Report on the TFG-MARA Meeting at the Technical Forum in Ljubljana*

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Abstract

Resources allocation in multiagent systems is a central research issue in the AgentLink community. The aim of the Technical Forum Group on Multiagent Resource Allocation (TFG-MARA) is to provide a venue for the exchange of ideas in this area and to foster collaboration between different European research groups. In this document we report on the first meeting of TFG-MARA, which was held as part of the Second AgentLink III Technical Forum at the Jožef Stefan Institute in Ljubljana, Slovenia, in February/March 2005.

1 Introduction

Negotiation over the allocation of resources is one of the central research issues addressed by the international multiagent systems community in general, and by the AgentLink community in particular. The aim of the Technical Forum Group on Multiagent Resource Allocation (TFG-MARA) is to provide a venue for the exchange of ideas in this important area and to foster collaboration between different European research groups. Special emphasis is put on the interdisciplinary character of the field, particularly on issues at the interface of the Socio-economic Sciences on the one hand, and Artificial Intelligence and Computer Science on the other.

At the level of individual agents, TFG-MARA is concerned with the compact representation of preferences, building on both classical decision theory and recent advances in logic-based representation formalisms. At the system level, the overall performance of a multiagent system for resource allocation can be measured in terms of various notions of social welfare as studied in welfare

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economics and social choice theory. Here we are particularly interested in "non-standard" notions of social welfare, including those imposing different fairness constraints on allocations. Another focus of TFG-MARA is the complexity of multiagent resource allocation problems. This includes the computational complexity of relevant decision and optimisation problems, as well as issues in communication complexity (length of negotiation processes, amount of information exchanged between agents). The scope of this TFG includes both (combinatorial) auction-based resource allocation mechanisms and fully distributed forms of negotiation. Finally, we are interested in the implementation of prototype systems, which can inform theoretical research by providing empirical data and a test-bed for negotiation heuristics.

In this document we report on the first meeting of TFG-MARA, which was held as part of the Second AgentLink III Technical Forum at the Jožef Stefan Institute in Ljubljana, Slovenia, in February/March 2005. We briefly cover the organisational aspects of the meeting, then review some of the highlights of the scientific programme, and conclude by discussing the main outcomes of the discussions that took place in Ljubljana.

2 Organisation and Structure of the Meeting

The first meeting of TFG-MARA was hosted by the Jožef Stefan Institute in Ljubljana, Slovenia, as part of the Second AgentLink III Technical Forum. The meeting took place in the afternoon of the 28th of February and the morning of then 1st of March 2005. It was attended by over 20 researchers from over ten different institutions in Slovenia, France, Spain, Portugal, Belgium, the Netherlands and the UK.

Given that this was the first meeting of this particular TFG, the focus of the scientific programme has been on spreading information about research activities at the participating institutions. Out of a total of four technical sessions, three were organised in the style of a workshop, although talks were slightly longer than usual and the informal setting of the event allowed for a more extensive (and often deeper) discussion than most workshops or conferences would permit. The following talks were presented at the meeting:

- *Maximal Classes of Utility Functions for Efficient one-to-one Negotiation*
  Speaker: Yann Chevaleyre (LAMSADE, Paris-Dauphine)
  Relevant publication: [6]

- *Complexity Issues in Multiagent Resource Allocation*
  Speaker: Paul E. Dunne (Liverpool)
  Relevant publications: [11, 12]

- *Notes on the Communication Complexity of Multilateral Negotiation*
  Speaker: Nicolas Maudet (LAMSADE, Pars-Dauphine)
  Relevant publications: [7, 14]

- *Efficiency and Envy-freeness in Fair Division of Indivisible Goods*
  Speaker: Sylvain Bouveret (IRIT, Toulouse)
  Relevant publication: [2]

- *Equitable Allocation of Earth Observing Satellite Resources*
  Speaker: Michel Lemaître (ONERA, Toulouse)
  Relevant publications: [19, 20]

- *Multiagent Resource Allocation: What to optimise, how, and why?*
  Speaker: Ulle Endriss (Imperial College London)
  Relevant publications: [4, 5, 13]

