# How Deep and Broad are the Laws of Emergence?

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## Abstract

Bruce Weber, evolutionary biologist and Susan Sgorbati, choreographer have been in a dialogue for the last several years asking the question of whether there are deep structuring principles that cross disciplines. While both professors at Bennington College, they developed a series of courses that explored these structuring principles in complex systems. Ideas such as self-organization, emergence, improvisation, and complexity were investigated through the lens of different disciplines and modes of perception. The inquiry was both intellectually driven and experientially driven. Students were asked to research and write papers, as well as move in the dance studio. Experiments in the studio led Susan Sgorbati to develop research that subsequently resulted in a national tour with professional dancers and musicians who are participating in a performance as part of this conference.

In this paper we will define concepts we have been using in our work and teaching, focusing on resonances between the different modalities. How to discern when organizing principles have relationships in common, and when they are specific to their systems seems an important distinction and line of inquiry that could have important implications for analyzing complex systems in a wide range of different environments from science to art to public policy.

## Introduction: Providing a Historical Context

Starting in 1999 Bruce Weber, a biochemist interested in how emergent and self-organizing phenomena in complex chemical and biological systems affect our ideas of the origin and evolution of life, entered into a collaboration with Susan Sgorbati, a dancer interested in emergent improvisation, a form she developed as a set of structuring principles for dance and music. They were able to collaborate in both teaching and research/creative work over a period of years at Bennington College, in an environment that fostered such interaction. We began with teaching a course in the emergence of embodied mind that was based upon reading the scientific writings on consciousness and embodiment of Gerald Edelman, Nobel Laureate and Director of The Neurosciences Institute in La Jolla, and who has visited the Bennington campus. Exploring the biological basis of consciousness brought us not only to utilize the conceptual resources of complex systems dynamics (theories of self-organization, emergence and the application of various computational models) but also to devise experiential work for the students involving perception, movement, improvisation, and the contrast of objective and subjective awareness.

In addition to continuing this class over several years, we also taught classes in

more general aspects of emergent complexity, where we drew heavily on the work of Stuart Kauffman of the Santa Fe Institute and the University of Calgary, and who also spent time at the campus. We looked for similar patterns that arose in different types of systems across a wide range of phenomena – physical, chemical, biological, cultural, and aesthetic. We ranged widely over such different subjects in order to ascertain if there might be a more general paradigm of emergent complexity beginning to affect our culture as suggested by Mark Taylor in his recent *The Moment of Complexity* (Taylor 2001). In the experientials that Susan developed for students in our classes, we studied the role of limited, close-range interactions vs. longer-range, global interactions, and also the correlation of constraints and selective factors and the likelihood of observable, global, aesthetic structures emerging. It was interesting to have the students report their subjective experiences during the process of emergence, something about which molecules are mute.

For Susan, the language and concepts of complex systems dynamics in general and the specific ideas of Edelman and Kauffman in particular, provided a context for discussing emergent improvisational movement forms. Her creative exploration of this science/dance interface has intrigued colleagues at The Neurosciences Institute, where she has been in residence for several weeks in the last four years. The Jerome Robbins Foundation, The Bumper Foundation, The Flynn Center for the Performing Arts and The National Performance Network Creation Fund (The Creation Fund is sponsored by the Doris Duke Charitable Foundation, Ford Foundation, Altria, and the National Endowment for the Arts, a federal agency ) have all supported her research.

**Defining Key Concepts**

We are interested in higher-order structures in complex systems that reveal themselves in scientific and aesthetic observations.

The scheme that we explored was based upon the following type of pattern unfolding over time:

individuals> self-organization>ensemble> emergence> complex system

We explored such a sequence in particular systems, such as the BZ reaction, Bernard Cells, self-organization in slime molds, and the various Kauffman's NK models, where N represents the number of constituents in a system and K the number of ways such constituents are related to each other. In physical, chemical, and biological systems studied we saw that self-organization (SO or perhaps more perspicuously system-organization) and self-structuring can occur spontaneously when a system is held far from equilibrium by flows of matter/energy gradients and the system has mechanisms for tapping such gradients (Peacocke 1983; Wicken 1987; Casti 1994; Schneider and Sagan 2005). The resulting structures from such SO processes involve an interplay of selective and self-organizing principles from which higher-order structures can emerge that can constrain activities at the lower levels and allow the completion of at least one thermodynamic work cycle (Kauffman 1993, 1995, 2000; Depew and Weber 1995; Weber and Depew 1996; Weber and Deacon 2000; Deacon 2003; Clayton 2004). Such emergent systems can, under special circumstances, display agency in that they select activities and/or behaviors that allow them to find gradients and extract work from them (Kauffman 2000). Sufficiently complex

chemical systems with agency, boundaries and some form of "molecular memory" are showing many of the traits of living systems and give clues to the possible emergence of life (Kauffman 2000; Weber 1998, 2000, in press). Further, Edelman's theory of neuronal group selection similarly invokes an interplay of selective and self-organizational principles giving rise to emergence of consciousness (Edelman 1987; Edelman and Tononi 2000; Weber 2003). In Edelman's model of how consciousness emerges there is a central role for both complexity and a process of reentry that can give rise to coherent neuronal activity in a "dynamic core" (Tononi and Edelman 1998). While exploring these concepts Susan developed experientials to help students understand the issues through an alternative modality to the experimental and mathematical.

