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# INTEGRATING AESTHETIC CRITERIA WITH A USER-CENTRIC EVOLUTIONARY SYSTEM VIA A COMPONENT-BASED DESIGN REPRESENTATION

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## ABSTRACT

It is well known that for any sort of evolutionary search we must represent the problem solution in a suitable manner since the choice of representation has a large impact on the type and efficiency of the evolutionary search procedure applied. Usually in evolutionary design applications either bit strings or real number parameters are used to encode the problem. However, during the initial design phase a 'design' may not be decomposable into real number parameters since the nature of the search space is not well understood and / or the designer wishes to maintain a highly flexible approach whilst establishing an initial configuration. The paper introduces the overall objectives of the project and discusses representation issues before presenting an object-based representation which tries to incorporate the ambiguity present during the initial design phase by working with design elements and objects as members of the chromosome. Ambiguity is particularly acute in this case as the overall project objective is the development of a user-centric evolutionary design system that includes aesthetic criteria evaluation. Following that we briefly describe the integration of user evaluation and simple rule based aesthetics

*KEYWORDS: Agents, Engineering Design, Interactive Evolutionary Design, Representation techniques.*

## 1. Introduction

The research described in the paper relates to user-centric intelligent design systems and creativity in design. Creativity is initially considered through the inclusion of aesthetics as additional design criteria within a planned, semi-autonomous machine-based design environment. The proposed system brings together agent-based machine learning, evolutionary computing and subjective evaluation in design space search and exploration for aesthetically pleasing, structurally feasible and usable designs. The aim is that the system will be capable of learning basic characteristics relating to aesthetically pleasing designs from user-evaluation within an evolutionary search process. It is intended that as the search progresses there will be a gradual lessening of the degree of user interaction allied with an increasing degree of autonomous machine-based solution evaluation involving both aesthetic and structural criteria.

Although research relating to artificial design environments is evident in the literature [1], [2], [3], [4],[5] there is little evidence of the integration of user evaluation, evolutionary search and exploration and agent-based machine learning With respect to the addition of aesthetics into computer-based design, much theoretical work (in the form of the development of computer models) is evident in this field but little application-based research has been done [6],[7],[8].

The figure above shows the main components of the IDS and how they interact with each other to create the User-System interaction loop. The primary purpose of the user is to define initial design requirements and to aesthetically evaluate the designs generated by the Evolutionary Search Exploration and Optimisation System (ESEO) during the initial

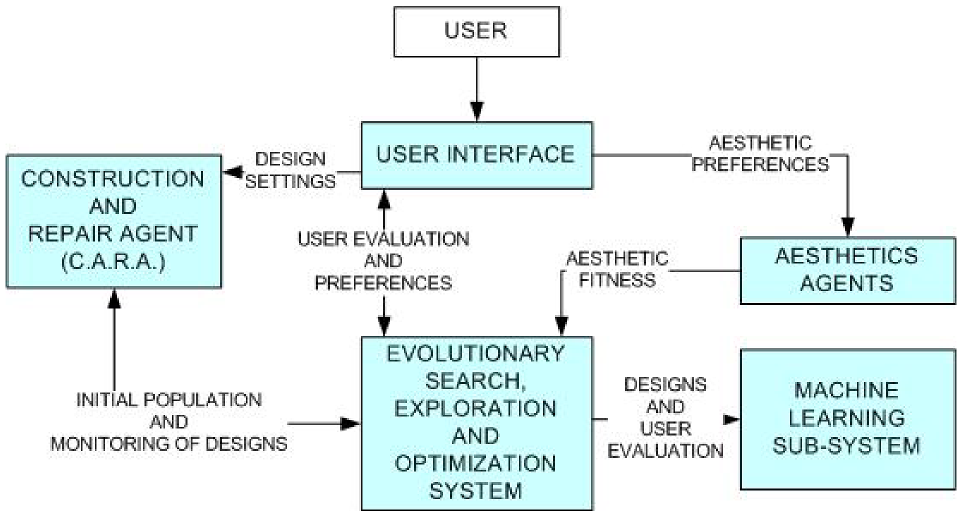


Figure 1. The Interactive Design System (IDS)

generations. The agents have multiple tasks which include the creation of the initial population based on design requirements, the monitoring of designs for feasibility during the ESEO processes and evaluation of aesthetics. The ESEO identifies design solutions that can be considered high performance in terms of the following:

1. Structural Feasibility and Stability: this includes the identification of solutions which represent 'feasible' designs and then categorising them on the basis of design stability. When using agents to assemble the initial population (e.g. CARA) whether or not to have infeasible solutions in the population depends on the rules supplied by the user to the assembly agents.
2. Materials Cost: this could be a primary objectives especially when dealing with the design of mass produced items where cost per unit is a critical criteria..
3. Aesthetics: this design criteria is very difficult to define [9] since aesthetic evaluation is a highly subjective activity. While structural stability and materials cost might be important factors, often it is just as important for the final product to be aesthetically pleasing. In the present work we aim to look at both the specific as well as the generic aspects of aesthetics.

