

Evolutionary Process, Epistemological process, and Emergent Hierarchies in Perception

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RUNNING HEAD: Emergent Hierarchies in Perception

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Abstract: Bateson's difference-based epistemology can be simulated by a Boolean network model. Bateson proposed that taking differences in differences would produce emergent hierarchies of knowledge. Simulating this proposal by taking differences in differences in a Boolean model generates hierarchical categories of perceptual stimuli. The crucial result is that these model-generated categories correspond to human perceptual categorical judgments. This convergence grounds model-defined emergence both to a broad epistemological framework and to human experience. The types of levels defined in the model are used as a basis for making distinctions among types of levels in evolutionary process and epistemological process.

KEYWORDS: perceptual categories; epistemology; process levels; logical levels; Bateson; knowledge; Boolean networks; emergence.

A dynamic system is characterized by a flow of changes over time. In a Boolean system these changes are binary, between two values, 0 and 1; they represent what we are calling here a flow of differences. Malloy, Jensen, and Song (2005), have mapped Gregory Bateson's difference-based epistemology onto an NK Boolean system; particularly relevant here, they proposed a way to represent attractor cycles in a Boolean dynamic system as visual patterns. Bateson, using the map/territory metaphor to distinguish between knowledge and what is known, proposed that what gets onto maps are differences and these differences and their transforms are "elementary ideas" (2000, p. 463). Moreover, Bateson goes on to note that "these differences are themselves to be differentiated" (2000, p. 463). Bateson takes the differentiation of differences even further, making it an important foundation stone of epistemology by proposing that the process of discovering relationships in the patterns of differences in differences leads to the emergence of a hierarchy of differences with important consequences for mind (see Bateson, 2000, pp. 454-471; 2002, p. 106). Bateson (2000), pp. 463, 464) proposes a mental experiment for the reader:

Let me invite you to a psychological experience, if only to demonstrate the frailty of the human computer. First note that differences in texture are different (a) from differences in color. Now note that differences in size are different (b) from differences in shape. Similarly ratios are different (c) from subtractive differences.

Now let me invite you... to define the differences between "different (a)," "different (b)," and "different (c)" in the above paragraph.

Malloy, Jensen and Song simulated the process of differentiating differences by building an analytic tool, TAO that uses the XOR operator to find the first derivatives of the flow of differences in attractor cycles. To examine Bateson's proposal, above, we extend that logic to higher order derivatives by applying the TAO recursively to the output of TAO. Thus we recursively take differences in differences in the states Boolean system to examine whether a hierarchy of levels emerges. In this study three realms of description converge on the concept of emergent levels in knowledge: Batesonian epistemology, a Boolean model, and human perceptual experience.

On a broader conceptual scale, Kauffman used NK Boolean systems as one leverage point for arguing that the self-organization of complex systems is a co-principle, along with natural selection, in evolutionary process. Bateson (2002, p. 139) argued that learning processes and evolutionary process are deeply related. But what kind of relationship do they have? Indeed he proposed, essentially, an identity: "epistemology is an indivisible, integrated meta-science whose subject matter is the world of evolution, embryology, and genetics—the science of the mind in the widest sense of the word" (2002, pp. 81, 82). Here we take a related but different approach; we assume that by evolution and embryology people mean theories of evolution and embryology, since we have only maps and never the territory. Thus we want to explore the relationship between how scientists conceptualize evolution and embryology and how they conceptualize epistemology. In this paper we will use the term epistemology to refer to conceptualizations of that subset of biological processes by which sentient beings come to know what they know. We want to frame the discussions in this paper as a meta-map in which we explore relation-

ships between maps of the biological processes of evolution and morphogenesis (embryology) and maps of that subset of biological processes by which sentient beings generate maps. The nature of that relationship is tied to the concept of levels. Bateson, given the intellectual discourse of his time, defined levels in terms of Russellian logical types and used levels as a central tool throughout his epistemology (2000, p. 279ff). The idea of levels is also central to dynamic systems approaches to biological process. Theorists such as Turing (1952) for embryonic morphogenesis and Kauffman (1993) for evolution assume that biological form is a process that emerges from the coupled interaction of lower level generating processes. The idea of levels is a complex topic spawning many confusions (Bostic St Clair & Grinder, 2001, pp. 291-308). We will use the results of an NK Boolean simulation experiment to clarify the idea of levels in both discussions of evolutionary process and in discussions of epistemological process, particularly how taxonomies are learned. To consider this less abstractly, what are the relationships between the evolutionary-developmental processes by which a particular living being, say a raven, comes into being and the epistemological processes by which that raven is placed by humans in a category called raven and the category raven is placed in corvidae and the corvidae are placed in the class aves?

