

Representation and Evolution of Lego-based Assemblies

Maxim Peysakhov, Vlada Galinskaya, William C. Regli

Geometric and Intelligent Computing Lab
Department of Mathematics and Computer Science
Korman Computing Center
Drexel University
Philadelphia, PA 19104
{umpeysak, uvgalins, regli}@mcs.drexel.edu

Abstract

This research presents an approach to the automatic generation of engineering designs. Our approach is to apply Messy Genetic Algorithm optimization techniques to the evolution of assemblies composed of Lego elements. Design evaluations are based on a set of behavior and structural equations. Initial populations are generated at random, and the system evaluates and assigns numeric fitness values to each member in the population. The design candidates for subsequent generations are produced by a user-specified selection technique. Single point crossovers are applied by using cut and splice operators at random points of the messy chromosomes; random mutations are applied with a certain low probability to modify individual nodes of the graph. This cycle continues until a suitable design is found or until the time limit has expired. We have selected the domain of Lego assemblies because it represents a sufficiently complex, multi-disciplinary design domain and includes a wide variety of realistic engineering constraints. Further, the domain is sufficiently discrete as to be tractable.

The main contribution of this research is not in the genetic algorithm itself, but rather in its application to the practical task of Lego design generation. Representing Lego designs as a mechanical assembly graph has a number of potential advantages over the assembly tree approach, which was mentioned as a limiting factor in earlier research. A labeled assembly graph is more expressive and can represent a greater variety of Lego assemblies, including kinematic mechanisms as well as static structures. The nodes of the graph represent different Lego elements, and the edges of the graph represent connections between elements. We have developed a graph grammar to define valid combinations of nodes and edges precisely and unambiguously. This language aids in classifying the Lego blocks and connections. For now we have used this notation only to formally define the requirements documentation. In the future, we plan to introduce another level of abstraction and represent Lego mechanisms as sentences in a language of Lego assemblies, rather than graphs, which will make it easier to validate the assembly against grammar rules.

Although the current system can handle only static structures composed of block-type elements, the general approach can be applied to much more elaborate kinematic mechanisms. We have developed specifications on the representation of wheels, gears, and axles, and their connections. Each structure has a number of attributes, such as weight, number of nodes, and size in each dimension. These parameters are used by the evaluation function

to calculate the fitness of the structure. Our eventual goal is to introduce simulation of electro-mechanical devices into our evaluation functions.

Figure 1 shows the result of evolution of static Lego structures with predefined geometric parameters. In these experiments, mutation and crossover rates were 0.01 and 0.7, respectively, and we used a *rank selection strategy* and *elitism* on a population of 100 members. In the first experiment the goal was to evolve a structure with a size of 10 Lego units in each x - y - z dimension with minimal weight. The resulting structure is shown on the left; it was discovered at generation 3367 and exactly matches the desired size. Also, it is one of the lightest possible structures that can be created from the set of elements that we have. In the other experiment, we evolved a pillar-like structure, with 2 by 4 base and length equal to 20, 40 or 60 Lego units and having maximal density. The output of the system is shown on the right. The resulting structures exactly match desired sizes and have very few defects.

We believe that this research creates a foundation for future work, and that we will be able to apply GA techniques to the evolution of more complex and realistic electro-mechanical structures.

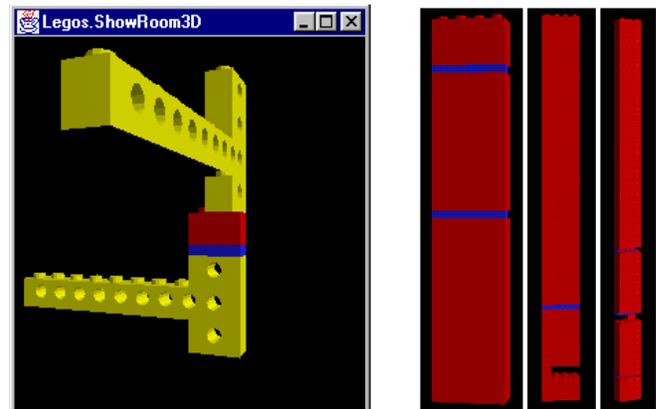


Figure 1: Experimental Results.

Acknowledgments

Support provided by the NSF Knowledge and Distributed Intelligence in the Information Age (KDI) Initiative Grant CISE/IIS-9873005 and CAREER Award CISE/IIS-973354 to William C Regli.