Organization Design Optimization Using Genetic Programming

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Abstract

This paper describes how we use Genetic Programming (GP), an evolutionary computational optimization approach, to help project managers find near optimal designs for their project organizations. Our GP model is a postprocessor optimizer for the Virtual Design Team (VDT), a project organization design simulator also developed at Stanford. Decision making policy, individual/sub-team properties, activity assignments and percentage allocation for each activity are varied by GP, and the effect on quality and duration of the project is compared via a fitness function. The solutions found by GP compare favorably with the best human generated designs.

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In the complex and rapidly changing business environment of the early 21st Century, designing an effective and optimized organization for a major project is a daunting challenge. Project managers have to rely on their experience and/or trial-and-error to come up with organizational designs that best fit their particular projects. This traditional method of project organization design is very costly. Based on Tatum's empirical research, managers adapt personal experience as the primary process in organizational structuring. They repeat successes, avoid failures, and make adjustments as required by project situation (Tatum, 1983). The Virtual Design Team (VDT) simulation system, based on the information processing theories of Galbraith (1977) and March and Simon (1958), was a successful attempt to develop an analysis tool for project organization design (Jin & Levitt, 1996). VDT now enables project managers to model and analyze project organizations before implementing them in practice. After extensive ethnographic research in engineering organizations to calibrate its parameters, VDT can predict the schedule, cost and quality performance for a user-specified organization and work process.

However, like the analysis tools that support many engineering design processes, VDT has no inherent ability to improve or optimize current designs automatically. The user must experiment in a "What if?" mode with different alternatives in an attempt to find better solutions that can mitigate the identified risks for a given project configuration. Based on her or his expertise, the user must set up the model, run the simulator, analyze the output, make changes to the input, and repeat these steps until an acceptable output is achieved. VDT relies on the expertise of the human user, and offers no guarantee of optimality. The problem has many degrees of freedom, so the search space for better solutions is vast, and exploring it manually is daunting.

In this paper, we demonstrate how we have designed and used a post-processor for VDT that uses genetic programming, an evolutionary computing method, to generate near optimal project organization designs.

Motivation and Points of Departures

Over the past 50 years, optimizers have been successfully developed and deployed for a variety of analysis tools aimed at predicting the behavior of physical systems such as structures, engines, or semiconductors. These optimizers, in conjunction with mature and extensively validated analysis tools, have enhanced the productivity of engineers by orders of magnitude, and have expanded the range and enhanced the quality of products created in many fields of technology.

In contrast, organizational analysis tools that can be used by managers to predict performance outcomes of alternative organizational configurations have only begun to emerge over the past decade. Starting with the Virtual Design Team research in the mid-1990s and the pioneering work of Burton and Obel (2004) in the late 1990s, there are now several agent-based computer models and rule-based diagnostic tools that help managers analyze candidate organizational configurations for a given set of task requirements and environmental constraints. However, to the best of our knowledge not much work has been done that can claim to optimize organization designs for real world organizations. One of the attempts we are aware of is a fuzzy multicriteria framework for the comparison of alternative organization structures of post corporations (Kujacic & Bojovic, 2003.)

Some attempts have been made in the past at developing a post-processor for VDT; however, those were of limited power and generality. For example, William Hewlett designed a rule-based "expert system" post processor for VDT that analyzes the outputs of a VDT simulation, and recommends small, incremental changes in the design of modeled organizations (Hewlett 2000). Hewlett's post processor was tested in a design charrette on a group of Stanford students; it showed that they were able to create better organizations when they used the post-processor than without it. However, there were many limitations of this initial post-processor. First, the post-processor did not solve for the optimal organization; it was only a small piece of an optimization strategy. It primarily focused on team sizes and suggested reallocating personnel between teams. Thus, after running the VDT simulator, a user had to take advice suggested by the post-processor, make changes in the original design, run the simulator again, and observe whether the optimization was beneficial. Then the user had to repeat this optimizing loop until the desired output was achieved. As a result, this process was an exhaustive, never ending search. Second, although this process was shown to be beneficial for some students with less project management design experience, it provided less benefit for more experienced managers.

