A Dynamical Account of Emergence

John Collier
School of Philosophy and Ethics
University of KwaZulu-Natal
Durban 4041, South Africa
collierj@ukzn.ac.za
Http://www.ukzn.ac.za/undphil/collier

For *Cybernetics and Human Knowing*

Abstract

Emergence has traditionally been described as satisfying specific properties, notably nonreducibility of the emergent object or properties to their substrate, novelty, and unpredictability from the properties of the substrate. Sometimes more mysterious properties such as independence from the substrate, separate substances and teleological properties are invoked. I will argue that the latter are both unnecessary and unwarranted. The descriptive properties can be analyzed in more detail in logical terms, but the logical conditions alone do not tell us how to identify the conditions through interactions with the world. In order to do that we need dynamical properties – properties that do something. This paper, then, will be directed at identifying the dynamical conditions necessary and sufficient for emergence. Emergent properties and objects all result or are maintained by dissipative and radically nonholonomic processes. Emergent properties are relatively common in physics, but have been ignored because of the predominant use of Hamiltonian methods assuming energy conservation. Emergent objects are all dissipative systems, which have been recognized as special only in the past fifty years or so. Of interest are autonomous systems, including living and thinking systems. They show functionality and are self governed.

1. Logical conditions for emergence

Emergence is usually attributed to things that have new properties not present in the phenomena from which they are formed. Some emergentists invoke notions of separate substances, causal independence and teleology that border on obscurantism. They believe that emergent properties must "arise from" but not be causally dependent on underlying or prior properties. Whether or not this position is coherent, it is certainly mysterious, and evidence in its favour is lacking. The only place in modern science that indeterminism is possibly supported is in quantum mechanics (even there the laws are deterministic). Otherwise, the evidence for determinism is very strong, certainly in the macroscopic domains where emergent phenomena occur. Furthermore, teleological causes are not known to work independently of the usual physical causes.

The metaphysical problems with explanatorily independent domains in a common world, together with the evidence for physical determination of all but the most fundamental properties justify the *principle of supervenience* (Kim, 1978; Rosenberg, 1978; 1985): If all of the (determinate) physical facts are determined, then all (determinate) facts are determined. Kim (1978) bases the principle on a general metaphysical position that the world is determined by its physical structure, whereas Kincaid (1987) suggests that the principle is empirically based. I believe that the metaphysical and empirical reasons are each sufficient independently, but combined they are stronger than either alone. Each answers certain doubts otherwise left open by the other. If emergence entails radical indeterminism the principle of supervenience rules it out. Nagel, however, (1961: 377) pointed out that although emergence is sometimes associated with radical indeterminism and/or teleological causation, this association is not essential. Let us assume that his usage, which follows C.D. Broad's (1925), is authoritative.

The major physicalist alternative to emergentism is ontological reductionism. Assuming physicalism and determinism, and a modest finitism implying the closure and self-sufficiency of objects on their composition (sometimes called *atomism*), ontological reduction is in principle always possible (Rosenberg, 1985: 62-64). This sort of reduction requires peculiar physical properties and objects (sometimes called "logical constructs"), as well as an artificial consideration of systems as closed. If we reject finitism, closure and logical constructs as the figments of a logician's imagination, microreduction is not so easily justified.

Microreduction does not easily account for the organizing effect of higher level (more extended) entities (Campbell, 1974). The reductionist must hold that these capabilities were present at the lowest level all along, and that nothing new has been acquired. From the reductionist perspective, composition, far from creating new capabilities, places constraints on the system that eliminate certain possibilities. The reductionist is forced to reinterpret the appearance of new phenomena as the elimination of available possibilities. Aside from the awkwardness of this interpretation, reductionism must find some way to reconcile the elimination of possibilities through composition with the continued presence of the possibilities in the underlying microstructure. I will return to this issue in section 3 below.

a) Descriptive conditions for emergence

Aside from the mysterious attributes of emergent entities that I rejected above, emergent properties and objects generally are assumed not to be reducible to the binary relations among their components[1], to be unpredictable from the properties of their compositional substrate, and to show new or novel properties that do not exist in their substrate. Any adequate account of emergence must account for these characteristics. The main problem with these qualitative characteristics is that they are hard to determine by observation alone and ignorance of details or confusion of epiphenomenal properties with real properties (the properties of the substrate on the reductionist view) can lead to mistaken evaluations of emergence. We need more precise characteristics at the very least.

