Generic Evolutionary Design of Solid Objects using a Genetic Algorithm

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Abstract

This thesis investigates the novel idea of using a computer to create and optimise conceptual designs of a range of differently-shaped three-dimensional solid objects from scratch. An extensive literature review evaluates all related areas of research and reveals that no such system exists. The development of a generic evolutionary design system, using a genetic algorithm (GA) as its core, is then presented.

The thesis describes a number of significant advances necessitated by the development of this system. Firstly, a new low-parameter spatial-partitioning representation of solid objects is introduced, which allows a wide range of solid objects to be appropriately defined and easily manipulated by a GA. Secondly, multiobjective optimisation is investigated to allow users to define design problems without fine-tuning large numbers of weights. As a result of this, the new concepts of acceptability, range-independence and importance are introduced and a new multiobjective ranking method is identified as being most appropriate. Thirdly, variable-length chromosomes in GAs are addressed, to allow the number of primitive shapes that define a design to be variable. This problem is overcome by the use of a new hierarchical crossover operator, which uses the new concept of a semantic hierarchy to reference chromosomes.

Additionally, the thesis describes how the performance of the GA is improved by using an explicit mapping stage between genotypes and phenotypes, steady-state reproduction with preferential selection, and a new lifespan limiter. A library of modular evaluation software is also presented, which allows a user to define new design problems quickly and easily by picking combinations of modules to guide the evolution of designs.

Finally, the feasibility of the generic evolutionary design of solid objects is demonstrated by presenting the successful evolution of both conventional and unconventional designs for fifteen different solid-object design tasks, e.g. tables, heatsinks, penta-prisms, boat hulls, aerodynamic cars.

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Contents

Bentley, P J & Wakefield, J P (1996). The Evolution of Solid Object Designs using Genetic Algorithms. In Rayward-Smith, V. (ed) *Modern Heuristic Search Methods.* Ch. 12, John Wiley & Sons Inc., 199-215.

Bentley, P J & Wakefield, J P (1995). The Table: An Illustration of Evolutionary Design using Genetic Algorithms. In *Genetic Algorithms in Engineering Systems: Innovations and Applications* (GALESIA '95), Sept. 1995, Sheffield (pp. 412-418).

Bentley, P. J. & Wakefield, J. P. (1996). An Analysis of Multiobjective Optimisation within Genetic Algorithms. Submitted to *Evolutionary Computation*.

Bentley, P. J. & Wakefield, J. P. (1996). Conceptual Evolutionary Design by Genetic Algorithms. *Engineering Design and Automation Journal v2:3,* John Wiley & Sons, Inc.

Bentley, P. J. & Wakefield, J. P. (1996). Overview of a Generic Evolutionary Design System. In *Proceedings of the 2nd On-line Workshop on Evolutionary Computation,* (pp. 53-56), Nagoya University, Japan.

Bentley, P. J. & Wakefield, J. P. (1996). Hierarchical Crossover in Genetic Algorithms. In *Proceedings of the 1st On-line Workshop on Soft Computing* (WSC1), Nagoya University, Japan.

Bentley, P J & Wakefield, J P (1996). Generic Representation of Solid Geometry for Genetic Search. *Microcomputers in Civil Engineering 11:3,* Blackwell Publishers, 153-161.

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