Definitions of emergence

The appearance of new phenomena for which no complete micro-reductionist explanation exist, can be called 'emergence'. We found on the internet many other definitions of emergence, emergent properties and emergent behavior. Also, some definitions of the with emergence related concepts 'downward causation ' and ' supervenience', were sought. An overview of the results is given here.

Emergence

- Emergent properties are those which occur only when two or more subsystems or components are assembled into a system. An emergent property is a property of the system but not of any of the components.
- Properties of complex physical systems are emergent just in case they are neither (i) properties had by any parts of the system taken in isolation nor (ii) resultant of a mere summation of properties of parts of the system. (Dictionary of Philosophy of Mind).
- The best way to explain an emergent property is to say this is what you get when something is more than the sum of its parts.
- Generally emergence is defined by saying 'the whole is greater than the sum of the parts'. In other words we cannot predict the outcome from studying the fine details. In some cases if we 'know' the outcome we can develop reductionist explanations to describe it - this is a one to many process, we break down the trait into multiple isolated parts. The reverse process, many to one - explaining from first principles what global features will appear, seems beyond us. The essence of the emergent phenomena however is that 'new' descriptive categories are necessary, in other words the features cannot be described within the vocabulary applicable to the parts, we require new terms, new concepts to categorise them. (Chris Lucas and Yuri Milov, 1997).
- Given a system with a global behavior completely determined by the local behaviors of its components, a global behavior is said to be emergent if it requires a set of descriptors which is different from the set required to describe the local behaviors. (Luc Steels, referenced by Nicholas Gessler, 1994).
- Emergent behavior, simply defined, is when a system seems to act in a more organised fashion than its individual parts are capable of. (Michael Marinez, 1999).
- Novel properties at a particular level of organization that are not evident in the unorganized parts (simpler levels). Emergent properties depend on the integration of parts that make the more complex level.
- Direct emergent properties are epiphenomena e.g. cellular slime mould and ants' nests, social consequences of individual held rules, e.g. being honest, recycling. Indirect emergent properties are the consequences of patterns being held to direct property at higher level e.g. genetic coding in cells of a organism; mind 'leaks' from a lower level up to be in a higher level as well.
- The assertion that 'x is an emergent property of y' might mean any of the following:
  - the appearance of x from y was surprising;
  - knowing y, I did not in fact deduce that x would appear;
  - knowing only y, I could not possibly have deduced that x would appear;
  - knowing only y, deducing that x would appear was not tractable;
  - x 'appears' when I look at y at a higher level of description;
  - laws governing x differ from, and are logical independent of, laws governing y;
  - and more...

The last possibility, where the emergence of x from y means that x requires whole new governing laws which do not follow from those of y, I shall unceremoniously banish to the past and thinkers such as Durkheim (1938) and Radcliffe-Brown (1952). This view, shared with the so-called British *emergentists* (see Alexander 1920, Broad 1925, or Pepper 1926; also see McLaughin 1992 for recent discussion) has for the most part fallen out of favour in the last few decades ... (1998).

- What is emergence? The appearance of a property or feature not previously observed as a functional characteristic of the system. Generally, higher level properties are regarded as emergent. A automobile is an emergent property of its interconnected parts. That property disappears if the parts are disassembled and just placed in a heap. (Chris Lucas, 1997/8/9)
- One is told that consciousness and other mental properties ‘emerge’ in an unpredictable way from the actions of neurons. Such claims are sometimes taken to have antireductionistic consequences. But is emergence an antireductionistic notion? With respect to ontology, we believe that the correct answer on this question is negative.

