Interactive Genetic Algorithms for use as Creativity Enhancement Tools

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Abstract

It is proposed that creativity can be enhanced through the use of interactive genetic algorithms (IGAs). Divergent and convergent thinking are important processes in creativity that we simulate through two separate IGA populations developed by different means. The convergent process hones in on specific designs, while the divergent process explore design possibilities in a fashion beyond pure mutation techniques typically used to introduce population diversity. This study uses Monte Carlo simulation to explore the effect of merging two populations developed by the divergent and convergent methods. The results suggest that population diversity benefits from these population combinations while not adversely affecting the ability of the user to find a goal design. This IGA has also been developed in Adobe Flash so that it can be deployed on the internet to conduct validation and studies of creativity.

Introduction

Interactive genetic algorithms (IGAs) are powerful tools that have been used in several ways in the design community, e.g., for the identification of preference, and for the generation of new ideas (Durant *et al.* 2004; Cho 2002). This generation of new ideas is particularly important to the notion of creativity. By using IGAs we hope to allow designers to enhance their creativity through design space exploration. Similarly, by engaging product users in the creative design process, we believe that the desires of the user can be more effectively met. Thus, moving the user to the ground level of the creative process may be a means of improving design. We believe that by exploiting the evolutionary nature of IGAs, we can explore a vast design space in an intelligent manner that will allow designers and users to identify new and creative designs that appeal to them.

In this article we will first provide some background on creativity, interactive genetic algorithms, and a framework for how IGAs can be synthesized for improved creativity. Following that, we will describe the design of an IGA that is tailored for use in creativity enhancement. Next we will test that IGA using Monte Carlo simulation to show the effectiveness of the IGA in aiding creativity and describe the development of an IGA tool developed for web-deployment. We will finish with conclusions, implications and suggestions for future work.

Background

Creativity

Creativity can be thought of as the act of developing problem solutions that are both novel and useful. It is not enough that a potential solution be different for the sake of being different, it must also be appropriate for its purpose. One way to consider the process of creativity is through the notion of convergent and divergent thinking (Brophy 2001). Convergent thinking is characterized by analyzing and refining one's ideas toward a single, best solution. While divergent thinking is characterized by developing new ideas that build towards new solutions that differ from each other. Thus, to be creative one must use divergent thinking to develop a number of potential ideas, but they must also use convergent thinking in order to narrow down their ideas into a few viable solutions.

In the framework of product design, it is important for designers to develop a wide variety of creative solutions to problems. Many product design processes suggest that the creative process has a period of broad idea generation followed by a period of selecting concepts. This is nothing more than divergent thinking followed by convergent thinking. However, simply suggesting that divergence must follow convergence ignores the reality of the way that people think. Humans do not simply turn on and off their creativity. People are creative at different times for different reasons. One important task is to develop methods that can help people to be systematically creative.

Tests of creativity draw on these divergent and convergent process notions. The "Unusual Uses Test" (UUT) asks people to think of as many different functions for an object as possible (Guilford 1957). This can be taken as a metric for divergent thinking. Tests of creativity like the "Remote Associates Test" (RAT) require people to generate a single 'creative' answer for each presented problem (Mednick 1962). Thus, it is linked to convergent thinking. We combine these two seperate abilities within a single creative task: To choose among possible designs that are varied in shape, and that over repeated trials allow honing in on a 'most creative' design.

Interactive Genetic Algorithms

Interactive genetic algorithms are a subset of genetic algorithms. Genetic algorithms, first rigorously explored by John Holland, are used to solve optimization and search problems by emulating principles of biological evolution (Holland 1975). By genetically encoding potential design options, a solution can be found through survival of the fittest. IGAs are similar to GAs, except the fitness function of the GA is replaced by a user evaluation of solution options. Dawkins proposed this idea first in the representation of tree-like graphical structures (Dawkins 1986). The concept has been applied to several fields where fitness functions are not apparent, such as visual design systems (Cho 2002), psychoacoustics (Durant *et al.* 2004), and complex systems (Buonanno & Mavris 2004; Kamalian *et al.* 2005).

