Research Experience and Interests

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I am interested in solving NP-complete problems related to graph theory, combinatorial problems, and cryptography by attacking them from three angles—mathematics, computation, and computing games. I am interested not only in solving particular instances of these problems, but in developing more efficient algorithms and techniques to approach the problems in general. Since many important practical problems related to routing, scheduling, resource allocation, etc. are NP-complete, progress in this area of research is of interest to everyone.

Background

My graduate work focused on several areas of combinatorics and cryptography, mostly using mathematical techniques. In my two Master's theses, I studied group actions on t-designs and large sets, with a particular emphasis on PSL(2,q) as an automorphism group. In my Ph.D. dissertation, I studied transformations of logarithmic signatures of permutation groups and discussed how they might be used to implement secure public-key cryptosystems.

I have also attempted to tackle questions of t-design existence computationally by focusing on techniques to solve other NP-complete problems it reduces to, including *maximum clique*, *zero-one integer programming*, and *exact cover by k-sets*. I approached the problem by implementing exhaustive search algorithms which attempted to significantly prune the search space. I briefly attempted parallelizing my algorithms, but even with a large cluster, the computational power still has modest limits compared to the vast search spaces of these problems.

Given the limitations of the traditional computational approaches, I started work in 2006 on an online game that solves instances of maximum clique. This is the first example of what I call a ***volunteer computing game*** (***VCG***)—a game that is an implementation of a volunteer computing algorithm. The main purpose of a VCG is to attract people to participate in volunteer computing efforts, and generally it is desirable to not only have the gameplay contribute to the solution, but a volunteer algorithm running in the background at the same time, so both the players and their computers are being utilized. With the help of several undergraduate students, we not only implemented a game that solves instances of maximum clique, but a framework that can be used to implement various games to solve various problems. The only requirements are that the problem can be modeled on a search tree, and the game has to map user choices into subtree choices in the search. There is still much work to be done in this area.

Current Research

With VCGs, the computational power of the computer is sought. Although this increases the available computing power beyond what might otherwise be available, with NP-complete problems there are still severe limits on the size of problems that can be solved. Better algorithms to solve these problems are needed. Most researchers who try to find such algorithms, prove they do not exist, or improve on the currently best known algorithms, generally come from a very narrowly defined group consisting of computer scientists, mathematicians, scientists, and engineers. I believe that a diverse set of fresh eyes on the problem will provide very valuable insights and I am using *human computing games* to accomplish this.

A ***human computing game*** (***HCG***) is a form of crowdsourcing in which problems are presented to participants in the form of an online game. While playing an HCG, the player is actually solving a real problem. Online games are an excellent choice because they appeal to just about

everyone, and provide a non-threatening venue in which to present problems that may otherwise be intimidating. Since games cast the net fairly wide, this allows for more diversity and the possibility of an unknown savant. The diversity increases the chance that someone will see the problem in a different way and think of a solution the researcher never could, since players have few preconceived notions of what may or may not work.

Most HCGs solve *recognition problems*—they harness abilities that most humans have, like image and sound recognition. I am interested in HCGs that solve *cognition problems*—problems that require more insight, ability, etc. I am interested not only in the solutions produced by humans, but the techniques they employ. The idea is to study how humans play the games so that their techniques can be turned into algorithms that are more efficient than current algorithms. To my knowledge, my research is the only attempt harness the insight of the masses to solve NP-complete problems, via games or any other technique.

Research Agenda

I plan to continue my research as follows.

1. **Human computing games for graph pebbling.** With the help of a team of undergraduate students, I am currently developing *Pebble It* (http://pebbleit.hope.edu), an HCG to solve graph pebbling problems. Players are presented with instances of graph pebbling problems and asked to solve them. All player moves are recorded so they can be replayed later. Once enough data is gathered, and the best players are identified, their techniques will be studied in the hopes that algorithms that are more efficient than what are currently known will emerge. Additionally, I will present to them specific unsolved instances of problems to see if players are able to do what the best-known algorithms are still unable to do. Several other problems related to graph pebbling will be implemented as games, and the data studied.
2. **Human computing games for graph problems.** The code from *Pebble It* was designed so that implementing games based on other graph problems would be relatively straightforward. I will implement games based on problems like maximum clique, traveling salesman, and lights out, study the resulting data, develop algorithms, and compare them with the currently best known algorithms for each problem.
3. **Study existing NP-complete puzzle games.** I will create versions of popular puzzle games based on NP-complete problems, like Minesweeper and Sokoban, which allow player moves to be tracked and studied. These sorts of games are a great choice since many people already play them so there is a good chance that sophisticated strategies unknown to the research community have already been developed.
4. **Volunteer/human computing games for search tree problems.** I will implement games that allow players to explore search trees in such a way that they can make intelligent choices, run volunteer algorithms in the background, and compete with each other to find the nodes corresponding to solutions of various problems.
5. **Graph pebbling algorithms.** I will also continue exploring graph pebbling and other combinatorial problems with more traditional approaches.

I am actively seeking funding to support my research. In July, 2009 I submitted an NSF CAREER award, focusing on my work with computing games. If that proposal is not funded, I will improve the proposal and resubmit it to either the NSF CAREER program or to the Social-Computational Systems program at the NSF.