Toward a Science of Consciousness: The First Tucson Discussions and Debates

edited by Stuart R. Hameroff, Alfred W. Kaszniak, and Alwyn C. Scott



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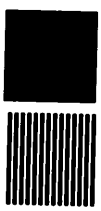
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45 A Framework for Higher-Order Cognition and Consciousness

Nils A. Baas

INTRODUCTION

The idea of viewing consciousness as an emergent property of the brain is not new. Especially Sperry has strongly argued this point of view (for example Sperry 1983). Recently also Hameroff (1993) and Scott (1995) have argued in the same direction. Our own interest in this comes from an attempt to understand how complex systems are built from simpler ones and how new properties are being created. Intuitively complex structures arise when more primitive structures are being put together in a nontrivial way. Certainly the brain is a complex hierarchical structure of neurons, and out of this complexity consciousness seems to emerge. The question is then: What kind of hierarchical complexity and what does emergence mean?

Therefore it seems fruitful to introduce a formal framework in which emergence, complex structures, and hierarchies can be discussed. The unifying concept we call a hyperstructure, which defines what reasonably should be called a higher-order structure or object (Figure 45.1).

EMERGENCE

The notion of emergence will play a key role in our approach to consciousness. Often emergence is being used in rather vague terms; therefore, we will introduce a more precise framework for emergence.

Intuitively, emergence is used as a name for the creation of new structures and properties. Therefore it has been intimately connected with the theory of evolution. We shall not discuss the history, development of emergence—or present-day approaches to emergence, but just refer to the references.

Which are the basic ingredients needed in order to explain what is meant by emergence? We need some primitive objects or entities. For something *new* to be created we need some dynamics or better—*interaction*—among the entities. But in order to register that something new has come into existence, we need mechanisms to observe the entities. This is intuitively the idea we have in mind and would like to express in a more formal language. But we can only represent events for which we have "meters" (Minch 1988).

We shall start out with a general notion of *structure* as our primitive objects or entities. Structures may in our sense be of an abstract or physical nature, for example, systems, organizations, organisms, machines, spaces, fields, symmetries, and concepts. Furthermore we assume that we have some kind of observational mechanism (or family of such) in order to evaluate, observe, and describe the structures. Of course such mechanisms can be defined in many ways—classically as numerical functions—but as we have seen in quantum mechanics more sophisticated ones may be needed (operators). In fact they may be very general (functors—in a category theory setting). We want to give a general procedure for how to construct a new structure from a family of old ones. So we start with a family of structures:

$$(S_i)\ i \in J \text{ (some index set, finite or infinite)}$$

Then we apply our observational mechanisms—*Obs*—to obtain properties of the structures:

$$S_i, Obs\ (S_i)$$

Next we subject the S_i's to a family of interactions—*Int*—using the properties registered under the observation (which could be a dynamic process). Hence we get a new kind of structure:

$$S = R\ (S_i, Obs\ (S_i), Int)_{i \in J}$$

where R stands for the result of the construction process.

We call S a *second-order structure*—as opposed to the S_i's which we consider *first-order structures*—the primitives of the theory. Specifying the observational mechanism is basic and we may also require some stability of the observed properties. The interactions may be caused by the structures themselves or imposed by external factors. Basically we are describing how to form a totality out of a family of structures. The observational mechanism may not only be of an external nature, but also of an internal nature.

In mathematics we have many examples of such constructions. Of particular interest in connection with emergence are *limits* in so-called categories, but we do not want to restrict ourselves to this situation. Also our notion of observation plays a crucial role. *Obs* is related to the creation of new categories in the systems (categories here in the philosophical meaning of the word).

Let us prepare the notation for further steps. First-order structures—our primitives—are denoted by:

$$S^1_{i_1}, i_1 \in J_1,$$

second-order structures

$$S^2 = R\ (S^1{}_{i_1}, Obs^1, Int^1)$$

and families

$$\{S^2_{i_2}\}, i_2 \in J_2$$

Second-order structures may now be observed by observational mechanisms Obs^2 (they may be equal, overlap, or disjoint from Obs^1), and they may also observe the first-order structures of which they consist. (We may allow first-order structures to be considered also as second-order structures $S^2 = R(S^1)$, in the same way as in set theory an element of a set may also be considered as a subset $\{x\}$.)

The collection S—which is more than a mere aggregate—is considered as a new unity, whose properties we measure by Obs^2.

