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Market-Based Control of Computational Systems: Introduction to the Special Issue

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Abstract We introduce the Special Issue of the journal on the topic of Market-Based Control of Computational Systems. The special issue collects six peer-reviewed papers arising from an International Workshop on the topic held in Liverpool, UK, in September 2008.

Keywords Market-based control, mechanism design, cloud computing, multi-agent systems

1 Introduction

The development of the Internet has enabled computational and other resources to be accessed remotely. Networked resources such as digital information, specialized laboratory equipment, and computer processing power may now be shared between users in multiple organizations, located at multiple sites, and working at different times. For example, the GRID networks of scientific communities enable shared and distributed access to advanced equipment such as supercomputers, telescopes and electron microscopes. Similarly, in the commercial IT arena, shared access to computer processing resources has in recent years drawn the attention of major vendors with companies such as Hewlett-Packard ("utility computing"), IBM ("on-demand computing"), Sun ("N1 Strategy") and Amazon ("Elastic Compute Cloud") announcing initiatives in this area. Sharing resources across multiple users, whether commercial or scientific, allows scientists and IT managers to access resources on a more cost-effective basis, and should achieve a closer match between demand and supply of resources.

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These systems typically involve multiple participants providing and/or accessing resources distributed geographically and owned by multiple stakeholders. Such distributed systems are also increasingly open, in that there may only be minimal requirements for participation, and participants may enter and leave the system at will. Accordingly, the software components representing participants may be designed and operated by software development teams independent of those responsible for the system as a whole (if there is indeed such a central entity). Thus, participants may not share the same interests, preferences or objectives as the system manager or even as one another, and so are best viewed as acting as autonomous, self-interested agents. This participant autonomy makes prediction of their local behaviour and interactions difficult; challenging, too, is the accurate prediction of global system properties.

Traditional centralised command-and-control methods of software engineering have well-known limitations in designing and managing these systems, particularly when the numbers of computational entities is large. Consequently, over the last two decades software engineers have begun to conceive of distributed computer systems as multi-agent systems, comprised of self-interested, interacting software entities, called agents (Luck et al, 2005). Similar large-scale systems of interacting, self-interested and autonomous actors (humans) comprise the domain of study of economics, and so computer scientists have begun to look to economics for models of distributed computation. The success of e-commerce has boosted this inter-disciplinary connection, as on-line marketplaces have required the pooling of software engineering and economic market design expertise.

Within economics, the design of marketplaces is known as *Mechanism Design* (Roth, 2002), a discipline which draws heavily on game theory (Osborne and Rubinstein, 1994). Mechanism design is the process of designing the "rules of the game" when two or more entities interact in some system. Market mechanisms include various types of auctions, barter mechanisms, negotiation mechanisms, and futures and derivatives exchanges (Mirowski, 2002). One prominent computer scientist, speaking of software engineering, has stated: *"All design problems are now mechanism design problems."* (Papadimitriou, 2001, p. 752). But mechanism design is not usually a straightforward task. Different interaction mechanisms have different properties: thus, particular mechanisms may or may not achieve desired global objectives (Jennings et al, 2001). Allocation of network bandwidth, for example, could be undertaken through an auction mechanism which would maximize revenues to the owners of the bandwidth, or a mechanism maximizing bandwidth utilization, or one maximizing the numbers of users, or one which best ensured network stability, etc. These different objectives may conflict, and so the design of an appropriate mechanism for a given application is usually a non-trivial trade-off between competing objectives. Each domain presents its own unique challenges for the mechanism designer, and there is no one mechanism which is appropriate for all circumstances (Klemperer, 2002). Indeed, it is common for economists to employ a mix of theoretical analyses, empirical experiments with human subjects, and computer simulation when designing important market mechanisms, as in the design of auctions for mobile communications licences conducted by the US Federal Communications Commission since 1994 (Guala, 2001; Nik-Khah, 2005).