IGAs fall within a broader category of interactive evolutionary systems (IES) that use a human in the loop to help solve problems. Takagi offers a detailed survey of this literature (Takagi & others 2001). While these tools have often been used to help improve design by using human intuition to help guide a GA through the selection of good designs, they have also been suggested as a tool to help designers improve their creativity (Nishino *et al.* 2001).

Synthesis

In this paper we develop an IGA that uses both convergent and divergent techniques to develop new solutions based on a user's response to previous design concepts. As we will discuss later, the divergent process uses unselected designs from a set of potential designs and high rates of mutation in order to expose the user to a wide range of potentially exciting ideas. The convergent process uses typical methods from IGA research to refine design ideas and allow the user to hone their creative design.

Interactive Genetic Algorithm Design

IGAs can help enhance creativity because they can facilitate both divergent and convergent thinking. In IGAs the evaluation function is based on users' preferences. Their selections from a previous population of design options influence the makeup of the new population. To enhance creativity, we want to expose users to new and interesting design concepts while retaining some of the characteristics that the user has already identified as well-liked. The only metric that we use to understand what a user likes is the selection of a design concept. If the user selects a concept, then that indicates the user believes that concept is creative. A concept that is not selected is presumed to be less creative. We recognize that favoring these selected individuals too much can quickly limit the range of the design space that will be explored, and so we wish to retain design characteristics that are well-liked, while allowing other aspects of the design to change, thereby exposing the user to new design concepts that may be unexpected, and interesting.

Real-valued variables are used in this study. This was done, in opposition to binary numbers, for several reasons. First, real-valued versions of genetic algorithms can be just as reliable in problem solution as binary-formed GAs. Second, real-valued variables can avoid difficulties associated with hamming distances that can often be an issue in binary GAs (Ingber & Rosen 1992). Finally, using real-valued variables reduced the size and complexity of the database needed to collect information during both Monte Carlo simulation and human user studies while still allowing the IGA to be investigated for creativity enhancement.

Roulette Wheel Selection

This IGA has been designed to explore the effect that divergent and convergent operations can have on the creative capacity of human users. To model convergence, we employed typical practices from the genetic algorithm community. We applied high rates of probability that 'fit' designs would become 'parents' to the designs of the following generation. We then submitted the newly created designs to a relatively low mutation pressure. This aspect of the IGA represents design refinement; it is the part of the process where the user can focus attention on specific characteristics of appealing designs and cause positive change towards a goal design. While the users' goal design is not known a priori, this process allows them to converge upon designs that they prefer.

Modeling divergence using IGAs can be thought of in several ways. One possible thought would be to apply very high mutation rates that could function on one individual at several variables. This type of divergence can be thought of as extreme random mutation. Such divergence is not systematic; it relies on very little information from the previous design set and its primary mode of exploration is the proverbial 'shot in the dark'. While mutation is critical for the algorithm it is not systematic. Therefore, in an effort to broadly explore the design space using information about the previous population, we provide high rates of parental probability to those individuals from the population that go unselected by the user. In doing so we retain portions of the design space that were deemed unfavorable by the user. Through combinations with other portions of the design space, and through typical mutation we will expose the user to designs that are unexpected.

In order to combine these two forms of parental selection, convergent and divergent, we decided to partition the new population into sets: one set developed by convergence and one set developed by divergence. User selection of four creative individuals from a population of sixteen individuals gave those designs a high probability of parental selection in the convergent process. On the other hand, in the divergent process the twelve unselected individuals had higher probabilities of selection. In both the convergent and divergent processes we used roulette wheel selection to determine parents. The difference in the process was the allocation of the roulette wheel to the individuals (Goldberg 1989). From a previous study, Kelly determined that supplying 80% of the roulette wheel to the selected individuals, such that each selected individual garnered 20% of the wheel while the remaining twelve individuals had 1.66% of the roulette wheel, showed good results in preference identification (Kelly, Papalambros, & Wakefield 2008). Therefore, we used that scheme in our convergent process. For the divergent process we used a similar wheel allocation, only we provided 80% of the wheel to the unselected twelve individuals and 20% to the four selected individuals, resulting in roulette percentages of 6.66% and 5% for the unselected and selected individuals, respectively.