An emergent property is, very roughly, a property that belongs to an aggregate of entities but is not a linear sum of the properties of the parts. This means that the mass of a large object would *not* count as an emergent property of the object, as the total mass is simply the sum of the masses of all its parts. Uncontroversial examples of emergent properties are harder to find. The solvent property of water is one candidate, for neither hydrogen atoms nor oxygen atoms in isolation possess this property and neither do they possess scaled-down versions of the property. Solvent action seems to emerge from a nonlinear combination of the properties of hydrogen and oxygen. (Colin).
- Self-organising systems have emergent properties: something that is a property of the system as a whole, not of any of the individual components from which it is made. Emergent properties are simple properties of complex systems and they are often surprising and unpredictable... Notice how the slope of a sand pile stays roughly constant. If it is shallower than this critical slope, it waits for more sand to pile up. If it is steeper, avalanches occur. The system self-organises to a constant slope. (Stepneys,1996).
- Emergent properties are characteristically attributed to structured collections of elements, where the emergent property is not an additive function of the properties of the elements of the collection, taken individually. (Rom Harre).
- Complexity *(as theory)* is about emergent phenomena, the emergence of new forms and capabilities out of previous forms and capabilities. It is the very opposite of reductionism. This new science presents both empirical an theoretical evidence of very fundamental incompleteness in the reductionistic approach to understanding the universe. Complexity is about the development, the evolution of wholes... Complexity is the science of emergence. (Larry Edwards, 1998)
- An emergent property is one which is not explicitly represented. Emergence is a recognised phenomenon in visual perception, examples of which are optical illusions where "phantom" shapes not explicitly represented are apparent. Emergence is often observed in the behaviour of designers, so it potentially plays an important role. It can be described as changing schemas since the old schema did not explicitly represent the property, a new one will generally be needed. Emergence is not limited to structure, it can also apply to function and behaviour. For example, an artefact may have functions beyond those for which it was intentionally created. (Robert Saunders, 1997)
- Emergence is a tricky concept. It's easy to slide it down a slippery slope, and turn it into something implausible and easily dismissable. But it's not easy to delineate the interesting middle ground in between. Two unsatisfactory definitions of emergence, at either end of the spectrum:
(1) Emergence as ‘inexplicable’ and ‘magical’. This would cover high-level properties of a system that are simply not deducible from its low-end properties, no matter how sophisticated the deduction...
(2) Emergence as the existence of properties of a system that are not possessed by any of its parts...
The challenge, then, is to delineate a concept that falls between the deeply implausible (1) and the overly general (2)...
(3) Emergent = ‘deducible but not reducible’.
(4) Emergent high-level properties are *interesting, non-obvious consequences* of low level properties...
(5) Emergence is the phenomenon wherein complex, interesting high-level function is produced as a result of combining low-level mechanisms in simple ways...
(6) Emergence is a phenomenon wherein a system is designed according to certain principles, but interesting properties arise that are not included in the goals of the designer.... (David J. Chalmers, 1990).
- Emergent property: one which cannot be observed locally in the subsystems, but only as a global structure or dynamic.
- Properties of a complex physical system are emergent just in case they are neither (i) properties had by any part of the system taken in isolation nor (ii) resultant of a mere summation of properties of parts of the system... For Mill, the key to the distinction between emergent and non emergent properties centers on a distinction regarding two different ways in which conjoint causes can produce an effect: Non-emergent properties are effects that are mere summations of each of the causal conjuncts, whereas emergent properties are effects that are not sums of the effects of each causal conjunct... A key determinant of whether a behavior is emergent on this view is whether removing any of the causal conjuncts prevents the remaining conjuncts from contributing their effects to the remaining system. If not, then the behavior of the system in question is non-emergent. If so, then it is emergent... (Pete Mandik).
- The unpredictability that is thus inherently in the natural evolution of complex systems then can yield results that are totally unpredictable based on knowledge of the original conditions. Such unpredictable results are called emergent properties. Emergent properties thus show how complex systems are inherently creative ones. Emergent properties are still a logical result, just not a predictable one. This can also include higher level phenomenon that cannot be reduced to it's simpler constitutes or it's origin. (David Kirshbaum, 1998/9).
- The weakest sense. An emergent property is one which arises from the interaction of ‘lower-level’ entities, none of which show it....Prediction. As above, but now we add the caveat that ‘the new property could not be *predicted* from

