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AGENCE INNOVATION DÉFENSE

Solving Organizational Multi-Robot Task Allocation Problems with Consensus-based Auctions

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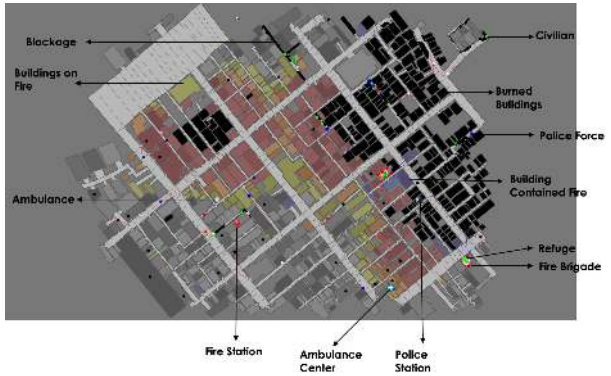
Research Objectives

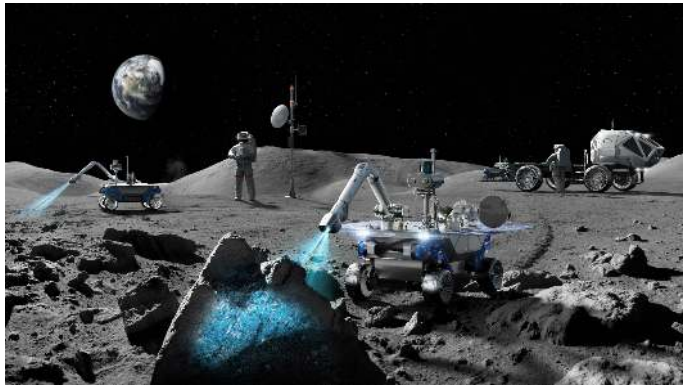
- Distribute a mission/tasks to the various agents in a (heterogeneous) multi-robot system, while ensuring that they are carried out collectively
- Coordinate the allocation of each robot's actions
- Accounting for operational constraints such as loss of communication, and **organisational models**
- Link with the operator in drawing up the plan and repair strategies

Search and Rescue



RoboCup Rescue https://rrl.robocup.org/

Exploration/Space Operations

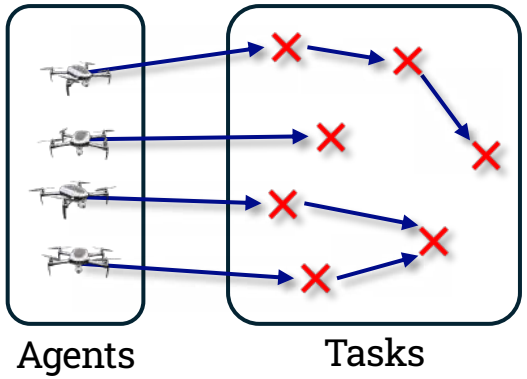


https://spaceambition.substack.com/p/space-robotics

Multi-Robot Task Allocation (MRTA)

Finding the answer to the question:

"Who does what, when, and in what order ?"

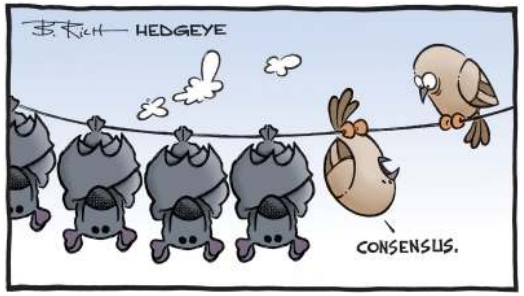


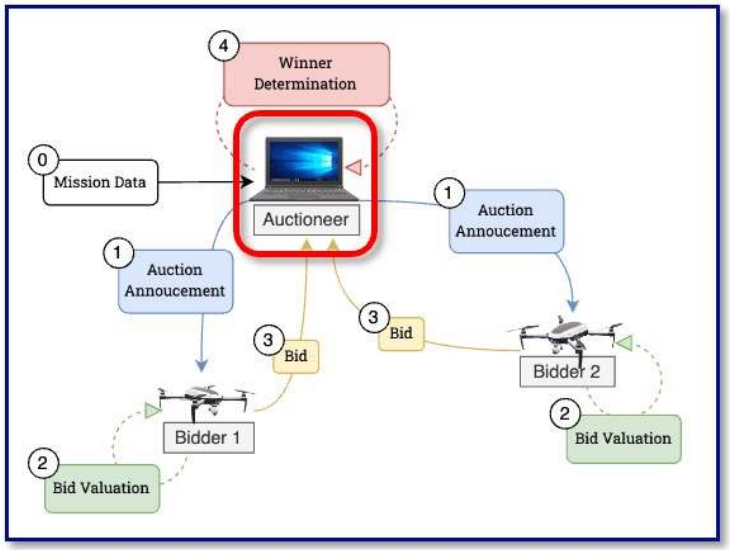
Optimisation goals:

Meet task requirements while maximising performance and optimising resource utilisation

- Meet tasks requirements
- Maximise the rate at which tasks are undertaken
- Minimise the overall cost of task completion to the group

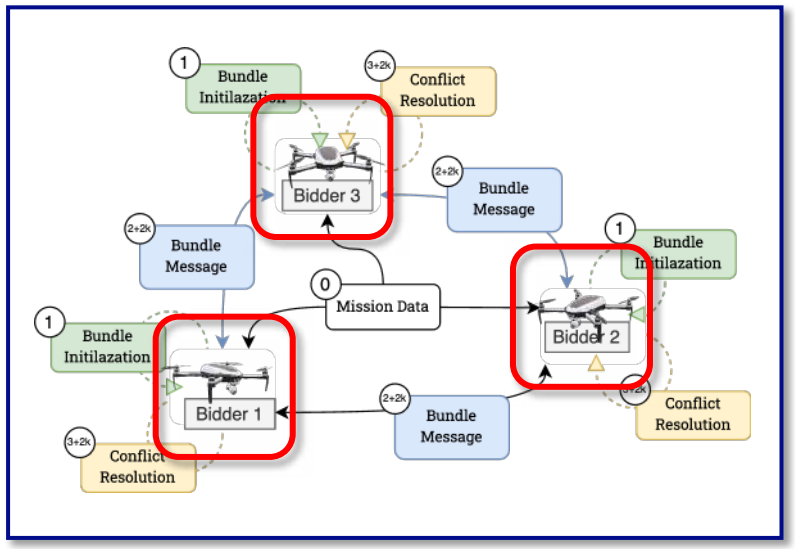
Auction-Based Methods: Centralised vs Consensus-Based