DIFFERENCES IN DIFFERENCES

Higher order derivatives

Clearly, differences are the basis of a Boolean system. An NK Boolean system consists of N nodes each taking inputs from K nodes. At any moment, T , the state of the N nodes is given in a state vector T (e.g., $\mathbf{S}_T = \{0110\dots\}$). As the system changes dynamically from T to $T+1$ to $T+2$, ..., the state vectors, $\mathbf{S}_T, \mathbf{S}_{T+1}, \mathbf{S}_{T+2}\dots$ describe a flow of differences. Malloy, Jensen and Song (2005) described TAO-1, a discrete analogue of the first derivative, which is an analytic tool based on the XOR operator and is used to find differences among differences. In logical terms, the XOR operator returns a 1 if either p is true or q is true (but not if both are true); it returns a 0 if both p and q are true or if both p and q are false. Another way to say this is that XOR detects difference; it returns a 1 if p and q are different and a 0 if they are the same. Suppose, in a 4-node system (see 4-Node Standard in Malloy, Jensen & Song, 2005), we have two state vectors (each showing the state of each of the four nodes in order) $\mathbf{S}_{T=1} = \{1001\}$ and $\mathbf{S}_{T=2} = \{1101\}$. Using XOR to compare each respective position of these two vectors across time, TAO-1 returns a vector of differences in differences (across time) $\mathbf{TAO-1} = \{0100\}$ because from $T=1$ to $T=2$ only the state of the second node is different.

In this paper we explore the utility of extending this logic to TAO-2, TAO-3, and so on (this is analogous to taking higher order derivatives). The point of this extension is to model Bateson's line of thought that there is a hierarchy of differences in differences in knowledge. TAO-2 is generated by recursively applying the XOR operator to the output vectors of TAO-1. This is the first step in specifying, in terms of a Boolean model, the hierarchy of differences suggested by Bateson. These higher-order derivatives will be described here as general analytic tools for exploring patterns in the flow of changes in N K Boolean systems. These calculations are performed by software called E42.

Table 1			
Recursive application of TAO to Basin 1			
Process	Level-1 Abstraction	Level-2 Abstraction	Level-3 Abstraction
Flow of Differences	Differences in {Differences}	Differences in {Differences in Differences}	Differences in {Differences in Differences }
Original State Vector	TAO-1	TAO-2	TAO-3
T=1	{1001}		
T=2	{1101}	2 vs 1 {0100}	
T=3	{1111}	3 vs 2 {0010}	(3 vs 2) vs (2 vs 1) {0110}
T=4	{1011}	4 vs 3 {0100}	(4 vs 3) vs (3 vs 2) vs [(3 vs 2) vs (2 vs 1)] {0000}
		1 vs 4 {0010}	[(1 vs 4) vs (4 vs 3)] vs [(3 vs 2) vs (2 vs 1)] {0000}
			(2 vs 1) vs (1 vs 4) vs [(1 vs 4) vs (4 vs 3)] {0110}
			[(3 vs 2) vs (2 vs 1)] vs [(2 vs 1) vs (1 vs 4)] {0000}

Examine the first column of Table 1 (based on 4-Node Standard, Malloy, Jensen & Song, 2005) which shows the four vectors of an attractor cycle of one basin. (While the term “basin” technically includes both an attractor cycle and the transients (tributaries) that lead into the cycles, we will use attractor cycle and basin interchangeably because the software automatically labels attractor cycles with the name of the basin in which the attractor resides.) Note that these vectors occur one after another deterministically in the dynamics of a small, four-node system and that, since they represent an attractor cycle, that the top state vector {1001} in Table 1 will occur again immediately after the last (bottom) state vector {1011}. To fully code the four vectors of that attractor cycle we would have a matrix whose rows would be the four vectors.

The second column (TAO-1) summarizes the comparisons made by TAO-1 (i.e., by the XOR function) between successive state vectors in column 1. At this point the reader should be able to confirm those vectors. Column 2 lists the TAO-1 vectors: [{0100}, {0010}, {0100}, {0010}] which together could be expressed more properly as a TAO-1 matrix. Notice that, whereas in column 1 there are four distinct patterns of differences exhibited in the state vectors of basin 1, the pattern of differences in the output of TAO-1 (second column) is less rich, exhibiting only two distinct vectors, {0100} or {0010}, among the four vectors listed. In a similar way to the above process,

TAO-2 (column three) is the application of the XOR operator to the output of TAO-1. The XOR operator generates the vectors shown in the third column (TAO-2) by comparing successive vectors listed in the second column and outputting a 1 for each node that is different and a 0 for each node that is the same.

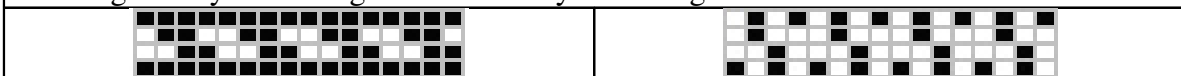
Notice that in the TAO-2 column the pattern of differences is even less rich than it was in the TAO-1 column; in fact there is only one pattern of differences, {0110}, among the four TAO-2 output vectors. That result should be directly confirmable for the reader. Finally, in the fourth column TAO-3 examines the differences among the (TAO-2) differences. Since all the vectors are identical in the TAO-3 column there are no differences in TAO-2 outputs. Therefore all TAO-3 vectors = 0. At any stage of recursive application, the total TAO ensemble of vectors is, of course, a TAO matrix. Table 1 demonstrates E42's functional operations onto which we are mapping Bateson's verbal descriptions of taking differences in differences. How this leads to a hierarchy of differences is implicit in Table 1 and will be developed below.

