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On Emergence and Explanation

Emergence is a universal phenomenon that can be defined mathematically in a very general way. This is useful for the study of scientifically legitimate explanations of complex systems, here defined as hyperstructures. A requirement is that observation mechanisms are considered within the general framework. Two notions of emergence are defined, and specific examples of these are discussed.

Key words : mathematical definition of emergence, complex systems, hyperstructures, observation mechanisms.

A propos de l'émergence et de l'explication. L'émergence est un phénomène universel qui peut être défini mathématiquement d'une manière très générale. Il est utile de le faire pour l'étude d'explications scientifiquement légitimées des systèmes complexes, ici définis comme des hyperstructures. Une conditiopn est alors requise : que les mécanismes d'observation soient eux-mêmes considérés comme appartenant au cadre général. Deux conceptions de la notion d'émergence sont alors définies, et des exemples spécifiques en sont donnés.

Mots-clés : définition mathématique de l'émergence, systèmes complexes, hyperstructures, mécanismes d'observation.

1. INTRODUCTION : TO EXPLAIN

Living as cognitive beings in a world of stability and change, we permanently face known and unknown situations, old and new phenomena — conversations, happenings, shifting perceptual patterns of the world, but not often true chaos, nor strict regularity. We usually cope with the complexity of ordinary life in a way so easy and by such

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seemingly simple patterns of behaviour — when seen from the higher level description of ordinary language (or 'folk psychology') — that it is astonishing to realize the underlying complexity of this 'problem solving behaviour' from a scientific point of view, i.e., when we try to relate descriptions of the body as a complex system and its environment (as given by physics, biology and cognitive science) to the life and actions (as experienced) of our daily world.

What does it mean to understand something ? In the sciences, understanding is related to — or even equated with — the notion of explanation. To claim that a phenomenon is well understood, some explanation must have been offered that is sufficiently precise, publicly communicable, and providing us with some kind of generative mechanism for the phenomenon : If you understand a particular solution to an abstract mathematical problem, you can explain this by proving it to be true step by step or by giving other kinds of logically convincing arguments for this solution. If you claim fully to understand a phenomenon or pattern in Nature, you are thought to possess an explanation of it in terms of some mechanism that can be shown capable to generate — in the explanation — the phenomenon in question. In the so-called sciences of complexity (e.g., non-linear dynamics, theoretical biology, complex adaptive systems, artificial life, artificial intelligence, cognitive science), "complex" phenomena, such as the appearance of life on Earth, the evolution of new species, or the structure of cognitive thought, are often considered as instances of some emergent higher-order structure that may be explained by the lower-level dynamics generating the collective behaviour or emergent property of the system in question. Thus the old idea of emergent evolution (cf. Blitz 1992) has recently attracted much attention and created new interest in the level-structure of the universe.

Can the emergence of really new properties in complex systems be explained ? If the sciences of complexity offer important new insights, theories, and methodologies for dealing with complex, higher-order phenomena (as we think they do), and if the traditional view of explanation cannot account for the explanatory strategies we find here, we should look for other accounts of scientific explanation. Perhaps the very idea of scientific explanation as a strictly deductive argument should be reinterpreted and explanations seen in a more dynamic and context-dependent setting, eventually themselves being emergent structures, "emergent explanations". We will show below how this intuitive idea can be made precise and explicated formally. Questioning traditional notions of explanation may lead to a more general view of what constitute genuine scientific understanding of complicated phenomena. We suggest to pay attention to a new general framework for description of higher-order structures (hyperstructures) which includes the mechanisms of observation, and which eventually allows for self-generation in such systems of new observational frames. New observers may also emerge in the system (Baas 1996).[1]