Centralised

vs



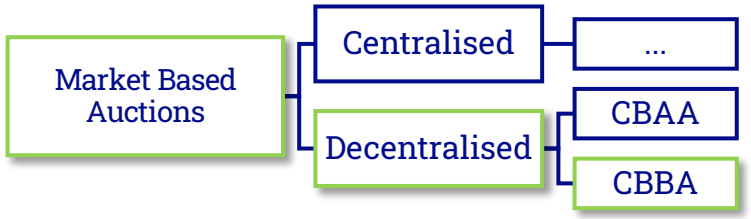
Decentralised

Consensus-Based Algorithms

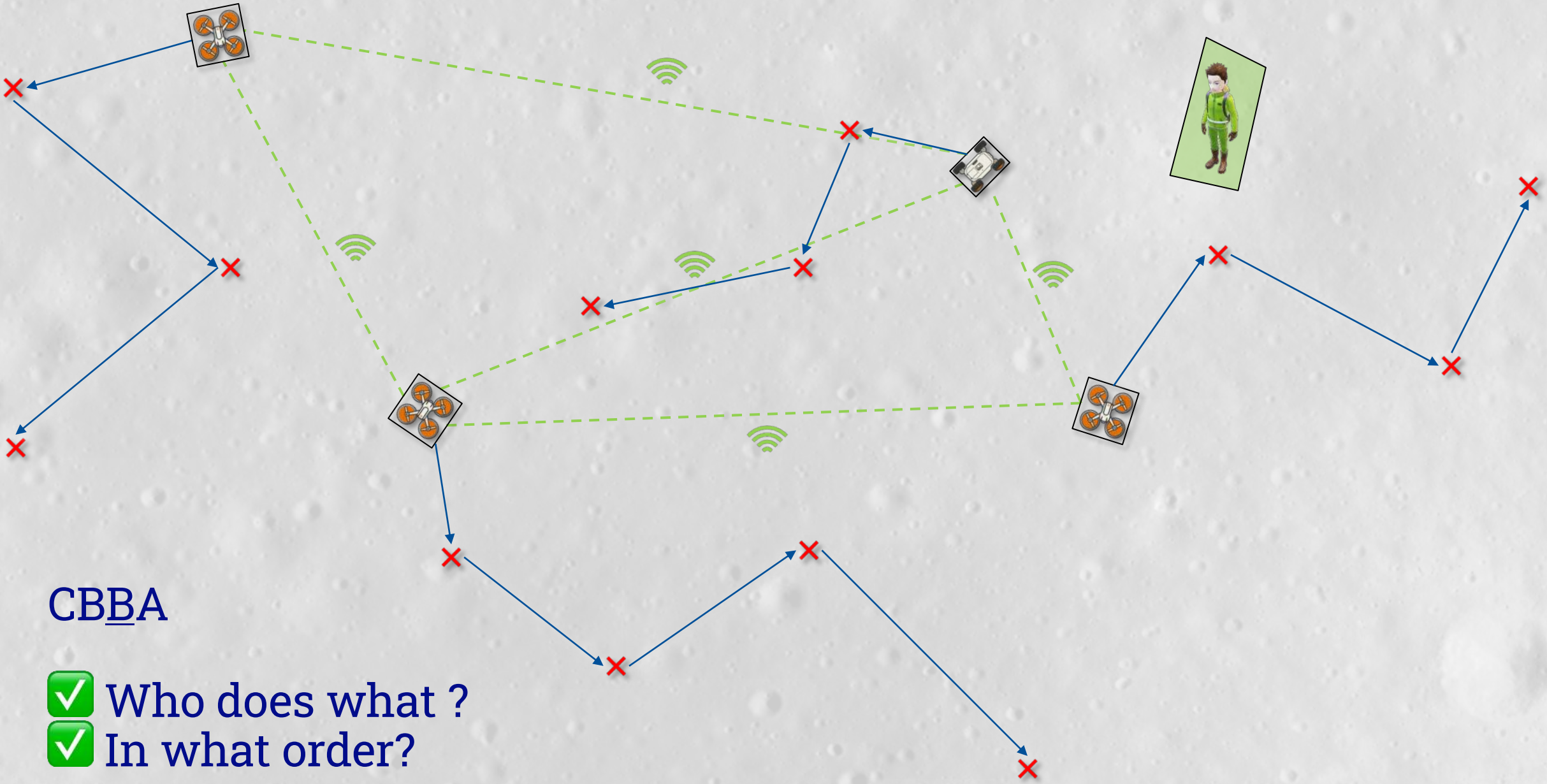
H.-L. Choi, L. Brunet, and J. P. How, Consensus-Based Decentralized Auctions for Robust Task Allocation, IEEE Transactions on Robotics, vol. 25, no. 4

Consensus-Based Bundle Algorithm

CBBA



F. Quinton, C. Grand, and C. Lesire. 2023. Market Approaches to the Multi-Robot Task Allocation Problem: a Survey. Journal of Intelligent and Robotic Systems 107, 2 (2023), 31.