Economists have traditionally considered mechanism design as a static, one-time, task, with the designer seeking to achieve an acceptable trade-off between conflicting objectives. But interaction mechanisms in complex systems may not remain static once in operation: intelligent participants may be able to exploit weaknesses or quirks in the mechanism, or may change their behaviours as a result of the mechanism (Gintis, 2000). Accordingly, system managers may need to intervene in the operation of a system to ensure that desirable goals are achieved, for example, by altering the rules of interaction, or by inserting new participants to act as catalysts for desired behaviours.

We believe that market-based methods provide a basis for design, prediction and control of many complex, adaptive computational systems. This is because markets provide a means to achieve system-level objectives, such as the efficient allocation of scarce resources, while still permitting components to act independently of one another. In addition, these objectives may be realized with minimal centralization and with each component using only information available locally. In other words, a market allocation mechanism may achieve desirable global outcomes using (to a greater or lesser extent) only local inputs. The global goals are achieved by the interaction mechanism co-ordinating the activities of the participants with what Adam Smith called an *Invisible Hand* (Smith, 1776/1977).

2 Workshop and call

Within this context, a major national UK research project, *Market-Based Control of Complex Computational Systems* (MBC)[1] was undertaken during 2004–2009, by the Universities of Birmingham, Liverpool and Southampton, and with participation by BAE Systems, British Telecommunications, and Hewlett-Packard. The project was funded by the UK Engineering and Physical Sciences Research Council (EPSRC), under an initiative to fund research on novel approaches to managing complex computational systems. With the support of this project, an international, refereed workshop on these topics was held in Liverpool on 1-2 September 2008[2]. Invited talks were given by four leading computer scientists and economists, and eight refereed papers were presented, along with presentations by the MBC project team. We thank Nicholas Jennings and Michael Wooldridge, from the MBC Project, and Helen Bradley, Ken Chan, Paul Goldberg, Wiebe van der Hoek, Judith Lewa, David Shield, Lisa Smith and Thelma Williams, from the University of Liverpool, for their assistance in planning and running the Workshop. Following the workshop, participants were invited to submit papers for this special issue, and we express our gratitude to the journal editors-in-chief, Jeffrey Rosenschein and Michael Wooldridge, for providing this opportunity. The submitted papers were subject to peer-review and possible revision before final acceptance/rejection decisions were made. We thank the following people for their willingness to undertake this peer-reviewing task: Krzysztof Apt, Nikolay Borissov, Andrew Byde, Kai Cai, Archie Chapman, Edith Elkind, Alessandro Farinelli, Nicholas Jennings, Xudong Luo, Huiye Ma, Peter Lewis, Efrat Manisterski, Paul Marrow, Tomasz Michalak, Dirk Neumann, Jinzhong Niu, Simon Parsons, Steve Phelps, Zinovi Rabinovich, David Sarne, Ioannis Vetsikas, Perukrishnen Vytelingum and Michael Wooldridge. Because some of the papers submitted included members of the special issue editorial team as co-authors, special arrangements were also made to ensure anonymous, confidential reviewing of these papers. We thank Michael Luck and five reviewers unknown to we three editors for helping with this process. We are also grateful to the journal staff, particularly Ms Chandini Joseph, for their assistance in preparing the papers for publication.

[1] See: `www.marketbasedcontrol.com`

[2] See `www.csc.liv.ac.uk/~peter/mbc/mbc-2008.html`

3 Papers in this Issue

The review process led to six papers being accepted for the special issue, and collectively they cover a range of topics and research methods in this exciting area. We now briefly introduce each paper in turn.

In many markets, opportunities arise and disappear much faster than human traders can successfully manage, so automated buying and selling is already commonplace on the world's financial exchanges (McBurney and Luck, 2007). The first paper in the special issue, entitled *Automated bidding in computational markets: An application in market-based allocation of computing services*, by Nikolay Borissov, Dirk Neumann and Christof Weinhardt (Borissov et al, 2010), presents a framework for automated bidding and a methodology for the design and implementation of configurable bidding strategies. The authors also present a new trading strategy for both providers and consumers, drawing on reinforcement learning, and this strategy is evaluated against selected benchmark bidding strategies in various market contexts. The authors then define a bidding language for communicating consumer and provider preferences to the market

The second paper, entitled *Resource allocation in decentralised computational systems: An evolutionary market-based approach*, by Peter R. Lewis, Paul Marrow and Xin Yao (Lewis et al, 2010), proposes a novel mechanism for resource allocation in fully decentralized systems with self-interested agents, a mechanism which requires neither a coordinating node nor complex inter-agent negotiations. The authors study the stability, convergence properties and robustness of their mechanism under various conditions, including competitive co-evolution of the participating agents.

