Final Report on the Technical Forum Group on Multiagent Resource Allocation during AgentLink III*

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Abstract

Negotiation over the allocation of resources is widely regarded as one of the central research issues in the international Multiagent Systems community. The field is highly interdisciplinary, drawing inspiration not only from Computer Science and Artificial Intelligence, but also the Socio-economic Sciences. The Technical Forum Group on Multiagent Resource Allocation (TFG-MARA) is an initiative aimed at providing a venue for the exchange of ideas in this timely and exciting area of research. This report documents the activities of TFG-MARA during 2005. This includes, in particular, meetings at the AgentLink III Technical Forums in Ljubljana in February/March 2005 and Budapest in September 2005, as well as the joint production of an extensive survey paper on Multiagent Resource Allocation.

1 Introduction

The allocation of resources is a central research topic in both Computer Science and Economics. To emphasise the fact that resources are being distributed amongst several autonomous agents and that these agents may influence the choice of allocation, the field is sometimes called Multiagent Resource Allocation (MARA). The questions investigated by computer scientists are often of a procedural nature (how do we find an allocation?), while economists are more likely to concentrate on qualitative issues (what makes a good allocation?). A comprehensive analysis of the problem at hand, however, requires an interdisciplinary approach. Here the multiagent system paradigm offers an excellent framework in which to study these issues.

The Technical Forum Group on Multiagent Resource Allocation (TFG-MARA) has been set up to respond to these challenges. It aims at (*i*) providing a forum for the exchange of ideas, (*ii*) building bridges between Computer Science and Artificial Intelligence on the one hand and the Socio-economic Sciences —in particular social choice

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theory, welfare economics, decision theory, and game theory— on the other, and (*iii*) fostering collaborations between different European research groups. The TFG-MARA initiative is being organised by the authors of this report and our meetings have been generously sponsored by AgentLink III, the premier Coordination Action for Agent-based Computing, funded by the European Commission's 6th Framework Programme (`http://www.agentlink.org`).

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 economics and social choice theory. Here we are not only interested in concepts assessing the efficiency of an allocation, but also 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 distributed negotiation schemes where allocations emerge as a consequence of sequences of locally agreed deals between agents. Finally, we are interested in the implementation of prototype systems, which can inform theoretical research by providing empirical data through experimentation and a test-bed for negotiation heuristics.

This is the final report on the activities of TFG-MARA during the year 2005. These activities included, in particular, two meetings organised as part of the AgentLink III Technical Forums in Ljubljana and Budapest. We report on these meetings in Sections 2 and 3, respectively. The group has also produced an extensive survey paper on Multiagent Resource Allocation; this is being reported on in Section 4. Section 5 concludes.

2 The Ljubljana Meeting

The first TFG-MARA meeting 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.

The focus of the scientific programme has been on spreading information about research activities at the participating institutions. To make the event as representative of European research as possible, we had issued a Call for Position Statements and, in the short time available, received a total of eight such statements. The meeting consisted of four sessions. The first three of these, broadly, addressed *complexity issues*, *fair division* and *auction mechanisms*, respectively. The fourth session featured a talk on *preference representation* and the presentation of several of the position statements received, many of which focussed on different *applications* of multiagent resource allocation techniques.

2.1 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 (LAMSADE, Paris-Dauphine), who discussed a MARA framework where 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 also *maximal* in the sense that 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 [7].

In the second talk, P. E. Dunne (Liverpool) reviewed recent results on the computational complexity of MARA problems, concerning both the issue of determining the existence of allocations with specific attributes and properties of a particular distributed negotiation regime [12, 14]. As argued by Dunne, a significant problem is that, excepting very restricted environments, all MARA methods 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 (LAMSADE, Paris-Dauphine) focussed on the different notions of complexity, in particular communication complexity, that are directly relevant to the agents engaged in negotiation. One may distinguish between the number of deals required to reach an optimal allocation, the number of communicative exchanges required to agree on one such deal, the expressive power of the communication language, and the complexity is the reasoning task faced by each agent at each step [16]. 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 [8].

2.2 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 [34, 37], while concepts such as egalitarian social welfare [36] 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 (IRIT, Toulouse) 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 [2].

Then M. Lemaître (ONERA, Toulouse) 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) [27, 28]. 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 (Imperial College London) 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) [5], and in particular a metric for assessing overall system performance (corresponding to a suitable notion of social welfare) [6, 15].

2.3 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 (Southampton) —the actual talk was delivered by J. A. Rodríguez-Aguilar— introduced a variant of the Vickrey auction mechanism for multiagent task allocation that also takes the issue of trust into account [10]. 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 (IIIA-CSIC, Barcelona) presented the iBundler system [21], 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 [22]. 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 (Liverpool) presented the JASA system, a platform that allows researchers in multiagent resource allocation to test different auction mechanisms by running simulations (`http://sourceforge.net/projects/jasa/`). 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).

