Steps to an Ecology of Emergence

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Abstract

How might we take steps toward understanding emergent hierarchies in a mental ecology? To answer that question we outline an epistemological framework which begins with two fundamental assumptions from the methodology of transformational grammar in linguistics—the centrality of human judgment based on direct experience and the proposition that the systematic nature of human behavior is algorithmically driven. We then set a double criteria for the understanding of any formalism such as emergence: What is formalism X that a human may know it; and what is human knowledge that a human may know formalism X? In the cybernetic sense, the two are defined in relation to each other. In answer to the first question, we examine emergence as a formalism, using Turing's work as a defining case and an N, K Boolean system as a specific working model. In answer to the second question, we frame the knowing of emergence in a broad Batesonian epistemological approach informed by modern developments in neural nets and discrete dynamic systems models. This epistemology specifies mental process as the transformation of differences across a richly connected network. As the relational reference point which integrates the two sides of the cybernetic question, we use human judgments of perceptual similarity to link emergent hierarchies formally found in an N, K Boolean model to hierarchies of perceptual similarity based on direct experience.

> I have said that what gets from territory to map is transforms of differences and that these (somehow selected) differences are elementary ideas.
>
> But there are differences between differences. Every effective difference denotes a demarcation, a line of classification, and all classifications are hierarchic. In other words, differences are themselves to be differentiated and classified. In this context I will only touch lightly on the matter of classes of difference, because to carry the matter further would land us in the problems of *Principia Mathematica*.
>
> 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.
>
> The computer in the human head boggles at the task.
>
> --Gregory Bateson (1972), pp. 463, 464.

In 1952 Alan Turing published a groundbreaking paper that laid the foundation for the concept of emergence. Within the constraints of a formal mathematical symbol system, he derived insights into how form self-organizes from the interactions among well-defined processes. He found that forms observed in nature (dappled patterns, radial whorls seen in leaves around stems) resulted naturally from the interplay of coupled equations that themselves had no hints of the higher order characteristics of the emergent forms. His insight required, in his words, “a good deal of mathematics, some biology, and some elementary chemistry.” These prerequisites for understanding this early formal example of emergence (not a word he used) were a substantial barrier; and for fifteen years it was largely ignored (Keller, 2002). Now, fifty years later Turning’s paper has become among the most seminal of the twentieth century (Keller, p. 108). And penetrating and extensive insights can be easily understood through more accessible formalisms, often derived from the languages of computing (e.g., Holland, 1998, p. 103, p. 125). For example, the gliders, generated by simple rules, in Conway’s cellular automaton, Life (e.g., Holland 1998, p. 138, Malloy, www.psych.utah.edu/dysys), skate across a computer screen, transforming and reforming as they interact. Gliders have become a canonical example of emergence.

The distinction between the level of generating processes and the level of wholes that emerge is the basis of the idea of emergent hierarchies. If interacting processes produce wholes with novel characteristics not found in those lower level processes and if the wholes are themselves processes that can interact and so produce even higher level wholes with yet again novel characteristics, then we have an outline of a process for emergent hierarchies.

Emergence was a fundamental process in Bateson’s epistemology (1979, chapter 3), although he did not use that term. The case of difference, that “there must be two entities such that the difference between them… can be immanent in their relationship,” is particularly relevant to this discussion. Prime examples discussed by Bateson of what is now called emergence are binocular vision, beats and moiré patterns.

To examine in detail how emergent levels develop in a model and, more critically, how those model-defined levels relate to human perception of emergent levels we will use a computer simulation, E42. E42 is an N, K Boolean simulation program (Kauffman, 1993) that generates discrete dynamic systems. N, K Booleans systems are computer simulations of the behavior of a net of N entities (nodes) each of which is connected to (i.e., takes input from) K other nodes in the network. These systems are Boolean because each node has only two possible states (0 or 1) and therefore the system is based on difference and the transforms of difference through a network. As such, N, K Boolean systems create a simulation context consistent with several of Bateson's criteria of mental process (e.g., differences, transformations of difference across a network, complex chains of determination, and, as we will propose, emergent hierarchies). Kauffman used his program to investigate the processes of biology; in contrast, E42 (Malloy & Jensen, 2002) is designed to explore the processes of human epistemology wherein the genesis of form and its apprehension is a central issue. More details on N, K, Boolean systems can be found in Kauffman (1993, 1995) and at Malloy (www.psych.utah.edu/dysys).

Under very broad constraints the reverberation of difference in N, K Boolean systems falls into repetitive cycles called basins. This falling into cycles is what Kauffman (1995) calls "order for free." That is, if biology is construed as a vast network of transformations of difference, then under certain general conditions it will self-organize into complex cyclic patterns. Figure 1 shows static snapshots of basin patterns from two small discrete dynamic systems generated pseudo-randomly by E42. Panels (a) through (d) are all from the same dynamic system. Panel (e) shows one basin from a different pseudo-randomly generated system; it is included merely to show that there are many systems, many ways to getting the appearance of striped camouflage. An interesting aside, and one that Kauffman links to genes and evolution, is that the four patterns of zebra stripes shown in (a) through (d) can shift, one to another, based on changing the state (0 to 1 or 1 to 0) of one or very few nodes on a particular iteration. The trick is knowing which nodes and which iteration.

