# Interactive Evolutionary Design in a Hierarchical Way

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## Abstract

This paper introduces a computational system framework for enhancing design in an evolutionary manner. The framework provides a structure for supporting design activities at the conceptual design stage at different levels of representation and manipulation. With this framework, designers can interactively manipulate design data and develop a solution in a hierarchical manner. Furthermore this system framework provides explorative and adaptive ability through its inter-links with a number of computational evolutionary and generative modules. In this paper, this system framework and its application in the design of wine glasses are presented.

## 1. Introduction

In modern design, we face a high degree of complexity and collaboration. Computational support must be provided for designers to explore alternative design solutions. The use of Artificial Intelligence and other advance computational technologies to reduce the burden of designers, and to enhance the design process is an important research area. Two aspects of enhancing design with computational systems are concerned in this paper: 1) supporting interactive manipulation of design at various representational levels, and 2) supporting generation, exploration and adaptation of potential design alternatives.

Designers often have to switch among different representations of the design problem and its solutions during the design process. While the activities at an abstracted representational level tend to dominate the early conceptual design stage, the representation of the design solutions becomes more and more complex and contains more and more details as the design process moves on. The existing Computer-Aided Design (CAD) tools can support detailed design tasks such as geometric modelling but offer limited support to conceptual design. In this paper we emphasise the importance in providing computational representation and

inference methods to support the process of developing an abstract design concept to a fully specified solution.

Analogous to the evolutionary process of nature, exploring design alternatives can be supported by simulating an evolutionary and generative process of designing. The development of an evolutionary system framework as a kernel of a computer based design support system for enhancing design process in an evolutionary manner is one of the main focuses of research by the authors. This framework was first proposed in year 2000 [3]. It provides mechanisms for manipulating design solutions and their generative process at different levels of representation.

A software prototype has been developed for building demonstration applications using this kernel. The implemented prototype constitutes a basic framework of a hierarchical evolutionary process for intelligent design support. Demonstrations have been developed using this kernel in the design of wine glasses. With this hierarchical evolutionary process, large numbers of alternative design solutions can be generated and evaluated. In this paper, an introduction to evolutionary design is presented first. The proposed evolutionary framework for supporting design in a hierarchical manner is then presented. Finally the demonstration prototype and the results of applying the evolutionary framework to generating wine-glasses are presented.

## 2. Evolutionary Design

Design involves an evolutionary process for searching solutions to achieve a goal. This evolutionary process may be treated as an endless activity, which means that the design process may not have a finite and identifiable end [2, 10]. Evolutionary Computation (EC) is a technique based on mimicking natural evolutionary process for survival. Together with Neural Network and Fuzzy Logic, they form the foundation of knowledge-based systems [13]. EC conventionally involves Evolutionary Algorithm (EA), Evolutionary Strategy (ES), Genetic Algorithm (GA) and Genetic Program (GP). All these techniques mimic the natural evolution of real life. Although there are some differences among these mechanisms in terms of their mutation and crossover reproduction, all involve a set of evolutionary solutions (evolving population) based on preferential selection of the fittest in an environment

(objective function). There are many articles and materials describing the working principles and the applications of EC [4][9][11].

Evolutionary techniques have been applied to solving searching and optimisation problems in various engineering fields, such as packing optimisation problems [8][9]. Recently, many new evolutionary design methods have been developed [1]. Some have applied evolutionary computation techniques to artistic, form and structural design [16][19][20]. Some also applied GA to graphic design and the creation of artificial creatures [17][18]. Other studies concentrated on methods for the exploration of possible design domains in engineering areas [6][7][12].

## 3. Interactive Evolutionary Design and Hierarchical Model

Most applications of evolutionary techniques concentrated mainly on the analysis and optimisation in detailed and routine design tasks, at later stages of design process. There is comparatively less research in supporting generative aspects in design, particularly at conceptual stages. This is related to the difficulty in acquisition and formulation of more abstract problems at early design stages when compared with design works at later stages, which emphasise analysis and optimisation.