CBBA

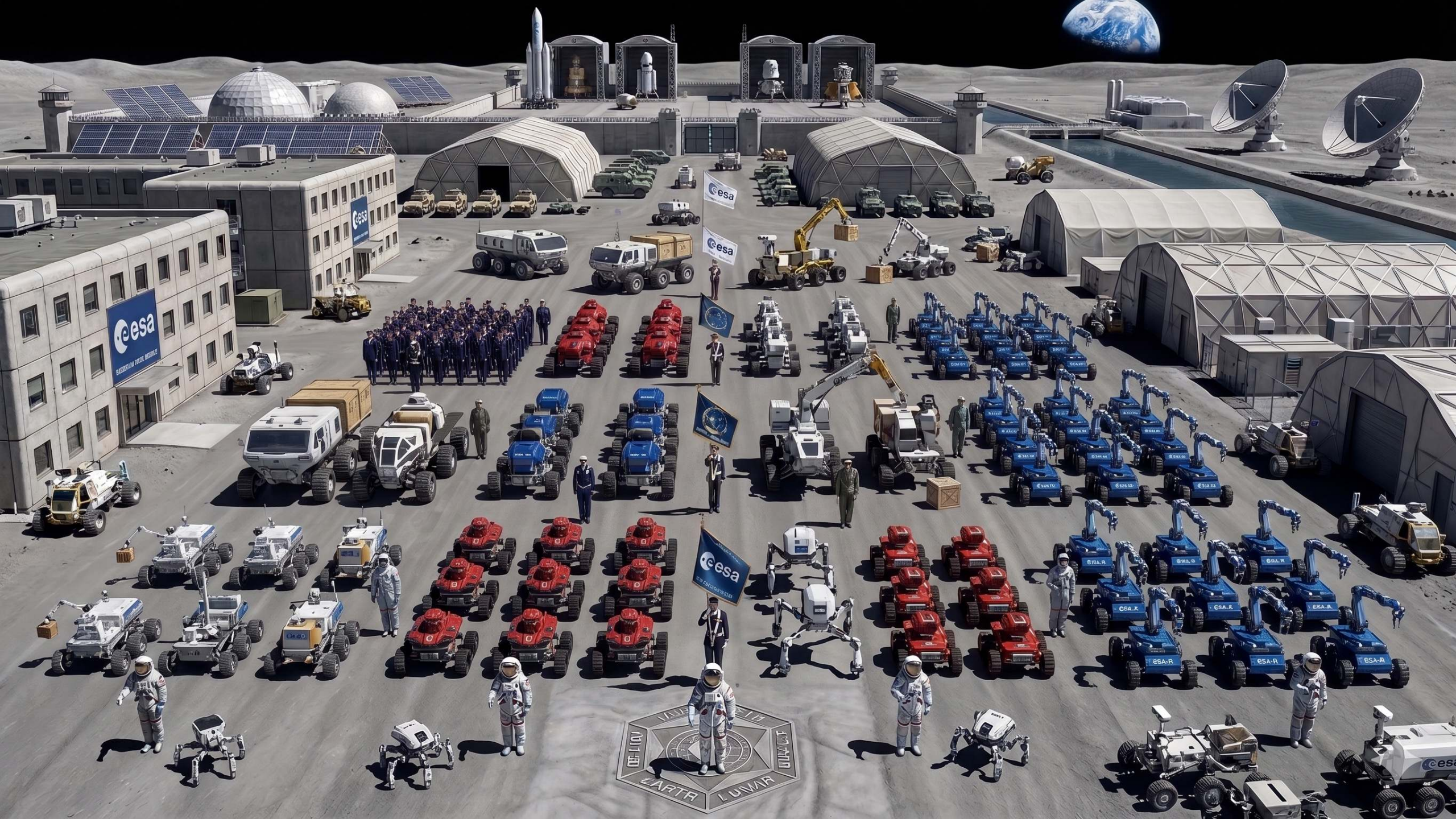
✅ Who does what ?
✅ In what order?

Limits

- Poor Scalability
  - Large message exchanges rates
  - Every agent considers every task

- Limited Control
  - Limited constraints types
  - Does not account for robots capabilities
  - Limited abstraction

  - Limited human-machine interactions (not the main focus of this contribution)


esa
EARTH
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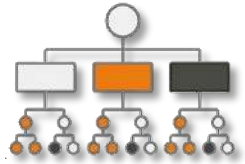
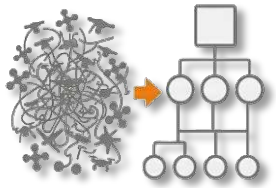
Advantages of Hierarchical Organisation



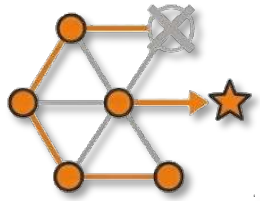
Clearly defined responsibilities

Each level has defined roles and authority



Large-scale coordination

Large groups are structured into smaller units



Robustness and adaptability

Units continue operating despite local failures

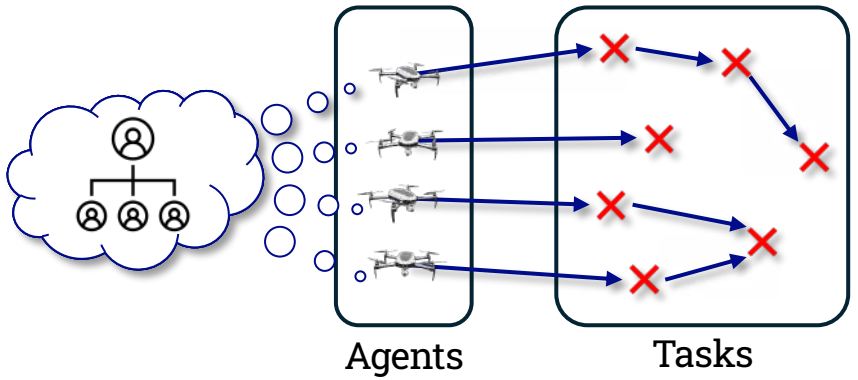
Our goal:

*integrate **Organisation Constraints and Organisational Models** in methods such as CBBA*

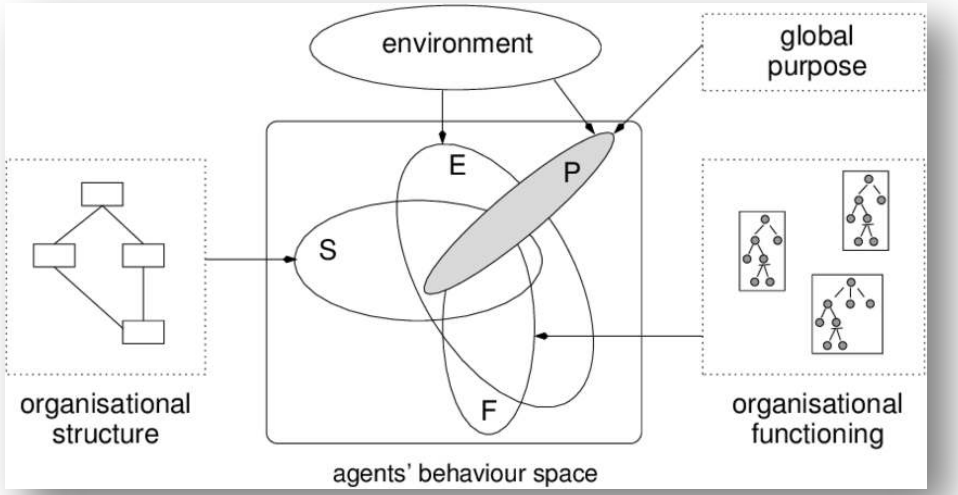
Org Multi-Robot Task Allocation
(Org-MRTA)

Answering the question:

"Who does what, when, and in what order,
given a specific fleet organization and the
constraints it induces?"



