ON THE EMERGENCE OF INTELLIGENCE

World Models, Life and Simple Organisms

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> "Anyone who looks at living organisms knows perfectly well that they can produce other organisms like themselves... Furthermore, it's equally evident that what goes on is actually one degree better than self-production, for organisms appear to have gotten more elaborate in the course of time. Today's organisms are phylogenetically descended from others which were vastly simpler than they are, so much simpler, in fact, that it's inconceivable how any kind of description of the later, complex organism could have existed in the earlier one."
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> –**John von Neumann**, "Theory and Organization of Complicated Automata." (1966).

Emergence as a Phenomenon

Emergence as a phenomenon is diverse and encompasses variegated phenomena that develop qualitatively new structures and behaviors beyond the framework of existing models. The old models are surpassed by the new, the sum is greater than it parts. However, unlike acts of creation, emergence does not have a creator per se: emergence happens as a decentralized process without the focused will of *one*. The many leap out of existing frameworks without singular control: the *many* evolve as a single entity, as new, as emergent.

The term emergence, of course, is used in numerous contexts to denote a variety of concepts. For example, biology speaks of slime mold (*Dictyostelium discoideum*) - an amoeba-like primitive organism that lives on the damp forest floor – as being able to emerge into a semi-intelligent yet decentralized mass.[1] Individual organisms collect together into a swarm of particles that, despite having absolutely no centralized brain, is capable of complex tasks. As proof of this in August of 2000, a Japanese scientist named Toshiyuki Nakagaki announced he had successfully trained slime mold to find the shortest path through a maze.[2]

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[1] See Keller and Segel's early work on slime mold, as well as Keller's recent thoughts in *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines* (2002)

[2] For more information about this experiment, see Johnson's, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software* (2001) page 11.

Without any standard cognitive powers, the swarm of slime emerged into a clever mass capable to solving the navigational puzzle without a leader, brain, command center, map or plan.

Emergence is used in biology, entomology[3], urban theory[4], thermodynamics[5], literary theory[6], cognitive science[7], anthropology[8], robotics[9], cross-cultural discourse[10], and computer science[11] to describe phenomenon similar to the maze-solving slime mold: entities that move beyond existing models without the aid of central control. In essence, emergence cannot be captured by imposing a grid or reducing the process into a matrix of events. Emergence itself is a decentralized network of simple local "stories" that transform into a metanarrative.

For the purposes of this essay, the scope of emergence will be focused on the concept of humans attempting to create systems that emerge as being intelligent. As Descartes' Dictum poses, how can a designer build a device which outperforms the designer's specifications?[12] The creation of emergent systems force a re-thinking of both what intelligence is and what generative conditions are required in order to create emergence itself. Emergence *itself* questions the foundations of intelligence: the maze-solving slime mold, the complex ant colony without a leader and the temperature-regulating architectures intuitively constructed by termites challenge the concept of brain-centric intelligence that humans traditionally cling to. Emergent intelligent systems are intelligent without a brain, and striving to

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3 See E.O. Wilson and Bert Hölldobler's *The Ants*, 1990.

4 See Jane Jacobs' *The Death and Life of Great American Cities*, 1961.

5 Ilya Prigogine, *From Being To Becoming : Time And Complexity In The Physical Sciences*, 1980.

6 Wolfgang Iser, graduate seminar entitled "Emergence in Culture and Emergence in Art", University of California Irvine, Winter 2005.

7 Within this context, I think of Francisco Varela's recent work which merges the emergent-like concept of autopoiesis with research in human consciousness.

8 André Leroi-Gourhan's *Gesture and Speech*, 1993.

9 See Rodney Brooks' *The Artificial Life Route to Artificial Intelligence: Building Embodied, Situated Agents*, 1995.

10 Wolfgang Iser in "The Emergence of a Cross-Cultural Discourse", in *The Translatability of Cultures* (Budick/Iser eds.), 1996.

11 See the *Artificial Life* proceedings volumes, as initiated by Christopher G. Langton.

12 Ashby, W.R. *An Introduction to Cybernetics.* London: Chapman & Hall, 1956.

construct these systems provides insights for understanding emergence within the context of the world and culture at large.

Emerging Intelligence and Life, Artificially

> Look to the ant, thou sluggard!
> Consider her ways and be wise:
> Which, having no guide, overseer, or ruler,
> Provideth her meat in the summer,
> And gathereth her food in the harvest.
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> – **Proverbs 6:6–8** (21st Century King James Version)

The fields of artificial intelligence and artificial life both strive for emergent systems. With computational systems in hand, the disciplines are primarily focused on generating intelligence and life independently from its standard biological media.