b) Computational conditions for emergence

A system is temporally predictable if and only if its time evolution can be calculated from its initial conditions specified within some region in phase space together with its equations of motion to be within some region of phase space at some arbitrary later time. More specifically, the trajectory of a system is predictable if and only if there is a region η constraining the initial conditions at t_0 such that the equations of motion will ensure that the trajectory of the system will pass within some region ε at some time t_1, where the region η is chosen to satisfy ε. For indeterministic systems, the values are determined to the extent determined by the probabilistic factors in the laws. Predictability in this sense applies to all closed Hamiltonian (specifically, conservative, holonomic) systems, including those without exact analytical solutions, such as the three body problem. The systems without exact analytical solutions can be numerically calculated in principle, if we have a large enough computer. The macrostate of a microsystem can be predicted similarly by

[1] If all relations including the dynamical organization of the parts were allowed, then one relation would just be the emergent entity. It would therefore be reduced to itself, and we would get nowhere. (See below on fusion.) If we allow binary relations, then we also allow all logical sums and products of these relations by that can be computed (sensu Church-Turing). My specific claim is that if an object is emergent, this set does not contain the emergent properties.

composing the trajectories of the microcomponments and averaging to get the expected macrovalues.

If we want to undermine predictability, at least one of the assumptions must go. The assumptions are 1) the system is closed, 2) the system is Hamiltonian, and 3) there exist sufficient computational resources. The last condition (3) is a shorthand way of saying that the information in all properties of the system can be computed from some set of boundary conditions and physical laws, where information is understood as an objective measure of asymmetry as in (Muller, 2007, also, but less rigorously in Collier, 1990b; 1996). As I will demonstrate later, all three of these assumptions are violated for some simple physical systems, including some in the solar system. It is worth noting that so-called emergent computation (Forrest, 1991) is really not a case of a violation of 3, nor are many models of 3 body systems that seem to demonstrate chaos or emergence. These are artifacts of the modeling process, and have no ontological significance. On the other hand, there are some systems that violate 3 because no computer could have sufficient power, let alone one connected to the system under study. I will give an example below in terms of Newtonian particle mechanics with gravity and friction that serves as an exemplar for emergence. More complex cases are just more nuanced.

Novelty does not necessarily follow from mathematical unpredictability, since there may be no new properties formed in unpredictable systems, but novelty is impossible with unpredictability, except in the trivial sense that a pile of blocks is novel with respect to the block components. The predictability of the macrostate of a system from its microstate (states of the components of its substrate) is just the condition of reducibility, so unpredictability is also required for and sufficient for irreducibility. The advantage of the mathematical rendition of the characteristics of emergence is that we have reduced three to one, except for possible additional requirements to ensure novel properties. Now the problem is to determine when computability fails in dynamical systems. That is when emergence begins.

2. Dynamical realism

Dynamical realism is a name that C.A. Hooker and I have given to a metaphysics that holds that what is real is either dynamical or explicable in dynamical terms. Something is dynamical if and only if it can be described completely in terms of forces and flows. We use the term in a book in progress on reduction in complex systems, but some of the basic ideas are in (Collier and Hooker, 1999) and expressed in an analysis of asymptotics and reduction in (Hooker 2004). Why dynamical realism? Basically, because nothing that is not dynamical can have any effect on anything else, so it is impossible to have meaningful knowledge of it. (This is just a material version of Peirce's Pragmatic maxim that any difference in meaning must make a difference to experience.) A similar consideration lies behind (Ladyman and Ross, 2007, pg. 29), except in that book structure plays the role of dynamics in Collier and Hooker. Depending on how science works out, the two may coincide, but I prefer dynamical realism because structure can be inert, and do nothing.

Logical characterizations can be useful, but they still need to be hooked up to the world in order to apply to anything. The problem with understanding emergence is to hook up the computational characterization to dynamical conditions. This turns out to be somewhat easier than it might appear, and involves the failure of one or more of the three conditions mentioned in section 1b above.

3. Reduction and supervenience

Before showing how the logical conditions for emergence can be connected to dynamical conditions, it is useful to clear up some confusions about reduction. Most of this has been done already by Ross and Spurrett (2004), Hooker (2004) and myself (2004a), so I will be brief. Kim (1998, 1999, 2005) argues that if supervenience holds (as I have granted above) then a supervenient system has no causal power that its substrate does not, therefore reducibility holds and emergence is false. We can grant the first conclusion that reducibility holds (in a certain way), but it is irrelevant to the conclusion that emergence is false, which I shall challenge.

