

Designing Economic-Based Distributed Resource and Task Allocation Mechanisms for Self-Interested Agents in Computational Grids

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1. Problem Statement

In computational grids, heterogeneous resources with different ownerships are dynamically available and distributed geographically. The users of the computational grids vary depending on their goals, time constraints, priorities, and budgets. Allocating their tasks to the appropriate resources in the grids so that their performance requirements are satisfied and the costs remain within their budgets is extraordinarily complicated. On the other hand, resource suppliers vary in their resource capability, availability, cost, and security policies. Allocating their resources to the proper users so that the utilization of the resource and the profit generated are maximized is also an extremely complex problem. Here, resource allocation refers to the resource suppliers' decisions to allocate resources to users, and task allocation refers to the users' decisions to allocate tasks to resource suppliers.

From a computational perspective, it is impractical to build a centralized resource or task allocation mechanism in such a large-scale, distributed environment. Meanwhile, providing incentives for both users and resource suppliers to participate in a computational grid is also challenging. It must be addressed in the resource and task allocation mechanisms, because this is the key to maintaining the stability of a computational grid.

The effective agents (both users and resource suppliers) in computational grids are inherently self-interested because of their different ownerships. Self-interested agents make their own decisions according to their budgets, capabilities, goals, and local knowledge without considering the global good of the entire grid. It is not realistic to build the resource or task allocation mechanisms for such a grid without considering economic issues. Hence, developing economic-based approaches is a promising direction for building efficient, scalable and stable resource and task allocation mechanisms without centralized controller for computational grids.

The key difficulty in building an economic-based resource and task allocation mechanism is in deciding the economic value of resource usage. Previously, people assume there existed a general currency to measure the cost of using a certain resource. But no one has addressed methods for translating the usage of different types of resources into grid dollars. This is an obstacle that keeps computational grids from being realistic because it is difficult to convince users that participating in computational grids is less expensive than purchasing more computational resources to obtain the same amount of computational power. Also, for resource suppliers, it is hard to evaluate the profit of putting resources into a grid without such a measurement. For both users and

suppliers, joining a grid will raise more security and maintenance cost than only having their own computational resources to execute their own tasks. They have to be convinced that the extra cost is worthwhile.

This research begins with developing a task-oriented mechanism for translating the usage of a resource into a common grid currency in computational grids. Based on the value of resource usage, both commodity market-based and game theory-based distributed resource and task allocation mechanisms are developed and investigated.

2. Value of Resource Usage

Previously, people set a price for a unit of a certain type of resource to measure the value of the resource usage in computational grid settings. For example, resource suppliers would set the price of a time slot of a CPU. The weakness of this approach is that the clock rates of CPUs in a grid vary a wide range. Setting proper prices for the time slots of all types of CPUs in a grid is infeasible. This approach also requires users to be aware how many resource units they need for a certain task in order to calculate the cost. It is too expensive for users to know all types of resource in the grid and find the ones that are the best for their tasks. Indeed, users do not care how many units of resources they need. What they need is spending less money to achieve better performance.

We believe that the mechanism of measuring the value of resource usage should be based on achieving a certain task by using the resource. The idea is to view the resource allocation to a task as a service. Different performance requirements result in different costs. In other words, the profit made by the resource providers depends on what kind of tasks they perform instead of the resource usage they sell. The performance criteria can be time constraints, security, maintenance requirements, and so on.

Different users have different performance criteria and requirements. They search for the cheapest resources that can satisfy their performance preferences based on their local knowledge, computational capabilities, and budget limitations. Users do not have to know how many resource units their tasks need and the exact time slots their tasks are executed on each resource. They do not have to be aware of the differentiation of resource capabilities either. They only need to know the resource consumption as a whole for a certain task in order to evaluate the outsourcing decision.

Suppliers try to allocate their resources to the most profitable tasks and to avoid their resource being idled as much as possible. Suppliers plan and schedule their resources based on their own costs, local knowledge, computational capabilities and users' performance preferences. Allocating resources to a certain task is a service provided by a resource supplier. The cost of a service is decided by how much resource it needs, how long it takes, and which levels of

security and maintenance are required. So the users' resource demands become service demands from suppliers. Different services result in different costs.

This task-oriented mechanism provides a feasible way for grid users to evaluate their outsourcing decisions. It also gives resource suppliers the incentives to provide their resources to computational grids.

3. Commodity Market-Based Mechanism

Market mechanisms have been extensively studied as resource allocation mechanisms for distributed computing systems. The users and the resource suppliers in a computational grid are easily translated into buyers and sellers in commodity markets respectively. Intuitively, the commodities are usages of resources such as CPU time slots, number of files needed to be stored etc. This is probably the reason for trying to set prices for resource units to build economic-based resource allocation mechanisms previously. However, this setting makes the measuring the value of resource usage extremely complex.

