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Commentary on "Genetic Programming and Emergence"

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Abstract In "Genetic Programming and Emergence" Banzhaf cogently demonstrates that emergence occurs constantly in genetic programming. I summarize the Emergence Test, which my colleagues and I introduced over a decade ago, which complements and substantiates Banzhaf's views.

Keywords Genetic programming · Emergence · Emergence test

The phenomenon of emergence has been an object of scientific and philosophical study (and debate) for centuries. Over the past few decades, with our ever-increasing ability to create putative emergence-in-a-computer, the importance of this phenomenon has increased substantively. Sadly, though the term "emergence" is bandied about quite excessively and unflinchingly, there is of yet not even a consesus as to its definition. As Banzhaf [1] notes, already in the fourth century B.C. Aristotle stated regarding said phenomenon that, "The whole is something over and above its parts, and not just the sum of them all." This epitomic statement has become rather iconic, and is often re-stated and equated with the meaning of emergence. Alas, once one commences to ponder upon the meaning of "parts", "whole", and especially "sum" it becomes clear that the phrase is rather ill-phrased. Indeed, as Banzhaf remarks, Aristotle was probably simply referring to the non-linearity in the resultant wholeness, an observation we would consider today rather simplistic, and—more to the point—which does not really provide us with an understanding or even a definition of emergence.

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Wisely, Banzhaf does not dwell upon this point too much. He provides a brief historic outlook and then goes on to examine the mechanisms of emergence. One major conclusion is that, “Downward causation is a prerequisite for emergence, but upward causation is necessary, too.” He quotes Stuart Kaufmann’s cogent rephrasing of Immanuel Kant: “The whole exists for and by means of the parts and the parts exist for and by means of the whole.” This circular relationship between cause and effect seems endemic to systems exhibiting emergence. As Banzhaf states, “The nature of the interactions (inner level, top-down and bottom-up) is now such that the entities that are observable on a certain level happen to be those whose causation is consistent between the different levels.”

Following this eloquent enunciation Banzhaf moves on to demonstrate his main point, namely, that emergence occurs constantly in genetic programming (GP). I think that Banzhaf makes a cogent argument for his case. As he correctly points out there are indeed multiple aspects of GP that make it amenable to emergence: multiple levels between genotype and fitness, allowing many-to-one mappings; the evolving entities or programs are active in the sense that the same outcome can be achieved in different ways; GP solutions are compositional, i.e., brought about through the composition of simpler entities, affording much freedom.

As a GPer of many years I have witnessed firsthand Banzhaf’s examples of emergent phenomena in GP: bloat, repetitive patterns, modularity, cooperation, evolvability. These are produced by evolution without being explicitly selected for.

These examples tie in nicely with our own take on emergence. Over a decade ago my colleagues and I took what Banzhaf refers to as the epistemological approach, defining an Emergence Test [2]. Assume that the scientists attendant upon a simulation-based experiment are just two: a system designer and a system observer (both of whom can in fact be one and the same), and that the following three conditions hold:

1. Design. The system has been constructed by the designer, by describing *local* elementary interactions between components (e.g, artificial creatures and elements of the environment) in a language $\mathcal{L}_1$.
2. Observation. The observer is *fully aware* of the design, but describes *global* behaviors and properties of the running system, over a period of time, using a language $\mathcal{L}_2$.
3. Surprise. The language of design $\mathcal{L}_1$ and the language of observation $\mathcal{L}_2$ are distinct, and the causal link between the elementary interactions programmed in $\mathcal{L}_1$ and the behaviors observed in $\mathcal{L}_2$ is *non-obvious* to the observer—who therefore experiences surprise. In other words, there is a cognitive dissonance between the observer’s mental image of the system’s design stated in $\mathcal{L}_1$ and his contemporaneous observation of the system’s behavior stated in $\mathcal{L}_2$.

The above three clauses relating design, observation, and surprise describe our conditions for diagnosing emergence, i.e., for accepting that a system is displaying emergent behavior [2].

I think our test complements Banzhaf’s view, and I can most definitely attest to many surprises emerging from my own work in GP…

While the issue of emergence is one of great interest, I, too, would pose the same question Banzhaf poses at the end of his essay: SO WHAT? Why should we care whether emergence occurs in GP? As long as we obtain nice, publishable (and sometimes profitable) results, can we not simply be as happy as clams?

Not quite. For the recognition of emergence in GP—and the study of its causes—can help us move the field of GP forward. One avenue of research, suggested by Banzhaf, is that of multi-level systems that are equipped with a multi-level selection mechanism for the emergence of entities on different levels. Other lines of research might also follow from an interest in emergence, e.g., the study of mappings (genotype-to-phenotype, phenotype-to-fitness), thus reifying a topic usually perceived as purely abstract.

Insight into GP will thus surely emerge.

References

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