Reduction is ambiguous in three ways. It might mean intertheoretic reduction, the reduction of fundamental kinds of things (substance, traditionally), or that certain particular entities (objects, processes or properties) can be eliminated without any loss of explanatory power in principle. Intertheoretic reduction is irrelevant here. The reduction of the number of fundamental kinds of things is best called *ontological deflation*. It is a reasonable hypothesis that all that exists is physical. Kim's argument shows that if supervenience, then ontological deflation – all causation is physical causation. I suppose it is obvious that this is not very controversial these days.

However, despite supervenience, if reducibility fails in principle for some entity, then it is emergent. If there is no possible argument (deductive or inductive) from the parts, their intrinsic properties, and (the computational closure of) their binary relations to the full causal powers of the entity itself, then reductive explanation fails in principle. In these cases, even if physicalism is true, they are emergent. This idea of emergence as irreducibility to components fits C. D. Broad's criteria (Collier and Muller 1998, see also Reuger 2000a, 2000b, 2004). Basically, Kim has committed a philosophical howler, and has missed the point entirely. He got on the wrong boat.

A slightly different approach to show Kim's mistake is due to Paul Humphrey's (1997a, 1997b) account of emergence, based in the idea of *fusion*. The idea is that dynamically connected components form a fusion, such that the properties of the components are not the same in the fusion as they are in the isolated components. Suppose the Earth and the Sun form a system. The fused system gives the Earth and the Sun properties that they would not have independently. Some of the properties of the independent components (like following rectilinear paths) no longer exist (the two orbit a common centre of gravity). Properties are emergent if they cannot be computed from the properties of the unfused components. In the Earth-Sun case the computation is relatively trivial, so there is no emergence. But this is not always the case, and I will give an example in section 5 below.

Whether we take the component approach or Humphreys' (they are not so different in spirit), Kim's argument is irrelevant. Kim's causation argument, on Humphreys' approach, concerns the component fused system, but does not consider the relation between the separated (unfused) and fused systems. On the component account Kim considers that causal properties of the already combined system, without considering the relation between the properties of the components and those of the system. In either case, Kim is looking at the wrong thing. The only reason his argument gives the any appearance of being relevant is that he plays on the ambiguity between ontological reduction and ontological deflation.

4. Hamiltonian systems and holonomic constraints

This is a difficult technical issue, with many complications, especially for specific systems, but it is central to my argument for both the dynamical characterization of, and existence of, emergent entities. I will therefore be painting a picture that ignores many subtleties, and I will be saying some things that seem to violate things that are well established in the literature of physics. Rather than go into details, I will point out right now that these apparent violations apply to specific systems and ignore the complete description of the systems in which they are embedded, or else use a very broad notion of a Hamiltonian system, or both. Thus we have descriptions of Hamiltonian chaos, quantum chaos and nonholonomic constraints on Hamiltonian systems that I will be saying are ruled out by my definition of a Hamiltonian system. The set of Hamiltonian systems in the sense I use here is, I believe, equivalent to the set of trivial machines delimited by von Foerster (2003), and the set of mechanical systems as defined by Robert Rosen (1991. Alas, I do not yet have a proof that satisfies me.

Newtonian mechanics is a very open theory that allows such things as unpredictability, indeterminate but mathematically fully describable systems, nonconservation of energy, and other bizarre phenomena that have been described over the years. Physicists intuitively rule out such cases with implicit or explicit assumptions that restrain the set of models to those we recognize as mechanistic. These restrictions have been formalized first in the Lagrangian formulation, and later in the Hamiltonian formulation of Newton's dynamics. The restrictions are often ignored in physics texts, so it is easy to let them slip past unnoticed.