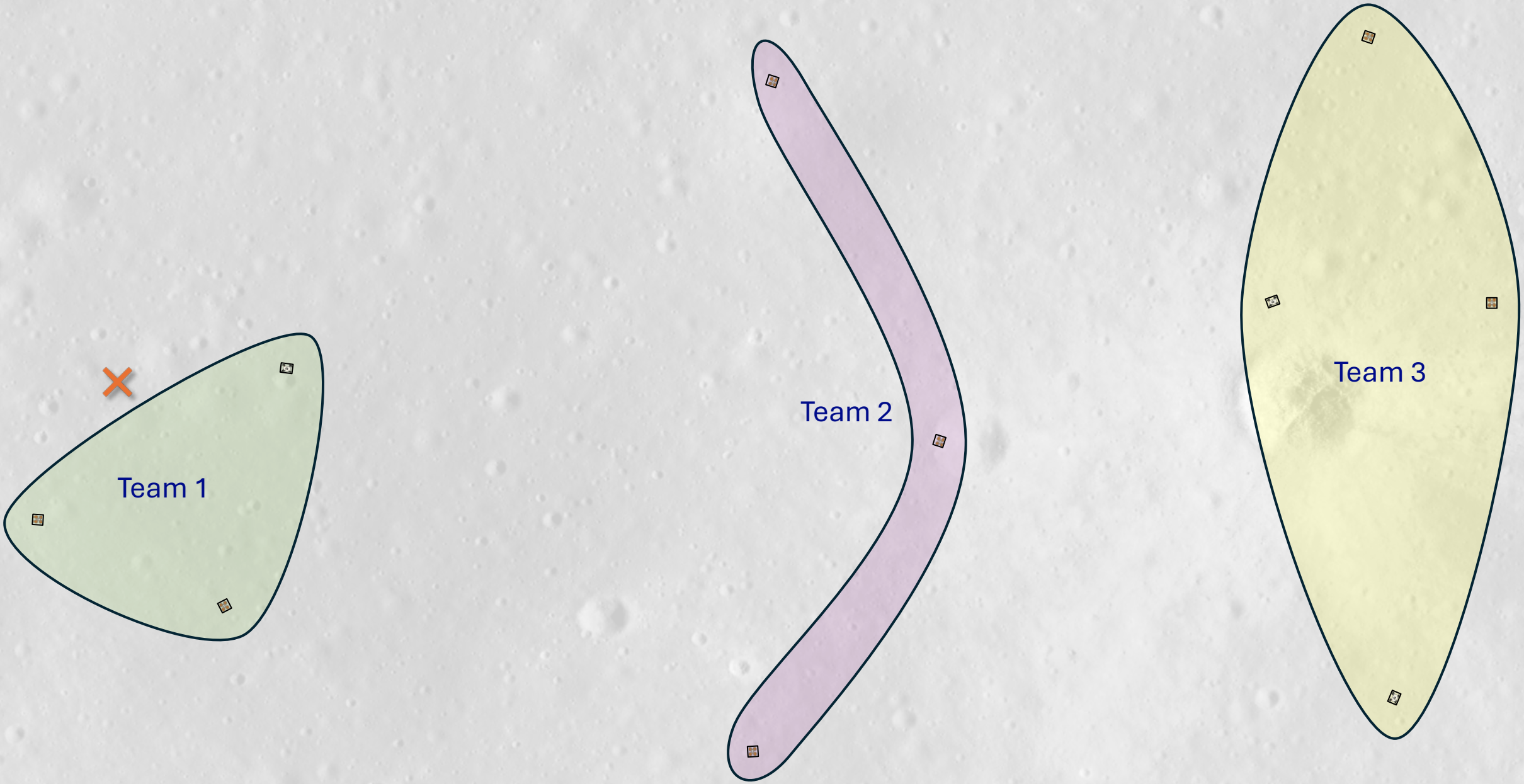
Organisational Modelling

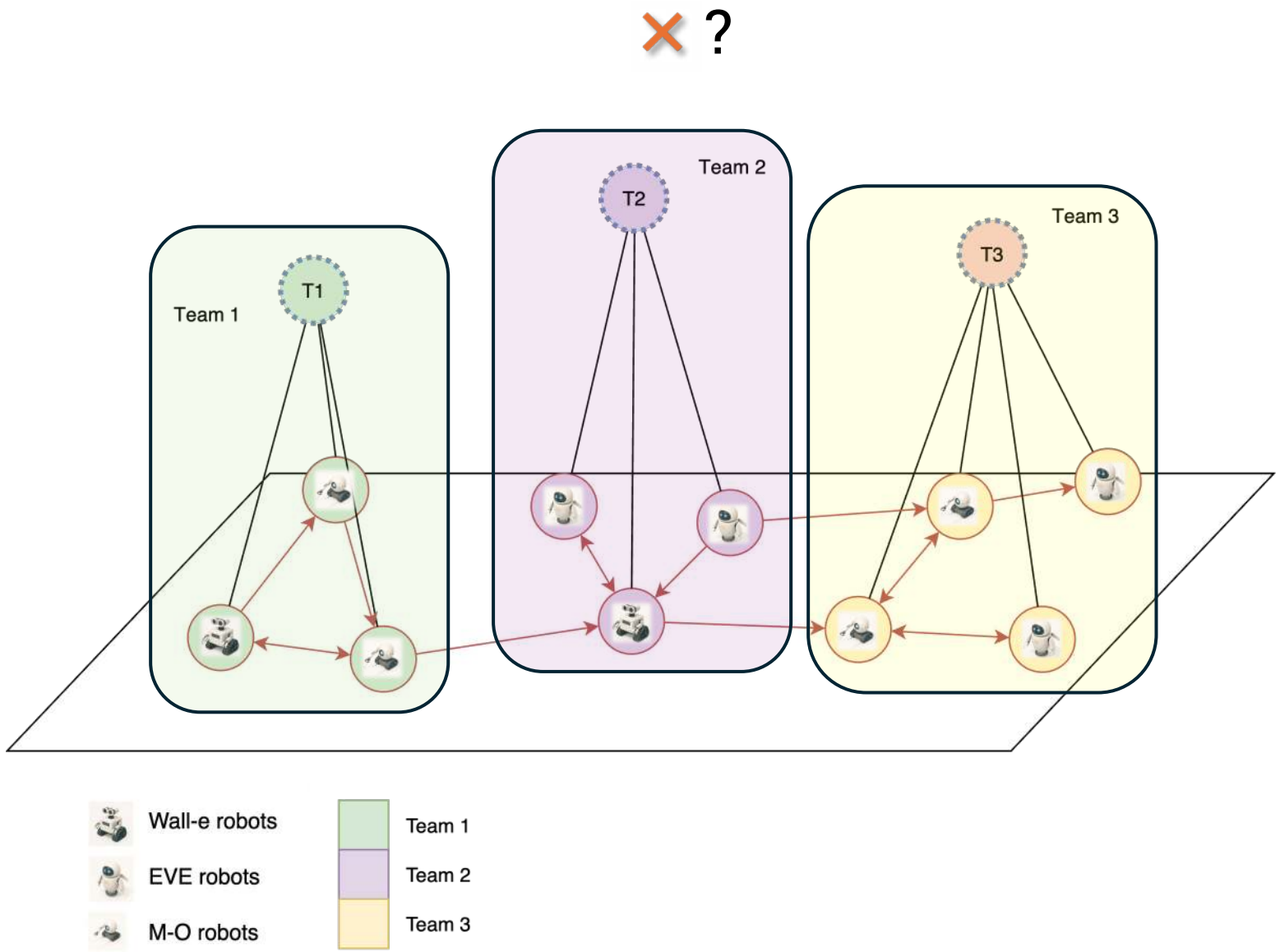


MOISE+

Hübner, Jomi & Sichman, Jaime. (2007). Developing organised multi-agent systems using the MOISE+ model: Programming issues at the system and agent levels.. Int. J. Accounting, Auditing and Performance Evaluation. 1-1. 10.1504/IJAOSE.2007.016266.

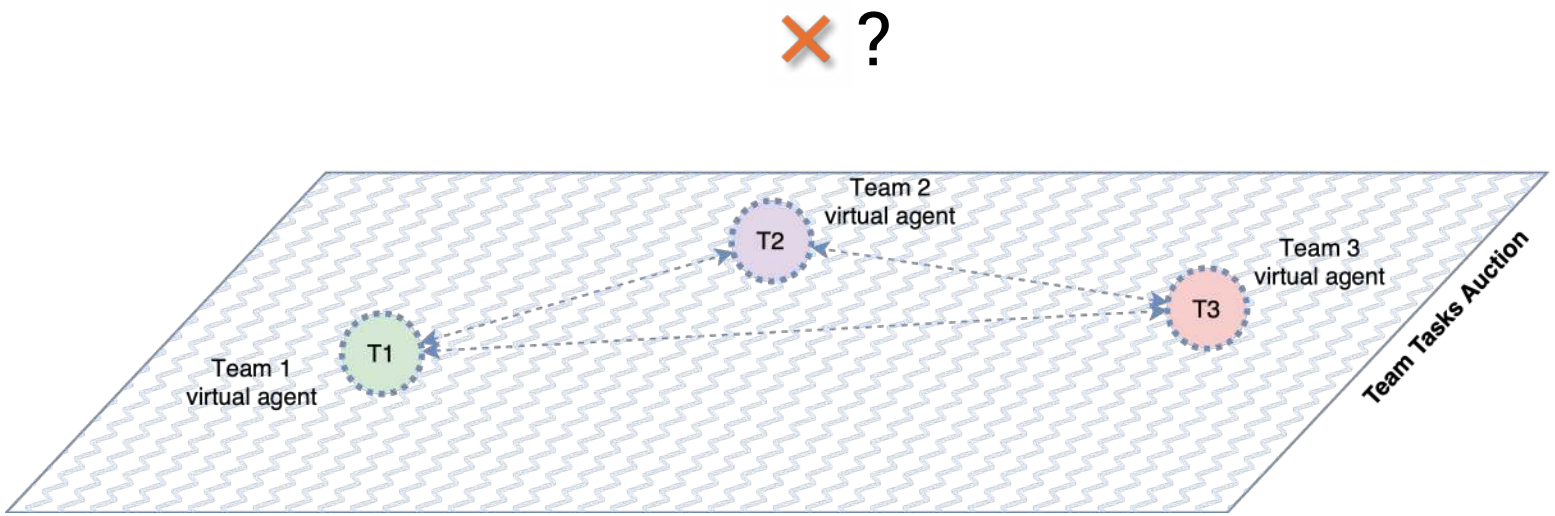
Structural Specification (SS)	**Functional Specification (FS)**	**Deontic Specification (DS)**
• Roles - r • Relations des roles • Groups - G	• Goals - G • Plans - p • Missions - M	• Permissions - per • Obligations - obl


Team 1
Team 2
Team 3



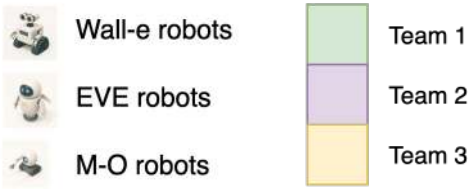
Who should take on the task?

- 3 teams
- 10 agents
- 3 role types



1. Group Allocation (CBAA)

- Which team should handle the task?