the knowledge of the lower-level properties'... Retrodiction or explanation. 'An emergent is a higher-level property, which cannot be deduced from or explained by the properties of the low-level entities'... (Santa Fe Institute, 1995).
- A standard sense of emergence is that "a property of a complex system is said to be 'emergent' just in case, although it arises out of the properties and relations characterizing simpler constituents, it is neither predictable from, nor reducible to, these lower level characteristics" (Kim, 1995). The standard notion of emergence does not specify if prediction or reduction is impossible in principle or in practice, or in what non-trivial sense one cannot predict such properties, or if the 'arising' of such properties are a consequence of descriptive or physical processes, etc. Many philosophers prefer supervenience for emergence as a concept characterising the dependence relation between entities or properties at different levels. (Claus Emmeche, 1997).
- The emergent theory asserts that there are certain wholes, composed (say) of constituents A, B, and C in relation R to each other; that all wholes composed of constituents of the same kind as A, B, and C in relations of the same kind as R have certain characteristic properties; that A, B and C are capable of occurring in other kinds of complex where the relation is not of the same kind as R; and that the characteristic properties of the whole R(A,B,C) cannot, even in theory, be deduced from the most complete knowledge of the properties of A, B, and C in isolation or in other wholes which are not of the form R(A,B,C). (C.D. Broad, 1925).
- A property designated by a predicate P in an ideal theory T is emergent if and only if the following conditions are met:
1. T describes a class of systems SC which are structured aggregates of entities described by T'; T' is an ideal theory of those entities, and the entities described by T strongly supervene on those described by T'.
2. It is epistemically impossible to identify occurrences of the property designated by P with any occurrence of a property finitely definable in T'.
3. Each occurrence of the property designated by P is an occurrence of one of a definable set of properties PC, which is modeled by T'. Each member of PC is epistemically indistinguishable in T' from some other member of PC. (David V. Newman, 1995).
- Emergence. The origin of things with a degree of causal autonomy from the existing causal level from which they arose. Causal autonomy prevents the emergent entities from being reducible to that from which they emerged. The properties of an emergent thing are not predictable from the properties at lower level... The complex properties from all the separate physical phenomena may collude in a way that transcends the effects of any one or several of them without having to posit any other mysterious force. Emergent properties exploit possibilities in nature that were not being exploited at the lower level from which these properties emerged... New powers that emerge are only possible in virtue of the higher level of organisation of matter that evolves... A transcendental argument from our experience shows this to be correct in regard to the irreducibility of social activity. It is the condition for the existence of our social products that we be the causal agents whose reasons are autonomous causes. The origins of human actions can be explained only by reference to social forms; the effects of human actions can be explained only by reference to the causal effects of beliefs... The rise of social reality can be traced in a causal chain from the pre-existing non-social reality, but once it exists, social reality cannot be synchronously reduced to the non-social part of reality. Autonomy is exemplified by the fact that explanation of certain physical states (namely, ones that are the result of intentional human activity) requires irreducible reference to beliefs. (Louis Erwin, 1997).
- A true emergent phenomenon is one for which the optimal means of prediction is simulation... So, emergent phenomena are those for which the amount of computation necessary for prediction *from an optimal set of rules, classification and analysis, even derived from an idealised perfect understanding, can never improve upon the amount of computation necessary to simulate the system directly* from our knowledge of the rules of its interaction. (Vince Darley, 1994).
- The theory of emergence involves three propositions:
1. that there are levels of existence defined in term of integration;
2. that there are marks which distinguish these levels from one another over and above the degrees of integration;
3. that it is impossible to deduce the marks of a higher level from those of a lower level, and perhaps also (though this is not clear) impossible to deduce marks of lower level from those of a higher. (Stephen C. Pepper, 1926).
- It is often stressed that the level at which distributed representations are described (i.e., the level of patterns) is higher than that of individual units and weights. This together with the fact that the behavior of the system results more from the interaction of the components than from the behavior of the components themselves, lead scientists to employ the notion of emergence when they describe working of the system. Connectionist distributed representations are emergent properties of the system. In most cases scientists are not able to provide explanations in mechanistic way by decomposing into components (units). But still emergent properties (representations) are in principle explainable although often not predictable except of the run of the full-fledge simulation of the relevant system. (Olga Markic).

