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On emergent properties, mathematical artifacts and power laws

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Wilson (2002, in this issue) reports that a simulated random spatial pattern of object abundance along a one-dimensional transect of contiguous sampling units results in linear relationship between log(variance of the objects) and log(block size of the sampling unit) and concludes that (i) this pattern is similar to the one reported by us (Anand and Li 2001) revealing that our results are nothing more than a mathematical artifact and (ii) emergent properties do not exist. We comment here on important distinctions not made by Wilson and take the opportunity to present a slightly expanded literature review on the topics.

Emergent properties

The existence of an emergent property cannot be argued unless a common definition is agreed upon. Wilson gives his: "a property of a system that cannot be predicted from the properties of its component parts". We accept this definition but feel that some important distinctions need to be made. Furthermore, we do not believe that from this definition, it follows as corollary (as Wilson claims) that emergent properties occur "when we are ignorant of the properties of the components". It is important however, not to forget some points made very well by Salt (1979). He suggested the following operational definition for ecologists very similar to the one that both Wilson and we accept: "An emergent property of an ecological unit is one which is wholly unpredictable from observation of the components of that unit". Salt suggested as corollary the following: "An emergent property of an ecological unit is only discernable by observation of that unit itself". We prefer Salt's corollary to Wilson's. Importantly, we distinguish between 'emergent properties' derived simply from ignorance and those derived from other things (e.g., self-organization).

Let us examine some other recent (but still relatively rare) uses of the term 'emergent property' in ecology, for example, in the works of Bown et al. (1999) and Smith and Long (2001). Bown et al. (1999) create a stochastic cellular automaton for modeling the dynamics of two interacting (fungal) species. They parameterize the model (neighborhood transitions) from results of pairwise experiments and compare the simulation predictions to larger-scale experimental microcosms. They find that the outcome of interactions at the local neighbourhood scale depends on the community-scale (spatial) patterning of individuals. They conclude that the dynamics of the microcosm is an emergent property of the system of interacting individuals that cannot be deduced from a study of the components in isolation. Smith and Long (2001) find that age-related decline in forest production is not simply the result of changes in the physiology of old trees. The decline is related more to changes in the structure of developing forest stands and that peak production 'almost invariably occurs as peak community leaf area is obtained'. They declare that substantial changes in canopy architecture, production efficiency, and tree population structure occur at the same time and that these are emergent properties, because they can be understood at the population level, but are not derived from individual tree physiological process. It appears that both uses of the term are consistent with Salt's (1979) use of the term, and we feel are also consistent with ours.

At no point do Bown et al. (1999), Smith and Long (2001) or we (Anand and Li 2001) comment explicitly on the relationship between emergent properties, ignorance, and predictability. We all imply that emergent properties are those that cannot be predicted (no matter how much information is ascertained, no matter how precise our observation) from component parts. If lack of information is randomness or chance (as in information theory), then it is interesting to note that randomness (or ignorance) can sometimes lead to emergent phenomenon (e.g., Ising model, random percolation, stochastic resonance). However, to say that the ignorance is the emergent property, as Wilson (in this issue) suggests, is painting with a much too broad stroke. Let us examine Wilson's remarks (2002) on cats and beefsteaks. He makes two important points about ignorance and erroneous statements/predictions: first, ignorance can be the product of imprecise scaling (measurement). Hence, we may describe an observed furry ball, snoozing in the sun, as a cushion, rather than as a *Felis domesticus*. Second, ignorance can be the product of failing to consider scale (hierarchical level) when observing a system. The cat and the beefsteak separated by a door are at one level, and the 'someone' who has the power to open and close the door is at another level, probably higher; we cannot predict the behaviour of the 'someone' from observing the cat and the beefsteak. We suggest that the first kind of ignorance, namely from imprecision of measurement, does not generate interesting[1] emergent properties. However, the second kind of ignorance, that about failing to consider hierarchical levels or scales, is more interesting.

Recent progress in theoretical science (biology, chemistry, physics) has shown that for some systems (e.g., chaotic systems, self-organizing systems), *no* amount of knowledge of the interactions between the component parts (at one level), can lead to reliable prediction of the system at a higher level (for several examples, see Ziemelis and Allen (2001) and articles in same issue). Recognizing the philosophical implications of emergent properties and the resurrection of philosophical discussions (e.g., Damper 2000, Rueger 2000, Cunningham 2001) attempts to provide a taxonomy of higher-order properties and distinguishes three classes of emergent properties: (1) "ontological basic properties of complex entities, such mythical vital properties", (2) "fully configurational properties, such as mental properties as they are conceived by functionalists and computationalists", and (3) "highly configurational/holistic properties, such as higher-level patterns characteristic of complex dynamical systems". Existence of such holistic properties has also been demonstrated mathematically (Li 2000). Wilson makes reference to classes (1) and (2), but fails to admit the existence of (3). Interestingly, Wilson gives the example of the "Resurrection of Our Lord and Saviour" generating unpredictability even "if we know all the properties of the components, and thus the processes operating". Freeman (2001) finds in emergent properties a neutral ground that makes it possible to develop "a theory of human experience that is religious yet lies wholly within the natural order and open to scientific investigation" and makes the argument that God and the soul are both emergent properties.

Mathematical artifacts and power laws

We (Anand and Li 2001) found that there exists a scale-free property (a power law) in vegetation spatial pattern. We called this an emergent property, because this is what power laws suggest based on recent observations in many other systems (see Brown et al. 2002, for several examples). Empirical power laws describe the hierarchical, fractal-like structure of a system, and have been shown to reflect simple generating rules (Schroeder 1991, Bak 1996). Could the power law be a mathematical artifact?

Wilson suggests that the way to know is to see if the power law holds for a randomly generated spatial pattern. This may very well be the case[2]. However, Brown et. al. (2002) recently review the literature on power laws and scaling and include several references to the fact that a variety of purely stochastic processes and combinations thereof can give power-law distributions (e.g., the Gutenberg-Richer law of earthquakes, Zipf's law for language, the Pareto distribution of economic systems). They suggest that it remains "an open question as to whether such widespread patterns reflect the operation of an interesting class of common mechanistic processes or just a large class of stochastic phenomena". Anderson (2001) answers our question after his experiments with arithmetic

1 At least in science, but the phrase 'cats as cushions' may be useful by poetic license.

2 Regarding the precise results of Wilson for random simulations, he mentions at one point use of the Poisson distribution but in another description (his footnote) it appears that he is using the uniform distribution. It is a well known result that the Poisson distribution is not a scale invariant distribution and a power law will not be observed unless the mean and variance are proportionally scaled. However, it is also known that uniform distributions can give rise to a power law relationship between the variance and the interval (scale). In our case, we found the underlying distribution to be lognormal. Perhaps a more relevant experiment with random simulations would specify mathematically, the distribution assumed, and then how sampling from the distribution was performed.

averaging of exponential curves. He makes the conclusion that "power-curve (law) emergence may constitute a methodological artifact, an explanatory construct, or both, depending on the locus of the effect". We have yet to determine the locus of the effect in our system. In other words, we have not yet determined the mechanism governing the detected power law. But, we suggest that a simple one exists, and should be easier to find than a complex one. This remains for the future.

Conclusion

The results of Anand and Li (2001) may be a mathematical artifact, but they may also be an emergent property of vegetation. This is because emergent properties do exist, but more importantly because emergent properties exist in many complex systems like ecological systems.

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