Methodologically, it should be noted that Malloy, Jensen and Song (2005) also describe how E42 is able to detect when it is in an attractor cycle, and when it does so to place matrix specifying that attractor in an archive. It then perturbs itself by pseudo-randomly changing the state of fifty percent of its nodes and monitors its own flow until (if) it detects another attractor cycle. E42 continue the previous three steps until it reaches a user-specified number of self-perturbations. Thus it constructs an archive of attractor cycles, often with hundreds or thousands of attractor matrices. As we will detail below, it then can then take whatever derivative, say TAO-2, and sort all attractors that have the same TAO-2 matrix into a single category. What we find is that at some TAO level, say TAO-2, there will many categories of attractors; within each category the attractors all have identical derivatives; between categories the derivatives are different. Thus E42 can generate sets of categories at TAO-1, TAO-2, TAO-3, etc. After summarizing how attractor cycles are visualized, we will return to examine how the categories at different TAO levels form a hierarchy.

Visualizing Basins

Rotate the state vectors in Table 1 to be column vectors; then put these column vectors on a grid with 0's represented as white cells and 1's represented as black cells. Figure 1a shows the original state vectors of attractor cycle detailed in Table 1. The system has 4 nodes (ordinate) and sixteen iterations are shown (abscissa). Black cells represent a 1 in a columnar state vector while white cells represent a 0. Since the length of the attractor cycle is four iterations, Figure 1 shows four passes through each cycle. Notice the visual form generated as the behavior of the system unfolds over time. Different attractor cycles generate different visual patterns; figure 1b shows the form generated by a second attractor cycle in 4-Node Standard.

Figure 1. Sixteen iterations (abscissa) of an N=4 node (ordinate) NK Boolean system showing four cycles through an attractor cycle of length = 4 iterations.



MAPPING PERCEPTUAL EXPERIENCE TO DIFFERENCE IN DIFFERENCES

Dynamic Constancy

Let us return to the patterns of differences in differences apparent in Table 1 for the recursive application of TAO to the output of TAO. 4-Node Standard gives us a sense that the variability in the attractor pattern becomes simpler as TAO is recursively applied. But 4-Node Standard (in Table 1) is too simple for another crucial insight which is that different attractor patterns can have identical TAO matrices. Since TAO matrices describe the changes in the flow of change, identical TAO matrices means that there are constancies in the dynamics of the flow. How shall we relate these kinds of dynamic constancies, which are a formal characteristic of the model, to Bateson's proposal that an essential characteristic of knowing is a hierarchy of differences in differences? We require a more complex system than 4-Node Standard to explore that mapping fully.

Figure 2 is based on another NK Boolean system with $N=36$ nodes and shows nine attractor cycles (basins) of length 4 iterations from that system represented as visual patterns. The top row (TAO-4) of Figure 2 shows the 36 nodes on the vertical axis and sixteen iterations (for each attractor) on the horizontal axis; thus each basin pattern of $L=4$ is shown repeating itself 4 times. In Figure 2 these nine attractor patterns are placed into categories in four different ways (bottom row through top row). The rows of Figure 2 are labeled TAO-1, at the bottom, to TAO-4, at the top. It is important to note that Figure 2 shows only representations of attractor cycles; it does not show representations of TAO vectors. While TAO vectors are never themselves represented they are the basis of the sorting of attractor patterns in each of the four rows. One final note on the presentation in Figure 2. Only the top row (TAO-4) of Figure 2 shows the visual patterns for all 36 nodes. The other three rows (TAO's 3, 2, and 1) are reduced; they cut off the top nodes and show only the bottom 21 nodes. The reason is to reduce the size of the figure for printing and to focus on the perceptually interesting parts of the patterns. The full patterns are available to the reader in the top row and it is these nine full patterns that are in fact being sorted in the lower rows. The reduced set of nodes makes perceptual processing simpler. The top 15 nodes (shown in the TAO-4 row of Figure 2) are necessary to distinguish basins 89, 74, 95 from each other and to distinguish basins 76 and 60 from each other.

