.) just three nodes are connected by pairwise linkages. Nodes connected with higher spreading activation strengths (equivalent to shorter links) are not distinguished. They are treated together as a single cognitive chunk, represented by one of the three vertices in Figure 3a. At the next level (Figure 3b.), the criteria for node recognition are changed. The process of network interpretation now recognizes nodes with linkage strengths up to twice the original, and the original configuration (Figure 3a.) unpacks into a new configuration (Figure 3b.) containing 6 nodes, 9 primary (direct node-to-node) links, and a vastly increased number of semantic pathways from one node to another. Repetition of this unpacking step, in which concept nodes closer and closer together in terms of spreading activation distance are distinguished, builds up a net in which the latticework is the skeleton of a Sierpinski gasket (Figure 3c.). Although the illustration has, for simplicity and clarity of depiction, been put in terms of a regular fractal based on triangular forms, identical remarks apply to fractal nets in general, where the structures may be much less regular and the mean numbers of links per node higher. Semantic networks with fractal properties have several attributes of the kind desired in thick structures. First, ideational content is directly encoded within the network. Second, the network ramifies within a circumscribed region of spreading activation. Yet within this region many (infinitely many, in principle) levels of interpretation can be accessed or stored. Moreover, on each deeper level (e.g. Figure 3c.) increasingly many activation pathways, each corresponding to different chains of meaning and signification, connect any two nodes. Such networks can be generated by relatively simple procedures that repeatedly carry out similar operations. This demonstrates that the transmission (and experience) of intensively rich cultural forms need not necessarily conflict with biological requirements (Lumsden & Wilson, 1981) for manageably simple programs of mental development.

There is clearly no limit to the thickness, in the sense introduced here, that can be attained with fractal semantic networks. This natural polysemic richness of individual semantic fractals is augmented when connections are added that run net-to-net. Interpretive activity then involves the channeling of thought along the linkage paths within and among thick nets. Thus semantic links that ramify extensively over large distances of spreading activation (corresponding, for example, to meaningful relations among the rituals used by a particular age class) are compatible with connections that embody multiple levels of meaning within circumscribed regions of semantic space (corresponding, for example, to the individual understanding and knowledge of a particular *rite de passage*). Both can be accommodated within the type of system discussed here.

Culture instantiated as a semantic network is not expected to be fractally complete in the sense of possessing a true infinitude of interpretive levels. The finite time available for socialization, together with limits on the resources available for neurological and cognitive development, will restrict the amount of interpretive elaboration an organism can produce. However, this appears to be a common characteristic of natural fractal structure: fractal properties hold more or less rigorously on specific scales of structural patterning (scales determined by e.g. spreading activation distance). Above or below these limits significant deviations occur. But within the range addressed by the scales the fractal pattern provides a concise, powerful model of the basic structural principles.

Protocol analysis, think-aloud procedures, and ethnographic reporting are examples of technique that provide maps of semantic networks, including specification of node-link connectivity and semantic distance among nodes (Newell & Simon, 1972; Geertz, 1973; Foulkes, 1978; Ericsson & Simon, 1984). Given such maps, the regression between, for example, a unit of spreading activation distance and the number of nodes or meaning-paths reported in a network will test for the presence of fractal structure (for examples of regression methods and fractal characterization see Mandelbrot, 1977, 1983). Thus, there seem to be promising ways of judging applications of semantic fractals to cultural transmission and thick description. Although empirical assessment is largely a task for the future, recent studies have provided data on three domains of undisputed relevance to culture: language, texts (stories), and musical performance.

To take language and music first: When the power spectra of the fluctuating loudness and pitch levels in ordinary speech or in song or instrumental performance are measured and then regressed against fluctuation frequency f on double-logarithmic plots, the power intensity levels are found to be well represented by a l/f dependence of the power spectrum on f (Voss & Clarke, 1975). This dependence holds across culture samples consisting of single pieces of music (e.g. recordings of Bach*s First Brandenberg Concerto), sets of related musical pieces (e.g. Scott Joplin's Piano Rags), as well as multi-hour excerpts from radio stations broadcasting classical music, rock music, or news and talk.