### 3.1 An Evolutionary Framework for Enhancing Design in Hierarchical Manner

Generative ability is a crucial part in supporting design, particularly at conceptual stages. Instead of achieving a well-defined goal (problem specification, and solution), a large number of diverse design solutions need to be generated and explored at various stages of the conceptual development process using different representations. This specific nature of design leads to the need for a support system capable of providing generative ability for the exploration of a variety of design solutions, or sub-solutions.

Design representation has been related to network, layer-network or hierarchy in many articles [14][15][21]. There is a consistent preference of a hierarchy structure for modelling design. Although it is doubtful whether this can be applied to all design tasks, there are numerous substantial design problems that exhibit in this way. This paper proposes an evolutionary system framework, which addresses the issue of evolutionary design representation. This framework was first proposed in year 2000 and the details can be found in [3].

Unlike other hierarchical models for design that are mainly based on geometrical reductionism and decomposition, the hierarchical levels of our proposed framework reflect various abstract representations of the designing tasks. In this approach, design can be related to an evolution of a candidate design solution from its most abstract form (the original problem) to the least abstract (the final and fully specified design solution). This evolutionary process transforms a given problem, a need or an idea for example, to a final design solution through a series of mapping from abstract representations to the less abstract ones.

Our evolutionary framework is structured in the form of a hierarchical network, which consists of network elements (nodes) evolving and interacting with others according to their "evolutionary mechanisms". Each network element basically evolves in the model under its evolutionary mechanism and interacts with other neighbouring elements

When applying this evolutionary framework to a design task, the hierarchical network represents the whole design task while each element in the network is an evolving sub-solution to the whole problem at a specific representation level. Each element (or sub-solution) has its own functions and meanings for the design task. Sub-solutions (nodes) include textual specifications, 2D drawings, key parameters for evaluation, or 3D geometric models. The final output of this network represents a design product such as a glass, a chair or a building.

### 3.2 Designer's Role in Evolutionary Design

With the great advancement in computational power and technologies, many computational systems and tools have been developed for supporting design. However, designers still play a crucial role in design, especially at conceptual design stage. It would be unrealistic to fully automate the whole design process and exclude designers in a computational design model. Thus, a design model should provide flexibility for designer-system interaction.

In our evolutionary framework, each sub-solution node is attached with an "evolutionary mechanism". When we have understood this specific node to a certain degree and suitable computational module can be formulated to act as an automatic evolutionary mechanism, the computational evolutionary mechanism can then be formed and the node can be evolved consequently.

However in practice there are many cases that the sub-solutions are not fully understood and suitable computational modules cannot be formulated. We still rely heavily on designers' expertise to do the job. In this case, designers play an important role. There are two ways in which designers may interact with the proposed evolutionary system: 1) designers fully manipulate the design at a specific representation and carry out the mapping from one representation to another, and 2) designers manipulate the rules, parameters and other control values of some preset computational evolutionary mechanisms.

In the demonstration examples presented in the following section, a designer can interactively manipulate the design task at various abstraction levels. In particular, an evolutionary mechanism of Genetic Algorithm (GA) is attached to show how designers can manipulate the evolutionary process of GA, through artificially selecting the preferred solution candidates.

## 4. Wine-Glass Generation and the Results

In theory, the evolutionary framework is a general model that can handle diverse applications in various areas. We have preliminary implemented a demonstration prototype of this evolutionary framework. The evolutionary framework prototype is implemented in Java as an applet, which can run on the Internet through web browsers.

The framework can also be integrated with commercial CAD tools as a system kernel that offers evolutionary and generative ability to enhance design. Figure 1 shows the integration of our framework with a commercial CAD tool, MicroStation, to generate wine-glasses. The framework is developed as a basic system kernel which offers generative and evolutionary ability for enhancing design, in particular for exploring and adapting potential design alternatives. The sophisticated representation of design objects, such as geometric modelling and visualisation, is not implemented. In this case, commercial tools can be used for this purpose.

