UNIVERSITAT
ROVIRA i VIRGILI

Introduction to **M**ulti **A**gents **S**ystems

Activity 2

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Abstract

The aim of this activity is to study the theoretical concepts described in the lectures about cooperation mechanisms between agents and apply these concepts to the practical exercise of the MAS course.

Contents

1. Overview

In this activity we will detail the different cooperation mechanisms between agents. Once explained the theoretical concepts related with these topics, they will be related to the practical exercise of the IMAS course.

2. Cooperation Mechanisms

Coordination is known as the process by which an agent reasons about its local actions and the actions of others to try and ensure that the community acts in a coherent manner.

Coordination mechanisms must be used in the following situations:

- An agent has choice in its actions within some tasks, and the choice affects its performance and that of the other agents.
- The order in which actions are carried out affects performance.
- The time at which actions are carried out affects performance.

In Figure 1, the cooperation hierarchy is shown. In this practical exercise, as we want the agents to cooperate we are going to analyze the "Cooperative Benevolent" branch.
On one hand, in implicit cooperation, a group of distributed cooperative agents behaves in a socially coordinated way in the resolution of a global problem without an explicit exchange of communication messages. On the other hand, in explicit cooperation presents an intentional sending and receiving of communicative signals.

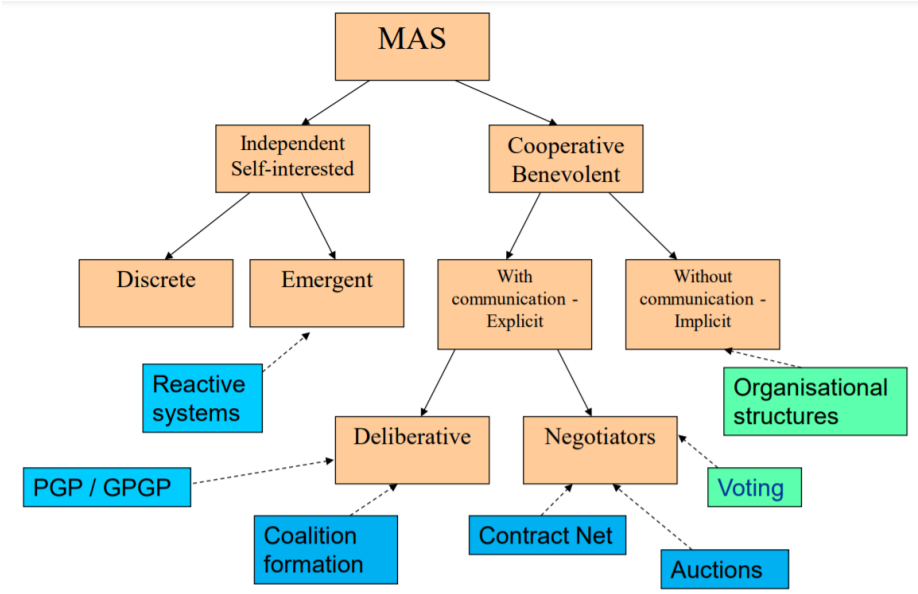

Figure 1. Cooperation Hierarchy

2.1. PGP / GPGP

Partial Global Planning and its extension Generalized Partial Global Planning is a distributed planning technique that integrates planning and execution instead of the usual Planning, Scheduling and Action cycle. It fits in domains that are dynamic and unpredictable, where tasks are implicitly distributed and each agent performs its own task.
This technique is implemented in 4 steps: (1) each agent defines its local plan, (2) local plans are exchanged between agents, (3) partial global plans are generated based on the previous local plans and finally (4) partial global plans are optimized.

2.1.1. Advantages & Disadvantages

This technique is useful in dynamic scenarios where the plan should be rapidly modified due to changes in the environment.
The disadvantages are the complexity of managing the data structures that this technique implies and the capability of reasoning that the different agents should have.