Within philosophy of science, a lot of work has been done on giving detailed accounts of what constitutes an explanation and what are the relations between explanation and the concepts of reduction, cause, system, determinism, probabilism, etc. We will not address this work here. We feel, however, that when it comes to such questions as the very generation of explanations, the discovery of new structures or principles, the appearance of new insights to the inquiring mind — i.e., the emergence of structures that can be said to explain a phenomenon — very little has been said. The feeling of having explained a phenomenon cannot simply reduce to the fulfilment of some algorithmic procedure by which — given a general law and some initial or boundary conditions — you can arrive at the phenomenon to be explained by executing this procedure. Of course, one can argue that it is the very laws of nature that has the explanatory power in physical science, so any research programme should attempt to discover such laws. However, in understanding complex systems, the challenge is often to understand the consequences of these laws on other levels of organization, i.e., to understand the history and complexity of the boundary conditions (compare Küppers 1992). In a way, understanding a system means creating some kind of generalized resonance !

Traditional deductive notions of scientific explanation have frequently been criticised for being too crude and reductive to account for complex mental phenomena. Hence, in a somewhat romantic vein, the mathematician G. Spencer Brown (1969) declared that :

> "To explain, literally to lay out in a plane where particulars can be readily seen. Thus to place or plan in flat land, sacrificing other dimensions for the sake of appearance. Thus to expound or put out at the cost of ignoring the reality or richness of what is so put out. Thus to take a view away from its prime reality or royalty, or to gain knowledge and lose the kingdom."

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[1] *The problem of self-generation of new observational frames is discussed from a similar though different point of view in Kampis (1991).*

We shall present a framework that may help to circumvent a pure dilemma of reductionism and holism — of gaining knowledge and retaining the richness of a world of emergent structures.

2. EMERGENCE AND HYPERSTRUCTURES

In the recent years the notion of emergence has been studied extensively, but often without making precise what emergence means. We will here use emergence in the general sense defined by Baas (1994a). The crucial point in this definition is the notion of an observer — in a very general sense, which makes it very flexible. Let us here just recall the basic idea.

In the study of complex systems one often sees that a collection of interacting systems shows collective behaviour. This is intuitively what we understand by emergence. In order to study the phenomenon further it may be useful to introduce a more formal framework as follows :

Let $\{S_i\}_{i \in I}$ be a family of general systems or “agents”. Let Obs^1 be “observation” mechanisms and Int^1 be interactions between agents.

The observation mechanisms measure the properties of the agents to be used in the interactions. The interactions then generate a new kind of structure

$$S^2 = R\,(S_i^1\ ,\ \mathrm{Obs}^1, \mathrm{Int}^1)$$

which is the result of the interactions. This could be a stable pattern or a dynamically interacting system. We call S^2 an *emergent structure* which may be subject to new observational mechanisms Obs^2. This leads to

Definition :

$$\text{P is an emergent property}$$
$$\Leftrightarrow$$
$$\mathrm{P} \in \mathrm{Obs}^2(S^2) \text{ and } \mathrm{P} \notin \mathrm{Obs}^2(S_i^1)$$

The observational mechanism may be internal or external.

Examples :

1. Coupling of dynamical systems.
2. Large collections of objects get new behaviour like in phase transitions.

3. Functionality of biomolecules in cells. The self-maintenance of a living cell is based on the structure of the cell and the functionality of its molecules : Though in general each type of macromolecule in virtue of its chemical properties (characterizable by chemical analysis) can enter into reactions with an infinite set of possible molecules, in the living cell each molecular species is committed to one or a small number of reactions that defines its specific *function* within the cell's metabolic system (e.g., catalysis of a part of a specific metabolic pathway).
4. The general situation of a client (C) and a server (S). With the interactive help from the server the client may perform tasks which none of them could do separately. Hence we get a second order agent (CS) which again may serve as a client in a new context (Baas 1997).
5. Consciousness is not a property of individual neurones, it is a natural emergent property of the interactions of the neurons in nervous system of the body in an environment. It makes a structure that is related to lower level interactions as well as higher level thoughts, and it represents a new observational mechanism of the entire system (Baas 1996).

General causes of emergence would be : non-linear interactions, large collections of limits, open-ended evolution in heterogeneous environments, context-dependence of properties in complex systems ...