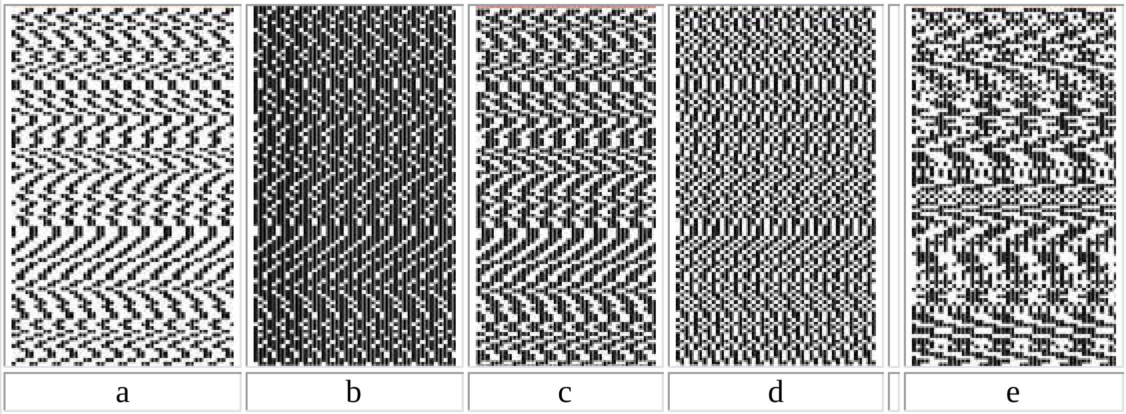


Figure 1. Camouflage-like striped patterns

The first four columns (a to d) are four basins from the same dynamic system. The fifth column (e) is a basin from a different dynamic system.

This approach to form as a self-organized persistent whole generated by the interplay of underlying processes pioneered by Turing has been a prime basis for defining emergence as a phenomenon and is still consistent with modern criteria (e.g., Holland, 1998, p. 225). Forms, in this tradition, are not things, although as with leaf patterns or animal spots, forms may be persistent enough to be taken as if they are things. In fact, they are persistent patterns emerging from ongoing generating processes (Holland, 1998, p. 225), each moment renewed. As Turing indicated, they are more like a stationary wave in a mountain stream which may appear to be static and stable; yet it is in each moment holding its form by the interactions of fluid processes (see www.psych.utah.edu/dysys to see dynamic representations of the patterns in Figure 1) .

Critiques of emergence

More elusive and more controversial has been the use of these model-generated insights and definitions as explanatory devices for “actual” phenomena. Keller (2002) provides a convincing history of the lack of success in developmental biology of mathematical models in general and of Turing’s morphogenic ideas in particular. In short, the contention is that the processes that generate the patterns of hair on a zebra are nothing like the processes underlying Turing’s derivations or E42’s simulations nor have the logico-mathematical models proved to be particularly useful to experimentalists in the details of their work, at least until very recently. On the other hand, Kauffman (1993, 1995) uses such models to address, with great conceptual power, major issues in biology; indeed, he proposed how such processes might parallel the origins of life and its evolution.

Goldstein (2002) in proposing self-transcending constructions as a formalism for emergence, summarizes several critical issues in conceptualizations of emergence such as its characterization by negation (an emergent characteristic is not found in the processes that generate it). He also points out that emergent levels, lacking detailed specification of how processes generate those levels, can be arbitrary. It is one thing to say that cells interact to produce tissues; but without detailed process specification, tissues are an arbitrarily chosen emergent whole for the interaction of cells. Goldstein also makes in a more general way the same critique that Keller made, that the processes which generate levels in a model are sometimes surmised to be the same processes that generate corresponding levels in the phenomena. As Keller (2002, p. 112) summarized the issue, “Turing’s foray into biology was of immense importance for the study of chemical systems, for the development of the mathematics of dynamic systems, even for many problems in physics. But not, it would seem for developmental biology.” As always in science, the useful application of a model is a discretionary art. We will return to this issue later.

Intuition as a legitimate methodology

We are primarily concerned here with epistemology and with Bateson’s notion of an ecology of mind. How might hierarchies of differences (see quote at beginning of this paper) and therefore hierarchies of pattern emerge in a mental system? There are several crucial epistemological frames to establish in answering that question.