2.2. Coalition Formation

Coalitions are collections of individuals working together for the purpose of achieving a task. The motivation of a coalition is whether a task cannot be performed by only one agent or when a task can be performed more efficiently between more than one agent.
Coalition formations may be **external** or **internal**. In **external** coalitions, an external agent imposes the coalitions to be formed, while the set of agents only will report their skills and the cost of that skills. In this case, as the decisions are centralized, it will be much easier and cheaper to create the coalitions.
On the other hand, **internal** coalitions are created by the agents themselves. They interact between them to discover the best alliances they can form to complete the tasks they have. Here the formation of coalitions will be much more expensive, as it will be hard for them to find the best way of creating them.

2.2.1. Advantages & Disadvantages

The advantage is clear: Union makes force. With coalition, a group of agents can achieve a goal performing a task that maybe they could not perform on their own.
The disadvantage is the overhead that creating these coalitions imply. When creating coalitions, the benefit of each coalition for each task should be calculated, as well as the different combinations of agents that can be created and the payoff distribution. Computationally, these calculations are expensive, and even more when we take into account that the negotiations between agents must be communicated in real time through messages.

2.3. Contract Net Protocol

The Contract Net Protocol is used to allocate tasks among autonomous agents. It mainly relies on a manager proposing a task to several agents. The latter makes a proposal among which the manager chooses to allocate the task. This task can then be divided and subcontracted. In this protocol, each agent can be either manager or contractor

1. The protocol is initialized by the manager, who sends a call-for-proposals to the contractors
2. The contractors can send either a proposal if they are interested or a reject if they are not. This proposal is provided with all the elements required by the manager to make its choice.
3. The manager chooses among the proposals the one that suits it best, and sends to the corresponding contractor an accept. It sent a reject to the other contractors to inform them of its decision.
4. Once the contract has been accomplished, the contractor informs the manager using an informed message. If there is a result to communicate, it is also communicated through the informed message. If the contractor cannot fulfill its engagement, it informs the manager through a cancel message.

2.3.1. Advantages & Disadvantages

The advantages of the contract net protocol are the following:

- Easily capable of dealing with very different viewpoints
- Distributes control and data to avoid bottlenecks
- Enables a finer degree of control in making resource allocation and focus decisions

As a disadvantage of this protocol we have:

- Easily overloads the network with exchanged messages
- With many tasks in hand, it can be difficult for the manager to find agents to perform the tasks.
- the manager cannot precise what it values most, it must choose from the proposals received from the agents.
- The failure of the task is only taken in consideration through the cancel message informing the manager that the task won't be addressed. There is no sanction for the agent.

2.4. Auctions

Auctions are a class of negotiation protocols that provides us methods for allocating goods or resources based upon competition among self-interested parties.
This class of negotiation is used in fields as telecommunications and tv licences, collectibles (painting, books, etc.), agricultural products (flowers, fish, tobacco), etc.
The auction participants are the auctioneer and the bidders. Both of them are supposed to be self-interested due to they are seeking to maximize their own payoffs and rational, because they always prefer a larger payoff than a smaller one.

2.4.1. English

The English auction is an open-outcry and ascending-price auction where the auctioneer announces an opening price or the reserve price. In English auction bidders raise their bids and the auction proceeds to successively higher bids and the winner of the auction is the bidder of the highest bid.
The best strategy is to bid a small amount above the previous bid until one reaches its private value and then stop. The bidders gain information by observing the other's bid.
The disadvantages of this type of auction are the following:

- The reserve price may not be met and the item may remain unsold.
- The auctioneer may cheat by overstating a reserve price or present a reserve price that does not exist.
- Susceptible to rings (collusions)
- Phantom bid: The auctioneer calls a bid that no one has made.
- Bidders can become carried away and overbid
- Vulnerable to shills: Person associated to the seller that pretends to be an enthusiastic customer
- In real life it can become complicated (voices, signals)

2.4.2. Dutch

The Dutch auction is an open and descending-price auction where the auctioneer announces a very high opening bid and then the auctioneer keeps lowering the price until a bidder accepts it and finally, the winner pays the price of its bid.
Bidders need to decide in advance the maximum amount that they are willing to bid. Also, a bidder must decide when to stop the auction (bid) based upon its own valuation of the commodity and its prior beliefs about the valuations of the other bidders. No relevant information on the valuation of the other bidders is disclosed during the process of the auction until it is too late.