Thus, we have broken parental selection into two pieces: convergent selection and divergent selection. For convergent selection, well-liked individuals have a high likelihood of becoming parents of the next generation. For divergent selection there is an increased likelihood that the unselected individuals will be parents for the following generation. We believe that this allows synthesis of the two types of thinking used in creativity.

During parental selection no parents are ever eliminated from the parental pool. This allows a parent to mate several times in populating the new generation. Further, parents are allowed to mate with themselves. Also, each set of parents produce only one offspring. No preference is given to which parent provides which portion of genetic material during crossover, and so there should be no effect in limiting the population's diversity.

Crossover

The mating technique used in this IGA is a simple single-point crossover. In this scenario the genetic material, design variables, from one parent are shared with those from another parent. Specifically, a random value assigns which string of variables will be shared from each parent, with one parent providing all data up to and including the index number provided by the random value, and the other parent providing all complementary information to complete the new design's chromosome. Thus, whole values are shared between the two parents. Therefore, unlike in binary crossover, it is impossible for a new design variable value to be generated in this type of crossover. This indicates that it may be beneficial to use a slightly higher than typical mutation rate to increase variable diversity.

Mutation

Mutation enhances the search of genetic algorithms be providing new and unique designs that may be well suited to a particular problem. In this IGA, we need mutation as a way of introducing new variable values into the population, as well as exposing potential exciting design spaces. To do this, we use single variable mutation at a specified probability for each individual in the new population. If an individual is designated to mutate based on the mutation pressure, then one of its variables is randomly mutated. Mutation is simply the random generation of a new real-valued number within the feasible design domain for that variable.

Definition of Final Algorithm

The final algorithm that was used in this study had the aspects mentioned above: real-valued chromosomes, divergent and convergent roulette selection, single point crossover, single child generation from a set of parents, and single variable mutation. The roulette wheel percentages for the selected individuals were 20% and 5% for the convergent and divergent roulette scenarios, respectively. Likewise, the roulette wheel percentages for the unselected individuals were 1.66% and 6.66%, respectively. Finally, the mutation rate for this IGA was 5%. The flow diagram shown in Figure 1 outlines the general procedure followed in this IGA and Table 1 provides a review of the IGAs specifications.

Table 1: IGA Settings

Chromosome type	Real valued
Number of variables	8
Mating scheme	Single point crossover
Convergent parental population	
—Selected individual roulette %	20%
—Unselected individual roulette %	1.66%
Divergent parental population	
—Selected individual roulette %	5%
—Unselected individual roulette %	6.66%
Mutation type	Single variable
Mutation rate	5%

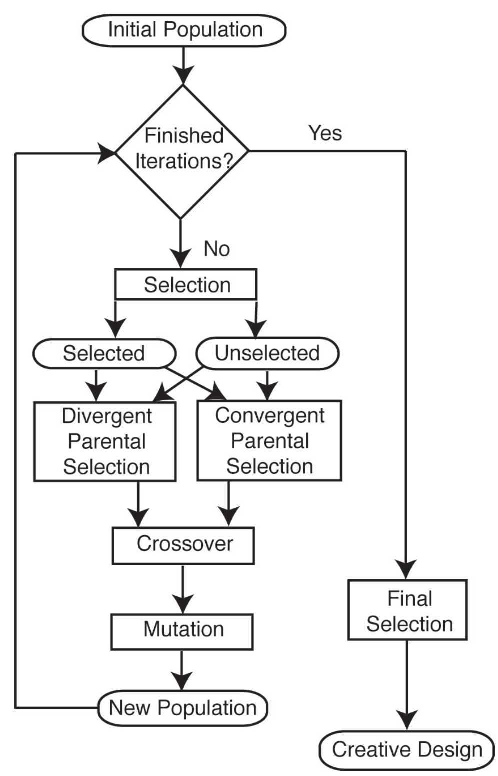

Figure 1: Flow diagram showing IGA process containing both convergent and divergent parental selection.