2.4 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 MARA 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 (IRIT, Toulouse) presented a synthetic review of these languages, especially from the viewpoints of complexity and succinctness [9, 26].

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 [5, 23] and P. E. Dunne discussed a concise representation language based on straight-line programs [11, 14].

2.5 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 have already been discussed above).

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 statement received from B. López and colleagues (IIiA, Girona).

3 The Budapest Meeting

The second TFG-MARA meeting was held as part of the Third AgentLink III Technical Forum at the Hotel Agro Panoráma in Budapest, Hungary, and was be hosted by MTA SZTAKI, the Computer and Automation Research Institute of the Hungarian Academy of Sciences. The Budapest meeting took place on the 16th of September 2005 and was attended by over 20 researchers from over a dozen different institutions in Hungary, France, Germany, Romania, Spain, the Netherlands, and the UK.

The scientific programme featured a presentation of the MARA Survey (see also Section 4), which had been completed shortly before the meeting, an invited tutorial on Fairness and Uncertainty by T. Gajdos, and two sessions with contributed talks reporting on recent research activities within the European MARA community.

3.1 Presentation of the MARA Survey

The first session of the meeting was dedicated to a presentation of the MARA Survey [4], reviewed in more detail in Section 4, followed by a discussion thereof. The same session also featured short contributions by P. E. Dunne (Liverpool), J. Padget (Bath), and P. Storms (Y'all B.V., Waalwijk) reporting on ongoing work closely related to the topics covered by the survey (in particular, complexity issues and application scenarios).

N. Maudet (LAMSADE, Paris-Dauphine) opened the first session by giving an overview of the topics address by the MARA Survey. These include, in particular, the representation of agent preferences, social welfare measures to assess the quality of allocations, centralised and distributed allocation procedures, complexity results, the choice of a suitable simulation platform to conduct experiments, and a representative sample of prestigious application areas demonstrating both the promises and challenges of MARA research. The ensuing discussion confirmed that other important areas (although, at least in part, covered in other work) include mechanism design (or, more generally, the game-theoretical analysis of MARA scenarios), the algorithmic aspects of finding a fitting allocation of resources, and issues pertaining to the presence of uncertainty in resource allocation problems.

The three short talks were then held towards the end of the session. P. E. Dunne reported on recent complexity results on the reachability of a specified target allocation by means of structurally simple and individually rational deals in a distributed negotiation framework. As demonstrated by Dunne, while many typical MARA decision problems are NP-complete, this kind of question can take us into the realms of

PSPACE-completeness [13]. Then J. Padget reported on ongoing work on the application of MARA techniques to problems in Grid computing, and in particular on a proposal involving multiple distributed auctions to achieve a satisfactory allocation of the available resources [24]. Finally, P. Storms gave an introduction to the Combined Project (`http://combined.decis.nl`), which is concerned with the development of large scale decision support systems in chaotic and complex environments, and to the first aid scenario studied in this project. In particular, Storms emphasised the need to model dynamic resource allocation problems, were the utilities of agents may change over time.

3.2 Tutorial on Fairness and Uncertainty

At the TFG-MARA meeting in Ljubljana, we had identified fair division as a topic that is of particular interest to the community and that could greatly benefit from a closer interaction between computer scientists and economists. To address this need, we decided to invite an expert in the field to deliver an in-depth presentation from the viewpoint of Economics at the Budapest meeting. T. Gajdos, CNRS researcher at the EUREQua research group at the University of Paris 1, gave an invited tutorial on Fairness and Uncertainty. The tutorial examined various connections between decision theory and social choice and showed how decision theory can provide a useful perspective in the context of the analysis of resource allocation problems, and, more specifically, for the identification and implementation of fair allocations.

Gajdos showed how social choice theory may be interpreted as a branch of decision theory if we regard, like Harsanyi, "moral behaviour as a special form of rational behaviour" [25]. The notions of fairness and uncertainty are related in at least two interesting ways. Firstly, people's perception of what constitutes a "fair" division of resources often involves the notion of uncertainty. For instance, a fair procedure for allocating a single indivisible resource to one out of two agents would be to flip a coin, *i.e.* here we interpret *fairness as uncertainty.* The second connection concerns *fairness under uncertainty.* Social choice mechanisms typically take the preferences of individual agents as input, but the actual quality of an outcome will often involve risk and uncertainty. For further details, we refer to the "tutorial roadmap" available at the TFG-MARA website (see Section 5 for a reference) and the relevant publications [18, 19].