The Lagrangian formulation for simple systems sets L = T – V, where L is the Lagrangian, T is the kinetic energy, and V is the potential energy. The integral of this is stationary on dynamically possible paths (Principle of Least Action). Dynamically, T is the flow part and V is the force part. Variation of the Lagrangian is determined by the force law (connecting forces to flows), generally in terms of generalized coordinates and their first derivative (velocity) – so the resulting equations are second order. The Hamiltonian can be based on the Lagrangian such that $H(q,\dot{q},t) = \sum_i \dot{q}_i p_i - L(q,\dot{q},t)$, where q is a generalized coordinate and p is a generalized momentum. The main difference, obviously, is the dependence on generalized momenta, thus the use of a 2n dimensional phase space instead of a n dimensional coordinate space. If *L* is a sum of functions homogeneous (i.e., no products of different degrees) in generalized velocities of degrees 0, 1, and 2 and the equations defining the generalized coordinates are not functions of time, then H = T + V = E, where E is a constant (i.e., the system is conservative) and I call such a system a *Hamiltonian system*. If the generalized coordinates do depend on time, then H is not constant, and H ≠ E, and the system is generally complex. Since all other constraints can be put into the formulation of the generalized coordinates, energy conservation is the only additional constraint on a closed Hamiltonian system. The same is true for quantum systems, which for closed systems are always Hamiltonian in current formulations of quantum mechanics. Quantum systems, therefore, are always simple, and cannot show either true chaos or emergence (Ford 1986). (Despite this, quantum chaos and emergence have been investigated; if real, these would require violation of the conditions on H = T + V.)

Hamiltonian systems have an overall force function (T) that is holonomic, i.e., depending only on the position coordinates and time (Holonomic Constraints, 2007), if and only if the force is conservative, an example being particles in a gravitational field. It is possible that component forces are nonconservative, but their combination must be. E being constant is also holonomic, as it depends only trivially on position coordinates and time. In general, if a system is holonomic it can do no *virtual work* because all virtual displacements are perpendicular to the forces of the constraints, so there is (would be) no force on them. This is really just another way of saying that the H of Hamiltonian systems depends only on (appropriately chosen) generalized coordinates and E. This is of central importance to the theory of dynamical emergence, as I will argue below.

An alternative way to express holonomic systems is in terms of the Lagrangian: a system is holonomic when the Lagrangian can in principle be expressed in terms of as many coordinates as the system has degrees of freedom. Such systems are integrable, though integration may in practice require numerical approximation. So holonomic systems can be understood as a whole through the integration of their parts and their partwise interactions. A nonintegrable system must be non-holonomic, and must thus not be a Hamiltonian system[2]. An important characteristic of nonholonomic systems is that their equations of motion cannot be separated from their boundary conditions. Conrad and Matsuno (1990) make clear the consequences for dynamical systems:

> Differential equations provide the major means of describing the dynamics of physical systems in both quantum and classical mechanics. The indubitable success of this scheme suggests, on the surface, that in principle it could be extended to a universal program covering all of nature. The problem is that the essence of a differential equation description is a separation of itself from the boundary conditions, which are regarded as arbitrary.

Conrad and Matsuno go on to draw conclusions about the application of the method to the whole universe (they claim the system breaks down, but it is actually compatible with "no boundary conditions" constraints on cosmological theories). Of more significance here is the breakdown of the separation of differential equations and boundary conditions in nonintegrable systems, exactly the ones that are nonholonomic (in which constraints like boundary conditions cannot be separated from the dynamics). In these systems, computation from partwise interactions fails, and the

[2] The necessity of nonholonomic constraints was pointed out to me by Howard Pattee, 10 Aug 2000, on my mailing list Organization, Complexity, Autonomy, see also Pattee, 1967.

system is in a sense holistic. In any case, its dynamics cannot be reduced to the dynamics and partwise relations. This is one of the conditions for emergence.

I've shown above that nonHamiltonian systems are also nonconservative. The next step is to bring the two conditions governing nonholonomicity together and argue for a common basis of for emergence in dissipative nonholonomic self-interactive systems.

5. Radically nonHamiltonian systems

It is generally recognized that Hamiltonian systems are mechanical. This idea of mechanical is summed up by their holonomic character, in an engineer's sense that all their constraints can be expressed algebraically and are basically geometric. Nonholonomic systems, on the other hand must have a constraint that is expressed as a rate of change, so their form cannot be integrated to an algebraic form, and they cannot be understood geometrically. Some examples of nonholonomic systems are a rolling wheel (friction matters) or a planet experiencing tidal dissipation (recall that holonomic systems are nondissipative).

