Universitat Politècnica de Catalunya
Universitat de Barcelona
Universitat Rovira i Virgili

Master in Artificial Intelligence

Introduction to Multi-Agent Systems

# Analysis of Cooperation Mechanisms

Deliverable 2

*by:*
Sebastian Berns
Helen Byrne
Johannes Heidecke
Sara Hoeksma Palazuelos
Maritza Prieto

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# 1 Introduction

In this report we analyze the cooperation mechanisms of the multi agent system (MAS) described in the previous report with the task of recycling the garbage in a virtual city.

## 1.1 Goal Definition

All the agents in our MAS are contributing to the goal of recycling the garbage in the city in an efficient manner (except for the SystemAgent, which is solely taking care of the state of the virtual city and not further interacting with it). In order for several agents to contribute towards solving a distributed problem, they need to be coherent (working towards the same goal) and competent (knowledge how to work together). While we define the competence of the agents in the following sections, we start with defining the common goal of the MAS, that ensures coherent behavior.

According to the project description, the MAS ought to maximize the benefits (points received by recycling centers) while minimizing the time to recycle garbage. The agents' decisions will be based on evaluating different possible plans with with this goal and often there will be a trade off between achieving maximum points or minimal waiting time.

For all possible plans of actions $p \in \mathbb{P}$:

$$\max_{p \in \mathbb{P}} b(p)$$

with $b(p)$ being the sum of benefit points achieved with the plan $p$, and

$$\min_{p \in \mathbb{P}} t(p)$$

with $t(p)$ being an evaluation of the waiting time corresponding to $p$. Looking at the specific domain of garbage recycling, it makes sense to punish exceptionally long waiting times over-proportionately. Hence $t(p)$ will be the sum of squared waiting times of all garbages between showing up and being picked up by a HarvesterAgent.

Combining our two subgoals, we get

$$\max_{p \in \mathbb{P}} \theta_1 \cdot b(p) - \theta_2 \cdot t(p)$$

with $\theta_1$ and $\theta_2$ weighting the relative importance of benefits and weighting time.

## 1.2 Analysis of necessary cooperation

The MAS is cooperative-benevolent, i.e. all agents work towards the same goal.

- **Harvesting Coordination**
- **Scouting Coordination**
- **Vehicle Coordination**

# 2 Analysis of Cooperation Mechanisms

## 2.1 Overview

## 2.2 Contract Net

### 2.2.1 General Description

The Contract Net protocol was developed by R.G.Smith in 1980 [Smi80] and is based on the way in which companies put contracts out to tender. There are five phases the protocol runs through to resolve a certain task:

- **Recognition**: An agent (called the "manager") recognizes a task that has to be done and that it cannot solve or does not want to solve.
- **Announcement**: The manager announces the task to all agents (general broadcast), a group of agents (limited broadcast), or specific agents (point-to-point announcement). The specification of the task includes a description of the task, constraints, and meta-information.
- **Bidding**: When an agent receives a task evaluate the task with respect to their specific properties and, if they are able and willing to solve the task, they submit a tender to the manager, indicating the relevant capabilities of the agent to solve the task.
- **Awarding**: A manager may receive several tenders for a task. Based on the information provided in the tenders, it chooses the best fitting agent or agents to execute the task. Chosen agents are called contractors for this task.
- **Expediting**: The chosen contractor or contractors then execute the task. If there is more than one contractor, further cooperation mechanisms might be necessary.

The Contract Net is based on a mutual selection process: Managers can select the best fitting tender and contractors can decide, for which announced tasks they want to create a tender.