The project is initially considering three test domains: bridges; liquid containers such as vases, wine glasses; chemical tanks, etc and street furniture in the form, initially, of bench type structures. These three domains have been chosen because of their differing design criteria and the need for differing forms of representation. The first domain is highly constrained, the second potentially requires some complex, non-linear shapes and the third looks similar to bridges but is actually far less constrained and offers interesting challenges re flexibility of reasoning

This joint research project involves the ACDDM Lab at Bristol UWE and the Institute of Machines and Structures at Cardiff University. The paper concentrates upon the primary stages of the overall research project and upon the first test domain i.e. bridges. These early stages have largely involved the development of highly flexible and robust representations of simple bridge structures and the subsequent identification of high-performance solutions via basic evolutionary algorithms. Evaluation of solutions has been solely in terms of spatial feasibility, simple structural analysis, cost / material weight considerations and simple aesthetic guidelines coupled with user evaluation.

## 2. Theoretical Overview

According to Rosenman [10] 'a recurring issue in all design research is the issue of representation'. This statement best describes the problem at hand. The issue of representation is central to any evolutionary system since the efficiency of the search as well as effectiveness of the evolutionary operators such as mutation and crossover is directly linked with the representation [11], [10].

Traditionally, in the case of genetic algorithms (GA), evolutionary strategies (ES) and evolutionary programming (EP) representations are based on binary or real number variable parameter strings. Such representations have their own advantages and disadvantages but many alternatives are also available [10], [11] and [12]. Bentley [13] states that component based representations 'allow increased freedom for evolution' whereas others (e.g. [14], [15]) have proposed hierarchical representations since design objects are complex entities with many related sub-systems / components that cannot be efficiently represented by a simple variable string. Peysakhov et al [16] use a messy GA to assemble structures from LEGO™ blocks using a representation based on assembly graphs. These representations indicate that for a representation to be flexible as well as robust a component based hierarchical representation is necessary. Coupled with this it is also necessary to examine what kind of stochastic search process would best suit this representation in terms of efficient negotiation of the design space which is equally important as the efficient encoding of the variable parameters.

Assuming we wish to achieve a high degree of solution search and exploration, population based approaches (i.e. approaches that search from many trial points initially well-distributed across the design space) would seem most appropriate. Genetic algorithms (GAs), evolutionary programming (EP) and evolutionary strategies (ES) appear to offer high utility. The basic difference between the three is their usage of evolutionary operators. GAs use crossover as the main exploratory operator [17]. ES is similar to a real parameter GA without crossover although 'recent ES studies have introduced crossover like operators' [17]. Finally EP [18] is a purely mutation based evolutionary algorithm where mutation is the only exploratory operator.

EP could be considered to represent the simplest of the above algorithms since it has just one operator namely mutation. Thus the representation is not restricted by the need to support crossover between differing variable strings. GAs are at the other end of the spectrum where the representation has to be robust enough to handle repeated crossovers while ensuring the validity of the children. ES, in its many varieties, such as ($\mu$, $\lambda$) and ($\mu$ +$\lambda$) lies somewhere between them. It is clear that it is necessary to assess the utility of the above algorithms in terms of the representations under development. Since EP and GA represent two ends of the spectrum it would be prudent to test the representation on these two before moving on to ES and hybrid methods.

## 2.1 Aesthetics

Aesthetics are defined by the Online Oxford Dictionary (www.askoxford.com) as 'the branch of philosophy which deals with questions of beauty and artistic taste'. Aesthetics have been governing humans from 'time immemorial' according to Staudek [19]. Furthermore, a common observation is that criteria for aesthetic evaluation are highly subjective. The New South Wales Road and Traffic Authority (RTA) report [9] states 'there are no hard and fast rules for what is good proportion' although 'guidelines' can be provided to make the design more aesthetic. It is therefore very difficult to integrate aesthetic criteria with machine-based design unless user interaction plays a significant role..