Depending on the case, the $\mathrm{Obs}^2(S_i^1)$ may have elements, or it may be an empty set if for instance Obs^2 does not or cannot observe anything. E.g., if S_i^1 is some physical properties of individual H_2O molecules, S^2 is water, and $\mathrm{Obs}^2(S^2)$ is viscosity, then $\mathrm{Obs}^2(S_i^1)$ would correspond to "the viscosity of an individual molecule", a property we cannot measure, so $\mathrm{Obs}^2(S_i^1)$ is empty.

We think that the present framework is quite useful for analysing the nature of emergence — in particular the dependence on observational mechanisms. In order to put this into a more mathematical framework *category theory* is very useful. We let the systems be represented as objects in a category and the interactions as morphisms. A complex system with interactions is then represented by a diagram. Since the morphisms are represented by arrows, this may be viewed as a process oriented representation.

The observational mechanism may here be thought of as functors. In categories we may form direct limits ($\lim\limits_{\text{Æ}}$) of diagrams, and in this case the $\lim\limits_{\text{Æ}}$ may be thought as both an observation functor (Obs) and a complexification process (R).

For a further discussion of emergence, we refer to Baas (1994a, b, 1996, 1997) and for the use of category theory, Ehresmann & Vanbremeersch (1987, 1994).

As we see it here *emergence* is just the same as *holism.* An *emergent* structure is a *holistic* structure.

We should emphasize, that from this refined notion of holism, it does not follow that 'the whole' cannot be analyzed, nor that it is always impossible to deduce the properties of the whole from its constituents and the observational mechanisms. Thus, within the general framework proposed here, one must distinguish between two different kinds of emergence :

A. *Deducible or computational emergence*. There exists a deductional or computational process or theory *D* such that P Œ $\text{Obs}^2(S^2)$ can be determined by *D* from (S_i^1 , Obs^1, Int^1).

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

(Clearly, further refinements are possible !) As argued in greater detail in Baas (1994a, 1996), examples of *deducible emergence* include compositional structures in engineering constructions, nonlinear dynamical systems, phase transitions, nontriviality of complexity of manifolds in topology and the Scott model of the l-calculus. In these cases, the various properties can be decided by well-defined procedures, so *Obs* can be seen as instantiating an algorithm leading to a set of properties. Examples of *observational emergence* include 'Gödel sentences' in a formal system (the *Obs* is the truth function ; cf. Gödel's theorem), and the property of membership of the Mandelbrot set and most Julia sets. Furthermore, it was indicated that the eventual semantic non-compositionality of a language would imply that the meaning of sentences in such a language was observationally emergent.[2]

In spite of the existence in mathematics of a large set of yet undecided statements or conjectures about mathematical properties that may exemplify either deductible or observational emergence, it is a general observation that the most transparent and clear-cut cases of the two kinds of emergence are found within the logical and mathematical domain. Nevertheless, the distinction may also have considerable potential value in the empirical sciences, for instance in the ongoing discussion of reductionism and the explanatory relations between various theories. To give an example, it is a sensible intuition that the *autonomy* of biology in relation to physical science (as discussed with yet no definite conclusion by for instance Mayr 1988, Rosenberg 1985, Kincaid 1990) is, so to speak, grounded in the observational emergence of specific properties of biosystems, such as the self-reproduction of living cells. For theoretical biology it is of interest to determine in what sense such observational emergent properties, as studied by Artificial Life models, can or cannot be considered as real instantiations of living entities (compare Pattee 1982, Kampis 1991, Emmeche 1994).