### 2.2.2 Application to Practical Work

**Harvesting Coordination:** The coordination of harvesting garbage can be solved by using a Contract Net protocol. Newly detected occurrences of garbage are recognized by the Harvester Coordinator and then announced to Harvester Agents. This announcement can either be a limited broadcast to all Harvester Agents or even a point-to-point announcement to specific Harvesters of the right type that are currently idle. The Harvesters can individually evaluate which of the announced tasks fit well enough to their current situation (based on garbage types, current location, free capacity, planned route, etc.) and then submit tenders for these tasks. The HarvesterCoordinator can then choose the most suitable candidate(s) to take care of the garbage. If several HarvesterAgents are selected to solve a single task (e.g. because their individual capacity does not allow one HarvesterAgent to take the entire trash), they can use further coordination mechanisms to split up the task among them, or the Harvester Coordinator assigns the exact distribution of splitting up the task. Since the bidding process is based on several attributes (distance, capacity, targeted recycling center, etc.), we are facing a multi-attribute negotiation.

**Scouting Coordination:** The Scout Coordinator could use a Contract Net to announce the tasks of visiting cells that have been idle for a long time (and thus have a high probability of neighboring a building with garbage). Scout Agents can then submit tenders, e.g. containing how many steps they need to reach the idle cell and a numeric evaluation of the "idleness" of the path to this cell. This would be a multi-attribute-negotiation.

**Vehicle Coordination:** Potentially, when an upcoming collision of two vehicles is detected, the CoordinatorAgent can announce a task to the involved Agents (or their Coordinators) to resolve this collision in the best way they can come up with. The Coordinator Agent then chooses the best plan of avoiding the collision, based on a metric such as the number of extra steps required.

#### 2.2.3 Advantages and Disadvantages

The Contract Net is well applicable for this problem, because:

- The goal of collecting all garbage is dividable into several subgoals: one for each occurrence of garbage in the city
- The subtasks of collecting individual garbage are sufficiently complex and it is worthwhile to spend effort into distributing them efficiently.

The disadvantages are the computational effort due to the exchange of messages, and the time delay for deliberation and waiting for responses

### 2.3 Auctions

### 2.4 Coalitions

### 2.5 PGP

### 2.6 Voting

## 3 Chosen Cooperation Mechanisms

### 3.1 Scouting Coordination

As part of the global goal definition of the MAS (see section 1.1), one important subtask is to efficiently detect new garbage on the map. New garbage should be quickly detected in order to allow its harvesting. As rational agents, Scout Agents and the Scout Coordinator want to maximize the expected performance of this task.

We have chosen to employ a combination of cooperation mechanisms in order to best fit the scouting coordination task. This task is a special case of the multi agent patrolling problem, a problem that has been thoroughly investigated by the research community. [Alm+04] have investigated a variety of different approaches for this problem and conclude that the best approach on most classes of map topologies is a TSP[1]-based Single Cycle Approach. A cyclical path based on TSP-algorithms is computed for all cells of the map and Scout Agents patrol on this path in the same direction with more or less equal distances between them on the path. In order to achieve and uphold this equidistance, e.g. after collisions, we combine this approach with GPGP.

A near optimal TSP path through the map will be calculated based on some common heuristic-based algorithm (calculating optimal solutions is unfeasible since the TSP problem belongs to the class of NP-complete problems).

The SAs keep their local viewpoints updated with their current goals and actions - this will always be to follow their given path and to find garbage. If a situation arises in which a SA has to change its path to avoid a collision, (this coordination is described in Vehicle Coordination Mechanism), then this change of path will be updated to the SA's local viewpoint and then passed to the scout coordinator (SC) who will keep a partial plan of all SA local plans. The SC will calculate how best to keep the SAs equidistant following this change of path, e.g. by keeping all SAs stationary until the collision-avoiding SA is back to its original given path, and then it will pass these instructions back to the individual SAs. The SAs will now have updated local plans and will follow these new actions. In this way the SAs will continue, ensuring they are at equidistant points on their path to maintain our optimal map search. The same mechanism will be used to

### 3.2 Harvesting Coordination

auction vs. contractnet: harvesters don't have any incentive to get a task assigned with more resources (e.g. steps) than needed. auction does not yield advantages but needs more computational effort and implementation complexity.

### 3.3 Vehicle Coordination

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