- *Trust-based Mechanism Design*
  Speaker: Raj K. Dash[1] (Southampton)
  Relevant publication: [9]

- *Towards Automated Procurement via Agent-aware Negotiation Support*
  Speaker: Juan A. Rodríguez-Aguilar (IIIA-CSIC, Barcelona)
  Relevant publications: [15, 16]

- *JASA: A High-performance Open-source auction Simulator*
  Speaker: Steve Phelps (Liverpool)
  Software available at `http://sourceforge.net/projects/jasa/`

- *Logical Languages for Compact Preference Representation*
  Speaker: Jérôme Lang (IRIT, Toulouse)
  Relevant publications: [8, 18]

To make the event as representative of European research as possible, we had issued a Call for Position Statements in early February. In the very short time available, we received a total of eight such statements:

- Sylvia Estivie (LAMSADE, Paris-Dauphine)
  A Platform for Multiagent Resource Allocation

- Peter Gradwell and Julian Padget (Bath)
  Distributed Resource Allocation for Grid Computations

- Geert Jonker (Utrecht)
  Mechanism Design for Airport Traffic Planning

- Beatriz López, Pere Urra, Silvia Suárez and Isabel Cuevas (IIiA, Girona)
  Multiagent Resource Allocation for Collaborative & Competitive Scenarios

- Ana Madureira (GECAD, Polytechnic of Porto)
  Multiagent Systems for Distributed Manufacturing Scheduling

- Philippe Mathieu and Marie-Hélène Verrons (LIFL, Lille)
  GeNCA: A Generic Negotiation Model and API

[1]Due to problems with obtaining a visa, R. K. Dash was not able to attend the meeting and the actual talk was therefore delivered by J. A. Rodríguez-Aguilar.

- Paul Valckenaers and Paul Verstraete (PMA, KU Leuven)
  Stigmergy and Multiagent Resource Allocation

- Sieuwert van Otterloo (Liverpool)
  Games and Logic for Mechanism Verification

Six of these position statements (as well as the last of the aforementioned long talks) were presented in the fourth and final session of the meeting.

The meeting concluded with a discussion of future activities. These will include, we hope, a further meeting at the next AgentLink Technical Forum and the joint production of a survey of issues in Multiagent Resource Allocation. The position statements received by the organisers, full details on the presentations given at the meeting, and information on ongoing activities, are all available at the TFG-MARA website:

`http://www.doc.ic.ac.uk/~ue/MARA/`

3 Scientific Programme

The first three sessions of the meeting, broadly, addressed *complexity* issues, *fair division* and *auctions*, respectively. The fourth session was, by its very nature, more diverse in the topics addressed: the long talk in this session provided an overview of logic-based languages for the compact representation of agents' *preferences* over alternative bundles of resources, while most of the position statements concentrated on different *applications* of multiagent resource allocation techniques.

3.1 Complexity Issues

The talks in the first session demonstrated that the term "complexity" can have a number of different interpretations in the context of MARA. Firstly, there is the *computational complexity* of problems such as finding an allocation that maximises a suitable metric. Secondly, the area of *communication complexity* is concerned with the length of negotiation processes and the amount of information exchanged by negotiating agents. A third dimension concerns the *structural complexity* of resource exchanges (*i.e.* the number of resources and/or agents involved in a single deal).

This third aspect of complexity was addressed in the talk by Y. Chevaleyre, who discussed a MARA framework where rational but myopic agents negotiate over the allocation of indivisible resource in a distributed manner. While, in general, structurally complex deals are necessary to guarantee socially optimal outcomes of negotiation (here: allocations that maximise the sum of individual utilities), in case all agents are using *modular* utility functions to model their preferences any sequence of deals involving just a single resource each will eventually result in an optimal allocation. Chevaleyre showed that the class of modular utility functions is *maximal* in the following sense: no strictly larger class of utility functions can still guarantee socially optimal outcomes of negotiation conducted by means of deals involving only a single resource at a time [6].

In the second talk of this session, P. E. Dunne reviewed recent results on the computational complexity of multiagent resource allocation, concerning both the issue of determining the existence of allocations with specific attributes and properties of a particular distributed negotiation regime [12]. As argued by Dunne, a significant problem is that, excepting very restricted environments, all methods for multiagent resource allocation ultimately face issues of computational intractability. Such is the case whether one employs highly centralised mechanisms, e.g. combinatorial auctions, or more distributed methods.