One may go even further by using the concept of a living system as an *autopoietic* system (Maturana and Varela 1980), i.e., a system organized as a bounded network of processes of production, transformation and destruction of components that regenerate and realize the very network and its boundary and thereby constitute it as a unity in this new (autopoietic) space of relations. This property can, we suggest, be understood as the observational emergence in the physical space of systems that realize their own self-production, boundary and self-observation (through the boundary's distinctive or selective property, which is based on molecular recognition reactions by the

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[2] *In formal string systems, compositionality can be defined as the condition that there exists a computable function* F *such that* $M(s) = F(M(s_1), ..., M(s_k))$*, where the* s*'s are the syntactical relations and* M *is a semantic "meaning function". If we take* Obs *as our* M*, then* compositionality *amounts to deducible emergent meaning, whereas* non-compositionality *would imply the existence of observationally emergent meaning. As opposed to formal systems, the meaning of sentences in natural language are often context-dependent, i.e., the meaning of a sentence (such as "He saw the light") is not simply deducible from the meaning of its components, but dependent of the larger discourse in which it is placed. Thus,* observationally emergent meaning *constitutes a problem for the semantic analysis in the Tarski tradition (which is set theoretical, truth functional and compositional), as well as for classical AI that follows 'the formalist motto' of deducing semantics from syntax (cf. Haugeland 1985): "If you [or the AI system] take care of the syntax, the semantics will take care of itself".*

membrane-bound proteins), and thus being 'cognitive' in this primitive sense.[3] If this is true, an autopoietic system is autonomous because it realizes observational emergence of itself as an observer.

Hyperstructures are multi-level emergent structures.

Definition :

A hyperstructure of order N is given by

$$S^N = R(S^{N-1}_{i_{N-1}} , \mathrm{Obs}^{N-1}, \mathrm{Int}^{N-1}, S^{N-2}_{i_{N-2}} , ...)$$

extending the construction in the definition of emergence. This is a cumulative structure, not necessarily purely recursive. For more details, see Baas (1994a, 1994b, 1996).

The client/server situation may easily be extended to a hyperstructure of the *N*-th order clients or servers. Within the living realm, one can observe hyperstructures as realized by multicellular organisms and the community structure of ecosystems. Consciousness may be seen as a hyperstructure of mental representations embodied in the central nervous system and capable of self-observation and self-interaction.

Hyperstructures may be thought of as an organizational scheme or design principle. The role of Obs — which may also be an interacting environment — may also allow for evolution to be incorporated.

The point is to combine the notion of *emergence* and *hierarchy* into the notion of *hyperstructure*.

Our point of view — as we will try to argue — is that wherever a problem, a situation or a structure can be organized into a hyperstructure, this has an explanatory power.

3. The observer

As already emphasized, the notions of emergence and hyperstructure depend critically on an observer. We think that this is natural in as far as phenomena have to be explained through observational facts (even in the abstract sense of facts).

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[3] *Cognitive in the sense of Maturana and Varela (1980) where a cognitive domain is the entire domain of all interactions in which an autopoietic system (an organism) can enter without loss of identity. We think that the framework proposed in this paper allows for an interpretation of the theory of autopoiesis that adequately integrates evolution and emergence of autonomy into the theory.*

An example : When we model phenomena in thermodynamics by statistical mechanics we may view temperature and pressure as emergent properties and phase transitions as emergent phenomena. These are parts of collective behaviour which in many cases are well understood in a reductionistic sense in physics. However, temperature has been introduced as a formal parameter ad hoc. A deeper level of explanation — not yet reached — would be to see the *laws* of thermodynamics derived from the laws of Hamiltonian mechanics, i.e., such that temperature would *emerge*.

More informal examples may be the emergent properties of hyperstructures of biological and social systems which are deeply dependent of the existence of observers intrinsic to the system. As argued above, the single cell with its membrane bound proteins constitute an observer of some aspects of its immediate environment (other molecules that can be recognized as signals or nutrition), and multicellular organisms depend critically on inter-cell signalling. On a higher level, most if not all institutions of a human society have self-observing mechanisms (e.g., evaluation and assessment in research and production), as well as mechanisms for observing other institutions.

4. MATHEMATICS

One may ask whether a phenomenon like emergence (or holism) can be made mathematically respectable. Our answer is absolutely yes !