As a start, our epistemological approach has two fundamental assumptions (Bostic-St. Clair & Grinder, 2001). Both of these assumptions are explicit in Chomsky's transformational grammar which is a mapping from the intuitions of native speakers onto explicit structures, namely, recursive rule systems of great simplicity and formal power. First, let us focus on the paradigmatic centrality of human judgment based on direct experience (what Chomsky calls intuition). As an example, consider the sentence, "This pig is ready to eat." Is the sentence ambiguous, that is, does it have more than one meaning? The answer to that question and to the definition of the linguistic phenomenon of ambiguity in Chomsky's paradigm depends on the linguistic intuitions of native speakers of English as they experience that sentence.

The second assumption (also explicit in Chomsky's paradigm) is that human behavior is rule driven; moreover, in the linguistic paradigm, it is assumed that native speakers have internalized the grammatical rules of their native language so that their intuitive judgments are based on these rules. A monolingual speaker of English, while able to make judgments about important linguistic phenomena in English, would fail to do so when presented with Spanish or Chinese sentences. Language structure must be well-learned before a person's direct experience with a sentence leads to appropriate intuitive judgments. Chomsky specified a set of simple recursive rules as a model that allowed researchers to determine with little effort what the actual claims of the model are and what (based on their own linguistic intuitions) constitutes a counterexample to the model's claims so as to make mapping from intuition to rule system open to challenge and refinement. In this paper we propose N, K Boolean systems as a simple set of recursive rules in the same spirit.

In this epistemological framework, the intuitions about emergence based on Turing's math required a deep commitment to learning the symbolic language system he used. The same is true in the more accessible ideas based on neural nets and their generalization to emergence, (e.g., Holland, 1998). Even the relatively simple logic of an N, K Boolean system requires a fair commitment to learning its formal language (Kauffman 1993, Malloy & Jensen, 2002). Computer simulations, which perform all the onerous steps of a derivation quickly and fluidly, simplify the task greatly; still, following the logic of a simulation is often less than trivial. And even if sufficient mastery of a recursive rule system (derived or simulated) is attained so that solid intuitions regarding the formal conversation about emergence is possible, the issue still remains, To what do these intuitions apply beyond the realm of the model? Warren McCulloch (1965) suggested a possible direction.

The Embodiment of Mind

The cybernetic conceptualization of neural nets as a basis for mental process was pioneered (Varela, Thompson, & Rosch, 1993, p. 38) by McCulloch & Pitts, 1943. Later, enmeshed in a culture that deeply presupposed the Cartesian mind-body split, in our era manifested as the hidden homunculus of cognitivist theories, McCulloch articulated a general framework for the embodiment of mind (1965). He revised the Psalmist spiritual question, "What is a man that Thou shouldst know him?" to a stringent double criteria for simultaneously understanding both formalisms and human epistemology in relation to each other (1961): "What is a number, that a man may know it, and a man, that he may know a number?" Here, in this question stated in cybernetic form, the two are known in relation to each other. Properly to define emergence by this relational criteria is to propose formalisms for emergence in relation to an explication of the nature of the *kind* of human knowledge that would allow us to know and to use these formalisms.

McCulloch (1965, p. 6) uses Russell's definition of a number: "A number is the class of all those classes that can be put into one-to-one correspondence with it." As an example, he notes that "7 is the class of all those classes that can be put into one-to-correspondence with the days of the week, which are 7." He further notes that while some mathematicians may question whether this is all that a number means, it is sufficient for his purposes which is to define a number in a way that a person can understand it. For the other side of his question, he refers to his earlier work with Pitts and summarizes the theoretical importance of it. In short, he lays the ground-work for the now familiar argument that the logic of neural nets is sufficient for knowing in general and for knowing numbers in particular. Indeed, Holland (1998, p. 96ff) describes how a neural net can easily sort odd from even, and Varela, Thompson, & Rosch (1993, p. 155ff) demonstrate the same capability in a simple cellular automaton. McCulloch proposed and then met a stringent double standard: He specified a double—(a) what is known and (b) an epistemology of the knower—in such a way that both terms of the double could be set in relation to each other.

Every theory about the world, each formalism, every model and metaphor about emergence, or about any other phenomena for that matter, presupposes, typically unconsciously, some framework of the nature of being human. Often this presupposition is hidden and unexamined in the social milieu of the scientist espousing the formalism. McCulloch is proposing that this fundamental relationship between an idea and a framework about the nature of the being that proposes and knows the idea, largely ignored by scientists, be addressed explicitly. As McCulloch points outs (1965, p. 7) the first part of the question is easier to answer; it is the second part, regarding the nature of human knowing, that is more difficult. And, in the end, it is the relationship between the two that is most penetrating and useful.

The objective pretense won't do. The theory is not out *there*, outside of us, to be validated or falsified by data collected out *there*. Nor can subjective experience alone suffice. Knowing is neither here nor there. Knowing is the relationship between here and there. At the final moment, when a person decides a particular theory or model is relevant or useful or otherwise embraces it, it is a human making a human judgment about a human construction. McCulloch's double requirement that we be explicit about the relationship between the nature of the formalism and the nature of being human is critical. What is formalism X that it may be known by a human, and a human that s/he may know formalism X?