In his talk on the subject, N. Maudet focussed on the different notions of complexity, in particular communication complexity, that are directly relevant to the agents engaged in negotiation. These may be captured by the following questions [14]: How many deals are required to reach an optimal allocation? (Some results related to this first question were also presented by Dunne [11].) How many communicative exchanges are required to agree on one such deal? How expressive a communication language do we require? And finally, how complex is the reasoning task faced by each agent at each step? This task of deciding what to do next also involves the identification of potential (mutually beneficial) deals. Maudet concluded by giving examples of concrete protocols designed to tame this last aspect of complexity [7].

3.2 Fair Division

The talks in the second session emphasised the fact that a wide range of different metrics are available to assess the quality of an allocation of resources [1]. Pareto optimality and utilitarian social welfare (given by the sum of individual utilities) are well-known examples in the multiagent systems community [21, 23], while concepts such as egalitarian social welfare [22] or envy-freeness [3], which capture a notion of *fairness*, have received less attention to date. Some of the issues discussed concern the design of mechanisms that balance efficiency and fairness considerations, as well as the computational complexity of such mechanisms.

In the first talk of the session, S. Bouveret interpreted the concept of fairness in the sense of envy-freeness. An allocation of resources is called envy-free if and only if no agent would rather have the bundle assigned to one of the other parties. Bouveret discussed the computational complexity of problems such as deciding whether there exists an efficient (*i.e.* Pareto optimal) and envy-free allocation when the preferences of individual agents are represented in a succinct manner. It turns out that many of these problems are located at the second level of the polynomial hierarchy.

Then M. Lemaître reported on the application of MARA techniques to the allocation of earth observation satellite resources (such as taking specific photos) amongst the different stake-holders in a large space project (e.g. different countries or companies) [19, 20]. Here the range of feasible allocations is not only restricted by physical constraints, but the exploitation of the resources should be both efficient and fair (a stake-holder's benefits should be roughly proportional to their original investment). Lemaître presented a model based on the egalitarian interpretation of social welfare that favours allocations in which the agent currently worst off is doing as well as possible.

In the final talk of the second session, U. Endriss gave an overview of the most important parameters of a multiagent resource allocation problem, including the options available when choosing an allocation procedure (centralised or distributed), a language to encode agent preferences (balancing expressive power and succinctness) [4], and in particular a metric for assessing overall system performance (corresponding to a suitable notion of social welfare) [5, 13].

3.3 Auction Mechanisms

While many of the speakers discussed distributed resource allocation frameworks, the third session concentrated on centralised approaches to MARA, namely auctions. The topics discussed included the addition of non-standard constraints into combinatorial auctions, and issues in mechanism design. This session also included the presentation of a general-purpose platform for building and testing auction-based systems.

The talk prepared by R. K. Dash introduced a variant of the Vickrey auction mechanism for multiagent task allocation that also takes the issue of trust into account [9]. In this approach, the degree of trust placed in an agent is related to the performance of that agent in previous rounds, as reported by its peers. Issues in mechanism design are also discussed in the position statement received from S. van Otterloo (Liverpool), who introduces a modal logic for describing agent interaction protocols that includes modal operators to refer to concepts such as preferences and strategies.

In the second talk of the third session, J. A. Rodríguez-Aguilar presented the iBundler system [15], an agent-aware negotiation service designed to solve the winner determination problem for combinatorial auctions, subject to various types of constraints that need to be met by a feasible allocation. A typical constraint in a multi-unit reverse auction, for instance, would be to postulate that no bidder should be awarded all the items of a given type. This can be seen as a safety constraint (relying on a single supplier may be considered a high risk), but it is of course also related to the issue of fairness in resource allocation discussed earlier. The particular range of constraints that can be specified in the iBundler system was inspired by applications of MARA techniques to industrial procurement [16]. Negotiation events in industrial procurement, involving multiple highly-customisable goods, pose serious challenges to buying agents when trying to determine the best combination of offers from providers. Typically, a buyer's decision will be subject to a large variety of constraints that may involve both different attributes of the same item and attributes across multiple items.