Monte Carlo Simulation Studies

To understand the effect of splitting the parental populations between convergent and divergent processes we employed a Monte Carlo simulation of a guided search using Matlab. For this study the settings of the IGA were as described above. The variable in this case was the amount of the new population that was developed from the two different parental populations. We allowed this to vary from a population that was fully comprised of the divergent parental population to one that was fully comprised of the convergent population. We allowed mixing of the different populations at ten percent intervals, and in each case we conducted 10 000 trials.

The test chromosome was eight variables long, again consisting of real-valued numbers, and each variable had a range from 0 to 10. Mutated variables were random numbers restricted within these bounds. To test the IGA, we used a randomly-defined goal design as the desired 'creative' design. While this may seem restrictive and counterintuitive to the intent of creativity this was done to test the ability of the IGA to find a goal design, which could be perceived as a yet unknown creative design to a user, while still preserving a large range of available options to the user. We also defined the initial population as a randomly-generated set from the eight variable design space. The goal of this study is to show that the IGA allows convergent thinking to occur while still maintaining the varied design space associated with divergent thinking.

The fitness of each individual was its Euclidean distance from the goal design. The four individuals closest to the goal design were the selected individuals and garnered their appropriate share of the roulette percentage as described in Roulette Wheel Selection. The twelve remaining individuals were unselected and treated likewise. Each of the 10 000 trials ran for 50 generations before conclusion. While this is a small number for a GA, it is a large one for a IGA. Reducing the number of generations helps avoid user fatigue.

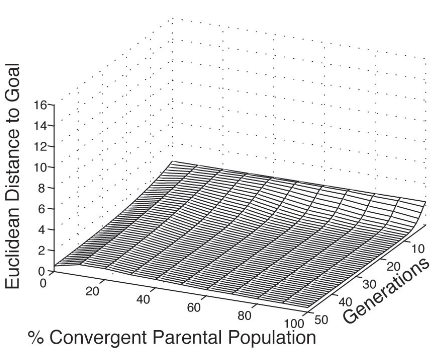

Figure 2: Effect of generation and percent of convergent parental population on the mean of the IGA population from the goal design.

Figure 2 presents the effect that varying parental population has on the IGA population's mean distance from the desired goal design over the course of 50 generations. We see that as percent convergent parental population varies from 0% (entirely divergent) to 100% (entirely convergent) the average value of the population's Euclidean distance to the goal design generally improves over the generational process. However, we see that a fully divergent process actually increases the average of the population's distance from the goal. A similar pattern exists in the standard deviation of the population (figure not shown), both generationally and in relation to the parental process. This suggests that this form of IGA can be useful in identifying predefined goals, and hence facilitates convergent thinking. Previous work has shown that this correlates well to an individual's ability to identify their preferences using the IGA (Kelly, Papalambros, & Wakefield 2008).

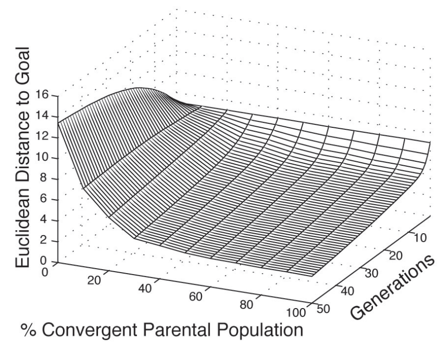

Figure 3: Effect of generation and percent of convergent parental population on the range of the IGA population from the goal design.