Figure 1 shows the interface of the proposed evolutionary system kernel which is integrated with Microstation. In this demonstration, the task of designing wine-glasses is supported from generating the most abstract features of wine-glasses in the top-right window, to producing 2D profile of the wine-glasses, and then to using evolutionary mechanisms including a Genetic Algorithm, to obtaining the final details of each wine-glass in the generated glass series. The changes made in the upper representation levels will propagate to the lower ones, and

consequently the final 3D models of the generated wine-glasses will be visualised using the commercial CAD tool.

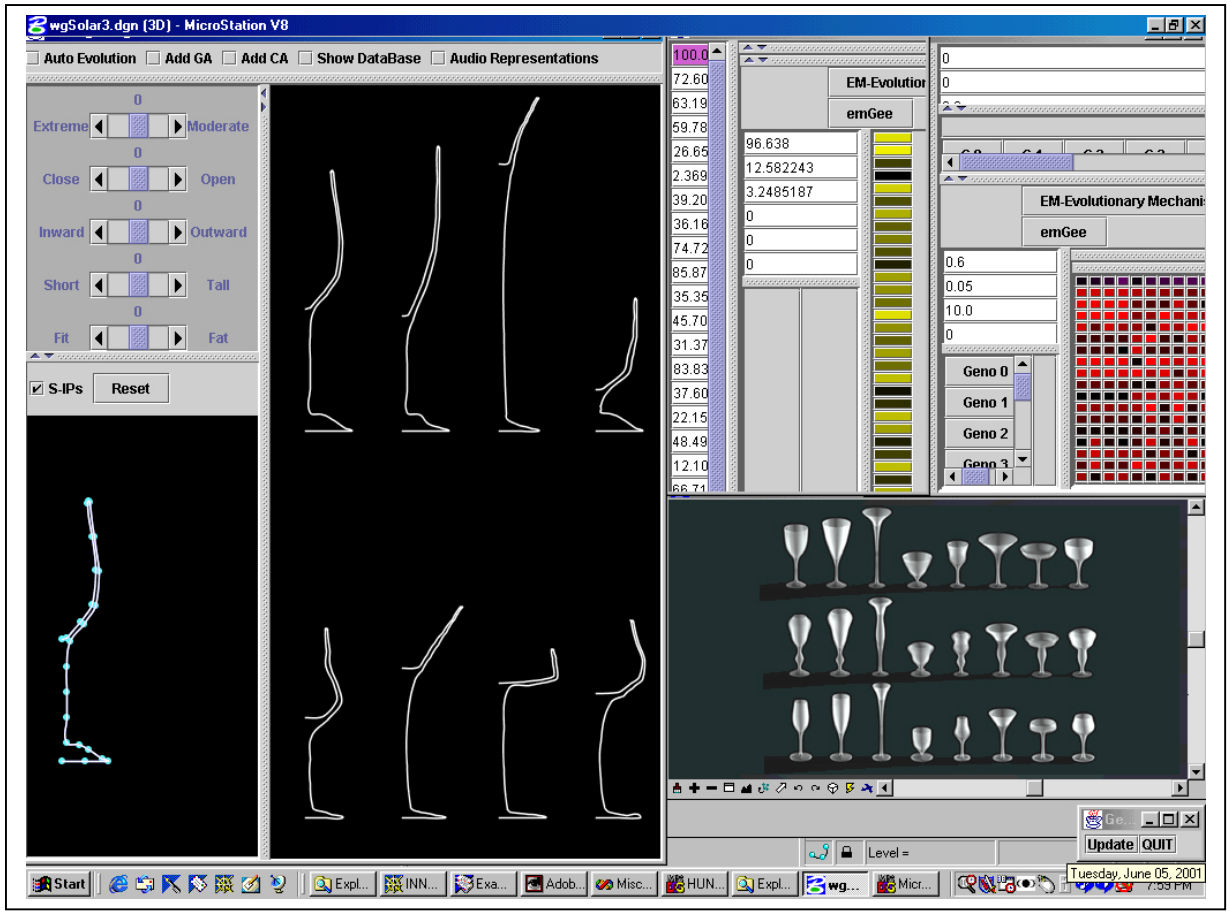


*Fig.1 The demonstrative evolutionary framework that generates wine-glasses.*