Many people have tried to quantify aesthetics. One of the pioneers of this field, George D. Birkhoff, proposed 'aesthetic measure theory' (Birkhoff cited in [19]) which based aesthetic perception on two properties: complexity and order. While order depends on the geometrical aspects of the design being evaluated complexity depends, as the name suggests, upon the overall complexity of the design. According to Birkhoff, symmetry and balance is important while complexity is not desirable. Thus Birkhoff's aesthetic measure 'M' is defined as the ratio of Order and Complexity (or Order divided by Complexity). To obtain the value of 'M' for any design we would need a suitable evaluation technique for the particular type of design (to obtain Order and Complexity values) [20].

In our particular case we are initially interested in aesthetic evaluation of bridges. Much work has been done in this particular topic by Miles et al [6], [7] at the University of Cardiff. Building on this and other works on bridge aesthetics the RTA have prepared an excellent set of guidelines on bridge aesthetics [9].

## 2.2 Interactive Evolutionary Design

Interactive Evolutionary Design (IED) [21], [5] as the name suggests combines interactive designing process with evolutionary search and optimization techniques. According to Parmee [4] 'interactive evolutionary design strategies support the extraction of optimal design information, its presentation to the designer and subsequent human-based modification of the problem domain based upon knowledge gained from the information received'. This cyclic process is supported by continuous interaction between the designer and an evolutionary search and exploration system. IED can be considered to be part of the Interactive Evolutionary Computing (IEC) field as described in Parmee and Abraham [22]. Much work is evident in the IEC field e.g. Carnahan and Dorris [23], Gero and Rosenmann [24], Takagi [25], Sims [26] to mention a few.

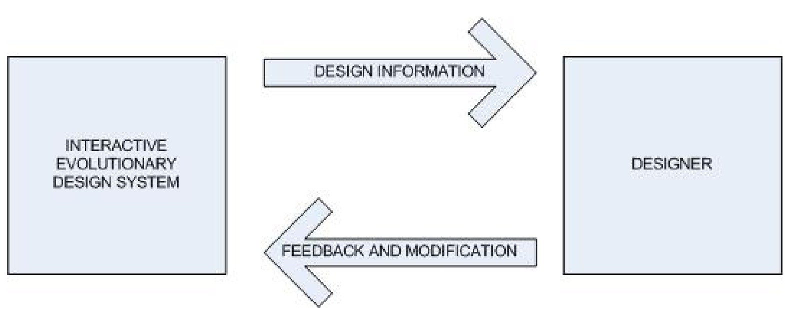


Figure 2. An interactive design system.

This generic design system has two sub-components, namely the designer interface and the search and exploration engine. Research in both these sub-components can be found in the literature. But the problem lies at the interface of the two sub-components, in other words how best to combine the interactive part with the evolutionary part so that information extraction from the evolutionary search and subsequent modification of the problem through user feedback can be done in the most user friendly and efficient manner. As Parmee [27] states 'best utility can be achieved from systems that enhance the designer's inherent capabilities…'. One such novel system is the Interactive Evolutionary Design System (IEDS) [21]. A novel concept in the IEDS is to use software agents [27] as a buffer between the user and the evolutionary process to help in design information extraction and control of the evolutionary process.

## 3. Representation Issues

In any evolutionary optimisation process we find that the representation chosen plays a very important role in determining search efficiency and the quality of the solutions obtained. Mainly there are two classes of representations, string based and tree based. While tree based representations are used with Genetic Programming systems, variable strings are used with GA/EP/ES systems.

Our initial goal was to create a representation which not only was flexible in terms of the possible designs that it could represent but also robust enough to be used for design search, exploration and optimisation.[28]. To ensure a high degree of flexibility it is best to avoid pure string based real number representation (see section 3.2). A collection based object oriented representation has therefore been developed. Here a single population member (chromosome) is a collection of primitive elements that represent a design. 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). Here the LEGO™ bricks are the primitive design objects which when used again and again at different positions and orientations give us a complete structure. 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. An argument was initially made for the use of a design grammar based GP system but initial investigations in this direction indicated that such a system would take away the flexibility by trying to force the mapping of the design onto a tree structure and by the complexity relating to maintaining feasibility during evolutionary operations.