Time series data with l/f properties are particularly interesting because, while correlations within them (measuring, for example, the degree of association between two pitch events n time steps apart) are only moderate in magnitude, they extend over time intervals of all sizes. They are not restricted to short times only. In terms of the nomenclature I have used above, one can characterize these series as having order on a multiplicity of interrelated levels. The order, however, is not rigid or deterministic: It possesses an intrinsic degree of unexpectedness or "novelty." The graphs of the dependent cultural variable (for speech and music, loudness and pitch) against time are fractal curves (Mandelbrot, 1977; Gardner, 1978).

In order to move from behavior to ideational representations, let us consider those frequent instances in which the performance of a text or piece has been rehearsed sufficiently (as in a theater play or musical recital) to be encoded as an explicit procedural script. The representation laid down in memory then comprises a chain of nodes. Each node encodes a single speech unit or pitch event of the kind measured by Voss & Clarke. The intervening links connect the nodes meaningfully in terms of their separation in loudness, acoustic frequency, etc. (Note that a cognitive procedure that only recognizes nodes separated by a specified number of links gives access to the multiple levels of order underlying the final behavior.) Ideational representations like this are semantic fractals in the sense introduced here; they are perhaps the simplest semantic forms with fractal content, since the nodes are connected only pairwise. In a semantic fractal that is a network, chains of nodes will interconnect with others, creating multiple pathways from node to node.

Just such a network pattern is produced by the cyclic pattern of interpretive activity that underlies our everyday understanding of stories (narratives) as found in folklore, mythology, and literature. Having assessed the strategies people use to recount and remember stories, Trabasso and van den Broek propose that when we listen to or read a story, we apply a recursive procedure that partitions the story into a hierarchy of narrative levels (Trabasso & van den Broek, 1985; Trabasso, van den Broek, & Suh, 1989; see also Stein & Glenn, 1979; Bower & Morrow, 1990). On each level, the parts of the story follow an orderly progression: scene setting, character specification, problem specification, character action choice, consequences and character reaction, and so on. On subsequent levels, story segments previously treated *en bloc* are themselves subjected to the recursive procedure and unpacked into compound segments, each organized on lines similar to the larger segments. Lines of causation cross-link multiple sub-plots that develop in parallel. While much further empirical work is needed, these early data suggest that a fractal architecture of the kind discussed here may be a near-universal property of narrative and textual systems.

V. Discussion.

Semantic fractals provide an initial model of culture units that are thick - i.e., culturgens that embody many levels of meaning. There are, of course, important limitations to the initial conception that should be stressed. These follow from the property of self-similarity, a generic property of fractals. On each structural level, the organization of the fractal (and thus, from the interpretive point of view, the local pattern of inter-node connection) is much the same as that on every other. This similarity may appear in the form of a highly regular structural ordering, as in the Sierpinski gasket, or in the repeated appearance of similar statistical properties of connectivity and layout. It is the repetition, of course, that helps make fractals amenable to mathematical study, and while data such as that reported by Voss & Clarke and Trabasso & van den Broek indicate self-similarity in certain aspects of culture, a less constrained formulation is desirable. The expressive power of a mathematical treatment suited to culture*s full interpretive depth is likely to exceed the boundaries set by self-similar objects. The need for rigorous treatments of thick, non-self-similar objects may help to stimulate new mathematical interest in culture and sociobiological theory. This would be a most promising complement to empirical work and modeling via the current formulations.Semantic fractals are part of a theory suited to framing principles of design for thick symbolic systems, possibly including culture. Thus, despite the limitations imposed by the standard mathematical assumptions, semantic fractals provide a step in extending the concerns of modern human sociobiology beyond heritable units of culture.

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