2.4.3. FPSB

In First-price sealed-bid auction each bidder submits its own without knowledge of the bids of others. It is composed by two faces: 1) the bidding phase in which participants submit their bids and 2) the resolution phase in which the bids are opened and the winner is determined. Finally, the highest bidder wins and pays the amount of its bid.
In this type of auction the agent's strategy depends on its own valuation and prior beliefs about the other bidder's evaluations. A higher bid raises the possibility of winning, but lowers the bidder's profit if it wins. So, bidders are better off not bidding their true valuations but a small amount below it.

2.4.4. Vickrey

The Vickrey auction is a second-price sealed-bid auction, also known as uniform second- price sealed-bid or the philatelist auction. It is composed of two distinct phases: 1) the bidding phase and 2) the resolution phase. The highest bid wins but the bidder pays the amount of the second- highest bid.
Bidders adjust their bids upwards since they are not deterred by fear that they will have to pay too much. The price that the winning bidder pays depends on the others' bids alone and not on any action that the bidder undertakes.
In this case, the best strategy for the agent to bid its true valuation, so the bidders do not waste time in counter-speculating what the other bidders will do.

2.4.5. Advantages & Disadvantages

The advantages of the negotiation protocol Auction are the following:

- Markets may not exist for what the seller wants to sell
- The seller does not know how much an item is worth
- Create competition, enhances the seller's bargaining power
- Flexibility
- Less-time consuming and expensive than negotiating a price
- Simplicity in determining the market prices

The disadvantages of the auctions are the following:

- Winner's curse
- Lying auctioneer: the auctioneer may overstate the second-highest bid.
- Sniping: bidding very late in the auction in the hope that other bidders do not have time to respond and you can snatch a bargain. This is an issue, in particular in online auctions.
- Rings
- Revelation of private information

2.5. Voting

Voting is a cooperation mechanism which chooses the outcome of negotiation based on the inputs, known as votes, given by all agents to a set of competing options. In the scope of our project, since we have multiple *Fuzzy Agents* outputting their own results depending on the established configuration, but just one final result is expected from the user side, it could be appropriate to use a voting protocol in order to help the *Manager Agent* in the task of aggregating the different outcomes of the *Fuzzy Agents*. On the contrary, we don't see these kinds of mechanisms to be applicable to the other agents like the *User Agent* as they only make sense when multiple agents with the same objective perform the voting action.

The basic idea or aim of the voting negotiation is to rank the set of alternatives or options available based on the preferences or self-interests of each individual agent. It's assumed that voters are truthful, which means that the voters vote for the candidate they think is best. Self-interested agents can benefit from insincerely declaring their preferences, ranking the options differently based on the preferences of the others in order to vary the outcome.

It's also interesting to define a social choice rule that creates an ordering of the group alternatives so that the most socially preferred alternative is chosen. It has many desirable properties such as calculability (the preference ordering of the alternatives should exist for all the options), completeness (as the social preference relation should be defined for all pairs of alternatives), linearity (the social preference ordering should be antisymmetric and transitive over the set of options *O*), should have anonymity or no dictatorship (the outcome does not depend in which specific agents have certain opinions), unanimity or pareto efficiency (if all agents believe that A is better than B, then A should be better than A in the aggregated order), neutrality (the outcome should not depend on the order or naming of the alternatives) and independence of irrelevant alternatives (adding or removing an irrelevant alternative should have no effect on the winner of the voting process), although no voting mechanism fulfills all the properties, as stated in the Arrow's impossibility theorem.