Figure 3 further clarifies the idea of using an object based representation. A simple bridge design is basically divided into two separate collections. These are the **Span Element**

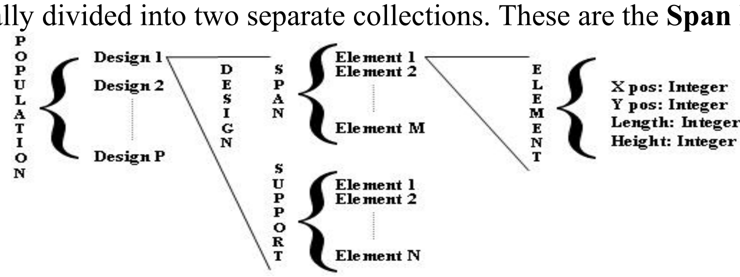


Figure 3. Details of the object based representation.

collection containing elements which form the span of the bridge and the **Support Element** collection containing elements which form the support of the bridge. In the case of a free span bridge the **Support Element** collection will be empty.

Each Element is basically a rectangle with properties as previously described. An Element can either be part of a supporting element collection or a span element collection. Since initially we are looking at a simple beam span bridge with and without supports and a bridge with angled beam span sections there are only two basic types of Elements required. These are the angled section Element (to be used as a span element only) and a simple rectangle Element which can be used as both spanning and supporting element. To extend the design into the third dimension all elements have a constant width. Thus only the profile of the bridge is relevant. An addition benefit of using an object based representation is that it can take advantage of the principles of object oriented programming such as inheritance. Thus if we wanted to add a new kind of element, say curved span section, we could easily do so by extending the basic properties of Element and adding the extra properties required for a curved section. To further elaborate on the representation we describe the manner in which a mutation operator acts on it.

## 3.1 Mutation

Let us assume the chromosome to be mutated represents the following design:

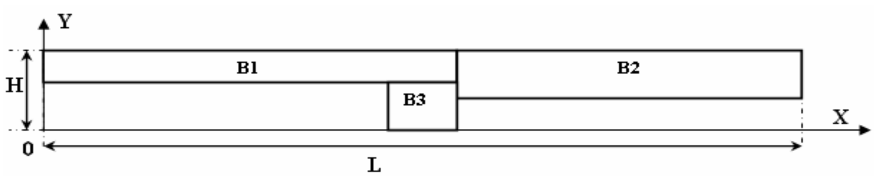


Figure 4. Design before mutation.

The above is a simple beam bridge with a single support (B3) and two span elements (B1, B2). L is the span and H is the maximum height of the bridge.

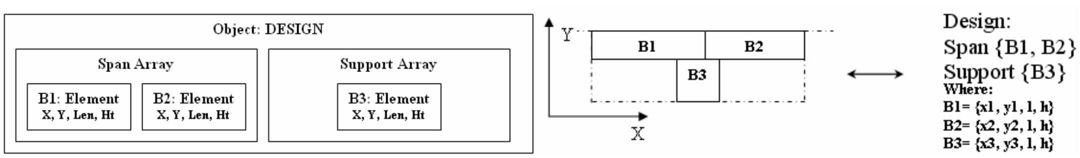


Figure 5. Structure of a design chromosome.

The mutation is rule based and a rule is selected randomly. There are separate rules for the two arrays of elements. The supports can only move left or right. Their height is based upon the thickness of the spanning element they support . Hence there are only 4 rules for supports i.e. two rules for left and right movement and two for increasing and decreasing width. The depth of each span element can vary but they must have a level upper surface and must be continuous with no overlap or space between them. Thus for a simple Element in a span there are just two rules namely to increase or decrease the span depth. Now for example if the selected rule for support (B3) is to move it left by a constant distance (say 2 units) and for span to decrease thickness of B2 support by constant units (say 2 units again) then the B3 object in the support array will have its X value attribute decreased by 2 units and B2 object in span array its height value attribute decreased by 2 units. The height attribute of the support will be automatically adjusted to make it continuous and remove any overlap at its new position.

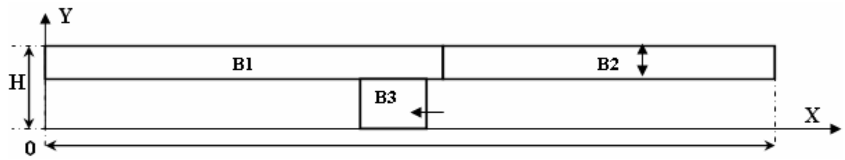


Figure 6. Design after mutation.

## 3.2 Advantages over bit / real number representation

The major argument against using real number/bit-string chromosomes is that at the start of the design activity it may not be desirable or possible to strictly parameterize a design. As the design process continues designs make the transition from abstract concepts to well defined specifications. Object based representation has the advantage that it can represent designs at all the levels. At the abstract level by using high level objects like Elements and at the design maturity level as a set of specifications. Their functionality can be added to, based on the changing requirements. Thus objects offer a relatively straightforward way to cover design activity at all levels. To produce the same in a simple string based chromosome we would require additional checks to ensure consistency of the chromosome is not violated once a bit or real number is added or removed or its functionality modified. The overall system would be overly complex and difficult to manipulate.