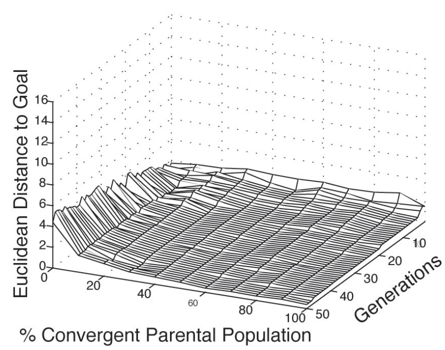

Figure 4: Effect of generation and percent of convergent parental population on the mean of the distance of best individual in the IGA population from the goal design.

Figure 3 shows how the range of the population's distance to the goal design is affected by the two types of parental populations. As generations increase, there is a reduction in the range of the population. But, with a more divergent parental process, this effect is lessened. Thus, while the diversity of the population is decreasing over generations, this effect can be reduced by using a more divergent process. Maintaining diversity is tantamount to the notion of creativity in this work, but converging toward a specified goal indicates the ability to appropriately refine a design, which is another aspect of creativity. Therefore, we must balance these two goals. Figure 4 shows the parental and generational impact on the average of the best individual in the population over the 10 000 trials. We see that a fully divergent parental population has a detrimental effect on the ability to find the goal design. But, as a portion of the population becomes convergent, we notice a marked and systematic improvement of the IGAs ability to get near the goal design.

Synthesizing the data from the Monte Carlo studies allows us to make an informed decision about the settings for the IGA that will be used in human user studies. We wish to maintain diversity amongst the population to promote the discovery of interesting designs while still allowing users to refine those designs so that they are appropriate for the intended application. Thus, we can see from Figures 2 - 4 that selecting a convergent parental population percentage of 30% appears to facilitate convergence while still allowing divergent thinking.

While the set of data explored in this Monte Carlo simulation shows promise for the IGA, we believe that a population that maintains a diverse range of individuals will improve the IGA's capacity to enhance creativity. It is therefore suggested that future Monte Carlo studies examine variations in the roulette wheel percentages garnered by selected and unselected individuals in the convergent and divergent processes. Further, it is possible that the fixed schema may have limited the ability of the IGA to adequately explore the design space, and caused premature convergence on a solution. If this is the case, we must reexamine the methods of crossover and mutation, and explore other techniques that would not provide this limitation.

GUI Development

For user studies we developed a web-based survey that interfaces Adobe Flash with a MySQL database through PHP scripting. The IGA functions of this survey were developed in PHP, but are algorithmically the same as those developed in Matlab. In this survey we want users to interact with the IGA in an example that specifically focuses on vehicle silhouettes to see how creative their resulting designs are.

We used Adobe Flash as a GUI front-end to provide smooth and visually appealing figures to users that could be generated quickly and parametrically. One idea for developing figures was to generate a detailed solid model, parametrically vary that model at discrete units within the design space, and then save those images in a database for quick access by the GUI. This approach needs a large number of variables, and requires a rather large picture database. Instead, we developed a spline function within Flash based upon the built-in curveTo() function. The curveTo() function is based on a quadratic Bezier spline, but cubic Bezier splines allow greater control. Thus, we developed an approximate cubic Bezier spline using two quadratic Bezier splines via midpoint extrapolation.

We conducted a vehicle shape study to determine the number of points for describing the vehicles shape. Numerous vehicle silhouettes were examined and transparently overlaid. This allowed experimentation with points and splines to determine the minimum number of points to capture a wide range of vehicle shapes. Twelve points were selected and shapes were generated by allowing the vertical and horizontal location of four control points to vary, see Figure 5. Thus, there were a total of eight variables.