We measure the value of resource usage through the task-oriented mechanism mentioned above. The commodities are services provided by the resource suppliers in computational grids. The price of a service originally set by a resource supplier depends on expected profit, the resource consumption, time, security, and maintenance requirements. It will be adjusted by the relationship of demand and supply in the market. In other words, resource consumption is not a commodity but the cost that the resource suppliers need to provide the service in the market.

Wolski et al [1] have proposed four criteria for evaluating economic-based resource allocation mechanisms in computational grids: grid wide price stability, market equilibrium, application efficiency and resource efficiency. Price stability ensures scheduling stability. Equilibrium measures the fairness of prices. Application and resource efficiency measures how well the grid works as a computational platform. These four criteria are also used to evaluate the market-based resource and task allocation mechanism developed in this thesis.

Furthermore, we need to consider the individual rationality of each individual agent in a grid. If a user would spend more money by outsourcing tasks than purchasing more resources, that user will not outsource the tasks. This is the most important criterion for building a stable grid and giving incentives to agents joining the grid.

4. Game Theory-Based Mechanism

The most obvious weakness of the commodity market-based mechanism for resource allocation in computational grids is that no such real market exists currently.

Coalition formation, a game theory-based mechanism, is a more practical approach for resource and task allocation in computational grids because of the following reasons: The tasks in a computational grid need intensive computational resources in real applications generally. Potential users who have such tasks are not individuals but organizations that already own a large amount of computational resources. Even so, these users need more computational power to execute their tasks at some times and most of their resources are idle at other times. Coalition formation provides a

cooperative mechanism for multiple organizations that have this problem to put their resources into a grid so that their resource requirements at peak times are satisfied without purchasing more resources.

In the real world, organizations have already started to negotiate with each other to pool their computational resources to execute large and complex tasks. Currently, human subjects execute the negotiation processes to establish certain resource and task allocation mechanisms. However, these negotiation processes only can be run to initialize a computational grid. Afterwards, if there are internal or external changes for the grid, the resource and task allocation mechanisms should be changed by resetting some other negotiation processes. This makes building efficient and adaptive resource and task allocation mechanisms for computational grids impractical.

Based on automatic distributed coalition formation mechanisms, we can develop resource and task allocation mechanisms for computational grids. To make agreements among organizations, automated multi-party negotiation protocols are established. The stabilities of these mechanisms are evaluated by the fairness of the payoff division mechanisms. Forming an optimal and stable coalition is a computationally intractable problem. The overhead of the coalition formation process must be considered. The efficiency of a grid as a computational platform should also be investigated.

5. Contributions

Researchers in the areas of high performance computing and multi-agent systems have studied applying economic-based mechanisms for distributed resource and task allocation problems. Wolski et al [1] became the pioneers in investigating the commodity market-based resource allocation mechanisms for computational grids. Sandholm [2] addressed the fact that the computing, communication, and privacy issues are deeply intertwined with the economic incentive issues.

The main contributions of this research are the followings: the development of a task-oriented mechanism to measure the economic value of resource usage in computational grids; the development and investigation of both commodity market-based and coalition formation-based resource and task allocation mechanisms in computational grids; the development of appropriate resource discovery mechanisms, negotiation protocols and resource planning and scheduling algorithms to support the entire allocation mechanisms; and the performance comparison of different mechanisms. The results reflect how critical it is to consider economic incentive issues for building efficient, stable and scalable resource and task allocation mechanisms for computational grids in real applications.

6. References

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CURRICULUM VITAE

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EDUCATION

Ph.D. Computer Science, Texas A&M University, USA, expected May 2005 (GPA: 3.85/4.0).

Dissertation: Designing Computational Economic-Based Distributed Resource and Task Allocation Mechanisms for Self-Interested Agents in Computational Grids.

Dissertation Advisor: Thomas R. Ioerger, Department of Computer Science, Texas A&M University.

M.S. Computer Science, Southwest Petroleum Institute, China, July 1999 (GPA: 3.9/4.0).

Thesis: Development of a Novel GIS Temporal and Spatial Data Model.

Thesis Advisor: Biao Sun, Department of Computer Science, Southwest Petroleum Institute, China.

RESEARCH INTERESTS

Multi-agent systems, agent-based computational economy, economic-based computational resource and task allocation mechanism design, coalition formation, automated multi-party negotiation, electronic combinatorial trade, combinatorial optimization, machine learning, cognitive modeling, situation awareness, natural decision-making, teamwork and data management.