2.5.1. Simple Voting Protocols

The following basic voting mechanisms are identified:

- **Plurality:** In this protocol the agent can give 1 vote to 1 of the alternatives so the alternative with the highest number of votes wins.
  One of the disadvantages of this system is the useful vote, when voters vote their second option because they know that their first choice has no possibility to win.
  Other problems are present in this type of voting mechanism, as the huge effect of irrelevant alternatives -- residual alternatives which will not be elected still subtract

votes from the most likely alternatives -- and the fact that with one vote we obtain scarce information about the preferences of each voter. On the other hand, it's a simple and very efficient system from the computational point of view. It also provides an equality system since 1 agent has 1 vote.

In our project, the main problems of this protocol do not hold true as the agents do not have information about the voting intentions of the other agents, polls, chance of winning or even past voting results.

- **Anti-plurality:** It represents the exact opposite of the 'Plurality' protocol, where each voter has a *negative* vote to give to the worst alternative, so that the option with less votes wins. The advantages or disadvantages of this protocol are the same as the 'Plurality' ones.

- **Best-worst:** By merging 'Plurality' and 'Anti-plurality' protocols, we obtain 'Best-worst' protocol, where each agent has a *positive* and a *negative* vote to give to the correspondant best and worst alternative. Each type of the vote has a certain 'weight' to be multiplied by and the option with more points wins.

- **Approval:** In this protocol, instead of assigning one or two votes per agent, we assign *k positive* votes so each voter selects a subset of the candidates. Again, the candidate with the most number of votes wins.

The following protocols are based on total orders in voting systems, where each voter provides a full list of the options, ordered according to the agent preferences (from best to worst):

- **Binary protocol:** The idea of this protocol is to evaluate all the options by pairs, where options 1 and 2 are first evaluated, the winner of which is evaluated with option 3 and so on. As the agent preferences are given in a sequential order (E.g. option 1 > option 3 > option 2), we check for each pair the number of voters that prefer one option over the other, and the most preferred wins.

  This protocol has an important disadvantage or problem: the order of the pairs to evaluate. If 3 options were presented and each one was preferred over another but unpreferred over the other, the organization of the pairs may influence the result where the last options may have more chances of winning.

Notice how this protocol does not hold some social choice rule properties like neutrality, as the order of the pairings is important, or unanimity, as the agents might believe that the winning options were not the best considered by the agents.

Overall, this is a costly protocol which outcome may be decided by the ordering of the alternatives to an extent where an option may win even if there was an alternative preferred by everyone over the winner or even if the winner was the worst alternative for some.

- **Borda protocol:** In this mechanism, each voter assigns a maximum *N* number of points to the best alternative, *N-1* to the second best, and so on. At the end, all the points are added across the voters and the alternative with the highest count becomes the winner.
  This protocol is computationally expensive as all the votes have to be summed and altering the number of alternatives (E.g. removing an irrelevant one) may totally change the outcome of the mechanism.

- **Condorcet protocol:** The candidates are again voted in order of preference but, as opposed to the 'Binary protocol', each candidate is compared to each other and the winner has to be victorious in all the comparisons.
  This protocol has a clear problem that is the possibility of circular ambiguities, described as the event in which no alternative is able to win all the others. In case this situation occurs, we may need to apply a certain heuristic in order to resolve the negotiation as keeping the candidate that wins more matches or taking into account the relative strengths of defeats (looking at the number winning votes or the winning margin of votes).
  In case of tie, another resolution method could be used in order to break the draw.

Finally, we could make use of linguistic information to represent the opinion of each voter with respect to each alternative or even introduce the management of uncertainty. The complexity of this option as well as the simplicity of our agents (they are not able to produce any kind of linguistic information) makes it clear that these mechanisms are not appropriate or should not be applied in our case project.

2.5.2. Advantages & Disadvantages

Voting protocols or mechanisms could be appropriate in the scope of our project, concretely in addition to the aggregation process that the *Manager Agent* performs once it has received all the outputs from the *Fuzzy Agents*.

There are different types of voting protocols, but all of them are problematic in one sense or another. If we decided to use any type of voting mechanism, we would advocate for the simplest ones which match the complexity introduced in the agents of our case project.