Some systems are nonHamiltonian, but are close to Hamiltonian. We can deal with such systems with approximations. This is a common method. Other nonHamiltonian systems step rapidly from one state to another (rapid is relative here), such as the onset of convection in a Bénard cell. The dynamics of these systems can be analyzed by comparing the micro- and known macromechanics, along with knowledge of the transition. This is how Bénard cells were in fact analyzed. However there is a large range of systems that are not close to step functions or close to smooth Hamiltonian systems. Such systems typically show sudden changes, for example, a wheel can loose friction suddenly, and a planet can slip from one resonant attractor to another. I conjecture that this sort of radically nonHamiltonian behaviour underlies all emergence. In particular:

1. The system must be nonholonomic, implying the system is nonintegrable (this ensures nonreducibility)
2. The system is energetically (and/or informationally) open (boundary conditions are dynamic)
3. The system has multiple attractors (see below)
4. The characteristic rate of at least one property of the system is of the same order as the rate of the non-holonomic constraint (radically nonHamiltonian)
5. If at least one of the properties is an essential property of the system, the system is essentially non-reducible; it is thus an emergent system

I don't claim that these conditions are independent; in fact I think they are not. I choose them because they are relatively easy to argue for in specific dynamical cases, and from that to emergence. I do claim, however, that the conditions are necessary and sufficient dynamical conditions for emergence. All are required for the emergence of systems, and all but the last for emergence of properties. If any is violated (perhaps implying the violation of others), there is no emergence.

Condition 3 is debatable. Bénard cells are a good case in point. They are set up so that only one possible state can be reached by the transition (there is only one possible attractor). It is possible to predict the convecting state from general knowledge of fluids and knowledge of the specific conditions, unlike systems with multiple attractors, for which it is possible to predict that one of several attractors will be reached, but the ultimate attractor is not predictable. On the other hand, it is impossible in the case of the Bénard cell to predict from the microscopic equations of motion what the macroscopic state will be. So in this sense Bénard cells show both unpredictability and novelty. I don't think we need to make a decision about how to classify such cases as long as we realize that they differ from the more general case.

6. Determinism, nonreducibility, unpredictability

Systems that satisfy the above conditions may be deterministic, but they must be dissipative. If dissipation is irreducibly statistical, then determinism is ruled out to at least this extent. However, since there is good reason to think that, overall, particle systems are deterministic, there is also reason to think that the Second Law of Thermodynamics, in its statistical mechanical form, must be compatible with determinism, and that we need some nonepistemic explanation for the chance or probabilistic character of dissipative systems, for example some form of relative chance based on relative information in the macrostate to the microstate (see Collier 1990a). This problem is too difficult to go into here, and is not really relevant. However, systems satisfying conditions 1-5 are irreducible and unpredictable. This is best shown with an example (Collier 2004a).

Mercury was found in the 1960s to rotate on its axis three times for each two times it revolves around the Sun. This was extremely surprising, since it had been thought that it would be in the same 1:1 harmonic as our Moon-Earth system. There are several more complex harmonic relations in the Solar System. It is well known that the three body gravitational problem is not solvable analytically, but it can be solved numerically, in principle, to any degree of accuracy we might require for any finite time (this is true for any Hamiltonian system – see discussion above). However, this case involves the dissipation of energy through tidal torques, unless the system is in some harmonic ratio. We would like, ideally, a complete explanation (possibly probabilistic) of why Mercury is in a 3:2 harmonic. Due to the high mass of the sun and the proximity of Mercury to the Sun, the high tidal torque dissipates energy reasonably quickly in astronomical time, so Mercury is very likely to end up in some harmonic ratio in a finite amount of time. The central explanatory problem then becomes “why a 3:2 ratio rather than a 1:1 ratio like our Moon, or some other harmonic ratio?”

We cannot apply Hamiltonian methods, since the rate of dissipation is roughly the same as the characteristic rate of the phenomenon to be explained. It is neither a step function nor near Hamiltonian. If the dissipation rate were small, then we could use an approximate Hamiltonian; if it were large, we could use a step function.[3] We are left with the Lagrangian. It is well known that these are not always solvable even by numerical approximation, if and only if the system is nonholonomic (see section 4 above). I will give an intuitive argument that the Mercury’s harmonic is such a case. Each of the possible harmonics is an *attractor*. Why one attractor rather than another? If the system were Hamiltonian, then the system would be in one attractor or another. In principle we could take into account the effects of all other bodies on Mercury and the Sun (assuming the universe is finite, or at least that the effects can be localized), and decide with an arbitrarily high degree of accuracy which attractor the system is in. However, given the dissipative nature of the system, it ends up in one attractor or another in finite time. If we examine the boundaries between the attractors, they are fractal, meaning that every two points in one attractor have a point between them in another attractor, at least in the boundary region. This is as if the three body gravitational problem had to be decided in finite time, which is impossible by numerical approximation (the problem is non computable, even by convergent approximation). Therefore there can in principle be no complete explanation of why the Mercury-Sun system is in a 3:2 harmonic. There is approximately a ⅓ chance of

