An Overview of the integration of aesthetics, component-based representations and machine-learning within a User-centric Evolutionary Design System

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ABSTRACT

This paper reviews the creation and subsequent extension of an interactive evolutionary design system with several novel features such as an inclusion of aesthetic criterion, object based representation and agent-based assembly/repair of solutions. We also highlight the various components of the system and describe how they solve some of the problems faced during the design process by the designer.

Categories and Subject Descriptors

J.m [**Miscellaneous**]

I.2.m [**Artificial Intelligence**]: Miscellaneous

General Terms

Design, Algorithms.

Keywords

Interactive Evolutionary Design, Software Agents, Aesthetics

1. INTRODUCTION

The following work relates to user-centric evolutionary design systems which integrate machine-based evaluation of engineering and rule-based aesthetic criteria with the designer's subjective aesthetic evaluation of design solutions. Although much research relating to artificial design environments is evident [1, 2, 3] there is little evidence of the integration of evolutionary search and exploration, user evaluation (of design solutions) and machine learning within a single design environment.

A detailed discussion of factors which make such a system difficult to implement within a real world context can be found in Machwe et al [4]. Such factors have led to an approach commencing with a relatively simple system before slowly increasing the complexity of the problem. The research has led to a generic framework for an Interactive Evolutionary Design Environment (IEDE) as shown in Figure 1. This has evolved from Parmee's Interactive Evolutionary Design systems (IEDS) work [5]

The initial problem formulation for the IEDE involved the design of simply supported beam bridges while incorporating simple engineering analysis and aesthetic evaluation (both rule based and subjective). Several novel concepts were introduced in this system. These include: the agent-based construction and repair of population members; agent-based aesthetic evaluation of solutions; an object-based design representation supported by a case-based machine learning sub-system. The reader is directed to [4] and [6] for a detailed description of the resulting interactive evolutionary design environment (IEDE).

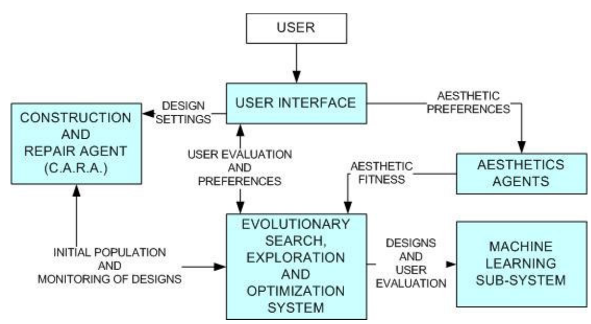

Figure 1. Interactive Evolutionary Design Environment.

An iterative development method was followed. With each iteration the complexity of the design being created increases along with the complexity of the other sub-systems such as the representation, fitness evaluation and learning.

Current work is extending the capabilities of the IEDE to handle greater complexity in terms of representation and aesthetic evaluation. We are now considering the design of 'urban furniture' in the form of novel and aesthetically pleasing seating arrangements for parks and other public areas. Simple structural analysis of the resulting forms is combined with both rule-based and user-led aesthetic evaluation at a more complex level than similar evaluation relating to the previous bridge structures.

GECCO'06, July 8–12, 2006, Seatlle, Washington, USA.

This review paper focuses on the IEDE with a special attention to its various components and how they have evolved during the iterative development of the IEDE. In this paper we will touch upon the following features of the IEDE:

1) The Object based Representation.

2) Construction and Repair Agents

3) Aesthetics

4) Machine Learning sub-system

We also look at possible extensions of the various components as the complexity of design increases.

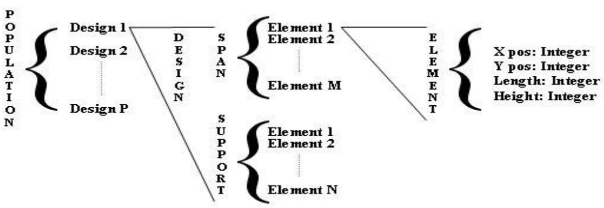

Figure 2. Representation for Bridge Design problem.

2. BACKGROUND

Interactive Evolutionary Computation (IEC) forms the background for this work. IEC involves the designer in solution evaluation during an evolutionary search and exploration process thereby ensuring human involvement within an iterative evolutionary design loop. There is a considerable body of work on IEC. Recent advances include the usage of knowledge-based encoding for fashion design [7] and the hazard icon work of Carnahan and Dorris [8]

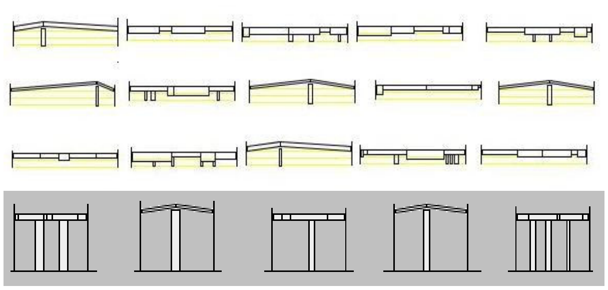

Figure 3. Some non-optimized/optimized bridge designs.