Therefore, the first basic voting mechanisms described seem to be the most fitting ones, given their ease of implementation, their computational complexity and their applicability to the nuances that our simplistic agents can even express. Concerning this concept of simplicity, we might decide for the one most natural to us which might be the *plurality voting*.

As stated, we believe that implementing any voting mechanism in our case project would only make sense given a set of similar agents (in terms of category or objective). That means that it would not make much sense to apply it to the hierarchy composed by the *User* and *Manager Agents*, as that would be a sort of *1-to-1* voting. It could make sense though to apply it to the set of *Fuzzy Agents* (at least to the ones that serve the same type of application). This voting mechanism could leverage the final aggregation computed by the *Manager Agent* by weighting the outcomes of the different *Fuzzy Agents* involved.

2.6. Organisational Structures

With the organisational structure we have established how the information would be controlled between each agent. The main goal of this structure is to coordinate the actions that each agent would undertake and avoid sending unnecessary information for each agent to obtain a more efficient model.
The organizational structure involves mainly three different processes: creation of roles, communication process and relationships reporting. The organization processes are divided in two phases:

- Establish the general organization structure (Strategic design)
- Establish the specify roles (Operational design)

2.6.1. Markets

Markets are mainly used in environments where we have exchange of goods. In these environments we need to take into consideration limitations of resources with respect to the demand. For this reason we implement auctions, class for negotiation protocols for allocating

resources. The advantage of this method is his flexibility, evaluating available markets and real time information.

2.6.2. Networks

Network is used when the environment requires collaboration between more than one agent to produce an outcome. The coordination between agents of these structures is achieved by mutual interest. The main advantages of this structure are its lower cost, flexibility and clear focus in the outcome.

2.6.3. Hierarchies

Hierarchical structures work better in environments with specialized functions. This structure produces efficient and quality results. The agents coordinate with each other through command levels in a closed environment.

2.6.4. Advantages & Disadvantages

In the table 1, we can see the advantages and disadvantages for each of the previous mentioned organisation structures.

Table 1. Advantages and disadvantages of Organization Structures

Organisation Structure	Advantages	Disadvantages
Markets	Flexible, real time information	Expensive process, limited by available information
Networks	Lower cost, flexible, clear focus	Limited networks, agent dependant on previous agent
Hierarchies	Specialized and collaborative agents, clear focus, levels of control	Agent limited by higher level agents, lack of flexibility

3. Chosen Cooperation Mechanisms

3.1. PGP / GPGP

Partial Global Planning is a technique that allows a system to work in a dynamic environment, where the plan has to be redefinable due to changes in the environment. Our context is not dynamic, so PGP does not add any value to our system.

3.2. Coalition Formations

The goal of coalition formations is to solve those cases where a task cannot be performed entirely by one single agent, or on the other hand where a task is done more efficiently if divided between multiple agents.
In our architecture, we have that tasks are small and doable by a single agent, so coalition formation would be adding an unnecessary overhead to the system.

3.3. Contract Net Protocol

We could maybe use the CNP cooperation mechanism if we assume that the manager agent broadcasts the requests to all fuzzy agents of certain characteristics and then selects the most acceptable using the aggregation method desired. However this interpretation of the CNP on our system is stretching a bit the definition of the CNP and thus we don't think that is the most suitable to fit the system's needs.

3.4. Auctions

Auctions, as previously mentioned, are supposed to be self-interested methods due to the participants (auctioneer and bidders) seeking to maximize their own payoffs and rationale, because they always prefer a larger payoff than a smaller one.
Since in our practical exercise the agents are considered benevolent and cooperative, we think that this method can not be applied. The agents do not compete between them in order to achieve their assigned task.

3.5. Voting

As stated in the *section 2.5*, introducing a voting protocol could make sense in the context of the *Fuzzy Agents* as it only makes sense when multiple agents (normally of the same type)

apply it as a cooperation mechanism. Given that our MAS only includes a single *User* and *Manager Agent*, we wouldn't advocate implementing a voting protocol for them.