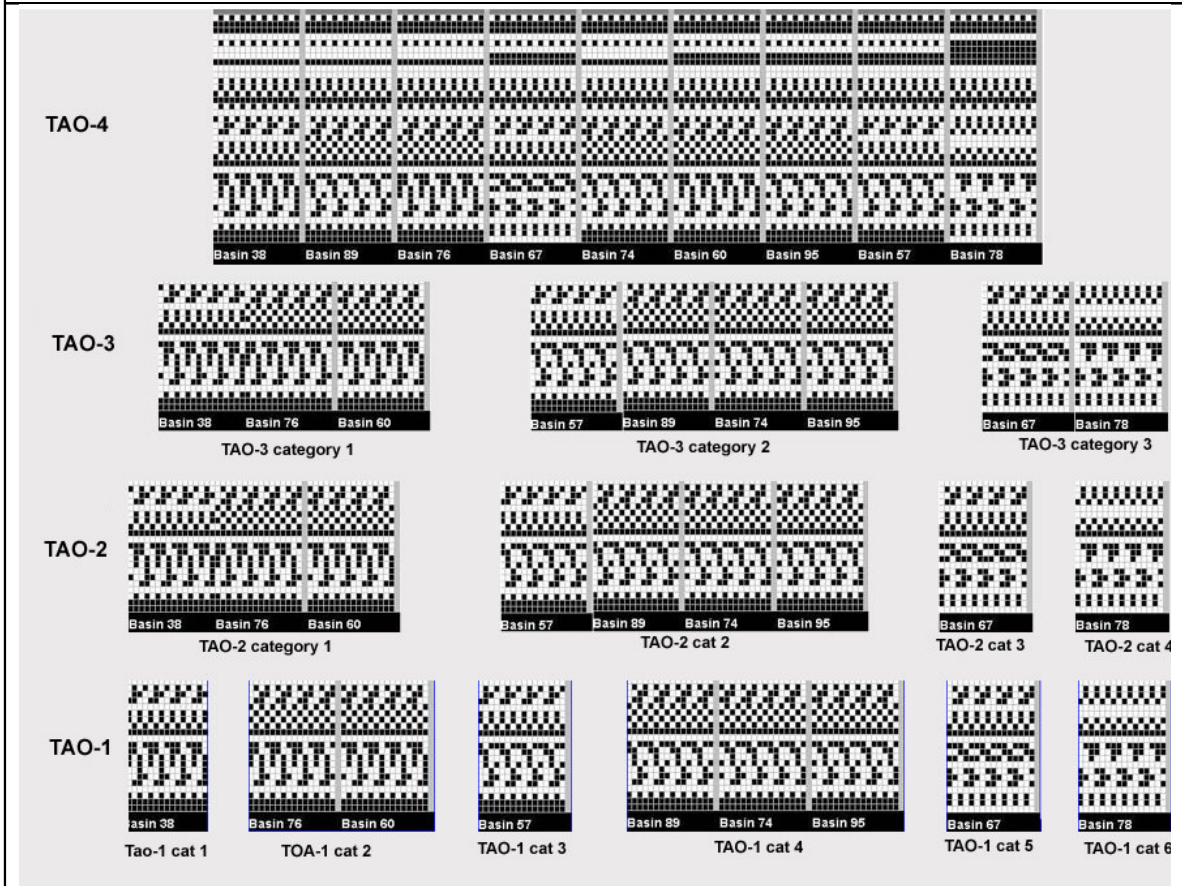
In the bottom row of Figure 2 the nine attractor patterns are sorted by TAO-1 matrix identity. For example, the three basins (basins 89, 74, and 95) in TAO-1 category 4 all have identical TAO-1 matrices. Similarly, the two attractor patterns in TAO-1 category 2 (basins 76 and 60) share identical TAO-1 matrices. The rest of the attractors shown in the TAO-1 row are singletons; they are the only instance of the category defined by their TAO-1 matrix. For TAO-1 category 1 (basin 38) none of the nine basin patterns share the same TAO-1 matrix. Another way to say this is that the changes in differences over time are constant for all basin patterns in the same category. The idea is that all attractor cycle patterns that are in the same category share a constant pattern in their flow of change at the level of TAO-1

Let us examine higher order dynamic constancies. Examine the second row, TAO-2, in Figure 2. For the second (TAO-2) the patterns are sorted into four categories, where all patterns in the same TAO-2 category have identical TAO-2 matrices. This means that the three basin patterns in TAO-2 category 1 (basins 38, 76 and 60) all have identical TAO-2 matrices. Thus basin 38 is now in the same category at the TAO-2 level

as are basins 76 and 60, whereas it was in a distinct category at the TAO-1 level. Basin 38 shares second order dynamic constancies with 76 and 60. To emphasize, at each level of this hierarchy the same nine basin patterns are shown, just sorted differently. TAO matrices are nowhere represented; they are the criteria by which the basin patterns are sorted. Based on identity of TAO-2 matrices, we can see in the TAO-2 row of Figure 2 that the nine patterns can be sorted into four categories.

In contrast to the four categories generated by TAO-2 matrix identity, TAO-3 matrix identity sorts the nine patterns into three categories (second row from top of Figure 2). For example, TAO-3 category 3 is defined by attractor cycles that all have identical TAO-3 matrices (basins 67 and 78). Notice that perceptually basins 67 and 78 are somewhat unlike each other; the characteristic by which they are placed together is a higher level of abstraction. We will examine this in more detail below, but for now it is metaphorically akin to placing both geese and blue jays in class aves. They do not greatly resemble each other but have abstract characteristics in common. The TAO-4 vector (fourth derivative) is identical for all nine patterns; therefore they are placed in the same category by TAO-4 (see top row of Figure 2).

Figure 2. Nine attractor cycle patterns sorted into a hierarchy of categories by the recursive application of the TAO operator which takes differences in differences. The TAO-4 rows show all 36 nodes while the other rows show a reduced set of nodes.

