Research Statement

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My main research expertise is in computational game theory. I am particularly drawn to problems that are fundamental and challenging from a worst-case computational complexity perspective. The standard solution concept in game theory is Nash equilibrium. A Nash equilibrium can be computed in polynomial time in two-player zero-sum games, but the problem is PPAD-hard for general-sum and multiplayer games. The problem becomes harder as additional elements of complexity are introduced, such as stochastic events, imperfect information, and repeated interactions. Even for two-player zero-sum games, many interesting games are so large that computational complexity analysis is irrelevant; for example, a popular form of two-player no-limit Texas hold'em has approximately 10^{165} states in its game tree. I have worked on approaches for game abstraction, which approximate the full game with a significantly smaller but strategically similar abstracted game. Perhaps the most significant achievement during my PhD research was the idea of real-time endgame solving to solve the later rounds of the game that we have reached in real-time to a finer degree of granularity than in the abstract game [7]; despite showing that this approach can fail theoretically in the worst case, it led to significant performance improvement in practice and was widely viewed as the key scientific breakthrough idea that ultimately led to superhuman play in no-limit Texas hold'em.

In addition to developing algorithms for abstracting and approximating Nash equilibrium strategies in large imperfect-information games, I have also worked on robust modeling and exploitation of suboptimal opponents, computation of human-understandable strategies, and development of new solution concepts. For the latter, I developed the concept of safe equilibrium [2], which is an alternative solution concept to Nash equilibrium that is robust to arbitrary degrees of opponents' irrationality. I also developed a new refinement of Nash equilibrium called observable perfect equilibrium that differs from existing refinement concepts and I believe is the most appropriate solution for many imperfect-information games including no-limit poker [1]. I have worked significantly on algorithms for games with more than two players, which are much more computationally challenging than two-player zero-sum games, yet prevalent in the real world. I have also worked on algorithms for computing Nash equilibria in stochastic games of imperfect-information (with potentially infinite duration) and in continuous games (where pure strategy spaces are infinite). While the main application domain during my PhD research was poker, I have subsequently applied several of the algorithms to problems in national security as part of a DARPA-funded consulting contract, e.g., [6].

Recently I have developed a strong interest in applying game-theoretic algorithms to improve modeling and treatment of cancer. I developed an algorithm that significantly outperformed the prior approach for computing a Stackelberg equilibrium in an dynamic game model of cancer evolution [3]. In this game model, the leader is a physician who selects amounts of two drugs to use for therapy, and the follower is a cancer population consisting of three cell types with different drug resistance properties. The follower selects a population size and a real-valued trait for each cell type. The population dynamics are governed by fitness functions, and the objective of the leader is to maximize a quality of life function. This game model is quite general and can be applied to many different cancer scenarios by modifying the fitness functions, quality of life function, and other game parameters. Many evolutionary game models of cancer have been studied, and several major cancer centers such as Moffit and Cleveland Clinic have researchers working actively in this area. The standard solution concept in evolutionary games is evolutionarily stable strategy (ESS). Informally, a strategy is an ESS if it is robust to being overtaken by a mutation strategy. Algorithms have been previously developed for computing ESS in two-player normal-form games. Recently I have developed the first algorithms for computing ESS in multiplayer [5] and imperfect-information [4] games.

References

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