Introducing the MARA Survey

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Foreword

- output of a collaborative process initiated during TFG-MARA I (Ljubljana, 2005)
- different persons took the responsability of different sections, plus crossed reviewing process
- to appear in *Informatica, 2006*

Introduction

Tentative definition...

MultiAgent Resource Allocation is the process of distributing a number of items amongst a number of agents

- *What* kind of items (resources)?
- *How* are they being distributed?
- *Why* are they being distributed?

Outline

- Type of resources
- Preference Representation
- Social Welfare
- Allocation Procedures
- Complexity Results
- Application Areas
- Simulation Platforms

Resources

- **continuous** vs. **discrete**
  physical property of the resources
- **divisible** or not
  continuous resources are usually (infinitely) divisible
- **shareable** or not
  same resource can be allocated to different agents at the same time
- **static** or not
  resources may be consumable (fuel) or perishable (food)...
- **single** vs. **multi-unit**
- **resources** vs. **tasks**
  very similar, but task allocation involves specificities (time constraints)

Preference Representation

Agents may have preferences:

- over the bundle they hold,
- over the bundles received by other agents (**externalities**)

The number of alternatives to consider (bundles of resources) is exponential, so we cannot simply rely on “naive” enumeration...

Main Issues

What are suitable representation languages for agents’ preferences (expressiveness, succintness, elicitation...)

Preference Representation

The survey discusses a number of representations, falling into two broad categories:

- **quantitative** preferences
  mapping bundles of resources to numerical values
  - *k*-additive form (*algebraic-based, synergies between items*)
  - weighted prop. formulas (*logic-based, bundles as models*)
  - straight-line programs (*program-based, computes value*)
  - bidding languages (OR, XOR, etc.)
- **ordinal** preferences
  binary relation over the bundles of resources
  - prioritised goals (*ordinal counterpart to weighted goals*),
  - ceteris paribus preferences (*"all other things being equal")*

Social Welfare

We need to assess the quality of an allocation from the viewpoint of the society as a whole. This typically depends on the preferences of individual agents, as studied in depth in **welfare economics** and **social choice theory**
So far, multiagent research has (almost) exclusively favored a **utilitarian** approach...

Main Issues

What notions of social welfare are relevant in the general context of MARA? In which specific application should we favour a given measure? Can we think of other measures?

Social Welfare

The survey discusses a number of notions of social welfare for both ordinal and cardinal agents' preferences

- Pareto efficiency
- Collective utility functions (utilitarian, egalitarian, Nash...)
- Leximin Ordering
- Envy-freeness
- Normalized utility

Allocation Procedures

Allocation procedures range from **centralised** (a single agent computes the final allocation) to truly **distributed** (sequences of local negotiation steps)

Main Issues

When should we prefer a centralised/distributed approach?
What kind of protocol shall we devise in a given circumstance?
Having fixed a protocol, what kind of properties can we prove?

Protocols

Auction protocols

- way of reporting preferences (*open-cry*/*sealed bids*)?
- number of rounds? descending or ascending bids?
- type of bids allowed (*bidding language*)?

Negotiation protocols

- basic *Contract-Net*
  (announcement / bidding / assignement / confirmation)
- extensions for bundle of resources, deals without money...
- concurrent *Contract-Net*
  (pre-bidding phase, levelled commitments)

Properties of Procedures

Examples of desirable properties of allocation procedures includes:

- **Termination** —is the procedure dead-lock free?
- **Truthfulness** —is there an incentive for agents to manipulate the procedure (e.g. by reporting false preferences)?
- **Convergence** —is it guaranteed to converge to an optimal allocation? Of course strongly related to strategies agents would implement...

Complexity Results

The allocation process involves, at different stages, **computational or communication resources** —and these resources are limited.
Complexity results indicate whether or not efficient algorithms can ever be found for different decision/optimisation problems

Main Issues

Global properties (Does there exist allocations with a given property?) **Negotiation properties** (Is there sequence of $\mathcal{X}$-deals leading from A to A'?) **Communication complexity** (Upper bounds on the length of these paths?)

Example of Results

Depends of the representation used to encode utility functions, but for most (expressive enough) languages, we know *e.g.* that:

- finding an allocation that maximises utilitarian sw is NP-hard
- finding an allocation that is both Pareto optimal and envy-free can be up to Σ_2^p-complete
- deciding wether there is a sequence of 1-deals leading from A to A' is NP-hard
- upper bound on the length of shortest path of 1-deals is $\leq n^m - m(n-1)$ and $\geq \frac{77}{256}2^m - 1$

Application Areas

The survey introduces and discusses four problem domains:

- **iIndustrial Procurement** (IP)
- **Earth Observation Satellites** (EOS)
- **Manufacturing Systems** (MS)
- **Grid Computing** (GC)

Constraints of Applications (Examples)

- allocation of resources have to be efficient, but also to **fair** (EOS), **safe** (IP), or **robust** (MS)
- allocation problems may involve hundreds (IP) or even thousands (GC) of resources to be allocated
- users have to report **preferences**, **constraints** (IP, EOS, MS, GC), and even **negotiation strategies** (IP)

Simulation Platforms

In many cases, some assumptions do not hold, or theoretical results simply cannot be proven: it is then useful to do experimental work using simulation

Main Issues

Simulation vs. implementation, simulating time, agent modelling, extensibility and integration

The survey introduces a number of simulation frameworks:

- Swarm
- RePast
- Desmo-J
- AScape
- DEx

Conclusion

- Type of resources
- Preference Representation
- Social Welfare
- Allocation Procedures
- Complexity Results
- Application Areas
- Simulation Platforms

We didn’t investigate (enough/at all): game-theoretical aspects (strategies, mechanism design), algorithmic aspects...