# 4. Introduction of Agency

Initial testing of the representation involved freeform assembly of simple structures such as a linear span and stepped arch using GA, EP and agents (for comparison). It was found that agents are able to assemble free form structures quite easily and with respect to agent based assembly, evolutionary methods are slow. Thus we decided to merge the evolutionary and agency approach. Since agents were good at building structures and evolutionary methods are efficient in terms of search and optimisation it was decided that the agents would create the initial population of bridge structures and an evolutionary system would perform search, exploration and optimisation within the space of possible structures. Also during these potentially disruptive processes any changes made in the structure would be monitored by the construction agent to ensure that the resulting structure is correct.

These Construction and Repair Agents (CARAs) at present have a simple task of assembling various structures with various sizes and shapes of span and supports. There are no restrictions on the placement of supports and other design characteristics. But as part of the future work agents will be given specifications of the designs to be built including restrictions on placement of supports and types of span sections used. Thus the CARAs will be told what the design environment is and they will create initial population designs within it. Then the evolutionary process will take care of the SEO process with the CARAs keep a check on design changes.

# 5. Introducing Simple Structural Criteria

Having demonstrated how the object based representation can be used to assemble simple structures it is now necessary to test the feasibility of the approach in terms of subsequent

SEO processes. The CARAs can currently create three kinds of bridges. These are: Simple beam bridges without support (Type 1a), Simple beam bridges with supports (Type 1b) and Simple beam bridges with sloping span sections and supports (Type II).

Thus an initial population can consist of a mixture of three designs. In the next section these designs will be assessed in terms of the designer's aesthetic preferences in addition to structural and cost criteria. However, during this initial establishment of a flexible, feasible representation solution fitness is assessed by applying simple length depth ratios whilst also minimising material used. Column design is assessed via simple buckling criteria. It is not considered necessary to include loading other than beam weight during this preliminary work which is merely evaluating the developed representation.

## 5.1 Fitness Evaluation for Type 1A

Type 1a consists of a simple concrete span bridge without supports. This is treated as a simple beam deflection problem under UDL. For analysis purposes we use a simple heuristic that the ideal length to height ratio for a span element is 20:1. The closer a span section is to this deal ratio (R) better is its fitness. '$L_i$' and '$H_i$' are the length and height of the ith span element.

$$F_i = | R - (\frac{l_i}{h_i}) | \tag{1}$$

$$Stability = \frac{1}{(1 + \sum F_i)} \tag{2}$$

To ensure the overall integrity of the structure the above equations are used. As we can see the closer the dimensions of the span elements are to the ideal ratio (*R*) the lower will be the value of $F_i$. At the minimum all $F_i$'s are equal to zero and thus stability is equal to one. Taking into account material usage (M) the net fitness function then becomes:

## 5.2 Fitness Evaluation for Type 1b and Type 2

Type 1b is a simple span bridge with supports. Here we take into account the buckling in the columns due to the weight of the loaded beam. The formula for buckling load is:

$$P' = \frac{\pi^2 EI}{H^2} \tag{3}$$

In equation 3, P' gives the maximum possible load, E is the modulus of Elasticity, I the moment of inertia and H the height of the column. Thus if the load on a column is greater than P' it will buckle. The load on column is simply determined by first finding the length of the beam between the supports on left and right of the main column and then calculating the load on that length of the beam and the weight of the section (using density of concrete). This is then divided by two to give the loading for the central column. If a column has thickness sufficient to prevent buckling then it can both increase and decrease in thickness. Otherwise when selecting mutation rules for a support which is in danger of buckling, the only option available is to increase the thickness. Here the fitness of the structure is calculated as above. In the case of the sloping element the only difference is that the length taken is the sloping length and the height taken is the 'thickness' attribute of the sloping element (instead of the actual height).

## 6. Test Results

The test problem was to span a 50m gap. A simple EP system was used with a population size of 100 designs. Tournament selection was used as the selection operator with a tournament size of 10. The system was run for 100 generations. A few members from the initial population are shown below.