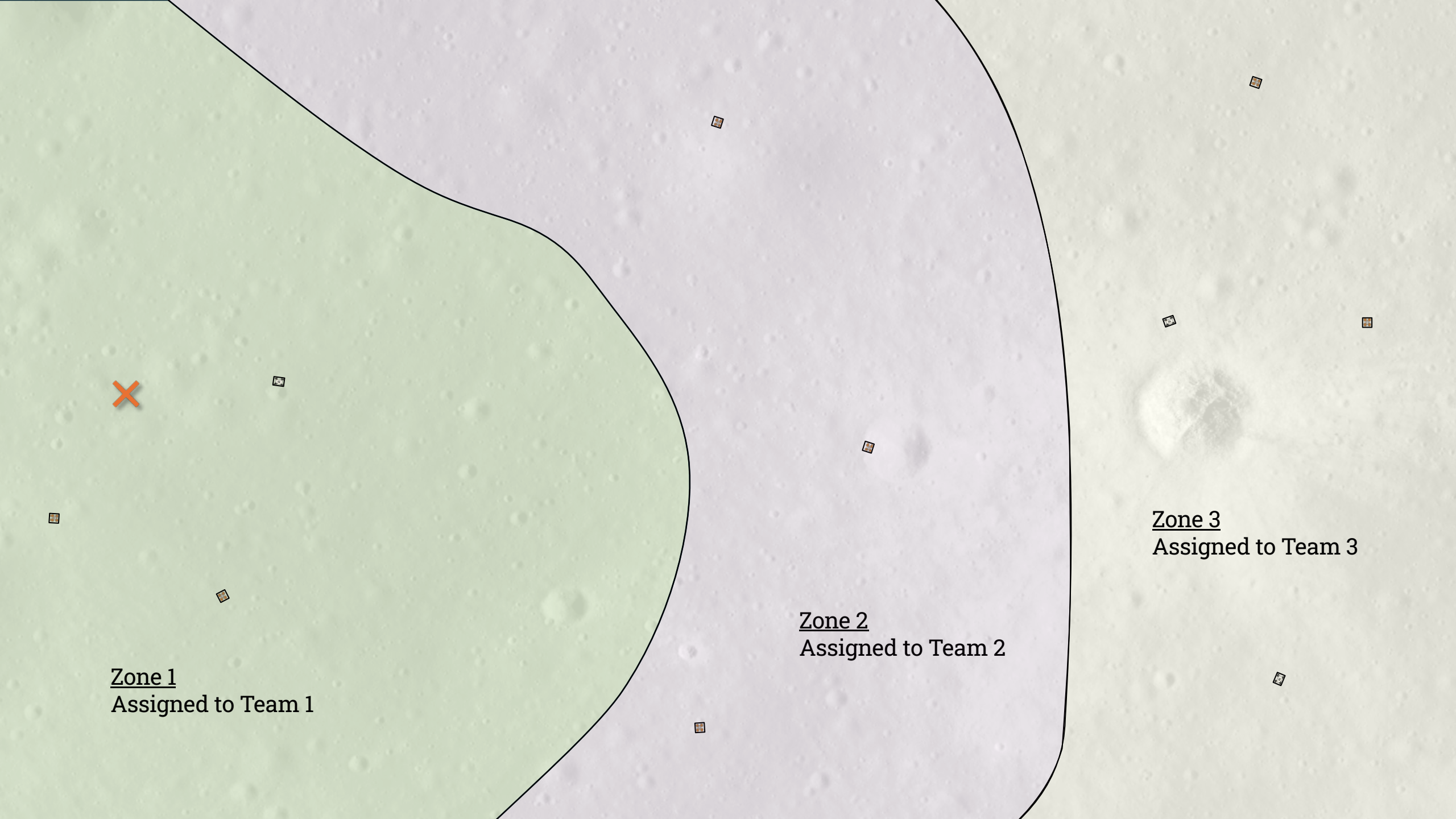
Possible Allocation Conditions

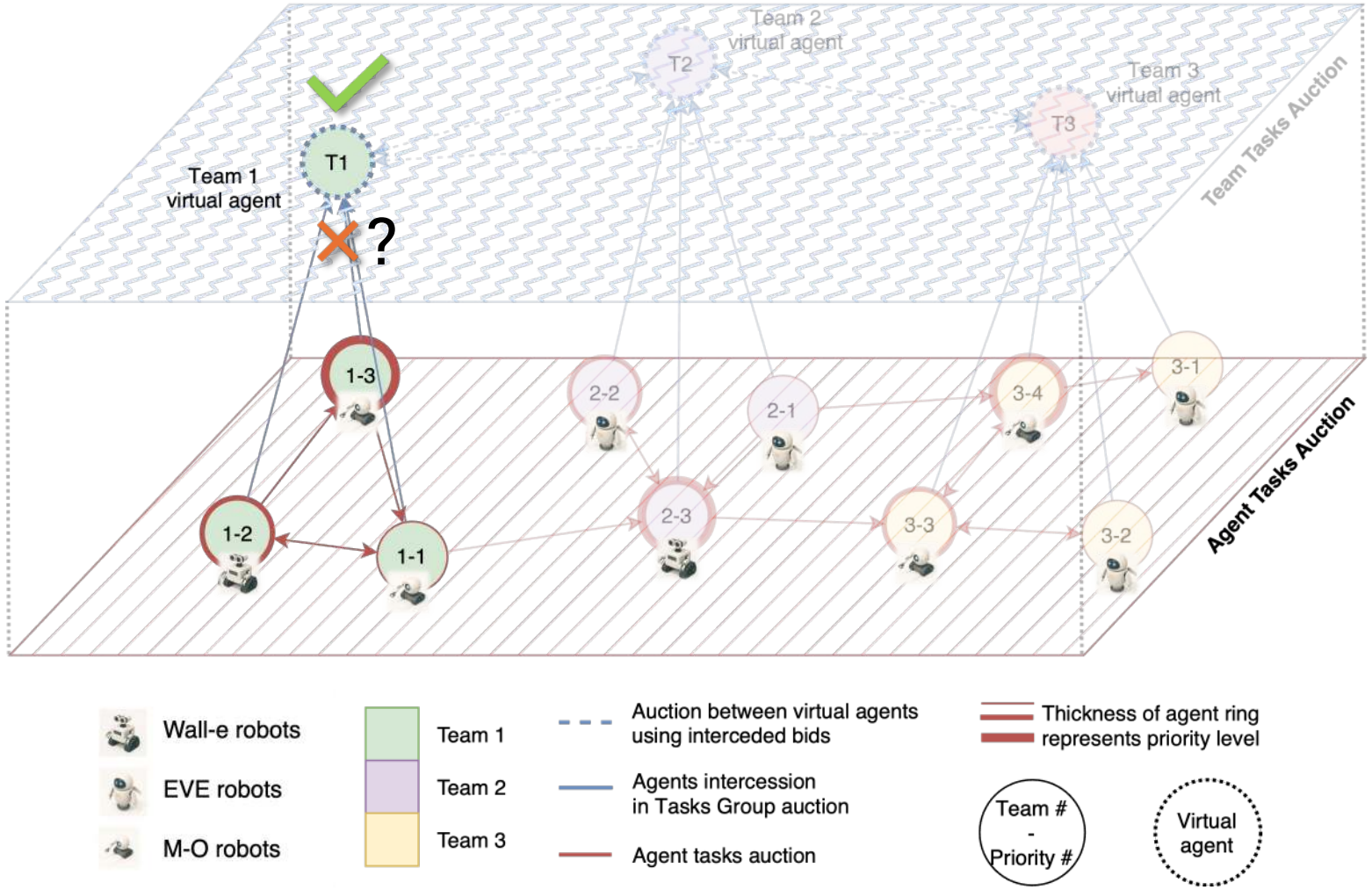
Do I bid?

- Hard constraints:
  - Organisations constraints
    - Roles – goal type permissions/obligations
    - Zone – group assignment

How much do I bid?

- Optimisation criterions:
  - Cost functions (bidding logic)
    - Distance
    - Battery consumption
    - Displacement time
    - Work load
    - ….