The discipline of Artificial Intelligence (AI) tends to focus on constructing computer-based models of human intelligence, striving to develop systems that emerge as exceeding human skill and intellect. Problems within the discipline tend to focus on the manipulation of language, mathematics, and logical puzzles. A few popular examples of these pursuits include IBM's chess-playing Deep Blue computer or the Turing Test, in which the intelligence of a synthetic system is measured by whether it can fool a human into thinking they are actually conversing with another human, not a computer. As such, Artificial Intelligence research tends to be brain-centric, or "top-down", with its thrust toward solving particular, centralized problems.

Related to this, Artificial Life (ALife) – although it is a complex field of research – is generally involved with attempting to create life-like organisms outside of biology. "Soft" ALife researchers believe that these synthetic creations are insightful tools to understand and gain a fresh perspective on life itself: the only thing that emerges from the process is a new vantage in which to consider the foundations of the living. Continuing further, "Hard" ALife researchers believe that the essential qualities of life itself can reside within a computer-based system: biology is not a required component of the living. Both hard and soft perspectives attempt to construct emergent systems from a "bottom up" approach by building computer-based models of cells, particles and simple interactions. Artificial Life attempts to produce complex systems that emerge from simple components, as opposed to Artificial Intelligence's "top down" approach that takes the human brain as the existing model to be surpassed.

Regardless, both AI and ALife attempt to build emergent, intelligent, life-like systems.

Obviously, not all people agree with the claims made by Artificial Intelligence or Artificial Life proponents. In terms of Artificial Intelligence, critics often claim that the problems solved by software bear little relation to real-world intelligence. Similarly, Artificial Life is hammered from the perspective that the key properties of life aren't extractable from their biological substrate. In essence, both disciplines are accused of constructing "toy worlds" to run their experiments that creates a simplistic model that is easy to emerge beyond. Within the full complexity of the world, computer models are immensely shallow: chess doesn't help one walk across the street or do ballet. A conversational computer system that passes the Turing test fails miserably as soon as you sneak a glance at its beige boxlike body. An artificial life system of cellular automata can convincingly illustrate pigmentation patterns in nature, but lacks the bandwidth of smell, sound and touch.

Ambler, the Ant, and Emergence: The World is Its Own Best Model

Computer models of the real world tend to especially clash with reality when they are asked to perform non-symbolic problems: like walking gracefully across a crowded room. From a top-down brain-centric "non-slime-mold" perspective, navigating through a real space poses a serious computational problem that strikes at the heart of how complex computational systems can often be outperformed by a lowly, brainless ant or cockroach. The "common sense" problem of just walking across a crowded room is incredibly difficult: while laser scanners carefully construct a God's eye view of the floorplan, an insect can skuttle along, bounce against a few obstacles and continue across the space without a centralized plan and emerging as a winner in a real world application. Outside of the pet hobbies of well-educated upper-class males (including mathematics, logic puzzles, and the odd conversation) computers don't really perform all that well. They don't "Turing Test" effectively to a world model of a seven-year old girl: although the system might be able to practice reading, it would have no idea how to physically get on to a school bus in the morning, dance with a group of friends, apply gobs of glittery make-up, or braid hair.

The real world is such a complicated system that it is almost impossible to not leave something out while creating an abstraction of it.

Rodney Brooks, a roboticist from MIT, noted this phenomenon after observing computationally monolithic mobile robots. For example, he noted that "Ambler" – a two-ton system built at Carnegie Mellon – took a thousand lines of code, a decade of research, and numerous hours of processing time to simply be able to construct an internal model accurately enough to allow the robot to walk across a courtyard of a mere 100 feet. Brooks saw that a brainless insect the size of a pinhead could easily navigate the same environment in a fraction of the time and intelligence, as set out to attempt to build models of these "dumb" systems: fast-reacting, nimble, real-world machines that operated around a few simple reflexes instead of a "master plan" Ambleresque map of the world.

What emerged was "Genghis" – a simple, small, six-legged robot with no central processing unit per se. In insect-like fashion, the football-sized mechanism had no brain, only a few reflexes of reach leg and a few heat sensors at its front to sense living beings. Using only 48 different routines[13] – a miniscule fraction of logic compared to a map-building algorithm – the insect emerged as being strikingly life-like and complex. "The software itself was certainly not profound. It was rather straightforward, in fact. The software's behavior, however, was profound. There was no place that represented the lay of the land out in front of Genghis, over which it must scramble. Further, there was no place inside the control systems of Genghis that represented any intent to follow something, or any goal to reach it. However, to an external observer they were the easiest ways to describe Genghis's behavior. There is a deep philosophical question lurking here. If Genghis did not have its intentions represented anywhere, then did it really have intentions? Or did it just appear to have intentions?"[14] Just as Nakagaki's maze-solving slime mold experiment illustrates, Genghis emerged – or appeared to emerge – intentionality and intelligence. By simply doing simple things well, a centralized representation of the world isn't required in order for an entity to emerge as a coherent, clever being.