This alternative modality is based on the aesthetic idea that important concepts such as agency, movement, embeddedness, memory, topology, and complexity arise in dancers and musicians in an improvisational system. Trying out a series of experiments with students and then with professional dancers and musicians based on simple rules and constraints, certain key concepts were formulated as a result of observations. They are:

1) agency: Individual dancers and musicians exhibit agency, or in this context the choice to move or to create sound. An essential aspect of this agency is the sensation of being "embodied". This feeling/cognitive state is based on a solo practice that incorporates a knowledge of a personal mind/body connection ( a kinesthetic awareness) and an attention to time, space, and boundary issues. Dancers and musicians who acquire advanced skills that include a diverse repertoire of gesture and sound practice ensemble awareness that develops the ability to simultaneously focus on the particular, the local interactions, and the global patterns around them.

2) movement: in this context, movement is the energy force driving the self-organizing system, creating the individual actions, the local interactions, and the global ensemble patterns. Movement is key as the system would be static without it. The impulse to move, to touch, to form connections as well as to move away from boundaries are essential actions by the performers. All living things inherently express their vitality in movement. Movement is an essential component in any kind of structuring process.

3) embeddedness: the elements of this particular system contain constraints and boundaries in a particular environment. The structuring patterns cannot be deconstructed from their environment. The global behavior is integral to the environment and will alter with any changes in the constraints. Time and space are essential components and will dictate the nature of structuring. For example, the relationship of movement, time and space within particular constraints will either create a coherent dynamic structure, a chaotic structure, or a rigid one that will halt the composition.

4) memory: structuring is an act of learning by the elements that are building the shape and patterns. Learning involves memory, reconstructing past experience into present thinking and action. This learning is essentially selectional, choosing certain patterns over others. Edelman speaks of "degeneracy" or many different ways, not necessarily structurally identical, by which a particular output occurs. (Edelman and Tononi 2000, 86) The ability to recreate patterns to refine structuring processes increasingly depends on degenerate pathways to find more adaptable solutions to build onto forms. The dancers and musicians exhibit this

complex system of memory in their building of compositional structures.

5) topology: In this way of structuring, a 'metatopology 'occurs where the system has the ability to operate on all levels at once (Sgorbati 2006, 209). Scale and amplification are important. According to Terence Deacon, a topology is "a constitutive fact about the spatial-temporal relationships among component elements and interactions with intrinsic causal consequences" (Deacon 2003, 282). Three levels of interaction exist at once: the local neighbor interaction, the small group ensemble locally, and the global collective behavior. The composing dancers and musicians need to be aware of all levels at once, signaling cues for moving the structure towards critical points of transition resulting in coherent forms.

6) complexity: dynamic compositional structures among dancers and musicians arise when simple rules are followed through improvisation based on certain constraints in the environment. This leads us to speculate that there are three interactive levels of analysis to these complex structures: systems approach (evolutionary biology), developmental approach (morphology), and psychological approach (meaning) as a way of observing structuring principles (Susan Borden personal communication with Sgorbati, 2006).

Complex systems dynamics gives a language with which to consider and discuss our experiences and the emergence of new aesthetic forms.

### Research in Emergent Improvisation - An Aesthetic Idea

The Emergent Improvisation Project is a research project into the nature of improvisation in dance and music. In this context improvisation is understood to mean the spontaneous creation of integrated sound and movement by performers who are adapting to internal and external stimuli, impulses and interactions. Ordinarily, we think of order and form as externally imposed, composed or directed. In this case, however, new kinds of order emerge, not because they are preconceived or designed, but because they are the products of dynamic, self-organizing systems operating in open-ended environments.

This phenomenon – the creation of order from a rich array of self-organizing interactions – is found not only in dance and music, but also, as it turns out, in a wide variety of natural settings when a range of initial conditions gives rise to collective behavior that is both different from and more than the sum of its parts. Like certain art forms, evolution, for example, is decidedly improvisational and emergent, as is the brain function that lies at the heart of what it is to be human.

Emergent forms appear in complex, interconnected systems, where there is enough order and interaction to create recognizable pattern but where the form is open-ended enough to continuously bring in new differentiations and integrations that influence and modify the form. It is by way of these interactions that particular pathways for the development of new material are selected.