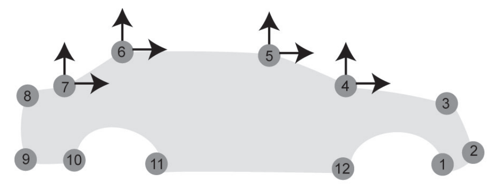

Figure 5: Vehicle silhouette defined by 12 points with 4 point locations variable in vertical and horizontal plane.

The database was created in MySQL and all calculations are conducted in PHP. Using MySQL we are able to track variable values and user selections, a capability not native to Flash. Therefore, we communicated to the MySQL database through PHP and back to Flash via PHP and XML code. While this code has been specifically defined for vehicle silhouettes it can be applied more generally to investigate any shape that can be defined parametrically.

Figure 6 shows a typical screen that users will see. Figures are randomly placed throughout the 4-by-4 matrix grid, and a black screen is briefly shown between generations in order to reduce the user's ability to clearly identify shape changes from one generation to the next.

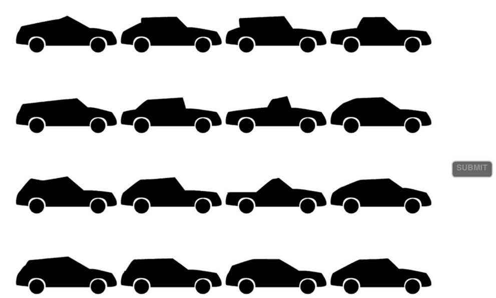

Figure 6: Screen capture of IGA GUI developed in Flash, MySQL and PHP.

Proposed User Studies

The program will present users with a randomly generated set of sixteen vehicle silhouettes, from this set users are asked to pick four designs that they feel are creative or interesting. Then the IGA process generates a new set of figures from which the user continues to make choices. We propose that this process be continued for 20 generations, and in the final generation the user will be asked to select a single design from this population perceived as the most creative. Following this we will query users regarding their choices. Specifically, we will ask them, "Do you believe that you have designed a creative vehicle? Why or why not?", "Can you describe what activities your car would be used for?", and "Please describe how you decided to make vehicle selections during the survey". These follow-up questions are intended to provide us with a basic understanding of how effective they felt the tool was. Their answers will also allow us to identify perceived problems and improve the IGA.

Before interacting with the tool, users will be instructed to use it to design a vehicle that they think is creative. Users in the first proposed studies will be students from the University of Michigan. They will be verbally instructed on how to interact with the design tool. However, they will be allowed to complete the survey on their own time through the web-based survey. Follow up studies will have an instructional component integrated into the Flash project describing program usage, and it will be deployed widely using the internet.

Beyond self-evaluation, the creativity of designs will be independently judged on a scale from 'very creative' to 'very mundane' by two experts in the field of industrial design. These individuals will also be allowed to read each individuals responses to the follow-up questions. Doing this will allow the judges to have some context for understanding why the user believed that their design was or was not creative. This judgement by experts in the industrial design field is intended to provide another measure that practically evaluates the tool's capacity in aiding creativity.

Conclusions and Future Work

In this article we have described the development of an IGA-based tool that is proposed to enhance creativity. The basis for this creativity enhancement is founded upon the principles of divergent and convergent thinking. This IGA promotes convergent thinking through typical GA principles that favor highly rated individuals. It promotes divergent thinking by allowing other individuals, those in the population that were unselected, to have a high probability of becoming parents. The use of mutation also allows the direct generation of new ideas. It is believed that by combining populations from both divergent and convergent process will allow users to be exposed to diverse designs that promote new ideas and then facilitate design refinement. We have conducted Monte Carlo studies that suggest that these methods may be useful in aiding creativity. However, the range of designs available appears to be too low. Tthis indicates that parameter refinement or mating processes must be further examined before implementation.

A practical design tool was created using Flash, MySQL and PHP. A survey using this tool has not yet been widely circulated, but the plan is to use it to validate the methods proposed here. We also plan to compare the outcomes of this tool with another tool that can be controlled more fully by the user using sliders to adjust variable values.

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