In this quite general setting we propose the following:

Definition Of Emergence:

$$P \text{ is an emergent property of } S^2$$

if

$$P \in Obs^2(S^2), \text{ but } P \notin Obs^2(S^1{}_{i1}) \text{ for all } i_1.$$

So in this sense we may say that:

The whole is more than the sum of its parts.

This is what we shall call *first-order emergence.* In the next section we shall define higher-order emergence (Figure 45.2).

Let us finally point out that this also relates to cognition, which may be defined as "the emergence of global states in a network of simple components" (Varela, Thompson, and Rosch 1992). For more on emergence, see Appendix 1.

HYPERSTRUCTURES

Hierarchical structures occur often in biological systems. It seems that they have been favored by evolution. In studying multilevel systems, a basic problem is the passage from one level to the next. It is like going from one set of biological or physical types to a higher-order type. In a way this is analogous to type theory in logic. It is our opinion that going from one level to the next is exactly what emergence is about. Therefore, in developing a framework and theory for higher-order structures, emergence—in our sense—will play a vital role. We shall not only cover the classical hierarchical tree-type situation, but also the "flatter" network-type structures. All this will be embraced in our notion of a hyperstructure—so we shall now give a general introduction.

In our definition of emergence we considered structures at two levels: primitives, or first-order structures, and second-order structures. We may say that a structure formed as S^2 is a *complex* structure relative to its primitives. The "observer"—which could be just the environment of a system—represents a kind of *selection* mechanism giving rise to a process creating *new levels of structure.* This also gives *adaptation* relative to *Obs* (or environment). So we have a mechanism of *evolution* towards a higher-order

structure. Level structures are often thought of as *hierarchies*, but hierarchies with the traditional tree-type structure are insufficient for our purposes—though they will appear as special cases of our construction. We shall return to this later.

Next we proceed to form families of second-order structures. They are being observed to obtain new second-order properties and interactions, giving:

$$S^3 = R\,(S^2_{i_2}, Obs^2, Int^2).$$

In general, Int^3 may be interactions based on both first- and second-order properties. Now this process proceeds and we see that at each level of construction new properties or new behavior may emerge, giving room for *new interactions* and, hence, each level is necessary in order to get the last level's properties. The process of *Obs* is essential and shows that this construction is much more sophisticated than a recursive procedure, which may be considered a special case. The new interactions may not be meaningful at lower levels.

Finally, we form the *Nth order structure:*

$$S^N = \mathrm{R}\,(S^{N-1}_{N-1}, Obs^{N-1}, Int^{N-1,\cdots}), i_{N-1} \in J_{N-1}$$

This is a short way of writing an Nth order structure, which in principle may depend on all lower levels in a cumulative way and is more general than a recursive structure. The whole process we call *the higher-order structure principle*—the result of which we call a *hyperstructure,* in this case of order N (or an emergent structure of order N).

The underlying interaction graph in Figure 45.3 is much more subtle than merely trees (as for ordinary hierarchies) or general graphs or networks.

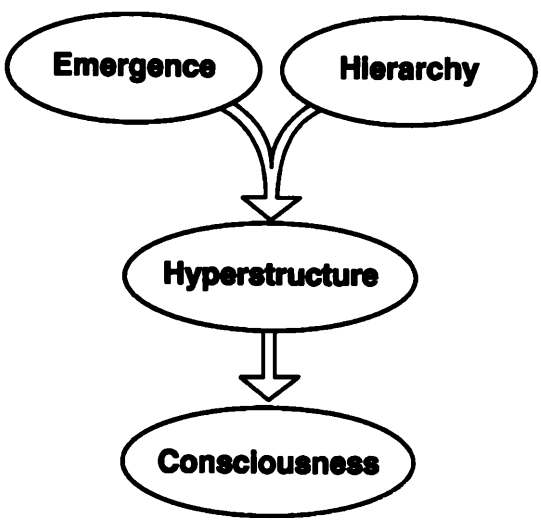


Figure 45.1 Hyperstructure in relation to consciousness.