Take for example the ways complicated ‘surfaces’ like manifolds are being glued together from elementary pieces. New topological and geometrical properties occur, but may often require sophisticated “observational” functors like cohomology theories to be detected and described.

Furthermore, in a knot — where is the knottedness ? It is a global property, having no meaning locally.

Or in a Moebius band — where is the *twist* ? Same thing again ! (See Penrose 1995).

Category theory is the mathematical language suited for discussing structures in general. A category consists of

1) Objects : X, Y, ...
   (like spaces, groups, algebras, ...)

2) Morphisms : X Æ Y represented by arrows
   (functions, interactions)

To each pair of objects we have a set of morphisms

Mor(X, Y).

A category is closed under morphism composition

f *g*
x ææÆ y ææÆ z
? ?
Óææææææææææææ?
g o *f*

meaning that if *f* and *g* are morphisms, so is also *g* o *f*.

We can form networks of morphisms as commutative diagrams and construct their categorical limits (figure 1).

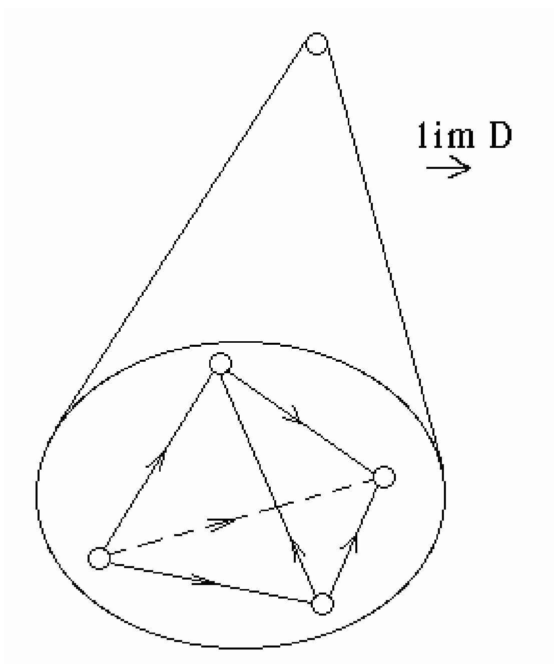

Figure 1.

D is a diagram or a network of interacting agents. The interactions are represented by the arrows. The lower large circle represents the network and the upper small circle represents the limit which is just one object reflecting the basic network properties. Thus, lim Æ D is an object which is a kind of synthesis of D and which is called the direct (or co-

)limit of D. Limits often play the role of emergent structures, see Ehresmann & Vanbremeersch (1987, 1994).

The limit construction may be viewed as a complexification process leading to new emergent properties in many cases according to some observational mechanisms. Specifically, if

$$D = \lim_{\text{Æ}} D_i \quad \text{in } C$$

$$F \text{ a functor :} \qquad F : \quad C \text{ Æ } E$$

say $F(D_i) = 0$ trivial object in E, but if F(D) is a non-trivial object in E, we may view F(D) as an emergent structure or property of the diagram. Again : *no mystery*.

5. MATHEMATICAL REDUCTIONISM AND NON-REDUCTIONISM

Within the framework of category theory we can beautifully illustrate the differences between reductionism and non-reductionism — as pointed out by Ehresmann & Vanbremeersch (1994). We appeal here to the figure 2 :

