Genetic Algorithms for Optimization of Lego Assemblies

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Abstract

This research presents an approach to the automatic generation of engineering designs. We apply Messy Genetic Algorithm optimization techniques to the evolution of assemblies composed of the Lego elements. We have selected the Lego assembly domain because it represents a sufficiently complex, multi-disciplinary design environment that includes a wide variety of realistic engineering constraints. Solution of this problem has great practical value. First, the growing popularity of Lego robot competitions creates a practical test bed for design generation and optimization tools. Second, optimization of Lego assemblies is closely related to the generation of real engineering artifacts, so similar principles and tools can be adapted to larger problems.

One of the most successful attempts to apply GAs to the task of Lego generation was made by J. Pollack and P. Funes and described in the paper *Computer Evolution of Buildable Objects.* They used an assembly tree to represent a Lego structure --- which, according to Pollack, was one of the limiting factors in their work. In our research, we are addressing this limitation by representing Lego designs as mechanical assembly graphs. This has a number of potential advantages over the assembly tree approach. A labeled **assembly graph** is more expressive and can represent a greater variety of the Lego assemblies, including kinematic mechanisms as well as static structures. Each chromosome is encoded as a labeled **assembly graph,** where nodes of the graph represent different Lego elements and edges of the graph represent connections and relationships among elements.

Another problem that we were facing was the absence of a notation for describing valid Lego assemblies. We developed a **graph grammar** to define valid combinations of the nodes and edges precisely and unambiguously. In the present system we used the developed 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 as graphs, which makes it easier to validate the assembly against grammar rules.

Design evaluations are based on a set of structural equations, which we are trying to optimize. Parameters for equations include number of nodes, size in each dimension, etc. Our eventual goal is to introduce simulations of electromechanical devices into our evaluation functions. The initial populations are generated at random. Users can specify the selection technique to be used to identify candidates for the new generation of design. Single point crossovers are applied by using cut and splice operators at random points of the messy chromosomes; random mutations are applied with a specified low probability to modify individual nodes of the graph. This cycle continues until the time limit has expired.

Figure 1 shows the result of the evolution of two static Lego structures with predefined geometric parameters. In all experiments, mutation and crossover rates were 0.01 and 0.7 respectively, and we were using a *rank selection strategy* and *elitism* on the 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 and minimal weight. The resulting structure is shown on the left. It was discovered at generation 895 and has size 10 by 10 by 6.8, which is sufficiently close to the target. 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 were evolving a pillar-like structure, with 2 by 4 base and length 60 with maximal density. The output of the system is shown on the righ. The structure exactly matches the desired size and has almost maximal density.

We believe that this research creates a foundation for future work, and that it will apply GA techniques to the evolution of more complex and realistic electromechanical structures.

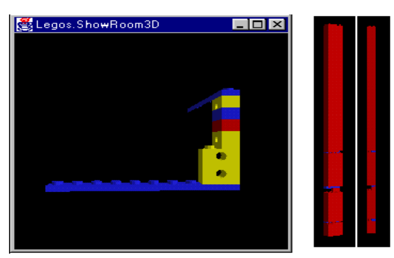

Figure 1: Experimental Results.

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