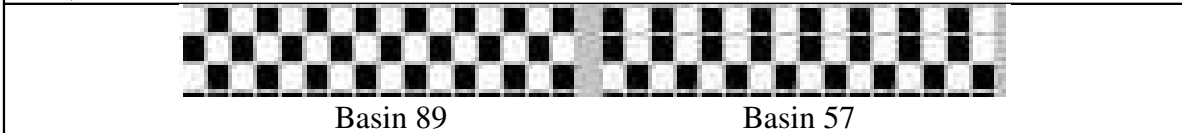


You are asked to look at the hierarchy of categories and check them against your own experience. Note that the same nine patterns are repeated at each level but are categorized differently. Are these perceptually plausible ways of sorting the patterns? If so, at what level? Note that in biological taxonomy a particular person may or may not sort life forms spontaneously as the taxonomy does; the question is after a person knows the taxonomy does the sorting make sense? Many people categorize the forms in categories with the same result as either the TAO-1 or the TAO-2 operations. Even if you didn't categorize them in exactly the same way as E42 did, do the TAO categories appear perceptually plausible? If you did categorize the visual forms differently (from either TAO-1 or TAO-2 or TAO-3) what are the differences? Human visual perceptual experience is taken as the reference point for evaluating the epistemological utility of the model-generated hierarchy in Figures 2. Readers are left to categorize the visual forms and compare them to the model-generated categories. Leaving readers to their own experience (as opposed, say, to a statistical analysis of performance measures of groups of humans) is deeply motivated by epistemological frames (see Bostic St Clair & Grinder, 2001, p. 71; Malloy, Bostic St Clair, & Grinder, 2005, pp. 105, 113) that place human judgment as the reference point for fields where the patterning being studied is that of humans.

Boundary Conditions.

The emergence of the kind of perceptual hierarchy seen here is subject to two broad boundary conditions. The first is that such hierarchies exist only for attractor cycle lengths that are powers of two ($L=2, 4, 8, 16, \dots$). If the attractor cycle length (L) is not a power of 2, other, interesting results happen, but not hierarchies. The nature of the phenomena that emerge when L is not equal to a power of two is beyond the scope of this paper. We have no formal description of this boundary condition but suspect it has to do with the fact that 2 is the basis for Boolean systems. The second boundary condition derives from the fact that perceptual similarity based on TAO vector identity is an “all things being equal” principle. It is possible to produce examples in which the Gestalt laws of proximity and closure as well as figure-ground relations overwhelm TAO identity (dynamic constancy) in human perception. The reader should be able to derive that the TAO-1 matrix for that subset of three nodes shown in Figure 3 is identical for both basin 89 and basin 57: TAO-1 will yield a series of **1** vectors since every node changes on every iteration in both basins. Therefore, for these particular three nodes, the TAO-1's are identical but, due to Gestalt organization, these details of the visual patterns do not look perceptually similar as predicted by dynamic constancy; rather they look very different to humans. Checkerboards and columns are perceptually distinct visual organizations.

Figure 3. Example of a boundary condition showing details from basin patterns 89 and 57. The same three nodes (vertical axis) are shown as they iterate across time (horizontal axis) for both 89 and 57.



DISTINCTIONS AMONG TYPES OF LEVELS

At the highest conceptual level, we are using the leverage of the formal relations within an NK Boolean system to examine relations among how evolutionary-

developmental processes are construed and how epistemological processes are construed. Within that broad project, there are two foci of interest in our discussion. One is the perceptual hierarchies just reviewed which act as the leverage point for the second focus, which is exploring the nature of various usages of the term “levels,” particularly as that term applies similarly or differently to emergence in biological evolution-morphogenesis versus emergence in epistemology. While we want to make distinctions between epistemology and evolution, we consider epistemology a biological evolutionary process that is a crucial part of evolution. In our meta-map, epistemology is one process integrated into other evolutionary processes: If an insect cannot sense the river of pollen drifting on the wind or if it cannot see the color of the flower, then it cannot find its way to the flower which consequently is not pollinated; and so the whole co-evolutionary trajectory of flowers and insects collapses. Stated more positively, in our meta-map the insect's ability to sense (know) the pollen gradient and so arrive at flowers supports further evolution of both species. It is difficult to conceive of the co-evolution of sentient beings with the web of life around them without their sentience.

Our entry point for the discussion of the broad questions posed here is the result described above: Bateson proposed that taking differences in differences produces a hierarchy of differences in what he called mental process and in what we are here calling epistemological process. We have operationalized that proposal by taking discrete derivatives (TAO) of the flow of differences in a Boolean system; this produced a hierarchy of categorical levels in model-generated visual patterns based on TAO-1, TAO-2, and TAO-3; this hierarchy is perceptually comprehensible to humans.

But what is a level? And what are the operations by which levels are generated? One useful characteristic of rigorous models (set theory, formal logic, NK Boolean systems) is that they are a well defined basis for examining such questions.