A possible example of the usage of the voting system could be a leverage of the outputs emitted by the different *Fuzzy Agents* of the same application, similar to a weighting factor. The *Manager Agent* would use the voting outcome to compute the final aggregation and provide the results to the *User Agent*.

As we are dealing with *Fuzzy Logic*, the voting that each *Fuzzy Agent* emits can be interpreted as the ranking of confidence that an agent has over the other agents results. The voting intention or decision could be inferred from the degree of support from the *Fuzzy Rules*, where the output of the *Fuzzy Agent* that activated the *Fuzzy Rules* with higher confidence or degree of support should be receiving the majority of votes.

3.6. Organizational Structures

Of the three organization structures we have discussed, we can conclude that the best structure for our model is Hierarchical Structure. This is determined on our assumption that our model implements specific functions in each agent on a closed environment. We have discarded Markets and Networks structures because we are not implementing negotiations between agents and we do not communicate with multiple agents at the same time to obtain the optimal path respectively.

4. Conclusions

After taking into account all the cooperation mechanisms explained above, we concluded that the most suitable for the task in hand is the hierarchical organizational structure. This is based on the previously discussed that each agent has a specific role and the system evaluates the decision from a top to down level in its implementation. It is worth mentioning that this conclusion is based on the assumed environment. In an environment with different characteristics we could have different sets of cooperation mechanisms implemented.

5. E-Portfolio

Our E-Portfolio has been implemented using Github. Our repository is hosted at: https://github.com/vbadenas/MAI-IMAS. There, you can find the following items of the project:

- The source project code
- The documents delivered in the IMAS subject
- A wiki page with a recording of the meetings performed in the subject

- A repository history with all the commits done during the project[1]

5.1. Meetings

A record of the team meetings can be found in the repository wiki page: https://github.com/vbadenas/MAI-IMAS/wiki

5.2. Tasks Distribution

Due to the actual COVID-19 situation, it's not possible for the team to meet in person and work physically together, so in the different meetings performed during this First implementation task, the work has been splitted into subgroups and later revised by all the team members.

We have decided to divide the activity into 6 different parts:

- Theoretical explanation of the different coordination mechanisms in the Cooperative Benevolent branch of the schema shown in Figure X.
- Integration of the coordination mechanisms in our practical exercise.
- Write the report
- Prepare the slides
- Preparation of the video schema
- Recording of the video

However, we would like to highlight the fact that although the work has been splitted into different parts, all the tasks have been put in common in the meetings. A discussion for each task has been performed in the different meetings in order to achieve a group decision for all the decisions taken along this report.

6. References

[1] Rahwan, Michalak, Wooldridge, Jennings (2015) Article "Coalition structure generation: a survey". Retrieved November 26th, 2020 from Chapter 13 of the book An introduction to MultiAgent Systems (M. Wooldridge), 2nd ed.

[2] Smith (December 1980). "The Contract Net Protocol: High-Level Communication and Control in a Distributed Problem Solver". Retrieved November 28th, 2020 from IEEE Transactions on Computers. C-29 (12): 1104–1113. doi:10.1109/TC.1980.1675516. ISSN 0018-9340.

[1] Needs to be taken into account that as some work was splitting in pairs, it could happen that one of the pair members does not appear in the commits history. Also needs to be taken into account that as the implementation was not completely independent, the integration of the code has been made in the meetings, so it's possible that one of the members appears more than the others because of this integration commits.

[3] "FIPA Iterated Contract Net Interaction Protocol Specification". fipa.org. Retrieved November 28th 2020.

[4] David Isern (2020). Cooperation in MAS (I): emergent cooperation PGP and GPGP. Retrieved November, 2020.

[5] David Isern (2020). Cooperation in MAS (II): coalition formation. Retrieved November, 2020.

[6] David Isern (2020). Cooperation in MAS (III): negotiation via auctions. Retrieved November, 2020.

[7] David Isern (2020). Cooperation in MAS (IV): voting protocols. Retrieved November, 2020.

[8] David Isern (2020). Cooperation in MAS (V): implicit methods. Retrieved November, 2020.