An ongoing research effort by Michael Murray, another PhD student in the Department of Civil & Environmental Engineering at Stanford, has begun to address a few selected aspects of the organization design optimization problem. The focus of Murray's research, like Hewlett's, is on the scheduling and resources of the project organization. This optimization tool combines operations research techniques (linear programming and branch and bound search) with artificial intelligence techniques (constraint propagation (Baptiste et al. 2001) and heuristic search (Cheng & Smith, 1994). The tool optimizes the macro resource sizing and scheduling to eliminate the most serious backlogs for project participants while respecting project priorities.

During the last few years, evolutionary computational methods have been used to optimize various kinds of systems in ways that rival or exceed human capabilities. For example, GP has produced optimization results for a wide variety of problems involving automated synthesis of controllers, circuits, antennas, genetic networks, and metabolic pathways (Koza et al. 2003). Prof. John H. Miller and his group at Carnegie Mellon University have done similar work, in terms of evolving organizations, but for simpler structures than our proposed research. In their research, they show that simple adaptive mechanisms allow for the creation of superior organizational structures. In addition, they conclude that, while they do not have proofs of optimal structures, the genetic algorithm was designed to solve difficult, nonlinear problems, and thus the structures that emerge from the algorithm should contain valuable hints about optimal form (Miller 2001).

Our Evolutionary Method for Organization Design

The way that our evolutionary method works is that our model initially generates a population of random but valid designs based on the original user input and a given set of constraints. Each individual design is then rated by a fitness function defined by the user. The fitness function reflects the importance of different measures of organizational performance to the user. For example, in a given project, meeting a fixed completion deadline may be the highest priority and total capital cost might not be as important, while in another project quality is the most important factor and the organization has more flexibility with regard to schedule and cost. Next individual designs are selected probabilistically for "survival"—i.e., each design's chances of being chosen are proportional to its fitness as defined above. The selected designs then cycle through the genetic operations of crossover (as in sexual reproduction) and mutation to generate a new population of designs. The steps repeat until an optimal or near-optimal solution is found, as shown in Figure 1.