3.3 Auctions and Negotiation

Two further sessions consisted of three contributed talks each. The first of these was devoted to issues surrounding *auctions and negotiation.*

A. Giovannucci (IIIA-CSIC, Barcelona) reported on recent work on an enrichment of the common combinatorial auction model, which allows the auctioneer (in a reverse auction) to specify so-called transformability constraints between goods. These constraints specify at what cost a certain bundle of goods could be transformed into an alternative bundle (or an alternative individual item). For instance, a producer of cars may initiate a reverse auction and purchase either a bundle of parts that could be assembled into a car or they may directly purchase a fully functioning car. The costs incurred by assembling the car in house rather than purchasing the final product determine the transformability constraints of the winner determination problem at hand. Giovannucci showed how the problem can be modelled using Petri nets and discussed an implementation of an auction solver for this type of auction [20].

In the second talk of the session, V. Robu (CWI, Amsterdam) discussed the use of "utility graphs" for the development of negotiation heuristics in mult-issue negotiations between two agents. In such a graph, each node represents one of the issues being negotiated. Two nodes are connected by an edge whenever the nodes are not preferentially independent. Robu showed how these graphs can be used to model an opponent during negotiation and how the graph gets updated as negotiation proceeds and more and more information becomes available [31, 32].

Then S. Estivie (LAMSADE, Paris-Dauphine) reported on an experimental study aimed at identifying how the outcomes of negotiation processes conducted by selfish agents agreeing on a series of individually rational deals to exchange single goods fare in term of egalitarian welfare, which is a measure to assess the equitability of a resource allocation [17]. More specifically, she demonstrated how the level of egalitarian welfare depends on factors such as the expressive power of the utility functions used by individual agents and the choice of a payment rule to divide the social surplus associated with a deal amongst the agents involved.

3.4 Other Presentations

The final session of the day featured three talks by researchers new to TFG-MARA, namely E. Pacuit (ILLC, Amsterdam), M. Schmitt (TU Hamburg-Harburg), and L. Gulyás (AITIA Inc., Budapest).

In his talk, E. Pacuit presented the *Adjusted Winner* procedure for the fair division of a finite number of divisible goods between two agents, developed by Brams and Taylor [3]. Pacuit showed how the procedure guarantees not only efficiency (Pareto optimal outcomes), but also equitability and envy-freeness, and how it only requires one of the goods under dispute to actually be divided. The ensuing discussion centered around two main themes: (*i*) under what circumstances would it be possible to generalise the ideas present in the Adjusted Winner procedure to scenarios with more than two agents; and (*ii*) is it possible to design a procedure that can account for richer classes of utility functions (in the original procedure, utilities are linear with respect to the portion an agent receives of a good being divided, and additive over different goods) [33].

Then M. Schmitt presented an overview of the activities in the Socionics Project [29], a large-scale interdisciplinary research programme at the interface of Computer Science and Sociology, which involves several German universities. In the final presentation of the meeting, L. Gulyás gave an overview of pertinent issues arising in the context of agent-based social simulation and presented several of the tools available to MARA researchers interested in experimental studies.

4 The MARA Survey

After the TFG-MARA meeting in Ljubljana, ten of the participants joined forces to put together a survey on Multiagent Resource Allocation. Our aim has been to produce a paper that can serve as a point of reference for research in the area, by giving an overview of fundamental issues and results, and also by pointing out some of the scientific challenges that seem particularly timely and important. The MARA Survey, which is also available on the group's website (see Section 5 for a reference), is due to be published in 2006 [4].

The paper is a survey of some of the most salient issues in Multiagent Resource Allocation. The topic is motivated by introducing four major *application areas* for MARA. We then argue that a first broad classification of MARA problems may be made on the basis of what *types of resources* are being allocated. Next, we review various languages to represent the *preferences* of agents over alternative allocations of resources as well as different measures of *social welfare* to assess the overall quality of an allocation. We also discuss pertinent issues regarding *allocation procedures* and present important *complexity results*. Our presentation of theoretical issues is complemented by a discussion of different *simulation platforms* of agent-based market places. Below we give a brief summary of each of the core sections of the document.

4.1 Application Areas

The MARA Survey introduces four application areas, namely *industrial procurement*, the joint exploitation of *earth observation satellites*, task allocation mechanisms in *manufacturing control*, and *Grid computing*. This part of the survey does both demonstrate the wide scope of MARA and underlines the urgent need to further advance the field to meet the enormous challenges still posed by such complex applications.

4.2 Types of Resources

We can distinguish different types of resources. For instance, resources may or may not be *divisible*. For divisible resources (such as electricity), different agents may receive different fractions of a resource. In the case of indivisible resources, it may or may not be possible for different agents to *share* (jointly use) the same resource (e.g. access to network connections as opposed to items of clothing). Other characteristics include whether a resource is *static* (as opposed to being, say, *perishable* or *consumable*), or whether an (indivisible) resource is available in *multiple units*. For many purposes, *task* allocation problems can be regarded as instances of MARA (if we think of tasks as resources associated with a cost rather than a benefit).