In [3] and [9] Parmee attempts to define various levels and types of interaction across a spectrum of IEC activity. Based upon this definition our current work lies towards the implicit end of this spectrum due to the combination of both quantitative, machine-based solution evaluation and user-led subjective evaluation. The user led subjective evaluation is further supported by a machine - based learning system which attempts to learn the user's subjective aesthetic preferences. This reduces the cognitive load on the designer and associated fatigue due to repeated design evaluations. [6]

3. REPRESENTATION

The representation used within the IEDE is object based [4] which results in a flexible representation in terms of the possible designs that it can represent whilst being sufficiently robust to be manipulated by evolutionary search and exploration algorithms.. The initial work involving bridge design used a collection of primitive elements to represent a structure.. For example any structure made up of LEGO™ bricks can be represented as a collection of primitive design objects each with a specific x and y position and a pre-defined length (along X) and height (along Y). We also have the flexibility of using different elements with different design properties by just including them in the set of possible design primitives. When it comes to the evaluation of fitness of the structure and checking the structural integrity we use secondary properties of the particular primitive element type (such as length, height and type of element).

Figure 2 describes the object based representation as used in the

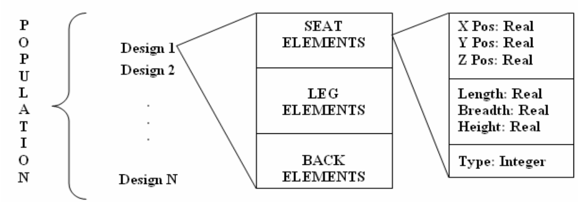

Figure 4. Representation of Benches

2-D bridge design problem. Figure 3 shows some of the non-optimized 2-D bridge designs generated using the IEDE and the final designs which were optimized using various engineering, rule based aesthetic and subjective fitness criterion. The present work dealing with urban furniture (seating arrangements) extends the representation into three dimensions. Figures 4 and 5 describe this extended representation.

The object based representation has been extended to support three-dimensional designs. Elements representing the seat, backrest and legs of a simple bench-type arrangement have been created. This shows the flexible nature of the object based representation which can used to represent almost any kind of design.

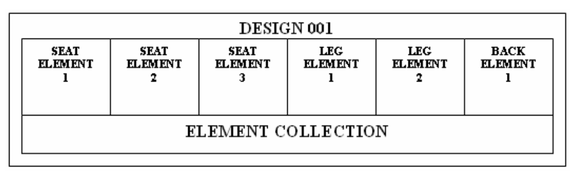

Figure 5. Basic structure of a Bench Solution

An additional feature added within the design representation for the simple bench is the concept of element design. Within the previous work all the elements were of the same design (basic cubic). In this case we have two kinds of elements namely a solid element and a 'grill' element. The basic difference between the two, other than the aesthetic-visual difference, is that a 'grill' element uses lesser materials and is lighter. Visual differences are also expected to play an important role in the designer's subjective evaluation of the solutions. These extensions, although simple at the moment, highlight the flexibility of a component based representation.

4. AESTHETICS

The fact that aesthetic evaluation is highly subjective is a common observation which is supported by several independent sources. Furthermore it is impossible to create a set of aesthetic rules which can be applied universally. We can only create certain guidelines to provide limited machine based estimation of aesthetics [4, 10]. This makes it particularly hard to incorporate aesthetic criteria as part of a design system and makes designer-system interaction all the more important. In the present work aesthetics are evaluated at two separate levels. On the machine side aesthetic fitness is evaluated using a set of rules (or guidelines). On the human side the designer has the option of ranking the solutions using subjective assessment. This ensures that while certain aesthetic rules are included within the design evaluation the subjective aspect of aesthetic design is not ignored.

Within the bridge design system rules relating to slenderness ratio of bridges, positioning of supports and thickness of span elements were used. These are also used in the bench design problem with an obvious increase in the number of such rules due to the three-dimensional nature of the problem

5. C.A.R.A.

The Construction and Repair Agent (CARA) is an important component of the IEDE. Without CARA the object based representation would not be able to generate any meaningful shapes.

The Construction Agent (CA) portion of CARA builds the initial design population using a rule base. This rule base can be made as flexible as required. At one end of the spectrum fully free-form designs can be generated by just random placements of elements at the other end a fully defined skeleton can be provided for the placement of elements.

Furthermore the CA has been designed keeping in mind possible extensions to its functionality. These extensions include the creation of an interactive agent-based, 'requirement gathering' interface which would form the first stage of a fully generative design system.

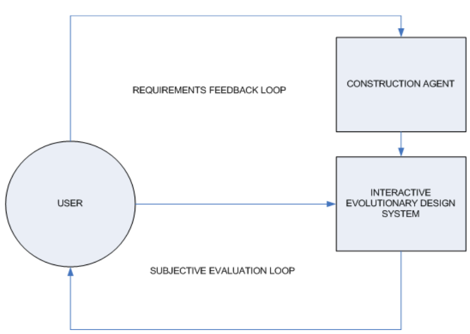

Figure 6. Basic Generative System.