Designers can act interactively to manipulate the design details at every level of representation, from basic features such as tall or short to details of geometrical parameters, of wine-glasses in the framework interface. Designers may also participate in the parameter setting and preference selection for Genetic Algorithm that is attached to the lower level of the system for exploring and adapting potential design solutions as shown in Figure 2. 3D models are then generated using commercial CAD tools for visualisation. Figure 3 shows some of the results of wine-glasses generated using the demonstration system.

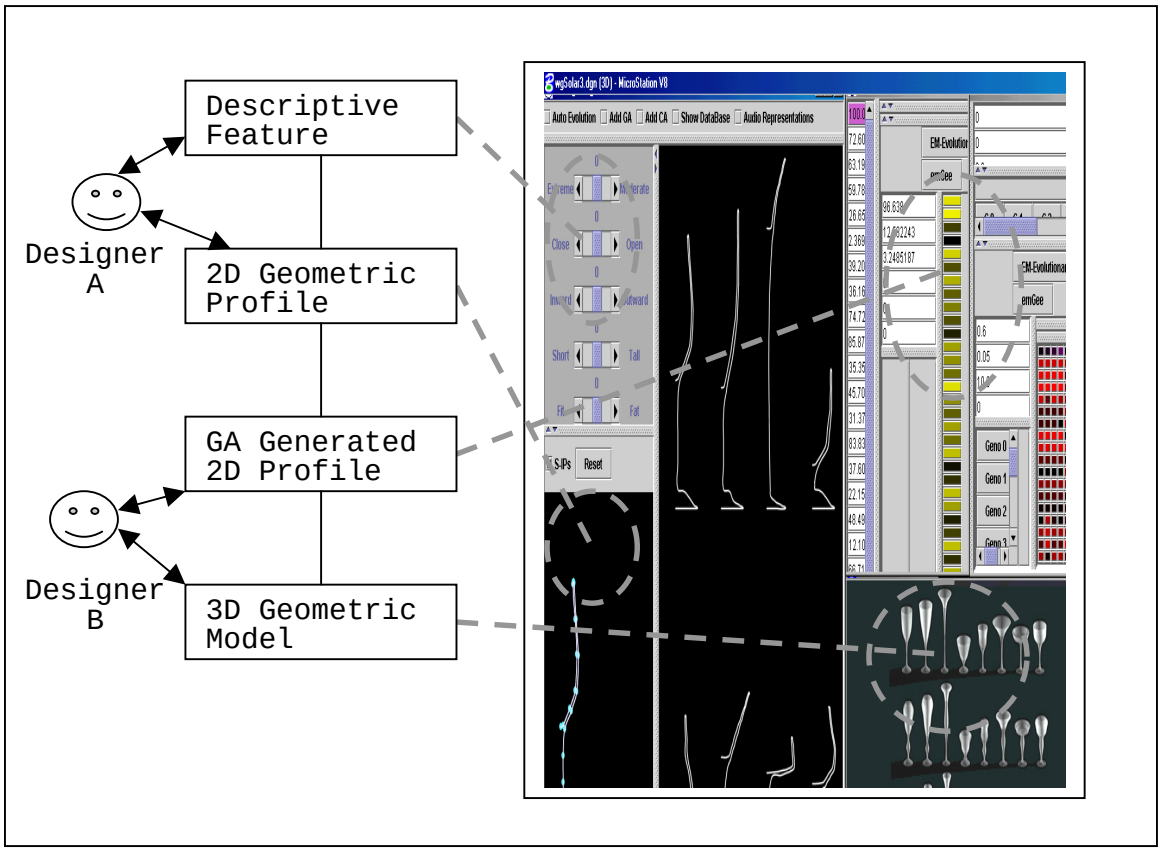


*Fig.2 Designers manipulate the system interactively at various representation levels.*