- Researchers in several fields have begun to explore computational models in which the behavior of the entire system is in some sense more than the sum of its parts. In these systems interesting global behavior *emerges* from many local interactions. When the emergent behavior is also a computation, we refer to the system as *emergent computation*. The point is to avoid any global control that could dictate the result of the computation process. Emergence is a process where any explicit definition of the result is avoided as far as possible. Instead of having only a single model, a population of independent models is created and the global control is replaced by a mechanism of *selection*. (Jari Vaario, 1995).
- Emergent computation is a type of computation that is bottom-up and not totally programmed. Only local information or very limited amount of information is used for a unit of computation. However, certain global information structure, which is often unexpected, is emerged from this computation. (Y. Kanada, 1995).
- Emergent computing examines the complex structures, behaviours and functions that arise from the interaction of large numbers of simple interacting processes. Examples of emergent structures in natural systems can be seen in the V-shaped formation of migratory birds, in the social organisation of social insect societies, or the complex structure of a snowflake.
- Emergence is the phenomenon of complex patterns of behaviours arising out of the myriad interactions of simple agents, which may each operate according to a few simple rules. (SHAI's AI Glossary).

Downward causation

- Downward causation is when a higher level of organization determines the appearance/behavior of a lower level of organisation.
- All processes at the lower level of hierarchy are restrained by and act in conformity to the laws of the higher level (Donald T. Campbell, 1974).
- In order for there to be downward causation, it must be possible for a whole to determine the behavior of its parts, rather than the other way around. (Teed Rockwell, 1999).
- Downward causation can be defined as a converse of the reductionist principle... : the behavior of the parts (down) is determined by the behavior of the whole (up), so determination moves downward instead of upward. The difference is that determination is not *complete*... The whole is to some degree constrained by the parts (upward causation), but at the same time the parts are to some degree constrained by the whole (downward causation). (F. Heyligen, 1995).
- The composition of matter from elementary particles that build upon each other to create energy (upward causation) cannot sufficiently explain nature. In downward causation, quantum objects are virtual "waves of possibility" that collapse into actual events upon measurement. It can be said that an electron is such a wave until measured, upon which it collapses into an actual particle. (Steve Bunk, 1999).
- If causal powers do emerge, then, within the framework of any reasonable naturalism, any causal consequences of those higher level emergent powers will themselves involve constituent levels of matter, or at least constituent levels of organisations of quantum processes. That is, *any* consequences of emergent causality will affect lower levels, constituent levels, of pattern and organization as well as the level at which the emergence occurs. More concisely, causal emergence implies downward causation. (Mark H. Bickhard, 1997).
- (1) In *strong downward causation*, an entity or process at a higher level may causally inflict changes or effects on entities or processes on a lower level, and the higher level entity is considered to have a substantial difference from lower level entities. The organizational aspect is a necessary but not sufficient condition of the higher level entity: By its emergence, an ontological change in substance takes place. Thus the higher level is held to constitute its own substance; it does not merely consist of its lower level constituents (this could be called constitutive irreductionism). Vitalism in biology and dualism in philosophy of mind may invoke strong downward causation of some version.
- (2) For *medium downward causation* it is not allowed higher level phenomena to influence directly on lower levels. This higher level entity, such as a cell of psyche, is a real substantial phenomenon in its own right, and this entity act as constraining conditions (a kind of formal cause) for the emergent activity of lower levels. The higher level states, already realized, are constraining conditions for the coming states.
- (3) In *weak downward causation* the higher level is seen as an organizational level (not a substance), characterized by the pattern, the structure or *form* into which the constituents are arranged. The higher level entity, for instance a biological cell, *consists of* entities belonging to the lower level (constitutive reductionism). This is not a physical reductionism; the forms of the higher level are believed to be non-reducible (form realism). It does not interpret boundary conditions as constraining conditions; rather the higher level form can (in terms of the theory of dynamical systems in physics) be seen as a stable or chaotic attractor in a phase space where the individual states (points in the