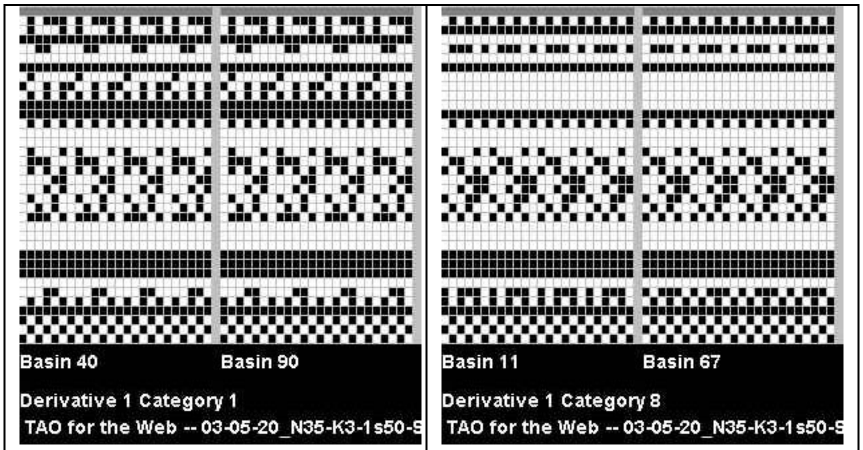
That a Human May Know It

What are dynamic systems that a human may know them? More specifically, how is it that humans can know the formalism named E42? To answer this, first we will examine in greater detail more examples of the structure of basins generated by E42; then we will develop and use the idea that we can take the discrete (XOR) analogue of the first derivative on the dynamics of a system.

As a start, let us examine how the images in Figure 1 represent the behavior of E42, which is an N, K Boolean system. An N, K Boolean system consists of N nodes, each taking input from K other nodes. This input consists of either a 0 indicating that the other node is OFF or a 1 indicating that the other node is ON. At any time, T, every node in the system uses a logical operator whose arguments are its inputs to decide if it will be ON or OFF for the next iteration (T+1). For example, if a node has two inputs and its operator is the logical AND operator, then it will be ON during the next iteration (T+1) only if both its inputs are ON during the current iteration (T). If another node is using the logical INCLUSIVE OR operator then it will be ON at T+1 if either one input or the other or both are ON at time T. If a node is using the logical EXCLUSIVE OR (XOR) operator then at T+1 it will be ON if its two inputs are the different (that is, either {0,1} or {1,0}); conversely it will be OFF if its two inputs are the same (that is, either {0,0} or {1,1}). The XOR operator thus detects difference and is related to Bateson's epistemology in important ways. Any legal logical operator can be used a system constructed by E42 and which operator actually is used by each node is decided pseudo-randomly when the system is first built.

The behavior of the system can be represented--and so known--as an array of twinkling nodes (Kauffman, 1993, p. 182ff). But this is not the only way to represent and to know its dynamics. Both Figures 1 and 2 represent a system's behavior not as twinkling nodes but as a historical trace.

Examine Figure 2, which has finer detail than Figure 1 and shows output from a different pseudo-randomly generated dynamic system than those that generated Figure 1. This system has N = 35 nodes. The vertical axis contains the 35 nodes while the horizontal axis tracks time (iterations). Look at Figure 2 (a), basin 40. The first column shows the state (ON = black square and OFF = white square) for each the 35 nodes arrayed as a vertical vector. The second column shows the state of each node for the next iteration, and so on. Conversely, any given row shows the changes (or lack of changes) of a single node across time. Figure 2 (a) shows one basin, basin 40, that the particular dynamic system falls into. Panel (a) shows enough iterations on the horizontal axis for the system to cycle through basin 40 four times. The length of the basin is six iterations, so four times through the basin yields 24 iterations on the horizontal axis of Figure 2 (a). Of course, once in a basin the system will stay there forever unless it is perturbed. Figure 2 panels (b) through (d) show three other basins (each cycling 4 times).



(a) (b) (c) (d)

Figure 2. Four basins from a pseudo-randomly generated dynamic system. Panels (a) and (b) are perceived as similar as are panels (c) and (d).

The representation of dynamics as a historical trace generates a pattern resulting from the behavior of a system across time; more specifically, it shows the differences in the states of the full set of nodes as they change across time. These changes over time are the dynamic component of system's behavior. The 2-D patterns generated by changes in the states of an array of nodes (ordinate) over time (abscissa) are perceptible to humans as coherent wholes when a system is in a basin. In Figure 1, these patterns are evocative of the visual experience of striped camouflage, and it was this sort of coming-into-being of form which was the central point of Turing's paper. In Figure 2, the patterns are more abstract.