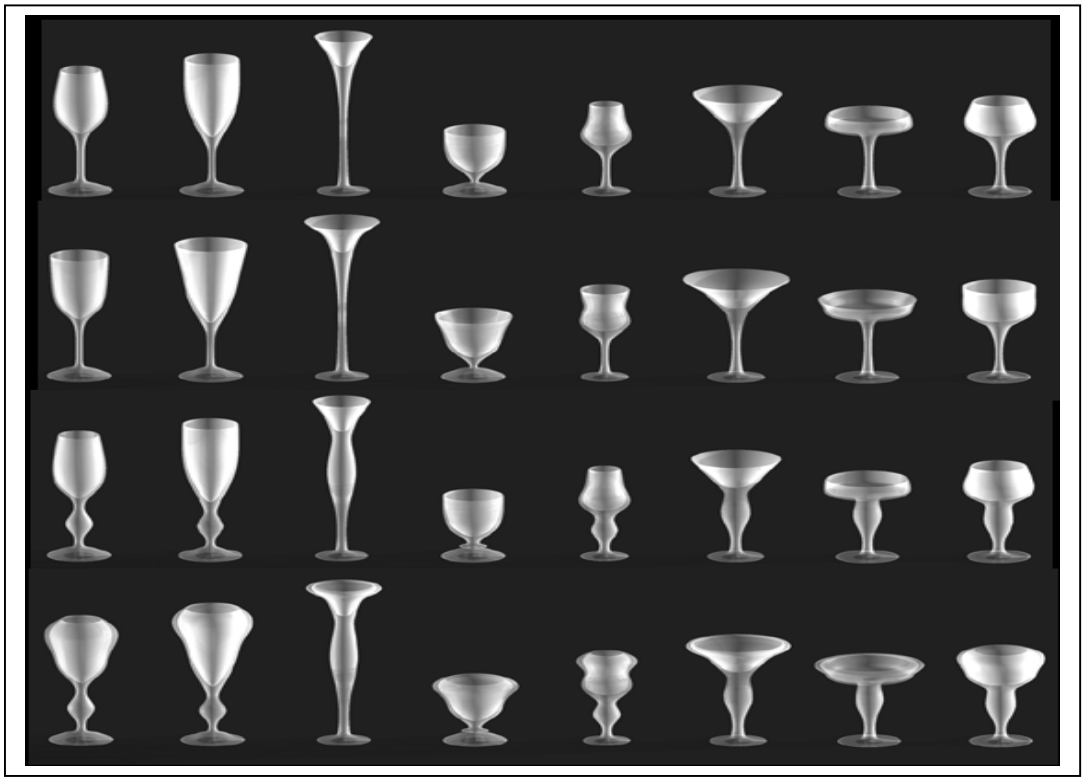

*Fig.3 Some results of wine-glasses generated with the evolutionary framework.*

## 5. Conclusion and Future Directions

Although there are some recent applications of evolutionary techniques in supporting design, the limitations of conventional evolutionary methods obstruct their providing more generative functions.

The first part of this paper gives a brief introduction to recent evolutionary design with evolutionary computation methods. The problems of these methods are also discussed. A flexible evolutionary framework is then introduced. This framework has a hierarchical network structure. The framework is structured with sets of evolving elements connected together. Each of these evolving elements has its attributes and evolutionary mechanism. Each element evolves in the model according to its evolutionary mechanism, and interacts with other neighbouring elements.

A demonstration software has been developed, and presented in the last section. Wine-glasses are generated with the proposed model that is integrated to a commercial CAD tool. Designers can interactively manipulate different levels of representation, from basic features such as tall or short to details of geometrical parameters of wine-glasses. Furthermore a genetic algorithm is used as an evolutionary mechanism that explores and adapts potential design solutions, through designers' selection of preferences.

The results obtained from this demonstration program showed that the framework provides a flexible and dynamic architecture to generate, explore and adapt design alternatives. Further investigation is required to study its potential application in other design areas.

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