One of the initiatives of the MBC Project was the design and operation of a research tournament, the *Market Design (or CAT) Tournament*,[3] which first ran in 2007. In this tournament, entrants create double auction marketplaces which compete with one another, in the same way that do the New York Stock Exchange, the Tokyo Stock Exchange, the Paris Bourse, etc. The software traders in these competing markets were created by the MBC project team, and they place bids and asks in one or other competing exchange according to their particular trading strategies and their past experiences. In the third paper in this issue, entitled *What the 2007 TAC Market Design Game tells us about effective auction mechanisms*, by Jinzhong Niu, Kai Cai, Simon Parsons, Peter McBurney and Enrico Gerding (Niu et al, 2010), the authors report on an analysis undertaken, following the 2007 CAT Tournament, of the entries to the tournament. The authors begin by classifying the entries in terms of the double auction mechanism rules and features each adopted, enabling a descriptive comparison of the different entries. Then, through simulation studies, the authors seek to connect these rules and features with competitive marketplace dynamics, in order to draw conclusions about which mechanisms are likely to be effective under different circumstances.

The fourth paper in the special issue, entitled *Multi-goal economic search using dynamic search structures*, by David Sarne, Efrat Manisterski and Sarit Kraus (Sarne et al, 2010), considers cooperative search strategies for agents engaged in costly search activities. In a context where there are both expected costs and expected benefits to search tasks, and where several different goals must be satisfied, the authors propose a framework which enables partitioning of the task into parallel and autonomous sub-tasks. The authors evaluate their proposed framework and show that it weakly dominates alternative cooperative and autonomous search techniques.

[3] See: `www.marketbasedcontrol.com/cat`

The second paper above, by Lewis et al (2010), simulates co-evolution of agents participating in a fully-decentralized resource allocation domain, as they respond to system events and to each other's actions. Indeed, in real marketplaces, traders develop strategies in response to the rules of the marketplaces in which they operate, whose managers may then respond with new marketplace rules, and so forth. This parallel with natural evolution has led in recent years to the application of evolutionary and co-evolutionary methods to the design of economic mechanisms, a topic which is reviewed in the fifth paper of the special issue. This paper, entitled *Evolutionary mechanism design: A review*, by Steve Phelps, Peter McBurney and Simon Parsons (Phelps et al, 2010), considers mechanism design as an engineering problem, and applies standard engineering design principles, such as iterative and incremental refinement of solutions, and seeking satisficing rather than optimal solutions.

A concern with imperfect (real-world) constraints rather than perfectly-optimal solutions is perhaps a key aspect of computational mechanism design. Some of these real-world constraints and attributes, such as budget constraints and preferences over risk, are considered by the sixth and final paper in the special issue, entitled *Bidding strategies for realistic multi-unit sealed-bid auctions*, by Ioannis A. Vetsikas and Nicholas R. Jennings (Vetsikas and Jennings, 2010). The authors examine these constraints for multi-unit sealed-bid auctions, extending prior work on single-unit auctions. Supporting their theoretical analysis, the authors then undertake a simulation which shows that bidders are able to maximize their utilities given the various constraints.

As these short summaries indicate, there are many different fronts in this area of market-based control of computational systems, and research is therefore proceeding across a wide domain. The methods being used also cover a wide gamut of approaches, from theoretical analyses to computational simulation to the creation of prototype systems. The broad domain and the diversity of research approaches makes the field an exciting one to be part of. We hope you enjoy reading the papers in this Special Issue!

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