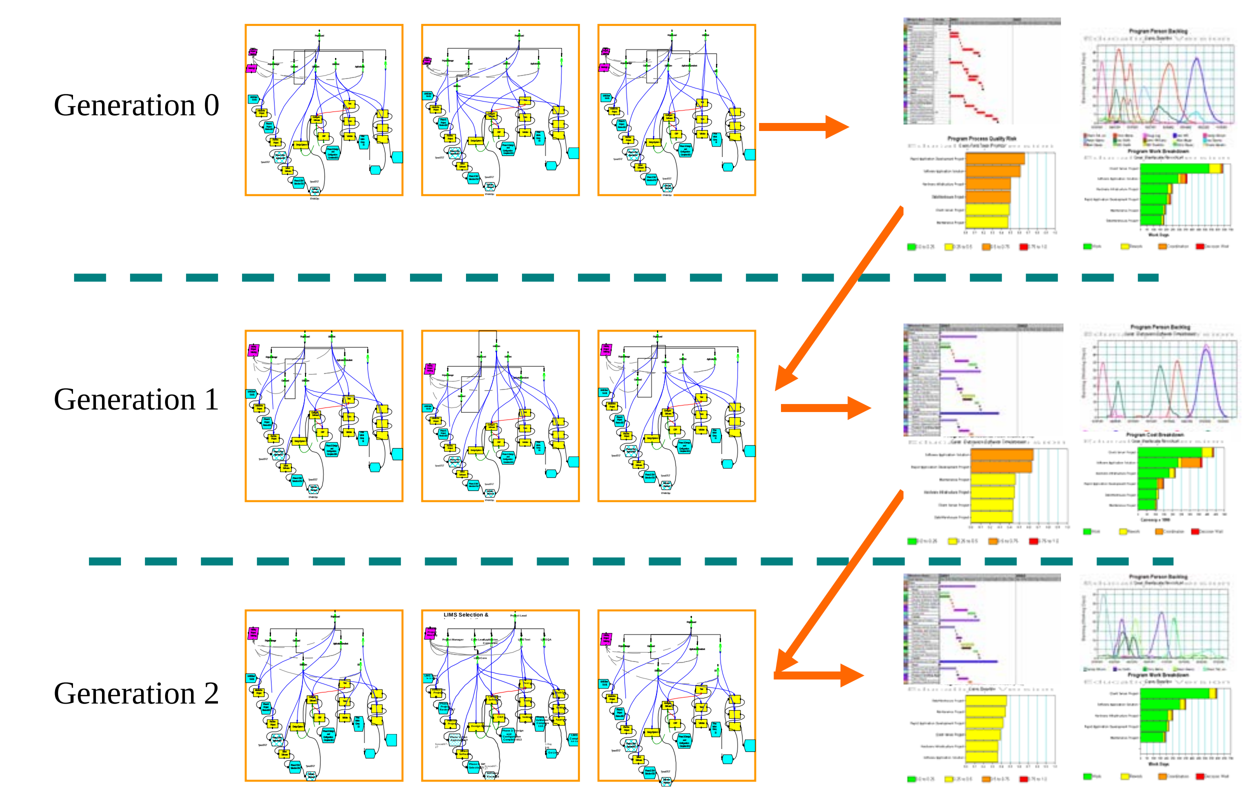

Figure 1—Evolutionary Computational Approach for Optimizing Organization Designs. Individual designs are selected for fitness in terms of desired output, and go through operations of genetic mutation and genetic crossover (as in sexual reproduction) to create new generations, until an optimal or near optimal solution is found.

Comparison Case Study Experiment and Results

Once we implemented the first version of our postprocessor optimizer, we applied it to a case study that has been used for several years in a project management course taught at Stanford. The results produced by our GP were then compared against the best solution discovered by student groups and senior project manager groups over the last 6 years. In this case study, student and project manager groups are given a biotech plant project organization and asked to modify some of the individual/sub-team attributes and organizational policy structure in order to reduce the project schedule duration as much as possible, while maintaining acceptable levels of quality risk.

We divided our case study experiment into two phases. In Phase I, we defined a simplified GP. In this process, we varied only the levels of the actors' skills. Then, we compared the results found by the GP with the known optimal solution. In Phase II, we kept skill levels constant, and varied the number of Full Time Equivalent FTEs (i.e., human resources) added to different positions. We also varied organizational policy attributes such as the levels of centralization, formalization and matrix strength and the assignment of activities to actors using GP. We then compared the GP results against the best solution found by previous student and manager groups. In the next two sections, we discuss the findings of this experiment.

Varying Actors' Skill Levels

There are seven positions (actors) in this project organization, and each one of these positions has two to eight different skills. The skills range from biotechnology to design coordination to mechanical/electrical, etc. There are a total of 29 skills for all seven positions. Each one of these skills can be set to three levels of low, medium, and high. Therefore, the total number of combinations that one could try to find an optimal solution exhaustively is $3^{29} = 6.8 * 10^{13}$. Thus, the sample space is vast and finding the optimal solution manually should be an exhaustive effort.

It should be obvious that the more skilled the actors, the faster the tasks get done, and the fewer the exceptions (i.e., when an actor requires additional information or a decision to complete part of a task, or the actor generates an error that may need correcting.). In this case where we are not concerned about cost, the optimal solution would be when the skill levels of all actors are set all to high. Knowing the above fact, in one scenario we set skill levels of all actors to "high", ran the VDT simulation and compared the results with the base results where we had the skill levels of all actors set to "medium". At the base level, we found that the simulated schedule end was March 28, 2001, and when we set all skill levels to "high", the project duration was reduced by 69 days and the simulation showed that the project schedule end would be Jan 17, 2001. Then, we ran the simulation again using the suggested solution by GP and we found identical results as when all skill levels were set at high.

As mentioned above, the outcome results found by GP were identical with the optimal case. However, interestingly, the suggested solution found by GP was not identical to the optimal solution. (i.e., there were multiple solutions that yielded identical optimal outcome.) Unlike the optimal case scenario, GP did not have to set all skill levels to "high". In fact, there were situations where the levels of some actors' skills were reduced from "medium" to "low", and still the outcome matched the optimal solution. For example, the "General" skill of the "Structural Design Sub-team" was reduced to "low", and the "Mechanical" skill of the "Construction PM" was kept at "medium".