[3] This is what we do in the Bénard cell case, inn which the rate of increased dissipation during the transition is high relative to the rates of dissipation in the two stable states.

3:2 capture, ½ of a 1:1 capture, and the rest of the harmonics take up the rest of the chances. The chances of a 3:2 capture are good, but not that good. The system is obviously physical, but it has a nonreducible property. This property fits Broad's notion of emergence.

Note that condition 1 is satisfied, since the system is nonintegrable: boundary conditions are dynamically involved in the capture in harmonic resonance. Condition 2 is satisfied for this reason as well, plus the system dissipates energy. Condition 3 is obviously satisfied by the existence of multiple attractors. Condition 4 is satisfied because the rate of capture equals the rate of dissipation (also implying radical nonHamiltonicity). Condition 5 is not satisfied in this case, but it is satisfied for the specific property of the ratio of harmonic resonance. This property is an emergence candidate because it is nonreducible (condition 1) and unpredictable (conditions 3, 4 and 5). Since there is nothing specific about the way the Mercury-Sun system with respect to harmonic resonance satisfies the conditions, all cases fitting conditions 1-5 above will have the same unpredictability and irreducibility.

To show necessity is fairly trivial. If condition 1 is violated the system is at least numerically computable, and hence predictable. If condition 2 is violated, the boundary conditions are fixed rather than dynamic, so they are holonomic. If condition 3 is violated we can predict the single attractor as we can in the Bénard cell case (which is a bit ambiguous in the context of emergence). If condition 4 is violated, then the system can be treated as approximately Hamiltonian, and it is predictable. If condition 5 is violated, there is no emergent property, perhaps just a chaotic system. Since none of these conditions are specific to the example, they apply to all cases. So I have given necessary and sufficient (but probably not independent) dynamical conditions for nonreducibility and unpredictability.

7. Novelty

Novelty is a tricky issue with dynamical emergence, since all of the causes are driven in some sense at the lower level. This is where Humphreys (1997b) idea of fusion is useful. The property of the fusion is not the properties of the fused components. Given that conditions 1-5 are satisfied, the new property is not a sum of the properties of the components either. The fusion is genuinely novel. In my own work I have focused on cases in which the emergent entity is a system, rather than a system property, and I have called the fusion of the dynamical unity property of the system *cohesion* (Collier and Muller, 1998; Collier and Hooker, 1999). This is just Humphreys' fusion applied to the system unity property. One could reverse the approach, and talk of the cohesion of properties wherever there is fusion (Ladyman and Ross, 2007). Thus, novelty, rather than being hard to get, is rather easy to achieve. This might be reflected in Broad's view that water is emergent from its components (whether or not he was right about this).

8. Individuation and Autonomy

Cohesion is also a property of individuation, because it not only binds together the components, but because the binding must be stronger overall than any binding with other objects (Collier and Hooker, 1999). This is reflected in the apt description of cohesion as *the dividing glue* (Collier, 2004b). The basic notion can be used effectively to distinguish levels in dynamic hierarchies (Collier, 2003). One variety of cohesion is autonomy, which is an organizational closure that maintains the closure so that the autonomy survives (Collier, 2006). Autonomy is thus a self sustaining form of cohesion, with is components contributing to the maintenance of the autonomy. Thus autonomy is functional in that it produces survival, and the components are functional inasmuch as they contribute to autonomy. This is the most basic form of function: contribution to survival, from which all other forms of function derive (Collier, 2006).

Levels of autonomy are possible, just like levels of cohesion (as in Collier, 2003), and we may have functional conflicts, as between body and cells, mind and body, and society and individual minds. Teleology is not a direct result of emergence, but it is made possible by it. There is nothing mysterious going on. It is all a result of comprehensible dynamics.

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