LECTURE 5

SUMMARY

1. Multiagent systems

- a **multiagent system** (MAS) is one that consists of a number of agents, which interact with one another
- a MAS distributes computational resources and capabilities across a network of interconnected agents
- a MAS is **decentralized**
- in the most general case, agents will be acting on behalf of users with different goals and motivation. To successfully interact, they will require the ability to
  - **cooperate**
  - **coordinate**
  - **negotiate**

  with each other, much as people do.
- can support distributed collaborative problem solving by agent collections that dynamically organize themselves.
- support a modular, extensible approach to design of complex information systems.

- important issues in MAS
  - inter-agent **communication**
    - of knowledge, intentions, beliefs
  - inter-agent **collaboration**
    - through negotiation among self-interested rational agents
  - **coordination** and **control**
  - **trust** in MAS
    - how autonomous agents decide to interact, cooperate, and rely on one another
    - trust mechanisms, management, and modeling

- **collaboration** vs **cooperation**
  - *collaboration*
    - agents are working together
    - creation of temporary relationships between different agents that allow each member to achieve their own goals
  - *cooperation*
    - agents are working together to achieve a common goal
    - in MAS cooperation, agents share a common goal, which is evaluated through a global utility function
    - planning

- inter-agent **cooperation** can be achieved through:
  - grouping
  - communication
  - sharing tasks and resources
  - planning
  - …

- **MAS organizations**
  - MAS organizations are defined by an assembly of classes of agents characterized by their assigned roles and a set of abstract relationships among the roles.
    - *acquaintance*
    - *subordination*
    - *conflict*
    - ….
  - possible **approaches** for MAS organizations
    - **horizontal modular**
      - different functional components are separated from one another a technique adopted for SE
      - horizontal design
      - architectures:
        - Prodigy, 1991
          - planning, learning
        - ICARUS
          - 1998, cognitive architecture
          - evolution of original architecture
    - **hierarchical**
      - vertical
    - **ant colonies**
      - simple rules of interaction
      - MAS, RL
    - **immune systems**
    - **evolution**
    - **…**
  - **MAS** Organizational paradigms
    - modeling complex systems
    - *hierarchies*, *coalitions*, *teams*, *congregations*, *societies*, *markets*, etc
  - **MOISE** organizational model for MAS
    - http://moise.sourceforge.net/
    - MOISE Framework
      - Organization-Oriented Programming of MAS
  - Agent roles
    - Role-based design in MAS
    - Role Oriented Programming (entities – roles – activities)

The two key problems in a MAS

- **agent design** (the micro perspective)
  - *How do we build agents that are capable of* ***independent****, autonomous action in order to successfully carry out the tasks that we delegate to them*?

- **society design** (the macro perspective)
    - *How do we build agents that are capable of **interacting** (cooperating, coordinating, negotiating) in order to successfully carry out the tasks that we delegate to them*?

Some views of the MAS field

- **agents** as a paradigm for **software engineering/DAI**
- **agents** as tools for understanding human (natural) **societies**
    - MAS provide tools for simulating societies, which may help shed some light on various kind of social processes.
    - E.g.
        - simulation of biological and natural systems
        - simulation of natural disasters (meteorology)
        - ecological models
        - socio-ecological systems
        - ecosystems management

Advantages of a MAS

1. It is decentralized and does not suffer from the "*single point of failure problem*" associated with centralized systems.
2. MAS model problems in terms of autonomous interacting component agents, which is proving to be a more natural way of representing various tasks, such as:
    - task allocation, team planning, user preferences, open environments, a.s.o
3. Provides solutions in situations where data sources and expertise are spatially and/or temporally distributed.
    - **classical view**
        - data are distributed
    - **another view**
        - data are not spatially distributed
        - multiple agents are used for increasing performance
4. Increases system performance
    - computational efficiency
    - robustness
    - maintainability
    - flexibility

International Conference on Autonomous Agents and Multiagent Systems (AAMAS)

- planning, multiagent RL, algorithmic game theory, multiagent path finding, social networks, knowledge representation and reasoning, a.s.o
- AAMAS 2023

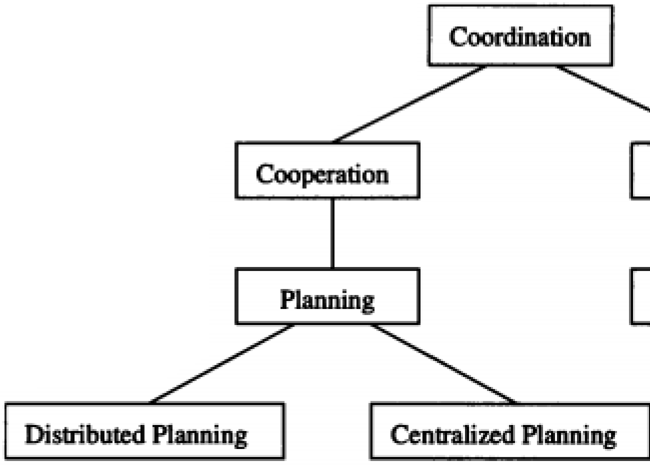
2. MAS characteristics ([2], Chapter 2)

- a MAS environment will have to provide a computational infrastructure for **interactions** between agents
    - protocols for agents to **communicate** and **interact**
    - **communication** protocols
        - enable agents to **exchange** and **understand** messages
        - e.g., the following types of messages can be exchanged:
            - *propose* a course of action
            - *accept* a course of action
            - *reject* a course of action
            - ….
    - **interaction** protocols
        - enable agents to have **conversations**