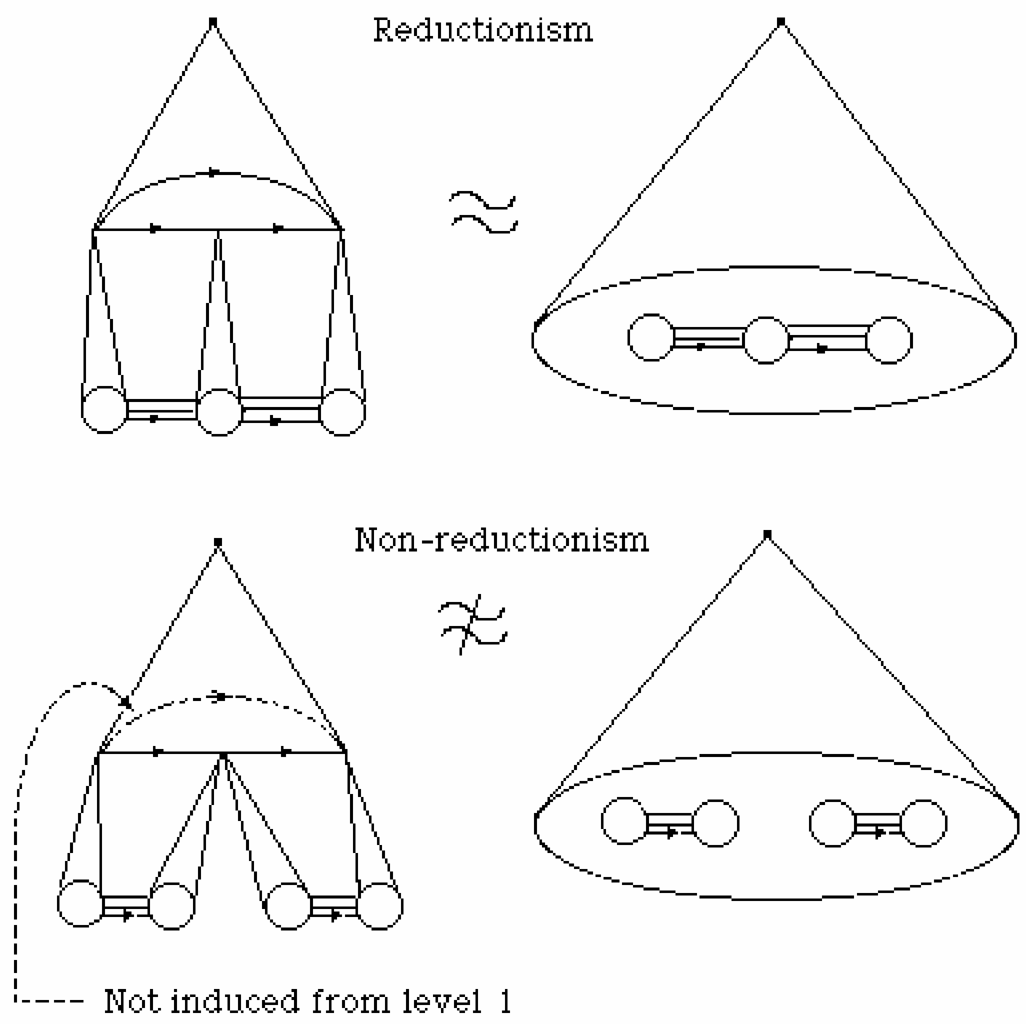

Figure 2.

The circles represent diagrams in a category, the horizontal arrows are morphisms, and the cones are limits. The arrows or morphisms represent here interactions. The diagrams show in the first case (figure 2, upper part) how higher level interactions may be *induced* from lower levels. In the second case (figure 2, lower part) it follows that higher level interactions may arise for purely mathematical reasons without being induced from lower levels.

6. EXPLANATION

Normally we mean by an explanation of something that there is a deductional procedure, an algorithm, leading us from something basic, well-known to the new thing. In essence this is reductionistic explanation as formally illustrated in the upper part of figure 2. An observer just singles out in a situation what is to be explained. Therefore deductive emergence is basically a kind of traditional reductionistic explanation, but with an observer as an additional enrichment (if not wanted, it can just be ignored !).

Non-deducible or observational emergence is more subtle. In this case there exists no algorithmic explanation. As we see in the figure in the case of limits a two level structure is needed to "explain" a structure. It cannot be explained or understood only from the primitive level. At level 2 new phenomena emerge (in this case caused by the composition properties in categories), which are needed at the next level. Even if there is no algorithm from the bottom up, still we would claim that this construction or figure is a perfectly good explanation — a second order emergent explanation ($\lim_{Æ}$ may be thought of both as a construction and as an observation).