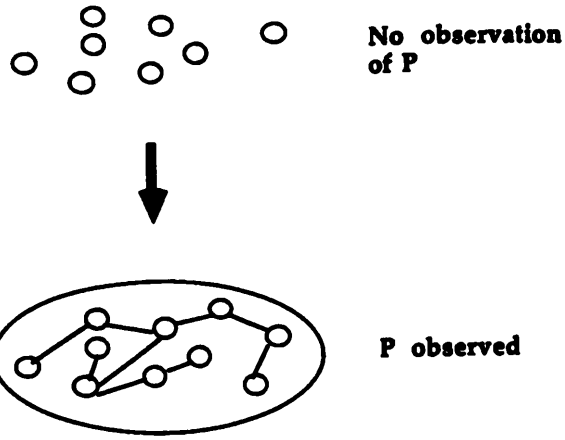


Figure 45.2 Emergence as a function of observation.

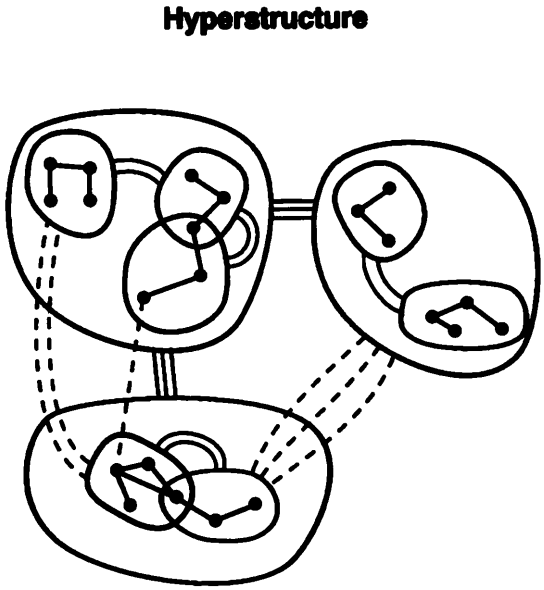


Figure 45.3 Schematic example of a hyperstructure.

We think that this is a general and important process that may be applied to a variety of structures (systems) in order to obtain new—*fundamentally new!*—structures with new emergent properties. Through the level structure, we also get orders of emergence and complexity, indicating a classification of such structures. *Nth order emergent properties are those of* S^N, *which is a cumulative structure.*

We shall not write down in technical details the rules of the interactions at the various levels, but just refer to Figure 45.3, which describes the intuition. It is worth noting that we allow (not require) overlapping aggregates and that creation of high-level interactions may cause changes in lower-level interactions. Hyperstructures allow for both "downward" and "upward" causation. As a model one may think of interactions of organizations and social systems. If needed, interactions may also be deleted (or forgotten) so that the system is only partially cumulative.

It is our conviction that *complexity often takes the form of a hyperstructure.* This is an extension of H. Simon's thoughts about complexity and hierarchies (Simon 1962). The formation principle we have described for hyperstructures may be useful in understanding for example cognitive and constructional processes. It is really a framework for studying problems of *complex design* (Dawkins 1986). In a sense it reflects the principle of evolution where observation and interaction are due to the various environments and the structures themselves. But in our model we allow for introducing new observations and interactions and controlling them, hence being able to influence the evolution and even speed up evolution. This flexibility clearly makes the structure more easily adaptable to various changes, and the *Obs* and *Int* mechanisms will allow for creativity (of non-predictable nature), learning, and so on.

Two basic questions for hyperstructures are:

1. How to build good models generating higher-order hyperstructures from first principles?
2. How to organize matter in a hyperstructured way and what are the properties?

We consider self-organization as a hyperstructured process.

For more on hyperstructures, see Appendix 2 and Baas (1994a, 1994b). We will next try to connect our framework with cognitive processes and consciousness.

HIGHER-ORDER COGNITION AND CONSCIOUSNESS

If we think of cognition as the appearance of global states or properties in a network of primitive components, we need a kind of *Observer* in order to recognize or register these new states or properties. The Observer could, for example, be some kind of sensory system. Therefore, cognition may be viewed as emergence in our sense.

The new states or properties will give rise to new interactions among networks again, new *Observations* and this will eventually lead to a hyperstructured process as a model for higher-order cognition.

Our point is that cognitive processes are not only *syntactic* but also *semantics.* The semantics are represented by the Observer. Reasoning is a combination of using syntactic rules, observations, and interactions over and over

again. For cognitive structures one could appropriately call this *emergent deduction* expressed as:

$$\frac{S^1}{\frac{S^2}{\vdots}}$$

like inference rules in logic. But this remains to be developed further.

We think that hyperstructures may provide a useful framework for describing and studying cognitive processes. As pointed out previously the use of Observers in the construction may cause nonalgorithmic behavior.