In the third talk, S. Phelps presented the JASA system, a platform that allows researchers in multiagent resource allocation to test different auction mechanisms by running simulations. The session also included a short discussion of the features ideally provided by such a platform. General-purpose platforms for (distributed) multiagent resource allocation are also discussed in the position statements received from S. Estivie (LAMSADE, Paris-Dauphine) and from Ph. Mathieu and M.-H. Verrons (LIFL, Lille).

3.4 Preference Representation

The definition of a multiagent decision-making problem requires, to begin with, the specification of the preferences of the agents over the set of feasible alternatives. In the case of multiagent resource allocation problems, the set of alternatives is the set of feasible allocations of resources and agents need to express their preferences over alternative allocations (or, at least, over alternative bundles to be assigned to them, in case there are no externalities). As there are exponentially many bundles to consider, it is not reasonable to ask agents to report their preference in an explicit manner. For this reason, several logic-based languages for encoding preference relations or utility functions over a set of alternatives have been studied in Artificial Intelligence. Such preference representation languages are often built on propositional logic, and allow for a much more concise representation of the preference structure than an explicit enumeration, while preserving a good readability and hence a similarity with the way agents express their preferences in natural language. In his talk, J. Lang presented a synthetic review of these languages, especially from the viewpoints of complexity and succinctness [8, 18].

The issue of preference representation also surfaced in several other talks during the meeting as well as during the general discussion. For instance, U. Endriss presented several comparative succinctness results regarding the k-additive form of representing utility functions [4, 17] and P. E. Dunne discussed a concise representation language based on straight-line programs [10, 12].

3.5 Applications

The theory and practice of multiagent resource allocation is relevant to a wide range of important applications. Participants reported on their work on the fair and efficient exploitation of earth observation satellites, industrial procurement auctions, airport traffic management, manufacturing control, and the timely allocation of resources in Grid architectures. (The first two of these applications have already been discussed earlier in this report.)

G. Jonker (Utrecht) discussed the challenges of devising an airport MARA system for the real-time allocation of runways to different airlines. A suitable allocation mechanism should balance efficiency considerations (to avoid the under-exploitation of resources) with fairness requirements (in the sense of balancing the resources allocated to different airlines in the long run), while also being incentive-compatible (to avoid manipulation)

P. Sousa (GECAD, Polytechnic of Porto) gave a brief overview of multiagent resource allocation in the context of manufacturing control. Applications to scheduling and manufacturing are also reported in the position statements submitted by A. Madureira (GECAD, Polytechnic of Porto) and by P. Valckenaers and P. Verstraete (PMA, KU Leuven).

P. Gradwell and J. Padget (Bath) are working on a MARA system for the optimal allocation of bundles of resources to support Grid computations. Here, distributed allocation procedures (rather than combinatorial auctions) seem particularly attractive, because assuming the availability of complete knowledge about all the goods and bids involved would be unrealistic.

Further applications, in particular in the areas of healthcare and transport, are discussed in the position statements received from B. López and colleagues (IIiA, Girona).

4 Conclusion

In conclusion, the first meeting of the Technical Forum Group on Multiagent Resource Allocation has been a highly successful event that is already paying dividends in terms of having initiated new collaborative research across different European institutions.

Two important "take home" messages that, arguably, have not yet been spelt out that clearly in the mainstream literature on multiagent resource allocation are the following:

- *Distributed approaches:* While much recent work on resource allocation has concentrated on centralised approaches, in particular combinatorial auctions, many applications are more naturally modelled as truly distributed MARA systems where allocations emerge as a consequence of a sequence of local negotiation steps.

- *Fair division:* A wide range of concepts taken from social choice theory can (and should) be utilised to assess the quality of resource allocations. Of particular importance are concepts such as envy-freeness and equitability that can be used to model fairness.

Apart from these two issues, the meeting has highlighted (1) the wide range of MARA-related *applications* currently being addressed within the AgentLink community, (2) the need for a precise analysis of the different aspects of the *complexity* of resource allocation problems, and (3) the many options available to model the *preferences* of individual agents.

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