Zone 1
Assigned to Team 1
Zone 2
Assigned to Team 2
Zone 3
Assigned to Team 3



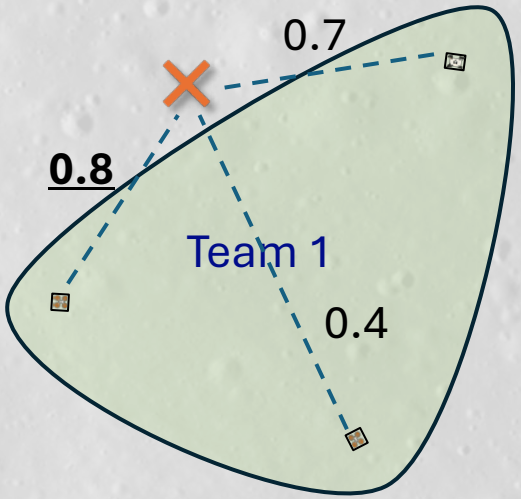
1. Group Allocation (CBAA)

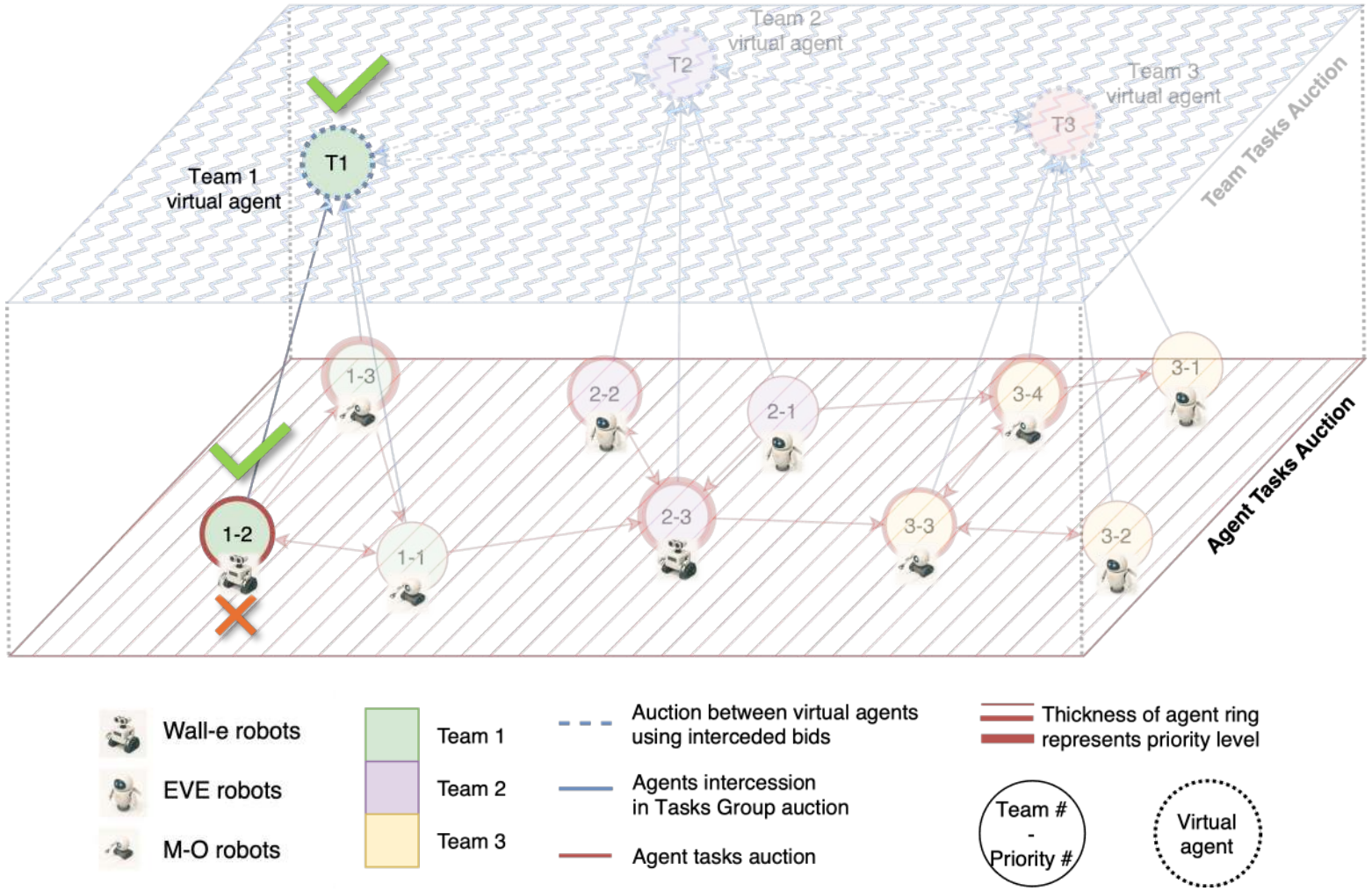
- Which team should handle the task?
  - Team 1 ✓

2. Agent Allocation (CBBA)

- Who in the team should handle the task?

$$Bid = \frac{1}{distance}$$





1. Group Allocation (CBAA)

- Which team should handle the task?
  - Team 1 ✓

2. Agent Allocation (CBBA)

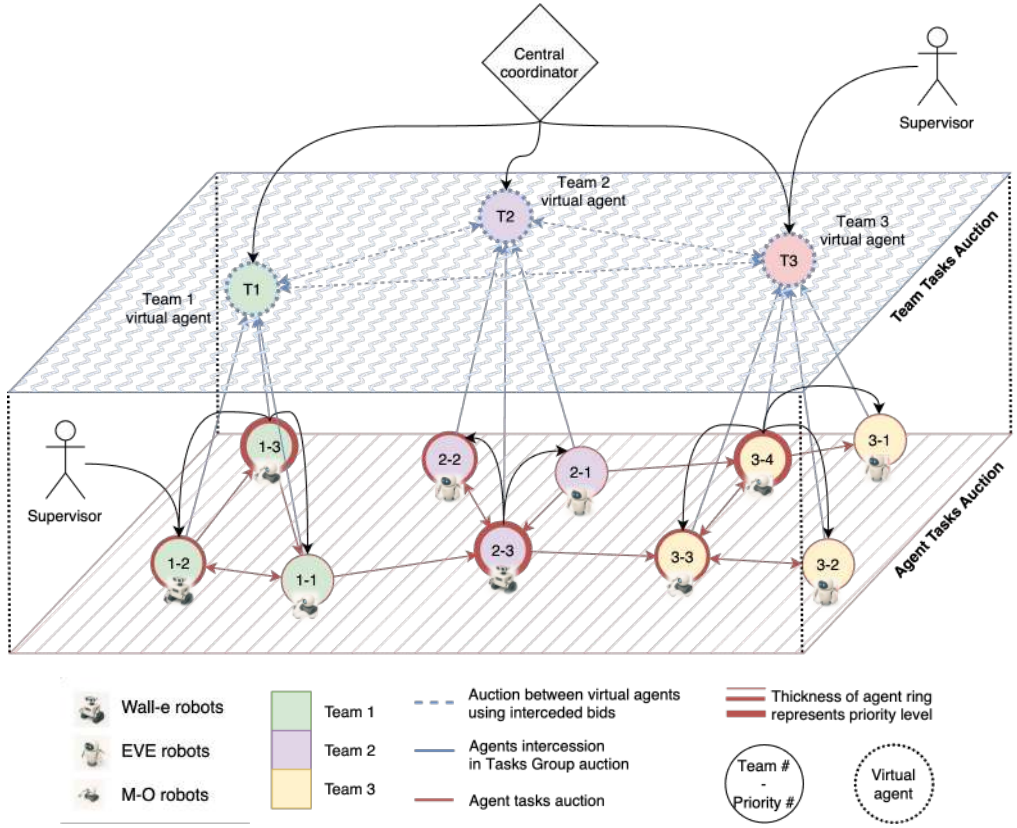
- Who in the team should handle the task?
  - Agent (1-2) ✓