The iterated limit construction is just a special case of a hyperstructure, which is a multilevel emergent structure. Therefore we will say that we have higher order — *N*-th order explanation of a phenomenon — wherever it occurs as a result of a suitable *N*-th order structure.

In our discussion of hyperstructure we have suppressed time, which should be added in a dynamical picture. But the basic ideas remain the same.

7. EMERGENT DEDUCTION (OR LOGIC)

In Baas (1996) the notion of emergent deduction was introduced. We may think of the scheme —

$$\frac{S_1, \ldots S_n}{S} \quad \text{rel (Int, Obs)}$$

meaning that S is an emergent structure — as an inference rule. A property observed in S, but not in the S_i's could then be said to have an emergent explanation. This extends to more levels and hyperstructures in general, and could lead to a *dynamical process logic* which we would call *emergent deduction*, which would be useful in order to explain and reason about emergent phenomena.

The important — and new — point is that emergent deduction is not only a *syntactic* process, but combines *syntax* and *semantics* in the reasoning and explanation. After all this is how much human reasoning occurs — for example mathematical thinking.

8. Emergent laws

In science we often search for fundamental laws that cannot be reduced as logical consequences of something else. But just as important as fundamental laws are it is vital to understand their consequences or what may be called *emergent laws*. These would be laws (or in general: organizational and dynamical principles) that emerge from the regularities in collective behaviour of structures — the laws that emergent structures obey. A striking example would be superconductivity. At the biological level, it could be natural selection of genetically based self-reproducing entities.

In forming hyperstructures there will be several levels of emergent laws, and they will provide explanatory tools in the sense of emergent explanation (see also Wilczek 1993).

9. Further discussion of the idea

Emergence and supervenience :

The attempt presented here to make precise the notion of emergence can be compared to a quite different though related approach, namely efforts in analytical philosophy to explicate notions of emergence and nonreducibility by refining the idea of supervenience (e.g., Teller 1984, Rosenberg 1985, Sober 1993, Savellos and Yalcin 1995). The basic idea is, that an emergent property might be one that supervenes on, without necessarily being definable in terms of (or reducible to) a physical base, even though physical facts somehow fix or determine biological and psychological facts. For example, one can (as Davidson 1970) deny that there are strict psychophysical laws even though mental characteristics are in some sense dependent, or supervenient, on physical characteristics. This means that there cannot be two events alike in all physical respects but differing in some mental respects, or that an object cannot alter in some mental respects without altering in some physical respects. Recently Kim (1994) has questioned if supervenient dependence signifies a special type of dependence relation, because the existence of a variety of ways in which one could explain why the supervenience relation holds in a given case. If so, it cannot constitute an explanatory account of the mind-body problem, and one may think that (just as with some varieties of the emergence thesis) it states the problem rather than offers a solution to it. Kim suggests mereological supervenience — the dependence of the properties of the whole on the properties and relations characterizing its proper parts —

to be a more promising notion if one wants to explain psychological properties as higher order properties of a whole organism that covary with its lower order properties.[4] We suggest that mereological supervenience should be understood as a special case of observational emergence, and suggest the framework presented above as a useful tool to develop, within the philosophy of mind, this concept further.

