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Senior Thesis: Prospectus
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Emergence and Complex Systems

The problem I would like to focus on first arises in discussions of physicalism. If we accept the view that the world is wholly physical and therefore that every phenomenon is reducible to a physical phenomenon, then we must answer questions about causal relationships that appear to be non-physical, multiply realizable, or abstracted away from concrete physical reality. In my thesis I would like to use existing models of causation as a framework for analyzing the causal structure of complex systems consisting of a large number of very simple 'agents' that each operate according to simple rules and know only about their local environments.

In his book, 'Turtles, Termites and Traffic Jams', Mitchel Resnick walks the reader through a software simulation engine called 'StarLOGO'. StarLOGO was designed to easily model large-scale collective behavior by individually programming thousands of small 'turtles'. With StarLOGO Resnick was able to simulate a host of interesting phenomena such as the aggregation of cells of slime mold into a contiguous whole, and the architectural prowess of termites building termite mounds.

In one particular example, Resnick simulated an ant colony foraging for food by requiring that each ant obey the following simple, micro-level rules (Resnick 67):

1) If you don't have food, walk around randomly.

2) If you bump into food, pick it up.

3) If you have food, walk towards the nest, releasing pheromones as you go.

4) If you don't have food and encounter pheromone, follow the pheromone trail.

5) If you have food and are at the nest, drop the food and turn around.

With only these simple rules - and the fact that pheromones diffuse slowly over time, the colony is able to efficiently collect food. Given a setup of a nest and 3 food sources, the colony will systematically collect all of the food, beginning with the nearest food source (see fig 1). The 'law' at the macro level appears to be 'to collect food by always starting with the nearest food source', which is very different in nature from the micro-level rules that cause it to be true. There is clearly some causal relationship here – the high level law is grounded in the 'hard' causation of the fundamental rules, but causation also seems present in the higher-level supervenient law alone. To what extent is it correct to say that the ants are "caused" to exhaust the nearest food source first - even though such a law is not encoded anywhere in the rules of the simulation? These are the kinds of questions I will try to tackle.

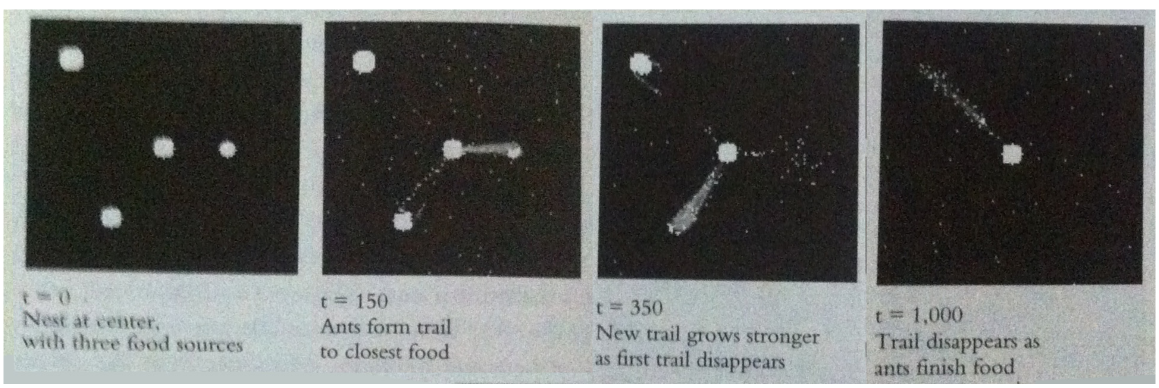

Figure 1 - Reproduced from Resnick (66). Demonstration of the pattern ants take when collecting food. The first pile is exhausted before the second is started.

It is possible to analyze the ant colony at multiple different, internally consistent levels. To go further, it is possible to learn much about the system without even being aware of the simple, basic rules that the ants are following. One might naively conclude that the ant colony as a whole is displaying 'intelligence' by seeking out the nearest food first. This represents a relationship analogous to that between physics and the special sciences. The 5 rules of ant behavior represent fundamental physical laws, while the macro level features are like laws in biology or chemistry.

In his essay 'Causal Explanation', Lewis introduces the idea of a 'causal history', where "the causal history of a particular event includes that event itself, and all events which are part of it… anything on which an event in the history depends is itself an event in the history" (Lewis(a) 217). The causal history can be seen as a kind of graph or web radiating backwards in time from the event in question. Each node represents an event and each line is a causal dependence relation. One event is said to 'cause' another if there is an unbroken chain leading from the first event to the second. Causal histories make sense if we treat the world as set of deterministic, discrete, interdependent events but they become problematic (or at least overly complicated) when we deviate from this assumption. For example, if we treat causes as probability carrying rather than binary (i.e. smoking 10 cigarettes a day leads to a 10% increase in cancer risk) the causal history graph must contain edge values as well as node values.

When we apply Lewis's model to the case of the ant colony we are forced to deal with the problem of exactly which path the casual chain from A:[colony sits in the middle of 3 food sources], to B:[ants consume food, starting with the nearest source] takes. If we take the 'high-level' approach and treat the colony as a single entity then we are forced to invoke concepts such as 'hunger' and 'intelligence' to explain the behavior – neither of which are encoded into the rules of the system. If we say that the causal chain must be low-level, then we fail to account for the collective nature of the behavior and that there are many (if not infinite) ways of implementing the macro-goal using the low level rules. In the first case, Lewis's theory is too general, in the second it is too concrete.

A significant amount of work has been done over the past two centuries in the field of causation. In my thesis I would like to use existing models of causation (starting with Lewis) as a framework for analyzing the causal structure of emergent features in systems exhibiting highly-structured collective behavior, such as the ant colony or slime mold examples above. Do micro and macro level causal relationships share the same nature, or is there a fundamental difference between the two because of the supervening and emergent quality of their interaction?

My preparation and inspiration for this thesis comes primarily from the work I did in 'Philosophy 149x: Philosophy of Science' with Professor Hall last semester. In that course my final paper examined the relationship between laws in fundamental physics and laws in the special sciences, and concluded that laws in the special sciences could be seen as a mechanism for leapfrogging over steps in the fundamental physics – often in ways that are insightful, elucidatory, and intelligible to human beings and modern day computers.

This is a joint physics and philosophy thesis – which I suspect will require further research into specific examples in physics that can be brought to bear on the topic of complex systems and emergence. I have taken many courses in the physics department including Quantum Mechanics, Statistical Mechanics, and Abstract Algebra. This experience, I believe will become important as I start to consider more concrete examples of complex systems.

Preliminary Reading List:

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Hofstadter, Douglas R. Godel Escher Bach: An Eternal Golden Braid. Penguin Group (CA):The 20th Century Edition, 2000. Print. [Only sections on formal systems and artificial intelligence]

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O'Connor, Timothy and Wong, Hong Yu, "Emergent Properties", *The Stanford Encyclopedia of Philosophy* (Spring 2012 Edition), Edward N. Zalta (ed.), URL = <http://plato.stanford.edu/archives/spr2012/entries/properties-emergent/>.

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