

REPLY TO D. GORDON

Gordon quotes Hempel as saying that a property of a whole is emergent if it cannot be explained from what is known of the parts. In a similar vein, the *Oxford English Dictionary* gives the scientific usage of emergent as "an effect produced by a combination of several causes, but not capable of being regarded as the sum of their individual effects" (Oxford English Dictionary 1989). The opposite of emergent is "resultant." For example, in physics a force can be resolved into orthogonal vectors. The sum of these vectors is the resultant. If the orthogonal vectors are measured but the sum of these vectors does not equal the observed direction of force, then the observed vector is emergent. In mechanics the situation would not be a common one, but as biologists we know of many examples of such situations. One such situation is given by Lande and Arnold (1983) in their discussion of measuring selection on correlated characters. We may know the intensity of selection on trait A (and its heritability) and the intensity of selection on trait B, but the outcome of selection may not be simply the sum of these two vectors. If there is a correlation between the two traits, then the outcome of selection is not simply the resultant sum of the selection on the independently considered traits but includes some interaction due to linkage, pleiotropy, or common physiological or developmental pathways.

I was careful to state in my paper that the experimental evidence for an emergent property of ant activity was found in the relation between the activity of a single isolated worker ant and two isolated worker ants. The activity of two ants, in isolation, is not equivalent to the sum of the activity of two isolated ants. The state of activity of a single ant, in isolation, is a consequence of the internal physiological, hormonal, nutritional, and neural characteristics of this ant. However, by appealing to these characteristics, we cannot predict the activity of two ants when they are allowed to interact. We need to know more about the interaction among ants before we can predict the activity of pairs of ants relative to this particular explanation. By Gordon's definition, this is an emergent property.

Gordon's analogy regarding football spectators is not valid. The experiment I performed was equivalent to measuring the amount of cheering of a single spectator isolated in a room and comparing it, not with the cheering in a stadium, but with the cheering of two spectators in the same room, and five spectators, and so forth. I would like to generalize up to an entire colony, but my experimental claims are about the difference between one ant in isolation and two ants in isolation.

My final comment is about the utility of the word "emergent." Appeal to emergent properties has, in the past, led to nearly mystical claims about the

comprehensibility of the properties of certain complex systems. Claiming that a property is emergent is not a claim that it cannot be understood. Rather, it is a useful tool for understanding the importance of organizational levels in the production of a character.

LITERATURE CITED

- Lande, R., and S. J. Arnold. 1983. The measurement of selection on correlated characters. *Evolution* 37:1210–1226.
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