Ordering Principles generate Levels

To put in perspective the results which show perceptual categories arranged in levels, let us examine the idea of levels more broadly. The sixth characteristic Bateson lists for what he calls mental process is a hierarchy of logical types (2002, pp. 83, 106). The theory of logical types has been subsumed by modern set theory based on the Zermelo-Fraenkl axioms, and logical types are sometimes now called logical levels. Any hierarchy of levels is generated by some ordering principle (see, for example, Bostic St Clair & Grinder, 2001, pp. 291ff). Consider a hierarchy of sets generated by the ordering principle of logical inclusion: Birds include corvidae and corvidae include ravens. Logical inclusion hierarchies are characterized by constriction (there are less corvidae than birds and less ravens than corvidae) and heritability (corvidae inherit characteristics of birds and ravens inherit the characteristics of corvidae). But how things are included in sets and what sorts of sets are at the same level depend on the sorting processes specified by the inclusion rule: Ships would be a set at the same level as planes if we are speaking of means of transportation whereas ships would be at the same level as wood debris if we are speaking of things that float in water. As a point of contrast, there are other ordering principles than logical inclusion for generating hierarchies of levels. For example, part/whole categories work differently than logical inclusion ordering principles (Bostic St Clair & Grinder, 2001, p. 332); a ship consists of a hull, decks, etc. The decks consist of bolts, planks and other parts. Clearly bolts do not inherit characteristics of ships; ships

float in water; bolts do not. Moreover constriction does not apply: There are more bolts than ships.

In principle, any discussion of levels is formally empty until the ordering principles which generate the levels are specified.

Process Levels

The flow of process can be construed to be ordered in levels; formal examples include, from computing, subroutines embedded in routines (Fortran), functions embedded within functions (Pascal and C), methods embedded within methods (Java) and, from psychological theory, the TOTE structure proposed by Miller, Galanter, and Pribram (1960). In these formal examples process is organized into levels by operations defined in well-formed languages; process flows downward and upward in the levels according to these operational rules, and woe to the programmer who muddles the ordering rules defining the levels of process. In dynamic systems theory a significant subset of models couple two (or more) nonlinear equations, the output of one process acting as the input of others and visa versa. Examples include the coupled diffusion reaction equations (Turing, 1952) underlying the emergence of self-organized form, the constrained generating procedures of Holland (1998), and the NK Boolean networks (Kauffman, 1993) used to generate hierarchical levels in this paper. Common to all these models is the emergence of a higher level of process as a result of the interactions of the lower order processes. We make a critical assumption: *Emergent levels are of their nature process levels*. In such a frame the schema for defining emergence is that coupled lower order processes generate a higher level of process which, typically, has characteristics that are beyond the characteristics of the generating processes.

By our own principle, above, if we construe emergent phenomena as levels of process, then those levels are empty until we specify the processes by which the levels are generated and ordered. In the world of models such as Turing's coupled diffusion reactions and Holland's constrained generating procedures we propose that the ordering principles are the mathematical derivations that demonstrate the emergence of higher-order process. But mapping the ordering principles in models to scientific descriptions of biological phenomena is nontrivial. In the case of Turing's coupled diffusion reactions the mathematical ordering principles implicit in his derivations have not mapped in a useful way to biological morphogenesis and have largely been rejected by empirical biologists (Keller, 2002). Another example of supposed emergent process levels in biology, used by Bateson and many others, is that of cells interacting to produce tissue and tissues interacting to produce organs; as Goldstein (2002) has noted, that is an empty example of emergent process because, in our terms, it begs for the specification of ordering principles by which one level of process generates the next level. In contrast, in the case of the visual hierarchy generated by E42, the ordering principle is TAO (taking differences in differences) and this ordering principle maps to the experience of humans as they sort the stimuli in categories by making distinctions among them. Note well, we are not saying that E42 is a model of neural activity in the visual system. Rather we are mapping the epistemological terms (taking differences if differences) posed by Bateson to the TAO function by suggesting that humans, in order to construct or use hierarchies like the one in Figure 2, make distinctions in distinctions. Both in the model and in descriptions of epistemology we have a well specified ordering principle for process levels. To emphasize, in general, models of biological (or other phenomena) are not the

phenomena; the map is not the territory. The question is whether the model maps to the phenomena in useful ways. And, when the phenomenon of interest involves emergent process levels, a useful mapping requires that ordering principles be specified in both the model and the phenomena and that the mapping between the ordering principles in the two realms be explicit. (Without such a degree of specification the model becomes metaphor, which, as Malloy, Bostic St Clair, and Grindler, 2005, point out can itself be useful in science but in a different way than explanatory models.) We argue that the simulation in this study provides a positive example of emergent process levels with well-specified ordering principles in both model and epistemological experience. We now generalize the discussion of the hierarchy in Figure 2 to human epistemological hierarchies in general.