In general we view organisms as examples of hyperstructures where we take cells as primitives—not meaning that we necessarily understand all the emergent processes involved. Depending on the purpose we could also have taken atoms or molecules as primitives. For these structures life—under any reasonable definiton—becomes an emergent property.

With respect to human consciousness, we will think of it as associated with the brain and considered a complex system of neurons. Based on available evidence (for example, Scott 1995, Sperry 1983 and references therein)we may take neurons as primitives and are led to the following suggestion:

The brain is hyperstructured and consciousness is an emergent property of high order.

Consciousness is therefore emergent in the same way as life is, but at different scales with different primitives and orders. This is similar to Alwyn Scott's (1995) point of view.

Assuming that the brain is hyperstructred in some way one may ask: *Are there areas of special importance for the coherent functioning of the higher-order level structures?* (Not meaning strict localization!) Broca's and Wernicke's areas may be candidates in such a scheme. This should be related to Edelman's theory of higher-order consciousness in Edelman (1989).

The hyperstructure hypothesis is supported by the cell assembly theory of D. Hebb and the work of T. Wiesel and D. Hubel on the structure of the cat's visual cortex (see Scott 1995 for a discussion).

Interesting ideas on higher-order cognition and consciousness are presented in Ehresmann and Vanbremeersch (1992). Their approach is basically within the framework of our hyperstructures, but it uses the language of category theory.

We hope that putting consciousness into the present framework may lead to new and interesting questions and ideally to experiments and a theory with predictive power. At the moment this is too much to ask. We should also emphasize that what we have said about consciousness is merely speculations based on selected available evidence and subjective interpretation.

QUESTIONS AND CONJECTURES. WHAT IS CONSCIOUSNESS? WHAT IS LIFE?

These two fundamental questions are not directly related but they are in a way very similar. In recent years there has been intense activity in order to characterize life and life-like behavior. This is what the new field artificial life is about (Langton 1988). Therefore it seems natural to search for a similar characterization of consciousness and conscious-like behavior. This leads to a new notion of *artificial consciousness* to be studied.

We suggest the following:

Conjectures

A. For a medium to have consciousness it must be organized as a hyperstructure.

B. Consciousness is a hyperstructured cognitive process.

These conditions should be considered as necessary, but not necessarily sufficient. Furthermore, this implies that consciousness is a *multilevel process* and that we may have *degrees* of consciousness. Clearly, human consciousness should be of a very high degree or order, but there may be higher! In this context consciousness is obviously an emergent phenomenon.

In Baas (1994b) we suggested that it could be interesting to form various new kinds of matter into hyperstructured materials using methods from nanotechnology. Such hypermaterials (or "nano-matter") could possibly represent a new kind of matter bridging the gap between living and nonliving matter.

Question 1 Could there also be some notion of consciousness—bridging the gap between unconscious and conscious? Is the difference basically a matter of difference in degrees of consciousness? Unconsciousness meaning low order consciousness?

As mentioned earlier, it seems natural as a starting point to take neurons as primitives in a hyperstructure for studying consciousness. But our framework allows for taking primitives at the nanoscale level as well in order to incorporate quantum effects. The importance of quantum effects have been argued by Hameroff (1993) and Penrose (1989).

Penrose argues that "there must be an essentially nonalgorithmic ingredient in the action of consciousness." It should be pointed out that nonalgorithmic behavior may not only arise from quantum effects, but also from structures associated with nonlinear interactions in the hyperstructure as pointed out in the section on emergence. Equally important is another statement by Penrose: "Consciousness is needed in order to handle situations where we have to form new judgements, and where the rules have not been laid down beforehand."

This motivates question 2.

Question 2 Is consciousness more of a principle of how a medium may form new Observational (semantic) mechanisms and structures in order to create and handle new types of situations, form judgments, and so on? Again, leading to "higher-order semantics" via newly created observational structures?

How can quantum mechanical effects possibly influence macroscopic processes such as consciousness? S. Hameroff has argued that quantum coherence among neural proteins may explain this. Cytoskeletal components such as microtubules may be particularly suitable for quantum level effects because of their quasicrystalline structure, proposed coherent excitations, and molecular, nanoscale dimensions (Hameroff 1993). He then suggests that microtubules and other elements of the cytoskeleton constitute the bottom level substrate in the dimensional hierarchy from whose highest level consciousness emerges. This is closely related to the question of quantum coherence and coherent excitations in biological systems (Fröhlich 1968, Ho and Popp 1993).