Two birds, one stone

- Org-CBBA approach ensures roles allocation and associated responsibilities are respected
- Org-CBBA approach leverages the hierarchy structure to gradually break-down and smartly explore the solution space.

- NOTE:

Method is applicable to any hierarchy structure and depth



(In fact, three birds, one stone: abstraction of decision making combined with intercession mechanisms, see you after the presentation for more information)

Experimental Setup

Flat CBBA Baseline

- All robots bid on all compatible tasks
- Standard CBBA allocation
- No organizational restrictions

Hierarchical Org-CBBA

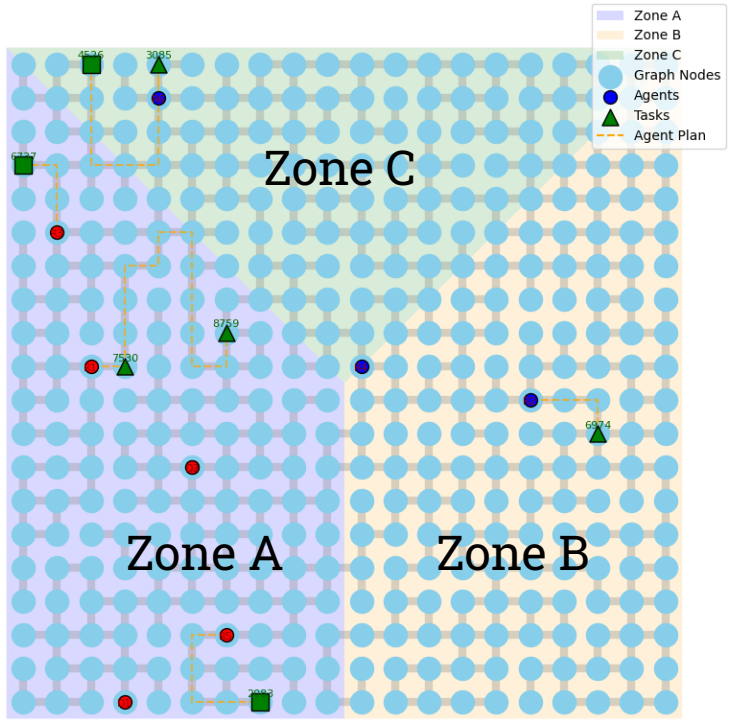
- Two heterogeneous groups:
  - Alpha: 6 robots
  - Beta: 3 robots
- Zone responsibilities:
  - Alpha → Zone A / Beta → Zone B
  - Shared competition in Zone C

Experimental Variables

- Variable task spawning rate in Zone A (constant rate in Zones B & C)
  → Multiple A/B workload ratios evaluated
- 10 randomized runs per configuration

Evaluation Metrics

- Fleet displacement → Allocation optimality / travel efficiency
- Bid computations → Computational and communication overhead
- Per-zone dispatch fidelity → Compliance with organizational constraints

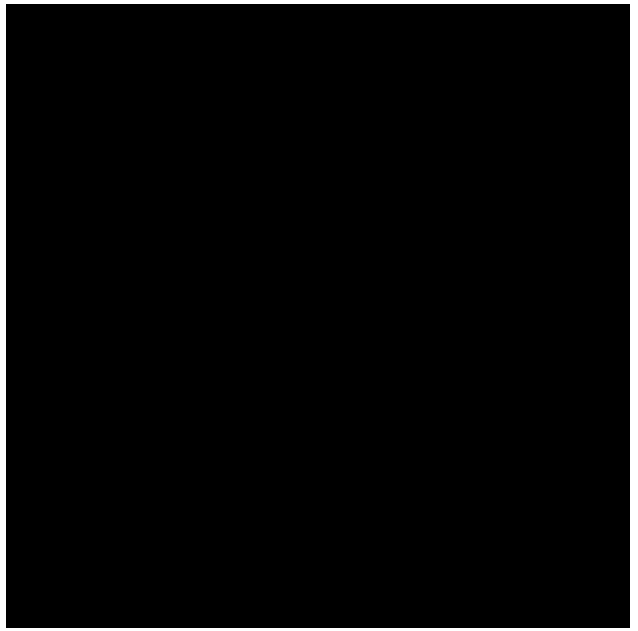


20×20 partially connected grid
(400 nodes, 70% edge connectivity)

Capability	Quantity
O	3
O,T	2
O,I	2
T,I	2

23

Experimental Results



Key Hypothesis

Hierarchical organizational decomposition

- reduces auction complexity
- constrains the explored solution space
- preserves allocation quality
- enforcing organizational validity

Results

- 42–62% fewer bid computations than flat CBBA
- <13% decrease average optimality gap despite organizational constraints
- Strict enforcement of zone responsibilities (Alpha → A, Beta → B)
- Significant reduction in decision-making overhead through hierarchical decomposition
- Benefits increase as workload asymmetry grows

Key Takeaway

Org-CBBA preserves allocation quality while drastically improving scalability and enforcing organizational coherence.

Summary of the Contribution

- Proposed a hierarchy structure agnostic approach.
- Integrate organizational constraints into the allocation process.
- Structure the decision-making process hierarchically.
- Improve scalability by guiding and reducing decision complexity.
- Improve the readability of the allocation process.
- Enable human intervention at different levels of abstraction.
- Preserve the convergence properties of CBBA.