In linking the creative work of art-making to the emergent processes evident in nature, there is basis for a rich and textured inquiry into how systems come together, transform and reassemble to create powerful instruments of communication, meaning and exchange. This project explores the ways in which

natural processes underlie artistic expression along with the possibility that art can help illuminate natural processes.

Conversations with scientists, particularly Bruce Weber at Bennington College, Gerald Edelman, Anil Seth, and John Iverson of The Neurosciences Institute, and Stuart Kauffman of The University of Calgary, have introduced Susan to the idea that, in living systems, self-organization produces complex structures that emerge dynamically. This idea resonated with her own work in improvisation and led us to speculate that there are deep, structuring principles that underlie a vast range of phenomena, producing similar evolving patterns in different environments: dancers collecting, birds flocking, visual representations of neuronal networks.

## New Forms in Emergent Improvisation

Movement appears to be a fundamental component of all living processes and we, as dancers, are moving and experiencing our own emergent sense of organization in this process (Sheets-Johnstone 1999). Working in this way with our students led Susan to observe and develop structuring principles for two emergent forms: *complex unison* and *memory*.

The *Complex Unison Form* is based on the observation of natural systems, which exhibit self-organizing structuring principles. In this form, open-ended processes are constantly adapting to new information, integrating new structures that emerge and dissolve over time. *Complex Unison* reveals the progression of closely following groups of individuals in space, to the unified sharing of similar material, and finally to the interplay of that material, which has both a degree of integration and variation, often displaying endlessly adaptive and complex behavior.

In the *Memory Form*, the dancers and musicians create an event that is remembered by the ensemble, and then reconstructed over time, revealing memory as a complex structuring process. This process by the dancers and musicians investigates multiple interpretations that draw on signals that organize and carry meaning. In this way, memory of the initial event is a fluid, open-ended process in which the performers are continuously relating past information to present thinking and action. This reintegration of past into present draws on repetition, nonlinear sequencing, and emergence to construct new adaptations. The *Memory Form* was inspired by the concept, “the remembered present” of Gerald Edelman.

## Notes Toward The Definition of a General Theory of Emergence

Entering into this discussion of a general theory of emergence feels like walking through a minefield. The dangers of generalities, of vague assumptions, of philosophizing about abstractions are everywhere. Artists and scientists have their own languages that describe the concept of emergence. Do the movement patterns of flocks of birds, schools of fish, neuronal networks, and ensembles of dancers and musicians have anything in common? Does our dialogue have something to contribute to our own communities as well as the culture at large?

Yaneer Bar-Yam, in his book *Dynamics of Complex Systems* states, “Thus, all scientific endeavor is based, to a greater or lesser degree, on the existence of universality, which manifests itself in diverse ways” (Bar-Yam 1997, 1). This suggests that there might be universal principles contained in the concept of emergence that might shed light on structuring principles for many disciplines.

Let us make perfectly clear that we are not interested in comparing apples to oranges. Dancers are not molecules. However, unlike molecules, dancers and musicians can relate their subjective experience during the process of emergent complexity. They are aware of what signals are effective in self-organizing structuring processes, and can reflect on multi-level attention spans that participate in these topological structuring processes. From our dialogues in the last several years as well as our work with students, we believe conversations between artists and scientists about emergence are important, and that a general theory may be possible.

It is not simple to define emergence from a scientific or an aesthetic point of view, and clearly harder to encompass both perspectives. One definition is from Terrence Deacon, who in his essay, “The Hierarchic Logic of Emergence” states that, “Complex dynamical ensembles can spontaneously assume ordered patterns of behavior that are not prefigured in the properties of their component elements or in their interaction patterns“ (Deacon 2003, 274). Artists experience their own sense of emergence. Gerald Edelman describes some of the basis for this experience. In his essay “The Wordless Metaphor: Visual Art and The Brain” he states, based upon current theoretical models and experiments, “Because it has no instructional program, but works by selection upon variation, the brain of a conscious animal must relate perception to feeling and value, whether inherited or acquired. These are the constraints –feeling and value- that give direction to selection within the body and brain” (Edelman 1995, 40). Edelman then describes how this complex process of continual recategorization of experience and movement of the body has links to motor features of artistic expression which we relate to as ‘memory’. “The notion of bodily-based metaphor as a source of symbolic expression fits selectionist notions of brain function to a T. As Gombrich has put it, the artist must make in order to match” (Edelman 1995, 41). He concludes the essay by stating, “I hope that artists will be pleased to hear that the process of selection from vast and diverse neural repertoires, giving each of their brains a unique shape, may be a key to what they have already discovered and expressed in their creative work. The promise of this idea is its ability to account for the individuality of our responses, for the coexistence of logic and ambiguity as expressed in metaphor, and for the actual origins of the silent bodily-based metaphors that underlie artistic expression. When scientific verifications and extensions of these notions occur, we will have a deeper understanding of how artistic expression, in an enduring silence of wordless metaphors, often historically precedes explicit linguistically expressed ideas and propositions. Art will then have a sounder and more expansive link to scientific ideas of our place in nature” (Edelman 1995, 43-47).