Varying Actors' FTEs, Organization's Policy, and Activities Assignments

In Phase II, we allowed the GP to vary the assignment of activities to actors, the Full Time Equivalent's (FTE) of each actor in 0.5 FTE increments, and organizational policy properties such as levels of centralization,

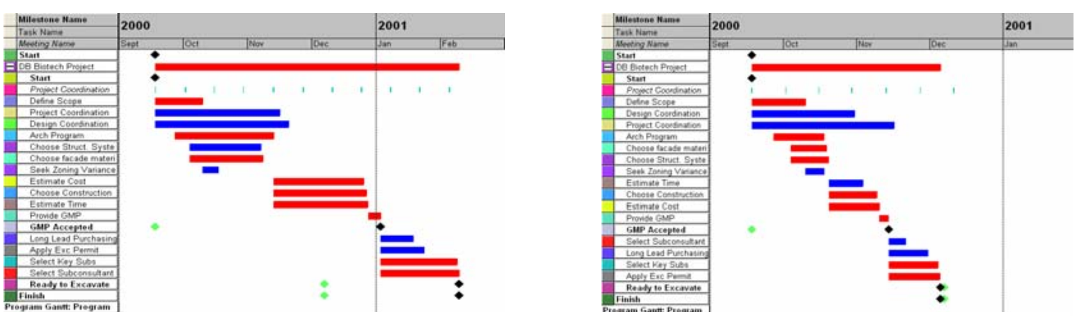

Figure 2— Comparison of Gant Charts before (Left) and after (Right) evolutionary process.
GP reduced end date from Feb 20, 2001 to Dec 5, 2000. This GP solution is better than the best solution (Dec 7) found by >40 student and manager teams for this problem over the last 6 years.

formalization and matrix strength using GP. Then, we compared the results with the best results obtained by more than 40 teams of students and managers over the past six years.

The best individual found by GP in generation 21 beat the best human-discovered solution by 2 days. The best human solution reduced project completion from Feb 20, 2001 to Dec 7, 2000; the GP-suggested solution reduced the project end date to Dec 5, 2000. This is shown in Figure 3 above. In addition the quality risks such as communication risks were improved as shown in figure 4 below.

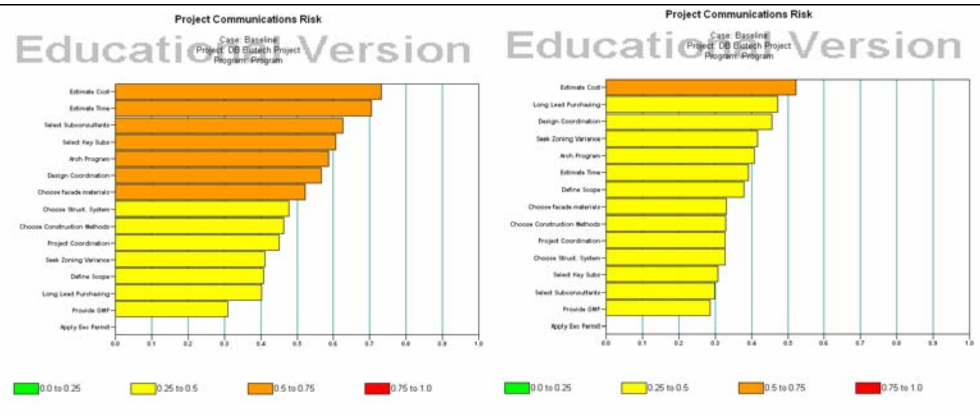

Figure 3—Comparison of Quality Risks before (Left) and after (Right) evolutionary process. Originally 7 out of 14 activities had quality risks higher than acceptable 0.5 thresholds (orange bars). With the suggested organizational changes, quality risks for all activities improved.

Conclusions

This research has made successful first steps towards the optimization of project organization designs. Instead of redesigning the project organization from scratch, a human generated design was used as a baseline. Several input attributes such as decision making policies, individual / sub-team properties, activity assignments, and actors' attention allocation—were adjusted using genetic programming to evolve the project organization design against a fitness function representing the goals for the project. The effects of the evolutionary process on simulated project duration and quality risks were noticeable. We compared the results produced by the GP with those generated by humans. Our GP post processor for VDT beats the best human trial-and-error performance of > 40 teams for this realistic problem.

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