This section of the survey provides an overview of such abstract characteristics of resources that form part of any MARA problem specification and that need to be taken into account before designing a resource allocation mechanism.

4.3 Preference Representation

Agents will typically have *preferences* over the bundles of resources they receive in alternative allocations and the representation language chosen to describe these preferences constitutes another important parameter in the specification of a MARA problem. The relevant section of the MARA Survey catalogues a number of different preference representation languages available.

We cover both *quantitative* preferences (utility functions) and *ordinal* preference relations. The former include the simple enumeration of the utilities assigned to different bundles, the so-called k-additive form, weighted propositional formulas, a representation language based on straight-line programs, and bidding languages for combinatorial auctions. The latter include prioritised goals and *ceteris paribus* preferences.

4.4 Social Welfare

The objective of a resource allocation procedure is either to find an allocation that is *feasible* (e.g. to find any allocation of tasks to production units such that all tasks will get completed in time); or to find an allocation that is *optimal*. In the latter case, the allocation in question could be optimal either for some central entity choosing the allocation (e.g. a solution to a combinatorial auction that maximises the auctioneer's revenue); or with respect to a suitable aggregation of the preferences of the individual agents in the system. This can often be modelled using the notion of *social welfare* as studied in welfare economics and social choice theory. Examples include utilitarian social welfare, where the aim is to maximise the sum of individual utilities, and egalitarian social welfare, where the aim is to maximise the individual welfare of the agent that is currently worst off. Social welfare is relevant to MARA, because it can be used to define a metric with respect to with we can assess the quality of a given allocation of resources.

This section of the survey provides a collection of definitions for social welfare measures and related concepts that may be useful to specify MARA problems. These include collective utility functions, the *leximin* ordering, and the notion of envy-freeness.

4.5 Allocation Procedures

The *allocation procedure* used to find a suitable allocation of resources may be either *centralised* or *distributed*. In the centralised case, a single entity decides on the final allocation of resources amongst agents, possibly after having elicited the agents' preferences over alternative allocations. Typical examples are combinatorial auctions. Here the central entity is the auctioneer and the reporting of preferences takes the form of bidding. In truly distributed approaches, on the other hand, allocations emerge as the result of a sequence of local negotiation steps.

The relevant section of the survey begins by discussing the respective advantages and drawbacks of using either centralised or distributed allocation mechanisms. It then gives an overview of different auctions protocols and (distributed) negotiation protocols; and it introduces the topic of *convergence* to a (social) optimum by means of local negotiation between agents.

4.6 Complexity Results

A growing body of work within the study of multiagent resource allocation considers various concepts of complexity, not only in the standard sense of *computational complexity* theory but also in terms of concepts such as *communication complexity*. Such work comprises both positive results —e.g. algorithms with provably efficient performance characteristics, properties of restricted classes of allocation settings, etc.— and a large collection of negative results that suggest many naturally arising decision and optimisation problems are unlikely to admit generally applicable algorithmic solutions.

Within this section of the survey we review extant work that has addressed such questions and catalogue related open problems.

4.7 Simulation Platforms

Our presentation of theoretical issues in the MARA Survey is complemented by a discussion of software packages for the *simulation* of agent-based market places. We start by giving an overview of the typical requirements to be met by such packages and then list some of the most relevant software products, such as *Swarm* or *RePast*, available to MARA researchers interested in simulation.

4.8 Other Topics

Topics that are explicitly *not* covered by the survey are are the *algorithmics* of MARA and the *game-theoretical analysis* of negotiation (and bidding) strategies. The former includes the design of algorithms for the winner determination problem in combinatorial auctions, and a survey of recent work in this area is available elsewhere [35]. The literature on game-theoretical issues in negotiation, multiagent systems, and computer ccience in general is vast and fast-developing. A good starting point for readers interested in the computational approach to game theory (and the game-theoretic approach to computer science) is the short paper by Papadimitriou [30].

5 Conclusion

This concludes our report on the activities of the Technical Forum Group on Multiagent Resource Allocation during 2005, the second half of the lifetime of the AgentLink III Coordination Action. We believe that this has been an extremely successful initiative. The AgentLink Technical Forum has not only initiated two stimulating scientific events in the field of Multiagent Resource Allocation, but also forged new collaborative efforts across research groups, and generally brought a significant portion of the European MARA community closer together. We expect the effects of this initiative to be felt for some time to come, both in terms of new technical results and further scientific events

Further details, including detailed programmes of the two meetings, abstracts of all talks given at these meetings, the position statements collected before the Ljubljana meeting, and the MARA Survey, are available at the MARA website:

`http://www.illc.uva.nl/~ulle/MARA/`

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