Nominalization Generalized

We can distinguish between a (dynamic) process and the (static) result of that process. The hierarchies shown in Figure 2 are instructive to clarify that distinction. In contrast to the flow of process in the dynamic systems simulation (E42) when it is running on a computer, the visual forms shown here on a paper page are the results of process; they are snapshots (static visual patterns). Interestingly, these static snapshots, arranged in categories of visual forms, are consistent with the logical inclusion sorting rules which place lower order sets into more inclusive higher-order sets. The snapshots are not the processes but, like elements in a set, can be tokens for those processes. Nominalization is a linguistic function by which an action (verb) is transformed to a noun. In this discussion we will generalize the meaning of linguistic nominalization to include all cases where a static result is generated from a dynamic process simply to have a single descriptive term. Thus the noun “attractor cycle” and graphs of attractor cycles, phase maps, and so on are considered here to be the result of nominalization. Note that nominalization is itself a noun referring to a process. The elements in sets are more like nouns than verbs (even when the elements of a set are the names of processes, those names are only tokens of the processes and are not the processes themselves actively running). The visual patterns shown here are nominalizations (in our generalized sense) of the flow of the Boolean processes. We propose that nominalization is a prerequisite for generating logical levels from the results of process levels.

We now have a series of ideas (logical levels, process levels, and the nominalization of process into static results) that can be applied as a qualitative analysis of the results of this simulation experiment and more generally to the issue of levels both in evolutionary-developmental learning processes and in those learning processes by which sentient beings make maps.

EMERGENT LIFE AND EMERGENT TAXONOMY

Types of Model-generated Process Levels

We now make explicit those characteristics of the model which we will use in the discussion of thoughts about evolution and thoughts about epistemology below. Two types of levels are apparent in this modeling experiment, one appears to conform to the logical levels defined by logical inclusion rules and the other to fit the description of process levels. Let us start with the logical inclusion hierarchy. The hierarchy apparent in Figures 2 in which categories of visual patterns generated by sorting by TAO-1 vector-equality are nested within the categories generated by sorting by TAO-2 vector-equality,

and so on through TAO-3 and TAO-4. Clearly this is a hierarchy of the static results of process (since the dynamic flow is nowhere to be seen on the page). This hierarchy can be described by levels of logical inclusion, and, as such, is in accord with the verbal proposal of Bateson (the sixth criteria of learning process). Let us examine this type of level in more detail. First, the hierarchy of TAO categories shown in Figure 2 exhibits the logical inclusion criterion of constriction; examination will demonstrate the lower order categories are included in higher order categories in a well-formed manner. Second, the hierarchy also exhibits the criterion of heritability, but this may require some careful thought to demonstrate. Focus for a moment on the three visual patterns (basins 38, 60, 76) in category 2 at the second level of abstraction (TAO-2). The characteristic that basins 38, 60, and 76 share and which results in their placement in the same second level category is that they all have identical TAO-2 vectors. Moreover, as noted above, this category (basins 38, 60, 76) at the second level of abstraction subsumes two categories at the first level of abstraction: At the first level of abstraction category 1 (basin 38) and category 2 (basins 60, 76) together comprise category 2 at the second level of abstraction. But, of course, at the first level of abstraction all the basins in categories 1 and 2, while they have different TAO-1 vectors, continue to share the characteristic of identical TAO-2 vectors. While they are in different categories at TAO-1 level, basins 30, 60 and 78 all inherit an identical TAO-2 vector. This is general across the whole hierarchy shown in Figure 2. The visual forms in each lower-order category inherit the sorting characteristics of the higher order category of which they are a part.

This modeling experiment also demonstrates three process levels. The first process level results in the appearance of attractor cycles, the second process level results in an archive of attractor cycles, the third in the appearance of a hierarchy of attractor cycles. We will now describe each of these process levels in some detail. First, in the classic sense of coupled nonlinear equations, the Boolean relations among the coupled nodes in the NK Boolean system generate emergent attractor cycles whose cyclic activity can be nominalized as visual forms. When the system is running, these attractor cycles are a cyclic flow of process which is a level above the Boolean operators that generate them. Second, the application of the TAO operator to the flow of differences in the attractor cycles is another level of processing, in this case, one manufactured by program designers. The second level is not emergent (as attractor cycles are from coupled equations). Still, the TAO operator is meta to the first process level in the sense that it acts upon the flow of differences in attractor cycles when the system is running. As described by Malloy, Jensen and Song (2005) the TAO operator is used by the system to discover its own attractors and to place them in an archive whenever it finds a new one. Thus, a (nominalized) result of this second process level is an archive of attractors. Such an archive might map to that aspect of the learning process of living beings which allows them to know (remember) their past attractor states and to recognize if they are in a new attractor or an old attractor, though such a mapping is not an important focus in this paper; the mapping is mentioned to clarify this second level of process and suggest that it may have some utility in a general epistemology. A third level of process, also manufactured by program designers, is the recursive application of TAO to all archived basins (as in Table 1). At each TAO level all those basins that have identical TAO matrices are placed in the same category. The result is the emergence of the hierarchical categories of the kind shown in Figure 2. In this case we argue that the hierarchy is emergent because, while we designed the recursive application of TAO, we did not

design or even expect the hierarchy, and, further, the categories only emerge under certain boundary conditions. In sum, the three process levels are 1) the coupled Boolean relations generating attractor cycles, 2) the system's search for attractor cycles using TAO and its building of an archive of past attractors, and 3) the system's recursive application of TAO to its archive of past attractors to sort them into the a hierarchy of categories based on TAO equality.