The central point here is epistemological. The simulation program runs in the circuitry of a computer which, without instrument or sensory representation, is unknowable in the particulars of its process at any given moment; we are examining here the first half of McCulloch's questions: What is (one example, at least, of) a dynamic system that a human may know it? Representing the processes of the dynamic system programmed into and running within a computer as a visual historical trace allow humans to know something about that dynamic system.

Dynamic Constancies for Differences in Differences over Time

An interesting aspect of Figure 2 is that, in the judgment of humans, patterns generated by basins 40 and 90, panels (a) and (b), resemble each other but are distinct from the patterns of basins 11 and 67, panels (c) and (d), which in turn resemble each other. Here we are using the linguistic methodology and the reader is asked to examine Figure 2 and make her or his own judgments.

For a discussion of the nature of emergent hierarchies, these obvious perceptual judgments are crucial. Before we can examine that issue though, we first will consider one more issue that is technical. In a way, we will ask the reader to engage in a thought experiment parallel to the one proposed by Bateson in the quote at the beginning of this paper involving hierarchies of difference. Figure 2 shows patterns that result from the historical trace of the differences in a system across time. Change over time suggests the possibility of a change (or lack thereof) in change occurring over time (that is, the discrete analogue of the first derivative). In essence, we use the XOR operator to discover whether the differences over time that generate a particular basin are themselves the same or different as the differences over time that generate another basin. As Bateson (1972, p. 464) points out, such hierarchies of difference are difficult to think about; even so, we will address them here.

The discrete analogue of the first derivatives of the basin structure for the basins in Figure 2 (a) and (b) are identical; so too are the derivatives of the basins shown in Figure 2 (c) and (d). The dynamic changes in differences are constant; that is, analysis by the XOR operator shows that the differences in differences over time are the same in panels (a) and (b) and likewise are the same in panels (c) and (d). In short, patterns that have the same first derivative—panels (a) and (b) or, alternately, panels (c) and (d)—look similar to humans. More details of this analysis of change can be found at "TAO: Analyzing and Perceiving Change over Time" at www.psych.utah.edu/dysys.

Emergent Hierarchies and Perceptual Categories

Thus, we have two possible levels in a proposed emergent hierarchy. The first level is realized by the basin patterns (zebra stripes in Figure 1 or the more abstract patterns in Figure 2) that are generated by the interaction of the Boolean processes that define E42. This level of emergence is the one proposed by Turing and is essentially the same level of emergent form as Conway's gliders in the game of Life since the interactive E42 software (as opposed to the static snapshots shown here) makes evident the dynamic movement of these basin patterns in a way similar to gliders. The second proposed emergent level is realized by the appearance of perceptual categories based on first derivatives performed on the emergent forms occurring at the first level. This second level of the hierarchy is based on examination of differences in differences (Bateson, 1972, p. 464). This emergent hierarchy is even more intriguing because of the correspondence between the well-defined levels of the model and human perceptual judgment.

Figure 3 shows a more interesting example consisting of six basins from yet another pseudo-randomly generated dynamic system that has 36 nodes. The length of a basin in Figure 3 is four iterations; so four times through four iterations yields the 16 iterations shown on the horizontal axis for each basin. Based on identical first derivatives, the model places the six basins into three categories of two basins each: category 9 (basins 59 and 68), category 1 (basins 31 and 36) and category 2 (basins 49 and 34). (The system has more basins and more categories, which are not shown here.) All basins in the same category have identical discrete first derivatives; and all basins in different categories have different first derivatives.

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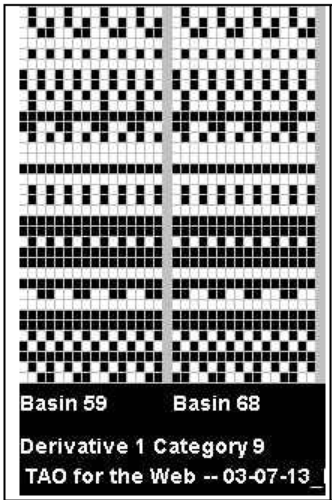
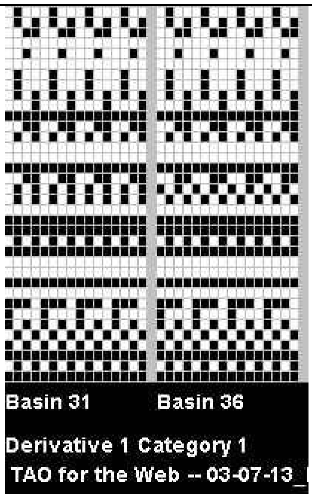
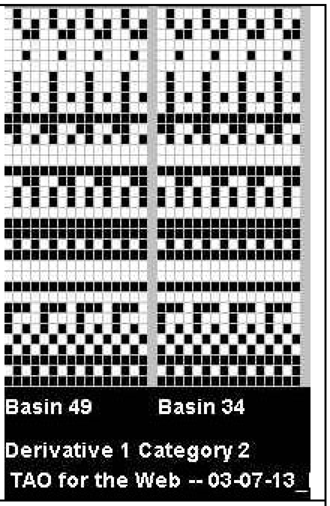
<td> </td>
<td> </td>
<td> </td>
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Figure 3. Dynamic Constancy. Three categories of pattern generated basins in a dynamic system. The categories are defined by the constancy of differences in differences over time. The three categories are then grouped into two meta-categories. The meta-categories are defined by constancies in the differences in the differences in differences over time.