This leads us to question 3.

Question 3 Could it possibly be the case that hyperstructures represent a kind of coherent organization of a medium that would stimulate or facilitate the occurrence of global quantum effects?

This is thought of as an extension of the situation in microtubules. Proteins are vibrant and dynamical structures, and the coherent excitations are cases of emergence. In a hyperstructured medium we may get excitations and vibrations at several levels, but could we then under favorable conditions expect a transfer or propagation of local effects to global effects via the same mechanisms that cause the emergence and tie the hyperstructure together? In general vibrations in hyperstructured media seem like an interesting phenomenon, and may be closely connected with consciousness.

CONCLUSION

We have presented a framework for emergence and higher-order structures and discussed higher-order cognition and consciousness within this framework. Based on this we have presented some thoughts and questions that we hope will stimulate further work on consciousness.

The appendices contain more details from Baas (1994a, 1994b), see also further references therein.

APPENDIX 1: MORE ON EMERGENCE

It may be useful to distinguish between two different notions of emergence—for quite deep reasons both mathematically and philosophically.

A. *Deducible or computable emergence* means that there is a deductional or computational process D such that $P \in Obs^2$ (S^2) can be determined by D from $S^1{}_{il}\ Obs^1$, (Int^1).

B. *Observational emergence* if P is an emergent property, but cannot be deduced as in *A*.

Let us indicate a few examples.

Deducible Emergence

1. Coupled or compositional structures (finite or infinite) where the components interact in known ways such that we can deduce or calculate the *new* composite properties. This is the case in many types of engineering constructions.
2. Nonlinear dynamical systems where, for example, simple systems interact to produce *new* and complex behavior. Chaotic dynamical systems may theoretically be of type A, but in practice may be usefully thought of as type B, and hence cases of borderline emergence.
3. Phase-transitions—emergence in the thermodynamic limit. Broken symmetries.
4. A simple and explicit example is the following. Given two simple dynamical systems:

$$S_1^1 : \dot{x} = ay$$
$$S_2^1 : \dot{y} = -bx$$

$Obs = Obs^1 = Obs^2$ = set of various properties of the system, including existence of periodic solutions.

P is the property of having a periodic solution.

Therefore $P \notin Obs\ (S_1^1)$ and $P \notin Obs\ (S^1{}_2)$. We then let the systems interact to form a predator/prey model *a la* Lotka-Volterra:

$$S^2: \begin{aligned} \dot{x} &= ax - cxy \\ \dot{y} &= -bx + dxy \end{aligned}$$
$$(a, b, c, d > 0)$$

It is a simple well-known fact that $P \in Obs\ (S^2)$, hence an emergent property (of type *A*) caused by the nonlinear couplings or interactions.

5. Depending on our choice of observables we can also create emergence linearly. Let us observe oscillatory solutions. We may consider linear systems with no oscillation, but when coupled linearly we observe oscillatory solutions.

   This shows the importance of *Observables* in our theory, and also how it gives great flexibility.
6. In topology, a manifold is a space that is glued together by locally Euclidean pieces.

$$M = \cup^{n}_{i=1} V_i / \sim$$

To study or observe such spaces one uses for instance cohomology theories K^*. We know that $K^*(V_i) = 0$ (trivial), but $K^*(M)$ may be very complex. Let $Obs = Obs^1 = Obs^2$ = set of properties including measuring the nontrivial complexity of K^*. P property of nontrivial K^*. Then $P \notin Obs\,(V_i)$, but

$$P \in Obs\,(M)$$

In this sense we may say that the nontriviality of $K^*(M)$ has emerged from the gluing construction. Lots of similar examples exist in topology and algebra where, for example, gluing is replaced by limits.