Explanation and insight :

On the subjective level, it is a common experience of mathematicians to have sudden “flashes of insights”. They involve the emergence in consciousness of a possible solution to a hard problem that has occupied the working mind (its conscious as well as subconscious parts) for a long time. The sudden “flash” is experienced as the appearance of the solution as a new structure, that in a sense can be observed at once, but nevertheless has to be worked out deductively in great detail and tested formally before it can be trusted. This experience has been vividly described by Poincaré (1956). The appearance of a new idea or a new orderly structure may often be similar to the detection of a pattern — or a special “short description”, rule or algorithm, that may generate the more complex situation that was the starting point (compare Chaitin 1987 ; Hofstadter 1995). Of course, such experiences are not confined to mathematicians and scientists ; a very common feature of consciousness in general seems to be the property of “overflow”. As described by Searle (1992), conscious states in general refer beyond their immediate content, and in extreme cases, we can have a thought in a flash, “That’s it!”, in which the immediate content tends to spill over, to connect with other thoughts that were implied by the content. A whole and complex situation — such as living together for a long time with “the wrong person” without realizing this (Searle’s example) — is suddenly seen in a new light, from a new point of view. It is as if a higher order observational mechanism has measured a property of a new structure that has been generated through the interactions of previous experiences. The characteristic phenomenon that conscious states refer beyond their immediate content is seen not only in the overflow phenomenon and in the “Aha! experiences”, but also in the well-known Gestalt shifts between figure and ground. We propose that these phenomena are

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[4] *However, this will probably not solve “the hard problem” (Chalmers 1996) of phenomenological experience and qualia.*

deeply related to the hyperstructured constitution of consciousness. (See also Scott 1996)

The emergent mind explained ?

Let us finally state some suggestions in order to put together what we have said about explanation, emergent laws and consciousness. To explain the mind without losing the very phenomenon, the explanation must not, to quote Spencer Brown again, “take a view away from its prime reality”. The traditional conflict between objective explanations of consciousness (the attempt to discover its lawlike relations with other things) and subjective understanding of consciousness (i.e., of its intrinsic qualities, phenomenal aspects, “what it is like”, etc.) may be transcended if we integrate the following ideas into the general framework of hyperstructures :

(i) If laws of nature are a kind of algorithms giving us highly compressed descriptions of the phenomena we can observe in nature (Chaitin 1987), the existence of observationally emergent properties (that cannot be computed from the lower level algorithms) shows the necessity of reformulating the notion of lawful explanation so as to encompass the historical generation of hyperstructures.

(ii) Any scientific explanation has objective as well as subjective aspects. As objective, the explanation can be publicly stated, explicitly and precisely (eventually in a formal mode), it can be critically discussed (and eventually tested), and it can generate adequate representations of the phenomenon to be explained (“explanatory power”). As subjective, the explanation must be understood and make sense to a competent observer; it must be fully or partly accepted as a genuine explanation (i.e., as one that generates the phenomenon) ; and it must thus mentally reflect the emergent structure of the phenomenon to be explained.

(iii) Not all of reality is objective; some of it is subjective and conscious (though still a completely natural phenomenon). For the objective reality, one can often maintain the traditional view of observation as something in which the observer is distinct from what is observed. For some aspects of the subjective reality, this model of observation cannot always be maintained.

(iv) Hyperstructures can be found existing in objective as well as in subjective reality.

(v) The methodology of a science of consciousness must concern itself not only with objectively observable behaviour (from the thirdperson perspective), but also with what has been termed the “endo-view” (Kampis 1991), or the first-person point of view (Searle 1992), or what we will call the observer observing the emergence of new structures from within the system, as exemplified in mathematical discovery or in other kinds of sudden flashes of insight.

(vi) In certain living systems with mind, at a high level new phenomena such as consciousness emerge as a construction process, in which Int and Obs occur at several levels, and in which (at least some) observation mechanisms are intrinsic to the system. Even though there is probably no algorithm from the bottom up, such a self-construction is a perfectly good explanation — a high order emergent explanation, open for further analysis.

The approach presented here does not view the mind as self-transparent, nor does it invoke self-introspection as a privileged observation mechanism ; rather, it relaxes the exaggerated expectations and quixotic hopes for some completely different sorts of explanations for conscious phenomena. Even if some aspects of consciousness, such as qualia, may constitute a particularly hard problem, other aspects may be explained within a refined framework of emergent hyperstructures. Without ignoring the richness of the phenomena of life and consciousness, we can still continue to work out better explanations.

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