The research into emergent improvisation gave us a series of experiments where we could observe dancers signaling each other in self-organizing structuring processes. This experience of witnessing new “emergent” forms among an ensemble of dancers gave us insights into what kinds of questions we might want to ask about structuring principles across disciplines. Some of these questions are:

Must a living agent, in order to participate in a self-organizing ensemble, be embodied? (Embodied, in this context, implies a tactile, kinesthetic sense of touch and boundary in time and space.)

In order for agents to structure themselves into groups where there is no outside instruction, must movement be central to forming?

Is connection, bonding or coherence among agents that create ensemble structures always connected to pleasure (which might include food, absence of pain, aesthetic beauty, building shelter)? Therefore, are ordering principles necessarily pleasurable?

In order for emergent structures to appear, must all topological levels be acting at once? Topological levels in this case are both local interactions, small group ensemble interactions, and global interactions as well as developmental principles, spatio-temporal principles, and constraints.

Does selection over time refine a structure as well as create new adaptable ones?

Is there a connection between adaptive functionality of a system and aesthetic beauty?

What does the relationship between Edelman's ideas of integration and differentiation and Kauffman's NK models tell us about structuring principles?

How do we measure in a dynamic system the exact point of criticality where the pattern emerges that describes the particular integration structure with the number and movement of the differentiated agents? Can we predict when those patterns will occur for any particular system?

Whether one is looking at flocks of birds, ensembles of dancers or neuronal networks, these questions, appropriately framed for the particular instance, seem pertinent. Questions of structure are of extreme importance across disciplines. While humans will always interact from a psychological framework unlike other living systems, all systems appear to need structuring in order to survive. Complex structuring is particularly challenging because of new ways of looking at nonlinear sequencing, communication across distances with spatio-temporal and kinesthetic signaling, analysis of particular constraints within a context, and new investigations into morphological concepts.

In this general theory of emergence, movement and structuring principles are key elements. Robert Laughlin (1998 Nobel Prize in Physics) has written, "Nature is regulated not only by a microscopic rule base but by powerful and general principles of organization. Some of these principles are known, but the vast majority are not" (Laughlin 2005, xiv). If the vast majority of principles of organization are not known, it is possible that they are there for us to be discovered on all levels, scientific as well as artistic. These structuring principles might be organized in levels of interactive analysis, analyzing, as in complex systems, such that we need to see the whole picture at once as well as individual levels. These levels include first the systems approach where much research is occurring. Second is the developmental or morphological approach, where much

research has occurred in relation to the development of organisms, but not much related to structuring principles, and the psychological approach, where the structuring of meaning and metaphor is integral to emergence and complexity, and can be directly related to social systems and artistic expression (Borden, personal communication with Sgorbati 2006).

Thus, in conclusion, we observe some common themes across scientific and artistic disciplines on emergence: It is a property that arises out of self-organizing ensembles. Movement is an essential component of the self-organization. Constraints are necessary as are boundaries of time and space. Structuring principles dictate the type and nature of the emergence. They are found in a unique ordering that is a relationship between integration and differentiation.

In our case, scientists and artists have begun a real conversation about a particular resonance to emergent structures across these disciplines. This theory suggests that living complex dynamical systems may share some unified experiences while making rigorous distinctions critical. (For example, molecular interactions are not sentient the way interactions among dancers are). As Edelman suggests in connecting pattern recognition, selection and creativity, it may be that all living systems move toward creative ways to structure themselves in their environment based on a higher degree of adaptability. What may seem destructive to one group may seem perfectly ordered and coherent to another. For the sake of this discussion, rather than put a judgment on order or disorder, it might behoove us to observe and describe the structuring principles we see around us in order to best understand them, to recognize them, and then to determine their efficacy or destructive power. We might then be able to determine which structures work best within certain constraints, the length of their life spans, how much learned information is necessary for agents to participate in building them and gain a deeper appreciation for the beauty in patterns around us. We conclude with a quote from Stuart Kauffman from *At Home in the Universe*:

> The emerging sciences of complexity begin to suggest that the order is not all accidental, that vast veins of spontaneous order lie at hand. Laws of complexity spontaneously generate much of the order of the natural world. It is only then that selection comes into play, further molding and refining… How does selection work on systems that already generate spontaneous order? .... Life and its evolution have always depended on the mutual embrace of spontaneous order and selection's crafting of that order. We need to paint a new picture. (Kauffman 1995, 8-9).

We look forward to continuing our exploration into these matters and to encourage artists and scientists to engage in this fruitful dialogue.

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