7. The Scott-model of the λ-calculus. Let X be a set, $[X \to X]$ = the set of mappings from X to X.
   Consider the *set* equation:

$$X = [X \to X]$$

Within set theory this is not solvable. In constructing a model of the λ-calculus D. Scott considered spaces D_i, with a special topology and continuous mappings $[D_i \to D_i]$. He started with a very simple set D_0, formed

$$D_1 = [D_0 \to D_0]$$

and inductively

$$D_{i+1} = [D_i \to D_i]$$

in such a way that they formed an inverse system

$$D_0 \leftarrow D_1 \leftarrow \ldots \leftarrow D_i \leftarrow \ldots \leftarrow D_\infty$$

where D_∞ is the so-called inverse limit.
For all i

$$D_i \neq [D_i \to D_i]$$

but in the limit

$$D_\infty = [D_\infty \to D_\infty].$$

Let us put this into our framework.
Set

$$S^1_i = D_i$$

$$Int^1 = \leftarrow$$

$Obs\,(D) = Obs^1(D) = Obs^2(D)$ = set of properties of D, being a solution of the equation $D = [D \to D]$.

$$P = \text{property of being a solution of } D = [D \to D].$$

Then we have:

$$P \notin Obs\,(D_i), \text{ but}$$

$$P \in Obs\,(D_\infty)$$

So we may say that the property of being a solution to the equation emerged through the inverse limit construction. For details, see Stoy (1977).

In these examples we assume that the various properties can be decided by well-defined procedures. Therefore *Obs* is really a procedure or algorithm leading to a set of properties. Some of these examples may look rather abstract and formal, but we think they will help us in better understanding the nature of emergent structures and properties.

Observational Emergence

1. A profound example here is Gödel's theorem (Gödel 1986), which states that in some formal systems there are statements that are true, but this cannot be deduced within these systems. Here observation is the truth function. We think of this as follows: first-order predicate calculus is complete in the sense that every true statement can be deduced from the axioms. If we now add further axioms to cover the theory of arithmetic, Gödel's theorem says that there will be true statements that cannot be deduced (internally). We view here the additional axioms as "added interactions" among the well-formed expressions.
2. Consider a dynamical system in some space. View the dynamics as an interaction and associated fractal-like sets such as attractors, repellers, Julia sets, and so on as newly created second order structures. *Obs* is deciding membership in these sets.

Penrose (1989) raised the question: Is the Mandelbrot set decidable? (That is, can membership be algorithmically decided; in our terminology, is it deducible?) In order to make the question mathematically meaningful, it had to be put into a new theory of computation over the real numbers developed by Blum, Shub, and Smale (1989).

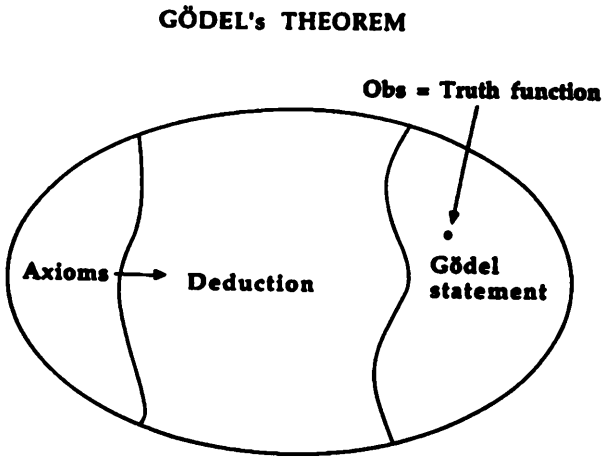


Figure 45.4 Schematic illustration of Gödel's theorem.

They showed that most Julia sets are undecidable. In 1991, M. Shishikura (1991) completed the proof of the conjecture that the Mandelbrot set is also undecidable.

So in a suitable choice of structure in our framework, we may view Julia sets (most of them) and the Mandelbrot set as observationally emergent structures.

3. Another example of the difference in our two notions of emergence is the following. In a formal string system we have a syntactic relation

$$s = R\,(s_1, \ldots, s_k)$$

Take as our *Obs* a semantic "meaning function" M. The question about semantic compositionality is then: Does there exist a (computable) function F such that

$$M\,(s) = F(M\,(s_1), \ldots, M(s_k))?$$

If yes, $M\,(s)$ is *deducibly emergent.*

If no, $M\,(s)$ is *observationally emergent.*

We have here only considered two basic classes of emergence. Clearly both can be further refined and subdivided according to additional complexity conditions.

The notion of observational emergence is quite profound as the examples show. Gödel's theorem as observational emergence may at first appear as a rather negative result for constructive purposes. But it is not. The reason is that we have incorporated the observational mechanisms in such a way that they can be usefully taken into account in further constructions—even if they are not deducible or computable. This is an important aspect that will be used in our hyperstructure concept. Our discussion here shows that even in formal, abstract systems profound emergence may occur—particularly in artificial life models. This seems to be contrary to a claim by Cariani (1991).

