Chapter 8

IMPROVING THE SCALABILITY OF GENERATIVE REPRESENTATIONS FOR OPEN-ENDED DESIGN

Gregory S. Hornby[1]

[1] *U. C. Santa Cruz, Mail Stop 269-3, NASA Ames Research Center, Moffett Field, CA, 94035*

Abstract With the recent examples of the human-competitiveness of evolutionary design systems, it is not of interest to scale them up to produce more sophisticated designs. Here we argue that for computer-automated design systems to scale to producing more sophisticated results they must be able to produce designs with greater structure and organization. By "structure and organization" we mean the characteristics of modularity, reuse and hierarchy (MR&H), characteristics that are found both in man-made and natural designs. We claim that these characteristics are enabled by implementing the attributes of combination, control-flow and abstraction in the representation, and define metrics for measuring MR&H and define two measures of overall structure and organization by combining the measures of MR&H. To demonstrate the merit of our complexity measures, we use an evolutionary algorithm to evolve solutions to different sizes for a table design problem, and compare the structure and organization scores of the best tables against existing complexity measures. We find that our measures better correlate with the complexity of good designs than do others, which supports our claim that MR&H are important components of complexity. We also compare evolution using five representations with different combinations of MR&H, and find that the best designs are achieved when all three of these attributes are present. The results of this second set of experiments demonstrate that implementing representations with MR&H can greatly improve search performance.

Keywords: evolutionary design, scalability, representations, complexity

1. Introduction

With improvements in software modeling packages and increases in computational power, there is growing interest in using artificial intelligence techniques to automate some of the design process. Automated design systems based on evolutionary algorithms (EAs) have been used to create interesting designs in a variety of different domains (Bentley, 1999; Bentley and Corne, 2001). Of interest is understanding how to improve existing computer-automated design systems so that they scale from designing merely a single component of a design to creating a large, complex design and all of its custom parts. In order to improve the ability of evolving design systmes (EDSs) to scale up for producing sophisticated designs, we need: a better understanding of scalability, metrics to measure designs scalability, and understanding of how computer-automated design systems enable scalability.Already various metrics exist for measuring what has been loosely defined as *complexity*, such as Algorithmic Information Content (AIC) (Chaitin, 1966; Kolmogorov, 1965; Solomonoff, 1964), Logical Depth (Bennett, 1986), and Sophistication (Koppel, 1987). These metrics vary in their degree of intuitiveness in measuring complexity. For example, the AIC of a random string will score higher than a string of the same length with hierarchies of regularities, whereas we are inclined to think that a string with the patterns is more complex. More importantly, existing complexity measures are not based on measuring characteristics of good design. Thus, rather than using these existing measures, a more useful approach may be to set them aside and develop new metrics that explicitly measure those characteristics that have been demonstrated to be useful for improving scalability.

In engineering and software development sophisticated artifacts are achieved by exploiting the principles of modularity, reuse, and hierarchy (MR&H) (Huang and Kusiak, 1998; Meyer, 1988; Ulrich and Tung, 1991), and these characteristics can also be seen in the artifacts of the natural world. Assuming that the principles of MR&H are necessary for achieving scalability, then by constructing an EDS capable of producing designs with these characteristics we can hope to achieve more scalable computer-automated design. Breaking down an EDS into its separate modules yields the representation for encoding designs, the search algorithm for exploring the space of designs that can be represented, and the fitness function for scoring the goodness of a particular design. Ideally, the ability of an EDS to create designs with hierarchies of reused modules should be independent of how designs are scored. In addition, the EA for exploring the space of designs can only find designs that can be expressed by the chosen representation. Thus for an EDS to achieve MR&H it must use a representation capable of encoding designs with these characteristics.

To be able to develop representations which can encode designs with MR&H we need to understand the fundamental attributes of design representations. One