Research Statement

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My research interests lie between computer science and economics, specifically around the intersections between *multi-agent systems* and *markets*. Their similarities — both involving multiple self-interested individuals and concerning global outcomes — help to form two areas of research: *agent-based computational economics* (ACE) and *market-based control* (MBC). ACE employs agent-based models to study economic and computational properties of (electronic) markets, whereas MBC leverages markets as interaction mechanisms between agents to achieve desired systemic properties. My current research work concentrates on these areas.

Automated Mechanism Design

A major issue in both e-commerce and MBC is *how to design an auction mechanism that exhibits certain properties*. Traditionally, a market mechanism is designed by hand and analyzed theoretically. The problems with this approach are exactly those that dog any manual process — it is slow, error-prone, and restricted to just a handful of individuals with the necessary skills and knowledge. Furthermore, some types of auction, e.g., double auctions, involve complex dynamics and are difficult to handle manually.

I have been working since 2004 with my advisor, Simon Parsons, upon an automated, *grey-box* approach to auction mechanism design, using machine learning and evolutionary computation. This approach combines methods for analyzing strategic interaction that are akin to white-box testing [NCP+08a] and black-box testing [NCMP08] in software engineering. More specifically, we define a tree-structured, parameterized framework of double auctions, model auction rules of a mechanism as building blocks, and use evolutionary methods to search the space for effective mechanisms. The search process includes a set of reinforcement-learning problem solvers to balance exploration and exploitation, aiming to explore more in the part of the search space that turns out to contain better-fit mechanisms.

The effectiveness of the grey-box approach hinges partly upon the diversity of building blocks. We collect auction rules from the literature, and design novel ones ourselves. For example, we introduced pricing rules and shout improvement rules to reduce transaction price fluctuation [NCPS06] and designed matching rules to maximize transaction volume [NPon] in double auctions. We presented a classification of these auction rules in [NCP+08a].

The grey-box approach makes use of a market design game called CAT to evaluate mechanisms found in the search space. A CAT game runs multiple markets in parallel and allows agents, each as a trader, to move between these markets. Previous work ran markets separately and compared different mechanisms in a rather indirect way, whereas CAT games put markets in direct competitions with each other reflecting the situation in the real world. We investigated the dynamics of games between markets that impose different charges and demonstrated the effectiveness of CAT games in differentiating market mechanisms [NCPS07].

Our experimental work is carried out using an open-source software package called JCAT [NCP+08b]. JCAT is part of a collaborative effort between CUNY, University of Liverpool, and University of Southampton in organizing the Trading Agent Competition on Market Design (CAT) [CGM+09] and is used as the server platform for the competitions. I am the architect of JCAT and the co-organizer of the annual CAT events.

We applied the grey-box approach to the domain of CAT competitions and successfully obtained mechanisms that can beat existing, manually crafted, strong entries into prior CAT competitions [NCP10].

Network Markets

Another aspect of my on-going work is on *network markets*, in which individual markets are linked together into larger markets. This kind of network market is important because so many basic products, including gas, water, and electricity, are traded in such markets, and yet it has been little studied until now.

My preliminary work on this topic [CNPew] examined the effect of different connection topologies on network markets in which the constituent markets are double auctions and the links between markets reflect constraints on traders in the markets. These constraints mean that a choice to trade in one market limits the trader's choice of other markets to use. We investigated the behavior of four different topologies — fully connected, ring, chain and star — and considered the speed with which markets converge to a steady state, the distribution of traders across markets in the steady state, and the overall allocative efficiency in the steady state. We found that for all of these factors, the connection topology can have a significant effect.

Market-Based Control

As the Internet is expanding into every corner of our everyday life, markets are gaining its presence in many domains, one of which is *cloud computing*. Cloud computing aims to provide distributed computing resources as services and make them as easily accessible as running water. The versatility of computing needs however presents many challenges, including how to dynamically balance the load of distributed service nodes in a fast and smooth way.

To address this issue, I, in collaboration with people from Beijing University and Microsoft SQL China R&D Center, propose a market-based method for dynamic data migration in *cloud databases*. Cloud databases are very large databases that are deployed in a cloud, run in the backend, and respond to queries from frontend services. The different natures of service based on cloud databases and different habits of human users lead to dynamic patterns of usage that are difficult to predict and deal with. In our approach, continuous double auction (CDA) markets are set up for database nodes to "buy" or "sell" their load whenever necessary so as to achieve a system-wide load balance. Each service node is associated with a buyer agent and a seller agent. These agents can make offers in a market close to them and adjust their offered prices and quantities of units of load based on the load levels on their nodes. Our experiments show that the markets achieve high allocative efficiency, and the system can respond quickly to changes in patterns of usage, significantly better than existing approaches in the literature. What's more, our approach incurs less communication overload and provides a more robust solution to the problem. The preliminary result [WYH+09] won the Best Paper Award at the 2009 WAIM/APWeb conference.

Future Directions and Interests

I plan to continue my work outlined above and extend this work into new domains.

Financial Markets

The current global financial crisis was triggered by subprime mortgage delinquencies and foreclosures in the United States. Technically speaking, it was due to the variety of virtual goods that the financial industry created out of mortgages and the markets that formed around these goods. These markets cascade and intertwine, leading to complex structures that are difficult to understand and evaluate. This issue may be related to problems in supply-chain networks, which have attracted much attention in research recently. But little work has been done in this field regarding the overall performance of such cascading markets, whether a certain market structure involves high risk, and what can be done to reduce the risk from the viewpoint of governments. The network markets research discussed above focuses on markets handling a single commodity, whereas the financial markets scenario involves markets handling multiple (although correlated) goods. This distinction and the damage the financial crisis have caused make the problem an interesting and important one to explore.

Cloud Computing

My approach to automated mechanism design can be combined with the domain of load balancing in cloud computing. The CDA mechanism used to tackle the problem of load balancing in cloud databases has been used in financial markets for many years and was chosen in our effort by heuristics. Better mechanisms may exist in the domain. My grey-box approach clearly has the potential of acquiring these mechanisms and of solving similar problems in distributed computing.

E-Commerce

E-commerce becomes more and more pervasive nowadays. Industry giants, like eBay, Google and Yahoo, bring in billions of dollars each year either by providing e-marketplaces to consumers or by selling search keywords in ad auctions. The auction mechanisms used in their businesses are, however, not perfect. One problem, for instance, is that their seller-centric auctions are not effective in matching demand and supply. A solution to this problem is to use double auction mechanisms. A number of follow-up questions need to be addressed, including: how to identify relationships between goods, how to map goods to double-auction markets, how to charge users fairly and easily, and what market mechanisms to use to maximize revenue or reach a combined set of goals.

The magnitude of impact and complexity of issues listed above constantly intrigue me to devote myself to these inter-disciplinary fields. In my future research, I plan to continue to apply economic theory and techniques from computer science to analysis and design of optimal mechanisms for existing and emerging domains.

References

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