A Meta-Map of Maps of Evolution and Maps of Epistemology

In this paper we are developing a meta-frame for the relations between theorizing about the biological processes by which life takes on its forms and theorizing about the epistemological processes by which we come to know those forms. As we have said, the utility of precise models is that they allow the development of well-specified and rigorous sets of relations that then can be mapped to other realms. Consider one such mapping from the analysis of our perceptual hierarchy results to biological taxonomy, which is a map, not of biological form, but of human knowledge of biological form. First we distinguish the *process levels* by which form comes into being from the *taxonomic levels* by which those forms are categorized. In the E42 model we know the processes by which the attractor cycles take on their forms; in the world of biology those processes are still not fully specified but current scientific work is producing descriptions of what those processes might be (Carroll, 2005). Following Turing, Kauffman, Holland and others, we assume a dynamic systems map of biological form as emergent levels of process. Both the form of attractor cycles in dynamic systems models and the form living beings are emergent flows of process, not things. The particular raven which just unzipped my day pack and is now seen flying away with my lunch is a self-organized flow of process levels, processes layered upon many levels of process across a long span of evolutionary time and across the developmental span of its lifetime. The Tao Te Ching says that the knowledge of the ancients was perfect. How perfect? They did not yet know there were things. What is the relation of that particular raven, not a thing but an unfolding instance of evolutionary-developmental process, to human taxonomies of biological forms? Individual beings exist; classes of beings don't: Ravens don't exist, nor do corvidae nor do birds (class aves).

Particular human beings do, however, exist, each doing many things, some of which might be called the epistemological process of making or at least using taxonomies. Here we distinguish between theories of the emergence of form and theories of the emergence of knowledge of form. We propose that the process of nominalization (generalized beyond its linguistic definition) is an epistemological process which is a prerequisite for the subsequent epistemological process which generates logical inclusion hierarchies like the biological taxonomy. It is not the existential beings that are categorized; it is an archive of biological field notes, other scientific descriptions, and human memories of the existential beings that are classified. Once dynamic process is frozen in static archives of some kind, then the process of taking difference in differences in those archives can commence. Following Bateson's suggestion and based on our modeling, we propose that one subroutine of epistemological process is taking differences in differences in differences in differences, and that this process can act upon (nominalized) scientific descriptions of the beings who are (construed to be) pure process. The particular subroutine of epistemology (taking differences in differences) produced in this study the perceptual experience of a hierarchy of categories, at least within certain

boundary conditions. In this simulation study the ordering principles for the processes that generate taxonomies are well-specified.

We propose to generalize those results: Making distinctions in distinctions is the specific mental process through which taxonomies emerge in general, including the biological taxonomy in particular. Accordingly, that particular raven, now eating my lunch on a ledge 200 feet up the canyon wall simply exists. The hierarchy in my mind (Aves, corvidae, ravens) is the result of the epistemological process of making distinctions in distinctions. In my mind I also construe the raven to be an example of evolutionary-developmental process. These two thoughts are somewhat independent; humans have categorized animals long before the theory of evolution. These theoretical frames (of evolutionary process and of epistemological process) precisely parallel the current study where we map the forms of life to the forms of the individual basin patterns shown in Figure 3, and both are construed as emergent from coupled nonlinear generating processes. We also map logical inclusion taxonomies in general to the hierarchies generated by TAO, and both are construed to result from taking differences in differences. In our meta-map, the epistemological processes of nominalization and taking differences in differences act upon the forms that emerge from the nonlinear dynamics of coupled processes. Humans can perceive the plausibility of the perceptual hierarchy in Figure 2 whether they spontaneously generated the same ordering principles or not just as they can perceive the utility of biological taxonomy whether they would spontaneously invent it or not. That raven, high on the ledge, who is now regarding me, does it generate taxonomies? And what are its ordering principles? If does so, where am I, and other humans, in its taxonomies?

Intuition, Scientific Description, and Tautologies

While in our discussions above we have reversed the order of his mapping, Bateson defines explanation as mapping a tautology onto a description. That comes up a bit short. Keller (2002, p. 5) grounds explanation in biology as “that which leads biologists to say *Aha!*” In those cases where we are studying human patterns, Bostic St Clair and Grinder (2001, p. 76) integrate these two types of explanation by proposing that mappings from formal models and instruments to scientific descriptions, as Bateson suggested, be validated by human judgment, by what linguists call intuition, by what Keller calls “*Aha!*” It is in this sense that the reader is asked to examine her or his own judgments with the perceptual hierarchy shown in Figure 2 as the central pivot point of the meaning of emergent hierarchies in human perception based on taking differences in differences.

All thoughts, all words, all descriptions, all models of what goes on in the world, including biological and epistemological processes, are themselves epistemological processes. The map is not the territory. Some maps are useful, some are not. Some even provoke an *Aha!* As for taxonomies, it is not the existential beings that are categorized; it is an archive of biological field notes, other scientific descriptions, and human memories of the existential beings that are classified. The existential beings are not nouns, they are processes; they are moving too fast to be gathered together in one place for our classification; they are busy today, flying around, opening day pack zippers, eating lunch, being born, dying.

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