There are two interesting perceptual observations with implications for the concept of emergent hierarchies. Both perceptual observations are related to what we will define as the principle of dynamic constancy. First, basins within a category are more similar to each other than they are to basins in other categories; this is the same point noted above in Figure 2. This first point is particularly applicable in category 9 where basins 59 and 68 are perceptually hard to distinguish and in category 2 where basins 49 and 34 are nearly as difficult to distinguish. The only weakening of this point is in category 1 where basins 31 and 36 have some elements that are perceptually quite distinct, distinct enough that some people might not put them in the same category. In fact, there are boundary conditions for this phenomenon (that categories based on first derivatives correspond to human perceptual judgments); these boundary conditions, while important, do not invalidate the phenomenon and are discussed in depth at www.psych.utah.edu/dysys.

Second, and of great interest for conceptualizing emergent hierarchies, is that, taken as a whole, some categories are more similar to each other than they are to other categories. To be concrete, notice that the basins in category 9, while closely resembling each other, are quite distinct from the basins in categories 1 and 2. In contrast, the four basins in categories 1 and 2, taken together, are relatively similar to each other across the first derivate category lines. They certainly resemble each other more than they do the basins in category 9. It is as if there is a possibility of meta-categories consisting of categories that are similar to each other. Could not the basins in categories 1 and 2 be placed together, all in the same higher-level category? The answer, at least the answer provided by the model, is yes. How would the model do this?

A first derivative implies a second derivative. Up to this point we have used the first derivative to examine the differences in the differences of the states of the system as it iterates across time. Now we will use the second derivative to examine the differences in the differences in the differences in the states of the system across time. In doing so what we find is that categories 1 and 2 (meta-category B in Figure 3) have identical second derivatives, while category 9 (meta-category A in Figure 3) has a distinct second derivative. This model-based processing of differences in the states of the system over time once again generates categories that correspond to human perceptual judgments.

Now we have three potential levels in a candidate for an emergent hierarchy. The first level is the appearance of form from the interaction of generating processes. The next level is the emergence of categories of form generated by the processes involved in taking differences in differences over time. The third level is the emergence of meta-categories of form based on taking differences in differences in differences over time. These levels, precisely defined in the realm of the model, correspond to human perceptual judgments. We propose that this is one way to operationalize Bateson's hierarchy of differences (1972, p. 463).

The Principle of Dynamic Constancy. The categories are examples of cases where changes over time themselves do not change. We call the perceptual similarity of patterns in such categories the principle of dynamic constancy and propose it as a new principle of perceptual grouping to be added to the well-known Gestalt principles of grouping (for a modern discussion, see Palmer, 1999).

We have now discussed in general terms what E42 is that a human may know it. The answer, then, to McCulloch's first criterion is that E42 is a formal model whose differences over time generate forms such that the differences in the differences in those forms generate a hierarchy of levels that can be known by humans through judgments of perceptual similarity. In short, the dynamics of an N, K Boolean systems can be known through perceptual judgments about patterns generated by the historical traces of its dynamics.

Goldstein (2002) proposed that emergent levels be considered as a "new *natural kind*, i.e., a construct reflecting how nature is parsed according to its observed regularities…" It would seem that the appearance of perceptual categories based on similarity judgments is a core example of this kind of parsing. But here we are parsing the output of a constructed model rather than spontaneously occurring patterns in nature. So we are proposing a model (which assumes that knowledge is based on difference and the transformation of difference) of how perceptual parsing might occur in natural settings.

The Human Reference Point

Let us return to our epistemological frame with a quote from Bostic St Clair and Grinder (2001, p. 76):

> "The linguist manipulates the syntactic, phonological, and semantic forms and judges and/or asks native speakers to judge whether the consequences are a well-formed sentence in the language, an ambiguous string or any one of an array of numerous other possibilities.

> The relevant reference point by the very nature of the research is internal to the bearer of the internal grammar – the native speaker himself.
>
> "To put the matter in a somewhat different form, suppose that we succeeded in constructing an instrument that purportedly arrived at the same judgments for visual inputs as those possessed by normally sighted people.
>
> "How would we know whether the instrument worked?
>
> "The answer clearly is that we would accept the instrument as accurate if and only if the responses of the instrument matched those of normally sighted people. In other words, we would calibrate the instrument by using precisely the same set of judgments (intuitions) reported by the people involved that we presently use in the absence of such an instrument.
>
> "Thus in fields where the patterning under scrutiny is patterning of the behavior of human beings, the reference point and the source of the judgments will necessarily be the human being."