With these robotic projects in mind, Brooks proposed that *the world serves as its own best model*. Because of the complexity of reality, the world is best un-abstracted when constructing emergent phenomenon.

And this makes sense, especially given the path of time that has preceded us. "It is instructive to reflect on the way in which earth-based biological evolution has spent its time. Single-cell entities arose out of the primordial soup roughly 3.5 billion years ago. A billion years passed before photosynthetic plants appeared. After almost another billion and a half years, around 550 million years ago, the first fish and vertebrates arrived, and then insects 450 million years ago. Then things started moving fast. Reptiles arrived 370 million years go, followed by dinosaurs at 330 and mammals at 250 years ago. The first primates appeared 120 million years ago and the immediate predecessors to the great apes a mere 18 million years ago. Man arrived in roughly his present form 2.5 million years ago. He invented agri-

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13 Borrowing from Computer Science, Brooks calls these routines "augmented finite-state machines" (AFSMs), each of which being as simple as the logic embedded in a basic soda machine: something that can only be in a couple of states and can store a few numbers.

14 Rodney Brooks, *Flesh and Machines*, page 50.

culture a mere 19,000 years ago, writing less than 5000 years ago and "expert" knowledge only over the last few hundred years. This suggests that problem solving behavior, language, expert knowledge and application, and reason, are all pretty simple once the essence of being and reacting are available. That essence is the ability to move around in a dynamic environment, sensing the surroundings to a degree sufficient to achieve the necessary maintenance of life and reproduction. This part of intelligence is where evolution has concentrated its time – it is much harder."[15] Acknowledging mobility, vision, and survival in a dynamic environment are key to constructing emergent systems that do not prop their emergent qualities on the straw man of a simplified world.

Conclusion: Real-World Thickness

> "In short, we need to look for systematic relationships among diverse phenomena, not for substantive identities among similar ones. And to do that with any effectiveness, we need to replace the "stratigraphic" conception of the relations between the various aspects of human existence with a synthetic one; that is, one in which biological, psychological, sociological, and cultural factors can be treated as as variables within unitary systems of analysis."
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> – **Clifford Geertz**, "The Impact of the Concept of Culture on the Concept of Man." (1966).

Emergence means many things, but fundamentally the concept challenges traditional notions of intelligence by proposing that complex behavior and model-surpassing can emerge without creation and without a central plan. Intelligence can arise as a result of several simple "stupid" micro-components to display "smart" macro-level complexity.

Within this process, however, the framework which is emerged *from* is key. As a result of models being constructed by humans, the decision whether a phenomenon is emergent or not is largely a subjective decision based on the observation of the viewer and a judgment about whether the current model has been actually surpassed. The observation/model subjectivity has created substantial debate in regards to whether artificial systems, for example, display true emergence: intelligent, autopoietic, living, or otherwise.[16] This argument can be thought of as a disagreement about whether the existing model is "real" or not, and whether it has actually been surpassed.

In an attempt to discern if actual emergence has developed, it is helpful to reduce the gap between the framework of the model and the real world. In his anthropological work dis-

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[15] Rodney Brooks, *Intelligence without representation*, page 141.

[16] See the *Artificial Life* proceedings volumes in the Santa Fe Institute Studies in the Sciences of Complexity, as initiated by Christopher G. Langton.

cussing the analysis of foreign cultures, Clifford Geertz takes a similar "bottom up" approach. As he puts it, "thin" description is only a conceptualization, while "thick" description is close to the ground, embodied, and situated. Thick description makes the gap between a sign and what it implies explicit, and is useful in revealing the interaction between actual cultural components.

Within the context of emergence, a thick description of the surpassed model is best. A thick model that is used as a reference point for emergence is stronger than a limited, simplistic system that permits the ordinary to "emerge" by just being above average.

To ensure that models are complex and robust, researchers like Rodney Brooks have proposed that the world is its own best model. Following in this attitude, the study of emergence within the context of artificial systems in general can caution – as Geertz did within the context of Anthropology – to use deep, complex models as a reference to measure the ordinary from the emergent.

And as slime mold can attest, nothing is as thick, of course, as the real world.

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