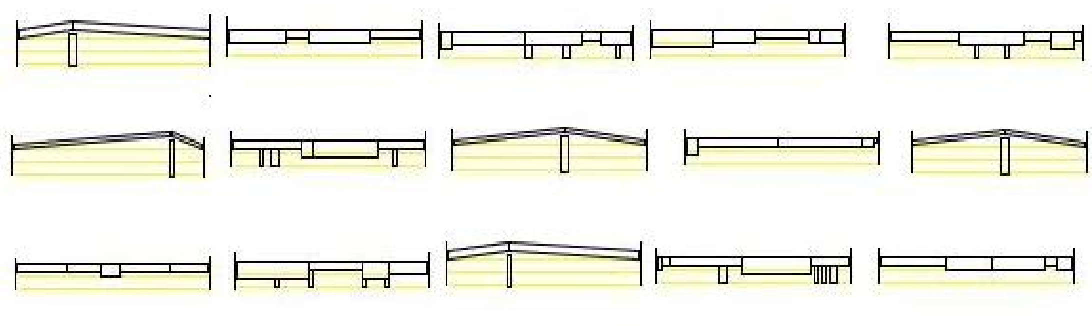

Figure 7. Sample of mixed initial population of bridge shapes.

We can see that the initial population consists of three different kinds of designs namely a simple unsupported span, a simple supported span and an angled span bridge. After 100 generations the optimal designs shown in figure 8 and 9 are achieved.

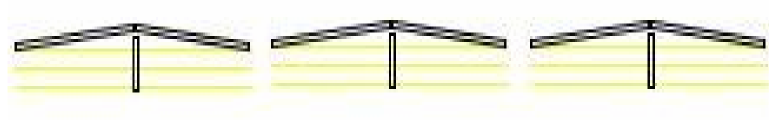

Figure 8. Run 1 optimized bridges.

Here we can see that angled span bridges turned out to be most efficient in terms of stability and material usage. This means that the other two design types have been evolved out of the population. A second run again produces optimal angled span bridges but in a different configuration suggesting that there may be several optimal configurations in this category.

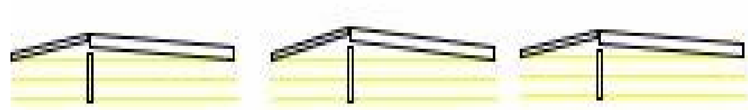

Figure 9. Run 2 optimized bridges.

## 7. Aesthetics and User Evaluation

Due to the subjective nature of aesthetics their evaluation can only be partially quantified through generic guidelines and rules [9]. Thus while aesthetically pleasing shapes can be explicitly specified to some extent complete aesthetic evaluation must also involve the designer. i.e. Aesthetic evaluation must take into account both rule-based and subjective factors. In the present system the following aesthetics have been coded:

1. Symmetry of support placement (A1)
2. Slenderness Ratio [9] (A2)
3. Uniformity in thickness of supports (A3)
4. Uniformity in thickness of span sections (A4)

Many other quantitative rules exist but, aesthetic evaluation has been kept relatively simple during these formative stages of the study where current design representation does not support detailed aesthetic evaluation. Each aesthetic is evaluated by a separate 'Aesthetic Agent'. The 'Aesthetic Fitness' is calculated as:

$$Aesthetic\_Fitness = \sum_{i=1}^{4} w_i A_i \qquad (4)$$

Where $w_i$ are the weights for each of the aesthetic rules ($A_i$ = A1 to A4) which can be modified at run time too. The 'User assigned fitness' (Ufit) is the ranking or fitness given to a design by the user on a scale of 0 to 10 (10 being the best). Furthermore the user can mark solutions for preservation into the next generation. Overall user evaluation operates thus:

1. User stipulates the frequency of user interaction (e.g. once every 10 generations).
2. User evaluates a preset number of population members from the initial population (usually the top 10 members in terms of stability, material usage and explicitly defined aesthetic criteria).
3. The EP system runs.
4. Population members are evaluated by the user every ***n*** generations.
5. Repeat steps 3 and 4 until user terminates the evolutionary process.

The fitness evaluation as given earlier has been extended by adding two more objectives called 'Aesthetic Fitness' and 'User Assigned Fitness' (Ufit), furthermore all objectives are normalized (between 0 and 1) and weights are added (w1 to w4) to each of the objectives which the user can modify at run time to steer the course of evolution.

$$Fitness = (w1 * Stability) + (\frac{w2}{Material\_Usage}) + (w3 * Aesthetic\_Fitness) + (w4 * Ufit) \qquad (5)$$

Figure 10 shows a few aesthetically pleasing shapes (after 30 generations with user evaluation at every tenth generation - see Figure 11). The aesthetic objectives (A1 to A4) are clearly reflected in them. The span elements are of the same size. The supports are of nearly uniform thickness and their placement is also symmetric.