How could it be otherwise?

In this framework, the correspondence between the hierarchical levels of the model and human perceptual judgments integrates the two sides of McCulloch's relational loop. It is the human that is the relational center when formalisms are generated and known.

What is Human Knowledge that a Human May Know Dynamic Systems?

We now address epistemological issues in the second part of McCulloch's question, What is a human that s/he may know a formalism? We will present one thread of thought in this regard.

The conceptualization of knowledge in terms of the "all or none" character of "difference" goes back in its modern computationally based form at least to McCulloch and Pitts (1943). The fundamentals of neural nets that they laid down have undergone various stages of elaboration and development by theorists like Hebb (1949), Holland (1975) and Valera, Thompson and Rosch (1993) among many others. And the rigorous focus on difference as the defining epistemological relationship was developed extensively by Bateson (1972, 1979), and continued in our own work by DeLozier and Grinder (1987) with application as a teaching method by Malloy (2001).

Bateson (1979, p.p. 89, 102, 106) proposes that difference is the basis of mental process which itself is the transformation of differences as they pass through a network. Moreover he proposed that these transformations lead to a hierarchy of levels. Also (1972, pp. 86, 87) he lists six criteria of mental process: "(1) Mind is an aggregate of interacting parts or components. (2) The interaction between parts of mind is triggered by difference. (3) Mental process requires collateral energy. (4) Mental process requires circular (or more complex) chains of determination. (5) In mental process the effects of difference are to be regarded as transforms (i.e., coded versions) of the difference which preceded them. (6) The description and classification of these processes of transformation discloses a hierarchy of logical types immanent in the phenomena." The second, fourth, fifth, and sixth criteria are particularly relevant to emergent hierarchies of a mental ecology as operationalized here by perceptual categories resulting from the analysis of differences in differences.

Bateson understood mental process in a general sense and argued strongly that evolving and knowing are parallel processes, that evolution is in fact a mental process. Since Kauffman (1993) had developed N, K Boolean systems, which are based on difference, as a model for biology and evolution an obvious extension was to examine Bateson's other great process, knowledge, using Kauffman's models. Thus, the E42 model itself was born out of Bateson's epistemology, that is, out of a theory that frames an answer to McCulloch's second question. The power of the N, K Boolean simulation tool is the explicitness with which it operationalizes that theory of knowledge. Using such an explicit model, we have seen here that, indeed, we can operationalize verbal statements about hierarchies of difference into precise computer-generated visual patterns that correspond to human perceptual judgments. Thus, the correspondence between the appearance of hierarchies in the model and human perception is not a post hoc realization but rather the result of making explicit a theory of knowledge.

McCulloch directs our attention to the relationship between any formalism and the specification of an epistemology within which that formalism could be known. In that regard there is, and we have focused unsystematically on one theme of its history, an elaborate intellectual frame casting knowledge as based in cybernetics and nonlinear dynamic systems theory and defined in terms of differences and transforms of differences circulating through networks. The nature of a human as a knower of emergent wholes we therefore define in the general terms of this frame.

Critical Concerns Revisited

Earlier, we focused on two telling critiques of emergent hierarchies. One is that the processes that underlie hierarchies can be under-specified, vague and post hoc with the result that the emergent levels which are named are arbitrary. In the case of the perceptual categories presented here, the Boolean generating processes, including derivatives based on the XOR operator, produce hierarchies in the E42 model that are well-specified, thus the model-based categories which emerge are not arbitrary but a deterministic result of those processes. The second critique is that, first, the levels in model and the levels in the actual phenomena are conflated and then the processes that generated the emergent levels in the model are assumed, without sufficient support, to be the same as the processes that generate the levels in the actual phenomenon. This is a deeper scientific issue, applying to all models and theories whether they address emergence or other concepts. It amounts to confusing the map with the territory. In our case this would be equivalent to assuming that the transforms of differences generated the E42 model are the same as the transformations taking place in a human perceptual system which generate corresponding levels of similarity judgments. This critique cannot, indeed should not, be dismissed in any definitive sense. It is crucial to keep a well-defined distinction between, on one hand, a model, and how it works, and, on the other hand, the phenomenon, and how it works. The sorts of logical operators and the kind of abstract nodes within the E42 model are surely not the same as neural activity in the human perceptual system. Neither abstract systems of logic nor the workings of a computer are the same thing as human physiology. In broader terms, the Batesonian *description* of mental process is not to be confused with mental process itself.