RESEARCH EXPERIENCE

Research Assistant, Department of Computer Science, Texas A&M University, 2000 – present.

- Developing Game Theory based computational economic strategies in combinatorial trading and building economic-based resource discovery and allocation mechanisms for Grid Computing.
- Developing a distributed multi-player computer game (RSF) for cognitive scientific experimentation of team training protocols (Funded by DoD/Air Force Office of Scientific Research).
- Developed Command and Control decision-making models for military team (e.g. Air Force AWACS crew) training systems. Developed agent capability evaluation models in multi-agent systems (Funded by DoD/Air Force Office of Scientific Research).
- Developed Natural Decision Making models for military tactical training system. Integrated this system with DoD Distributed Interaction Simulations (e.g. Onesaf Testbed) through DoD High Level Architecture (Funded by Army Research Lab in Aberdeen, MD).
- Developed distributed tactical training systems based on collaborative intelligent agents that can simulate and support effective command and control in virtual battlefield (Funded by Naval Air Warfare Center, Training Systems Division).

Assistant Professor, Department of Computer Science, Southwest Petroleum Institute, China, 1999.

- Developed GIS temporal and spatial 4D data models.

Research Assistant, Department of Computer Science, Southwest Petroleum Institute, China, 1998-1999.

- Developed a drilling simulator for driller training, which collaborates hardware simulation and 3D graphic software.

Research Assistant, Department of Computer Science, Southwest Petroleum Institute, China, 1996-1997.

- Developed a large Client/Server drilling database system for Tarim Oil Field.

TEACHING EXPERIENCE

Assistant Professor, Department of Computer Science, Southwest Petroleum Institute, China, Fall 1999.

- Taught Software Engineering for undergraduates.

Instructor, Department of Computer Science, Texas A&M University, USA, Summer 2004.

- Teaching Artificial Intelligence for undergraduates.

WORK EXPERIENCE

Intern Engineer, TuHa Oil Field, Xinjiang, China, 1997-1998.

- Developed a Geographic Information System platform for oil production management based on the legacy database infrastructure.

Market Information Analyst, XinFeng Cooperation, Sichuang, China, 1992-1996.

- Developed statistics software for supply chain management

PUBLICATIONS

- **He, L.** and Ioerger, T.R. (2004). Forming Resource-Sharing Coalitions: A Distributed Resource Allocation Mechanism for Self-Interested Agents in Computational Grids, the Super Computing (SC) 2004 conference, submitted.
- **He, L.** and Ioerger, T.R. (2004). Combining Bundle Search with Buyer Coalition Formation in Electronic Markets, the Sixth International Conference on Electronic Commerce (ICEC), submitted.
- **He, L.** and Ioerger, T.R. (2004). Combining Bundle Search with Buyer Coalition Formation in Electronic Markets: A Distributed Approach, in Proceedings of the Third International Joint Conference on Autonomous Agents and Multi-Agent Systems (AAMAS), to appear.
- **He, L.** and Ioerger, T.R. (2004). An Efficient Heuristic Bundle Search Algorithm for Buyers in Electronic Markets, in Proceedings of the 2004 International Conference on Artificial Intelligence (IC-AI), to appear.
- **He, L.** and Ioerger, T.R. (2004). Task-Oriented Computational Economic-Based Distributed Resource Allocation Mechanisms for Computational Grids, in Proceedings of the 2004 International Conference on Artificial Intelligence (IC-AI), to appear.
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- Zhang, Y., **He, L.**, Biggers, K., Yen, J., and Ioerger, T.R. (2001), Simulating Teamwork and Information Flow in Tactical Operations Centers using Multi-Agent Systems, in Proceedings of the Tenth Conference on Computer Generated Forces (CGF).
- **He, L.**, (1999), Development of a Novel GIS Temporal and Spatial Data Model (Master's Thesis).

PROFESSIONAL ACTIVITIES

Session Co-Chair, the International Conference on Artificial Intelligence, 2004.

Reviewer, the Sixth International Conference on Electronic Commerce, 2004.

HONORS AND AWARDS

Outstanding Graduate Student Scholarship from Southwest Petroleum Institute, China, 1997.

Excellent Engineering Project Award from Southwest Petroleum Institute, China, 1999.

Scholarship from Richard Tapia Celebration of Diversity in Computing Conference, Atlanta, GA, 2003.

LEADERSHIP

Social Officer, Computer Science Graduate Student Association, Texas A&M University, 2002-2003.

Coordinator, AI and Robotics Seminar, Texas A&M University, 2003-2004.

PROFESSIONAL MEMBERSHIP

American Association for Artificial Intelligence (AAAI).

Aggie Women in Computer Science (An ACM-Women Chapter).

REFERENCES

Available on Request.