Requirements gathering is the first stage of any kind of design process and such an interface would allow the designer to create a rule base for the construction of the initial population based on the gathered requirements. This rule base would then be used by the CA to create the initial population. This interface in turn could be extended into a generative system where the designer not only evaluates the solutions during a particular design cycle but also provides feedback to the CAs on the quality of solutions being generated. In the present work the rules for the CA have initially been kept simple. Figure 6 further clarifies this idea.

The Repair Agent is involved during the evolutionary search and exploration process. The agent ensures that designs remain feasible after undergoing mutation operations. Among other things the Repair agent prevents overlapping of elements or their becoming separated from the design. The Repair Agent allows us to maintain the structural feasibility of the solutions during the evolutionary design process.

6. MACHINE LEARNING

The Machine Learning sub-system plays a central role in reducing the cognitive load on the designer during the interactive design process. It is an online learning system which uses Case-Based Reasoning to learn the subjective aesthetic preferences of the designer. We have found that, due to the problem of representation of solutions to the learning system, Case Based Reasoning (CBR) is one of the most promising techniques [11]. A major advantage of using CBR is that the design information can be stored as it stands without needing to convert it into any other formats such as fuzzy variables or input values for neural networks. Such a conversion can take away essential information. The retrieval part of the CBR uses nearest-neighbour distance metrics to measure the difference between the new design and the designs in the case base. The design closest to the new design has its user-assigned fitness awarded to the new design (Figure 7).

Since CBR learning is online the Cases are not carried over from past runs. Initially the Case library is empty. After the first generation of user evaluations the Case library begins to fill. Solutions not examined by the user are assigned a zero fitness. Once there are a number of cases in the Case library the machine learning system starts ranking solutions and the user has the option to change the machine-assigned rank.

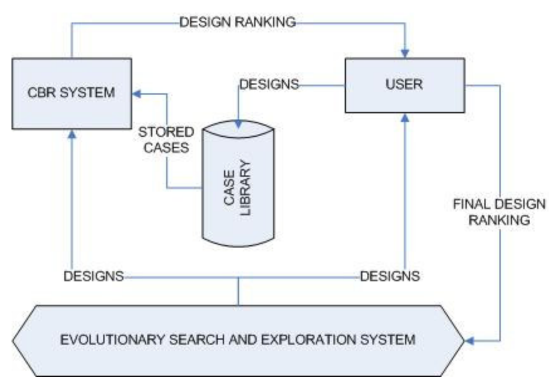

Figure 7. The Case Based Reasoning system integrated with the IEDE.

With the learning system operating in background the number of changes made by the user (to the machine assigned rank) would decrease with each generation as the machine assimilates user preference. This is assisted in part by the convergence of the population i.e. as the population converges it improves the resolution around the solutions initially preferred by the user. It must be kept in mind that without a machine learning sub-system the user would have to rank all the N% solutions shown to him consistently after every generation to ensure that the population converges to the desired designs.

The Case-based learning system has been implemented within the bridge design IEDE with relative success. For further information on the implementation and detailed results the reader is directed to [6].

7. GENERATED DESIGNS

In this section (Figure 8) we show some of the initial results from

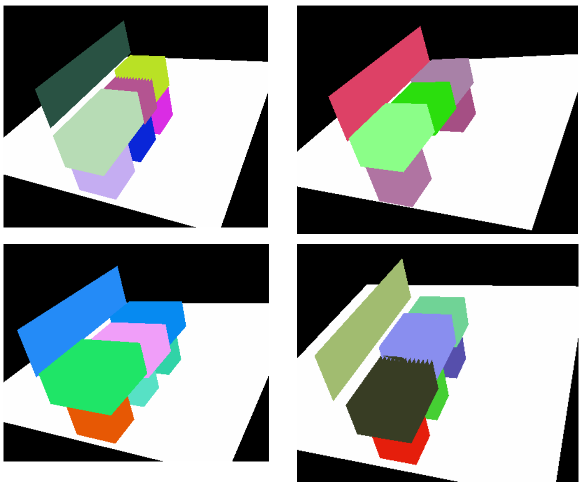

Figure 8. Some optimised bench designs.

the seating arrangement design system. The evaluations functions used engineering criterion as well as rule based aesthetics to determine the fitness of the solutions. Furthermore a well defined set of rules is used to create the initial population (using the CA).

Figure 9. Free-form interactively evolved seating arrangements.

Figure 9 shows some resulting designs when using fully free-form construction of the initial population (i.e. random placement of elements). Here only basic fitness criterion of minimising ground footprint and creating a well connected structure is used. For details the reader is directed to [10].

8. CONCLUSIONS

In this paper we have provided an overview of the various novel features of the IEDE and how they have evolved from basic requirements of an Interactive Evolutionary Design system (IEDS).

We also describe how the various components of the IEDE work together to provide a basic yet cohesive design tool. This paper also shows that the concept of an IEDS involving subjective criterion is difficult to implement without incorporating some form of machine learning. Finally we show how the IEDE can be extended into a fully generative system and what role each component would play within such a system.

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