The more interesting question, and the one that such a critique is aimed at really, is whether there is a well defined, well motivated and useful mapping between the processes in the two realms (see Bostic St Clair & Grinder, 2001). In the case of hierarchies of perceptual categories considered here, the claim is yes, the process mapping between model and phenomenon is well supported since for over a half century theorists have argued for the utility of reducing knowledge to a basis in difference and the model itself was built for the explicit purpose of exploring this substantive epistemological framework, particularly in Bateson's work. Specifically, Bateson's sixth criteria of mental process posits that transforms of difference should lead to hierarchies immanent in the phenomena. Thus the formal hierarchies of emergence based on differences in differences in the model are a critical part of an epistemological frame. And this relationship between the formalism of emergence and a theory of human as knower itself corresponds to human judgments (as the reference point) of perceptual hierarchies.

Emergence as Metaphor

The importance of metaphor's function in a mental ecology is so pervasive and useful as to be necessary. An important metaphor in western civilization, which is proper to religion along with certain areas of philosophy and metaphysics, is the designer metaphor—that an all-knowing, all-powerful being designed the universe. Something, split off and separate from the biological world, designs the biological world. Proper as it may be in religion, the designer metaphor is not proper to science. Turing set out to defeat the "argument from design," in the life sciences. The concept of emergence which his work eventually led to is a powerful metaphorical alternative to the metaphor of designer. In this function it allows discourse about many human ideas and experiences without the necessity of proposing a designer. Keller (2002, p. 90) documents that Turing intended for once and for all to "Defeat the argument from Design." He provoked a series of alternative models to theories and discourses that presupposed life needed to be designed and ultimately explained by a designer.

To be more specific, the power of the emergence insight is that wholes self-organize themselves as a natural function of the interplay of the processes that make them up. Turing and others have, at least within the realm of logic and mathematics, offered proofs of this. This is a logico-mathematical concept of great generality and power. Science doesn't follow the chain of causality back to the being, who external to the world, designed and created the world. It does use, however, a reductionist metaphor to follow causality down to sub-atomic particles or back through time to the big bang. While such chains might well someday be literal, tracing every link rigorously; in fact, their use is primarily metaphorical, coloring in the background the way we think about what is important in theory and data. The metaphorical frame of emergence offers an alternative background, supplanting long chains of metaphorical reductionist causality with local neighborhoods of process levels within which phenomena of interest self-organize into emergent wholes to be studied and understood in relation to those neighborhoods of process. As Keller (2002, p. 102) summarizes it, “Turing’s work… offered a way out of the infinite regress…” In fact, within the emergence metaphor, the reductionist chain can never be complete because there will always be gaps in that chain where sub-processes self-organize into higher-level processes whose characteristics cannot be found in the sub-processes. In short, we don’t always have to know or state the specific generating processes which produce particular wholes as we did with our category patterns in this paper. Rather, just knowing that there is rigorous logic supporting that possibility is an evolution in epistemology.

The underlying concepts of science influence scientists and nonscientists alike every day in metaphorical ways. In a general day to day context, having a way of understanding that leaves can form in an elegant whorl around a plant’s stem as a natural consequence of the processes of plant physiology or that organs might emerge out of tissues and tissues out of cells is a useful alternative both to thinking about life as designed by an external entity and to thinking in the materialist tradition of biology as a machine, a linear sequence of cause and effect. If formalisms, such as numbers, emerge as characteristics of neural networks, then, by metaphorical generalization, mental processes, ideas, the whole of mental ecology can be cast as an emergent characteristic of the processes of human biology—mind and body are an integrated whole. And they are integrated as a whole both in a metaphorical way and in a way that is susceptible to study through formal models, in whatever degree of specificity is required by a scientific question. They are integrated in a way which is “neither mechanical nor supernatural” (Bateson and Bateson, 1987, chapter 5). As such, the metaphor of emergence serves as a functional addition to the mental ecology of western society, with potential for contributing to integrating the mind-body split and moving toward mind and nature as a necessary unity (Bateson, 1972).

Steps to an Ecology of Emergence

How might hierarchies emerge in a mental ecology? To answer that question we have used McCulloch’s double criteria: What is emergence, that humans may know it, and human knowledge, that they may know emergence? In the cybernetic sense, the two are defined in relation to each other. In answer to the first question, we have examined emergence as a formalism, using Turing’s work as a defining case and an N, K Boolean system as a specific working model. In answer to the second question, we have framed the knowing of emergence in a broad Batesonian epistemological approach informed by modern developments in neural nets and discrete dynamic systems models. This epistemology specifies mental process, both verbally and in computer simulations, as the transformation of differences across a richly connected network. As the relational reference point which integrates the two sides of McCulloch’s cybernetic question, we have used human judgments of perceptual similarity to link emergent hierarchies formally found in an N, K Boolean model to hierarchies of perceptual similarity in human knowledge.

> The vast mystery of biology is that life should have emerged at all, that the order we see should have come to pass. A theory of emergence would account for the creation of the stunning order out our windows as a natural

> expression of some underlying laws. It would tell us if we are at home in the universe, expected in it, rather than present despite overwhelming odds (Kauffman, 1995, p. 23).

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