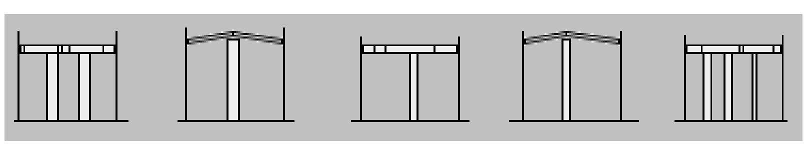

Figure 10. Aesthetics optimized shapes.

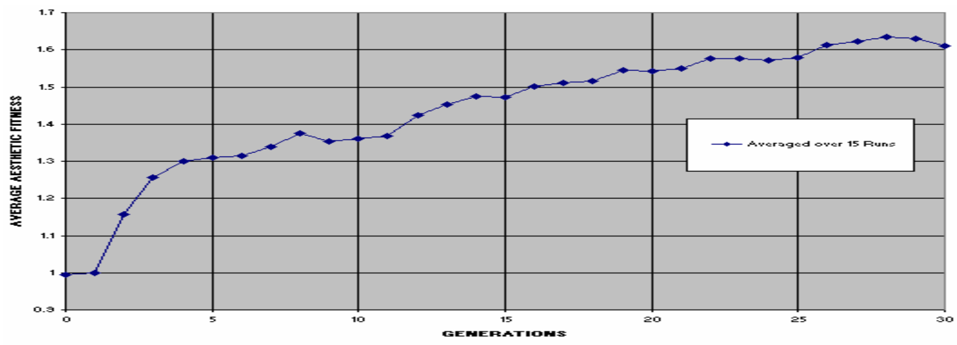


Figure 11. Variation of Aesthetic fitness with Generations (over 15 runs)

Furthermore comparing Figures 7, 8, 9 and 10 we find that as the user starts interacting with the system, the optimized shapes are not limited to angled sections but take on a variety of different aesthetically pleasing shapes. These satisfy the explicitly defined aesthetic guidelines (A1 to A4) as well as the implicit aesthetics of the user (Ufit).

## 7.1 Incorporating Learning

The next stage has been to implement some form of supervised learning system which takes user evaluation into account. A two level learning system has been adopted. Since there is a natural classification in the designs (i.e. angled spans, supported beams and unsupported beams) learning is attempted at two levels. The first level determines user preference for one of the three types of bridge design. This is achieved by evaluating the relative difference between user assigned fitness (or rank) for each type of design. The second level assesses what kind of features the user finds pleasing in the different designs. Again looking at figures 7, 8, 9 and 10 we find that for the angled spans there are two features which strike the eye immediately. These are the peak of the bridge (that is the location of the rise point) and the thickness of the span sections. We can convert such features into fuzzy variables to create an aesthetic model of the particular bridge type. For the angled section we use the following fuzzy variables to specify the aesthetic model:

1. Peak: Left, Central, Right
2. Difference in Span Thickness: Left Thicker, Equal Thickness, Right Thicker
3. Average Thickness: Low, Medium, High
4. Column Thickness: Low, Medium, High
5. User assigned fitness (Ufit): Low, Medium, High

Similarly models can be created for supported beam spans and unsupported beam spans. Based on this model a fuzzy rule generator has been implemented.

Given below are a few example rules generated by the rule generator component:
IF peak = Left AND delta-thickness = Right AND avg. thickness = High AND
col. thickness = Low THEN ufit = Low
IF peak = Right AND delta-thickness = Equal AND avg. thickness = Mid AND
col. thickness = Mid THEN ufit = High
IF peak = Central AND delta-thickness = Right AND avg. thickness = High AND
col. thickness = High THEN ufit = High

Using the above the system will attempt to build a rule based model of the user's aesthetic preferences.

## 8. Further Work

The results shown above plus additional thorough testing of the developed representation confirm a significant potential although it is intended to further explore alternative representations that may offer increased utility in terms of flexibility and robustness. In addition, further possible bridge types will be considered for inclusion in the initial population. It will be necessary to develop the structural evaluation procedures to some degree whilst avoiding conflicts relating to usability and computational expense. Ultimately the system will be required to give a comparative indication in terms of aesthetically pleasing design and likely cost whilst indicating structural feasibility. Best alternatives generated by the system could then be subjected to further, more rigorous analysis off-line.