We have here given a general framework for studying emergence, but we have not discussed the detailed causes of emergence. Let us mention as an observation two basic causes:

1. Nonlinearity of the interactions, meaning that there is no superposition, principle.
2. The number of structures (systems, entities) is often large (number $\to \infty$).

When these two conditions are satisfied, emergent phenomena will often occur. For a more general discussion of the relation between limits and emergence, see Ehresmann and Vanbremeersch (1987). We end this section with an old and provocative question: Does emergence in some cases—as contended by Mill, Lewes, and Morgan—rank among the *laws of nature* (Morgan 1923)?

MORE ON HYPERSTRUCTURES

Let us give some examples of known structures that may naturally be considered as hyperstructures—but without details.

1. Higher-order organisms viewed as evolutionary products.
2. Hypercycles in the sense of Eigen and Schuster (1979). Here the *Obs* mechanism registers the properties leading to intercyclic coupling and hence higher-order cycles.
3. Coupled nonlinear dynamical systems may often be viewed as hyperstructures through the appearance of, for example, limit cycles and attractors.
4. Higher-order logic and set theory. In the syntactic build up, no use of *Obs* is made. *Obs* would normally be thought of as part of the semantic structure. In a sense oracles may be considered as observers. Furthermore, higher-order (or high-level) languages and metaconstructions may also be viewed as hyperstructures.
5. Higher-order graphs and networks—formalizing the structure illustrated in Figure 45.3. This also extends the already existing notion of a hypergraph—which in our terminology is a second-order structure.
6. Various types of hyperspaces in mathematics. These are spaces of the form 2^X (or suitable subsets or iterations of this construction). 2^X = {set of subsets of x}. Fractals are naturally studied in spaces of this type.
7. Cognitive processes where we successively build up knowledge by "observations" and "interactions."
8. General technological constructions designed in a modular or levelwise way and metatype constructions in system theory.

It is important to notice that the higher-order structure principle can be used to synthesize new structures by varying the *Obs* and *Int* structures. To a large extent we can vary the "laws" or rules at each level, but in real-life evolution they are due to nature. *Obs* and *Int* may even vary continuously—by some kind of sensor-device. In other structures, *Obs*, for example, may play no role—as in higher-order logic considered syntactically. An important way to look at the interactions is as communication or information processing. For every level, the information-carrying capacity increases. In the successive formation of levels in a hyperstructure, we may have to impose more conditions depending on the situation—especially conditions on *stability* and *autonomy* seem to be relevant.

Hyperstructures should be thought of as a language—a framework—to describe complex problems, solutions, and situations. We may also generate a whole series of interesting questions and notions trying to associate hyperstructures with well-known structures, systems, concepts, symbols, signs, and so on, for example, hypernetworks, hyperlanguages, hyperdynamics, hyperalgorithms, hypercomputation, hyperforms, hyperpatterns,

. . . also, physical and social systems may be organized in this way leading, for example, to hypermaterials and hyperorganizations. In all the cases we have to specify *Obs* and *Int*. New observational structures may also emerge.

This is a very general and broad program, and further progress will depend on the study of *specific* examples of these structures from various angles: mathematical, physical, chemical, biological, and computational.

Also in nanotechnology, hyperstructures may represent a useful architectural scheme. It is absolutely conceivable that it could give new results combining emergence and levels of observation. The purpose is of course to design a system from which primitive building blocks construct new levels with new properties.

What kind of emergence of levels do we have in mind? Biological molecules emerge in a sense from lower-order molecules. Cells emerge from biological molecules. Organisms emerge from cells. Ordinary chemical (low level) molecules emerge from atoms. We do not claim that these processes of emergence are fully understood. But putting these together we get higher-order emergence—as we have tried to formalize in hyperstructures. Of course many more levels may be involved. It is important in the hyperstructural scheme to include the notion of an *Observer* as we have done. This will allow us to actively enter the evolution-process—if desired, and in many cases direct and speed up evolution. *So we get a scheme for man made evolution.* This should be compared with the recent methods developed for example by Beaudry and Joyce (1992) in order to mimic molecular evolution to obtain biological molecules with novel properties.

The possibility of getting new properties increases with the ability to manipulate lower and lower levels. It is also important to use the ability to complexify the lower nanolevels—as has been done successfully with the introduction of microchips and integrated circuits. Here we enter the world of quantum mechanics.

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