Comparing Artificial Phenotypes with Natural Biological Patterns

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ABSTRACT

As an aid in assessing artificial developmental encodings, this paper presents several common and uncommon features of patterns observed in biological organisms. Evolved phenotypes can be compared with both lists in order to assess the viability of the encoding that generates them.

Categories and Subject Descriptors

I.2 [**Artificial Intelligence**]: Miscellaneous

General Terms

Experimentation

Keywords

developmental encoding, artificial embryogeny, development, mapping

1. INTRODUCTION

Assessing the quality of artificial developmental encodings can be tricky [6]. While it is useful to measure the performance of evolving a particular encoding in a set task or benchmark [2, 4], there is also a need for task-independent metrics. The problem is that benchmark performance may not correlate to the the long-term goal of the field, which is to discover encodings with the expressive capacity demonstrated by the complexity of natural organisms. Since no artificial encoding has yet displayed such power, it is difficult to predict which encoding is headed down the right road, and which is simply performing at its limit.

This paper enumerates a set of general characteristics observed in natural organisms that can also be identified in artificially evolved phenotypes, making it easier to assess promising phenotypic characteristics independently of a task. While some of the characteristics listed below are

well known and not surprising, the intention is to make a point about what's important to consider in addition to performance, rather than to introduce concepts that are necessarily novel.

Most of the important characteristics center around different kinds of regularity, since it is a prerequisite for reusing genetic information in the phenotype [6]. Without regularity, the same information could not produce different parts of the same phenotype, removing much of the advantage of development. Both Turing [8] and Lindenmayer [3] were initially inspired by the patterns they saw in nature before they attempted to describe how those patterns could be generated. Turing eventually proposed his *reaction diffusion model*, which successfully produces patterns similar to those seen on animal pelts, and Lindenmeyer ultimately invented L-systems, which accurately grow plant-like morphologies. Thus, by identifying both the common general properties of patterns in nature as well as those that are unnatural, it becomes more clear for what phenomena artificial systems must account. The remainder of this paper characterizes patterns both natural and unnatural for this purpose.

2. CHARACTERISTICS OF NATURAL BIOLOGICAL PATTERNS

The following list describes both patterns present in individual organisms, and the way those patterns change over generations.

- **Repetition**: Multiple instances of the same substructure is a hallmark of biological organisms. From hair on the head to neurons in the brain, the same motifs occur over and over again in a single organism. Repitition in the phenotype is also called *self-similarity* [1].

- **Repetition with Variation**: Frequently, motifs are repeated yet not entirely identical. Each vertebrae in the spine is similar, yet they each have slightly different proportions and morphology [9]. Similarly, human fingers repeat a regular pattern, yet no two fingers on the same hand are identical. Repitition with variation is abundant throughout all of natural life.

- **Symmetry**: Often repetition occurs through symmetry, as when the left and right sides of a body are identical mirror images in classic bilateral symmetry.

- **Imperfect Symmetry**: While an overall symmetric theme is observable in many biological structures,

they are nevertheless generally not perfectly symmetric. Such imperfect symmetry is a common feature of repitition with variation. The human body, while overall symmetric, is not equivalent on both sides; Some organs appear only on one side and one hand is usually dominant over the other.

- **Elaborated Regularity**: Over many generations, regularities are often elaborated and exploited further [7]. For example, the bilaterally symmetric fins of early fish eventually became the arms and hands of mammals, displaying some of the same regularities. [5].

- **Preservation of Regularity**: Over generations, established regularities are often strictly preserved. Bilateral symmetry does not easily produce three-way symmetry, and four-limbed animals rarely produce offspring with a different number of limbs, even as the limb design itself is elaborated.

3. CHARACTERISTICS NOT COMMON IN NATURE

While it is important to recognize the patterns often produced through development, it is no less important to identify what is unlikely. This list of unnatural characteristics is especially cautionary because artificial developmental encodings often produce patterns of these unnatural types, implying that they may not be genuinely abstracting the underlying mechanisms of natural development. While a system that happens to produce a pattern of one of the types below may nevertheless be effective, if it *only* produces patterns of these types then that may be grounds for concern about its long term potential.

- **Overabundant Fractalization**: Biological organisms do exhibit fractal-like properties. Trees often branch into branches, which further branch into more branches, which branch into leaves [3]. The human body branches into four limbs that each branch into five digits. Blood vessels branch in self-similar ways as well. However, there is a limit to recursive self-similarity in nature. It is not common for an organism to be composed of beyond four or five layers of recursive branching, and most organisms are not exclusively fractal. Furthermore, branching does not proliferate radically from one generation to the next. Humans are rarely born with subfingers branching off their fingers.

- **Overall Perfect Regularity**: It rare that an organism is perfectly regular. For example, bilaterally symmetric organisms are not *overall* bilaterally symmetric. Neither are all limbs exactly the same in the same organism. For this reason, perfect regularity may in fact imply artificiality.

- **Brittle Modularity**: It is extremely rare that a repeated structure is reused in an inappropriate or bizarre location. While an arm can be conceptualized as a "module" that is reused in two different places, it is nevertheless almost impossible for a third arm to appear in nature based on the same arm design. Thus modules are not seen proliferating throughout the phenotype outside the constraints of established regularities (such as bilateral symmetry).

4. CONCLUSION

The position of this paper is that in addition to benchmark tasks, phenotypes produced by artificial developmental encodings should be compared against both natural and unnatural kinds of regularities in order to ascertain their long term potential. Such comparisons may reveal shortcomings of a particular encoding even if it performs well on selected benchmark tasks.

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