The introduction of such an interactive process also poses many questions such as:

- How many designs from each population should be presented to the user?
- How should these be selected?
- How many evaluations can a user be expected to perform before becoming bored and / or fatigued?
- Should our evolutionary algorithm be able to cope with small populations to reduce new solution numbers or would a steady-state approach be more appropriate?
- How detailed should the visual presentation of the designs shown to the user be? At present we are using simple stick diagrams. While these are adequate for initial testing processes, it is envisaged that designers would want to see much more realistic visualizations.

These questions are not new and have been repeatedly posed but seldom successfully addressed within the interactive evolutionary computing (IEC) community. The reader is directed to http://www.ad-comtech.co/Workshops.htm where output from three recent IEC Workshops held at the Genetic and Evolutionary Computing Conferences (2001, 2002, 2003) can be found along with extensive references to IEC applications. Takagi [25] provides an excellent overview of the area in his review paper. However, more recent developments are also of interest.

The integration of user preference and user adjustable objective weights is seen as the first step in achieving the ultimate goal of transferring aesthetic evaluations from the user to the design system. A profile based machine learning system is required which learns the preferences of the user as they use the design system. The assimilated information will be tagged under the profile name of the user. In this way whenever a particular user is using the system, the design system knows which set of assimilated aesthetic rules could be used.. Much work is also required to develop a fully functioning machine learning sub-system for the proposed design system. While first steps have been taken towards a fuzzy rule based learning system other techniques such as back-propagation also require investigation to facilitate the creation of aesthetic models for different classes of designs. Thus a generic rule generation system or a neural network based learning technique may be required. The CARA-EP representation will allow us to commence further exploration of these and other issues. The overall intention of the study is to significantly decrease the evaluation load on the designer as early as possible in the evolutionary process by introducing a multi-agent based learning environment that supplements and eventually takes over the aesthetic criteria evaluation.

Agent based learning could also be adopted. The following procedure is envisaged. A 'negotiating agent' approach [27] identifies those aspects of given sample designs which do or do not have aesthetic merit. The software agents will each represent a particular established aesthetic such as those proposed by Moore et al [7], Ngo et al [29] and [30] and these will be ranked by the user in terms of preference [31]. The agents will negotiate to determine the relative performance of the solutions of each population and return the 'best' solutions to the user in rank order. If the user disagrees with the ranking then changes to aesthetic preferences can be made. The system will then analyze the user preferences and adjust the agents' weightings to match. Thus rather than assessing each solution the designer can scan the characteristics of the best designs, assess whether the aesthetic preferences are operating appropriately and adjust as necessary. This procedure may initially occur at every generation but at a lesser frequency as the agents converge upon the designer's aesthetic preferences. The eventual outcome should be the identification of solutions that satisfy structural and cost criteria whilst also being considered by the designer to be aesthetically pleasing.

The eventual outcome should be the identification of solutions that satisfy structural and cost criteria whilst also being considered by the designer to be aesthetically pleasing. The basic thrust of the work is to establish whether or not this coupling of multi-agent activity to evolutionary search can be developed into a learning capability where agent memory contributes to preference selection. This would lead to semi-autonomous activity that, whilst significantly reducing the load upon the designer, ultimately results in viable and aesthetically pleasing solutions. The introduction of more than one designer each independently assessing aesthetic value is a natural progression which will add further layers of complexity that require investigation.

# 9. Conclusion

A comparative investigation of a number of evolutionary algorithms and associated problem representations has been carried out. An object based representation that allows the flexible generation of simple structures whilst being easily implemented within an evolutionary process (EP) has been developed. The effectiveness of an associated rule-based agency approach to develop initial solution populations and maintain and repair solutions in subsequent generations has been illustrated. The overall implementation has been tested in terms of the construction of three basic bridge structures, their simple analysis and the evolution of high performance solutions.

The tests showed that the CARA-EP system performed as expected. Thus it is worth further exploring this representation. Specifically there is need to formalise this representation and the surrounding framework to develop a standard EP based system. There is also need to expand the library of shapes used to include more complicated shapes to truly harness the systems potential.

With the addition of user interaction flexibility has been introduced into the system. The user can steer the evolutionary process towards aesthetically pleasing solutions. The addition of simple rule based aesthetics provides the user with a point of reference which s/he can use to guide the path of the evolutionary process. For example if the user finds the rule based aesthetics produces pleasing shapes then s/he can increase the weight of the Aesthetic Fitness objective and just allow the evolutionary process to continue without assigning fitness to solutions. At the other end of the spectrum if the user dislikes the shapes s/he can reduce the weight of Aesthetic Fitness and increase the weight of User Assigned Fitness while actively evaluating solutions.

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