state space) of the system is given by the configuration of the system's lower level entity properties and the dynamical equations that rule the time evolution of the system. (Claus Emmeche, 1999).
- The phenomenon of 'downward causation' can be interpreted as the quasi-effect of higher level patterning on the dynamics of the lower-level constituents of a self-organizing system. (J. L. Lemke, 1998).
- Downward causation is a difficult concept to define precisely because it describes the collective, concurrent, distributed behavior at the system level where control is usually impractical, rather than at the parts level where focal control is possible. Downward causation is ubiquitous and occurs continuously at all levels, but it is usually ignored simply because it is not under control... My conclusion would be that downward causation is useful insofar as it identifies the controllable observables of a system or suggests a new model of the system that is predictive. (H. H. Pattee).
- Mental causation. Hume claimed that even if events were caused by mental entities such as beliefs and desires, they would still be determined... Dan Dennett's concept of the Intentional Stance, for example, makes mental causation compatible with determinism by seeing it as a useful fiction, and implying that because that it is useful it is somehow more than a fiction. (Teed Rockwell, 1999).

Supervenience

- Notions on supervenience are attempts to distill the intuition that higher level properties depend on lower level properties. No change at the higher level without a concomitant change at the lower level is the motto. (Mark H. Bickhard with Donald T. Campbell, 1997).
- Mental characteristics are supervenient on physical characteristics. Such supervenience might be taken to mean that there cannot be to events alike in physical respects but differing in some mental respect, or that an object cannot alter in some respect without altering in some physical respect. Supervenience of this kind doesn't entail reducibility through law or definition. (Davidson 1980).
-The causal efficacy of the mental is threatened from two different angles: epiphenomentalism and reductionism. Roughly speaking, epiphenomalism claims that there can be mental differences among otherwise physically identical entities (objects, events, states,..), which means that there can be things which are mentally different can be physically identical and hence that mental differences have no physical impact... Reductionism on the other hand, states that mental characteristics can be defined or correlated away in terms of physical characteristics... But *if* reductionism is a sensible option then saying that the mental is causally efficacious is a misleading way of claiming that physical causes (in terms of which mental causes can be defined) have physical effects, which is uncontroversially true. The problem is to explain how supervenience of the mental on the physical entails the causal efficacy of the mental, without abounding a broadly physicalist picture of the universe... (Filip Buekens, 1997).
- A predicate p is supervenient on a set of predicates S if for every pair of objects such that p is true of one and not for the other there is predicate S that is true of one and not of the other. (Davidson, 1985).
- If a property is a supervenient property, then it is a dependent property in the sense it *cannot* occur unless determined by a physical property. (Andrew Newman, 1996).
- A quick and easy way to understand supervenience is to take it as a relationship between two sets (usually sets of properties or propositions), where fixing one set -- the supervenience base -- fixes the other -- the supervening set. A common example, taken from the early history of the word, suggests that moral properties supervene on physical properties. In other words, fixing all the physical properties in the world fixes all the moral properties. Alternatively, it is impossible that a world could be physically identical to the actual world while differing from it morally... 'Supervenience' must be broken down into (at least) *logical* supervenience and *metaphysical* supervenience... The former is a relationship of *a priori* necessity, requiring that we take a concept's intension as that which fixes reference for whatever world is actual. That is, a concept's extension is determined by its intension evaluated in *the actual world*... By contrast, *a posteriori* necessity grounds 'metaphysical supervenience' which features principally in talk about consciousness: some theorists maintain that while physical facts do fix facts about consciousness, the particular way in which they do so is an *a posteriori* matter... Making sense of metaphysical supervenience depends on taking intensions as specifying how to pick out referents in *counterfactual* worlds, *given* actual world reference... Setting aside intensional differences, the definition of supervenience in terms of fixing one set of facts by fixing some other set requires only that supervening facts cannot differ, given a fixed supervenience base. It does not require that facts in the supervenience base *imply* the supervening facts, in the sense that the supervening facts should be *derivable* from the supervenience base... A proposition naming supervening facts which are not derivable has *greater information content* than the formal system itself. Such a proposition carries additional information over and above what is contained in the formal system itself -- yet it still supervenes on the facts which describe the

formal system... Thus, establishing even logical supervenience does not *automatically* guarantee that all supervening facts may be *logically derived* from the supervenience base. (Mulhaug,1998).

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