- **characteristics of MAS environments**
    - provides an infrastructure specifying *communication* and *interaction* protocols
    - contain agents that are **autonomous** and **distributed**
        - agents may be *self-interested* or *cooperative*
- **agent communications**
    - fundamentally, an agent is an active object with the ability to
        - reason
        - perceive
        - act
    - **assumptions**
        - an agent has
            - an explicitly represented **knowledge**
            - mechanisms for operating on or drawing inferences from its knowledge
        - an agent has the ability to **communicate**
            - part **perception**
                - the receiving of messages
            - part **action**
                - the sending of messages

Coordination

- agents communicate in order to achieve better the goals of themselves and of the society/system in which they exist
- **coordination** is a property of a system of agents performing some activity in a shared environment
- **cooperation** is coordination between *non-antagonistic* agents
- **negotiation** is coordination among *competitive* or *self-interested* agents

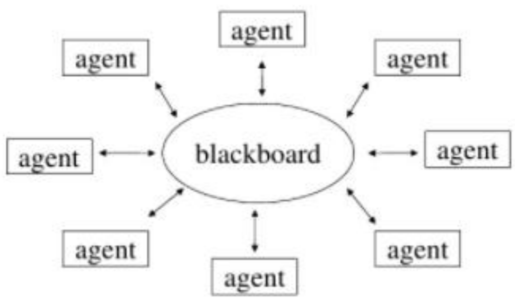


A taxonomy of coordination [2, Section 2.2]

Communication options in MAS ([3])

A. blackboard systems

- shared memory
- data repository
- the agents do not interact directly, but indirectly, through the blackboard

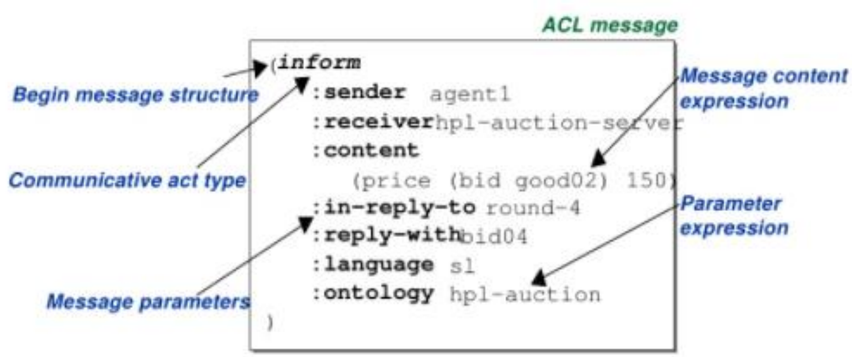


- information in the blackboard
  - data
  - current **state** of the problem
  - next **subproblems** to be solved
  - requests of **help**
  - **curremt task** of each agent
  - **intermediate results**
- **advanced blackboard systems**
  - **moderator/dispatcher agents**
    - the agents are registered in the blackboard
    - the dispatcher agent notifies the agents about changes in the blackboard
    - agents do not need to continuously check the blackboard
- **positive aspects**
  - flexible mechanism that allows communication/cooperation
    - *n* blackboards
- **negative aspects**

- centralised structure
- everyone must read/write from/on the blackboard
- single point of failure

B. direct **message passing**

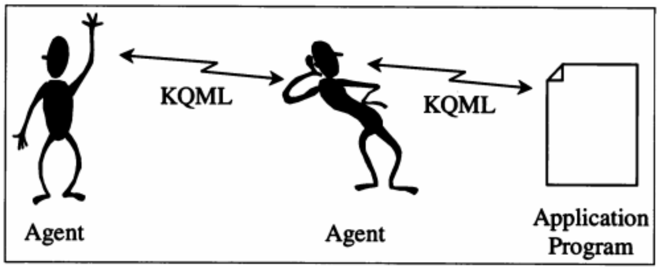
- **agent communication languages**
- **FIPA-ACL**
  - 1997
  - developed by FIPA
  - implemented in JADE framework
  - communication protocols
  - components of a FIPA-ACL message



  - FIPA-ACL **performatives** (e.g., **inform)**

```
(inform
      :sender     (agent-identifier :name i)
      :receiver   (agent-identifier :name j)
      :content    "door( now, open )"
      :language   Prolog)
)
```

- KQML **(Knowledge Query and Manipulation Language)**
  - 1994
  - an agent communication and coordination language
  - a protocol for exchanging information and knowledge
    - between agents and application programs



    - Lisp-like performatives

- **Knowledge Interchange Format (KIF)**
    - a logic language
        - standard used to describe things within expert systems, agents, etc.
    - declarative semantics
    - means for representing and encoding knowledge
    - a prefix version of first-order logic
        - with extensions to handle nonmonotonic reasoning

3. A dynamic MAS

- assumptions
    - a dynamic MAS consisting of $n \geq 2$ agents;
    - **deterministic** environment;
    - the **non-cooperative** case where each agent pursues its own objectives;
    - the system starts at time 0, moving discretely forward to time T, or until the state satisfies some termination condition;
    - the agents **evaluate** their outcomes based on the **final state**

- formally, a dynamic MAS is a tuple $<\mathcal{S}, \mathcal{A}, h, U>$, where
    - $\mathcal{S}=\Pi_i S^i$ — the joint state space
    - $\mathcal{A}=\Pi_i A^i$ — the joint action space
    - $h: \mathcal{S} \times \mathcal{A} \rightarrow \mathcal{S}$ — the transition function between states
    - $U=<U^1, \ldots U^n>$ — the vector of utility functions of respective agents $U^i: S^i \rightarrow \Re$
- at each time t, agents observe the state $s_t \in \mathcal{S}$
    - s_t consists of local states of each individual agent $s_t=<s_t^1, \ldots s_t^n>$, $s_t^i \in S^i$
    - then, the agents choose their action $a_t^i \in A^i$, producing the joint action $a_t=<a_t^1, \ldots a_t^n> \in \mathcal{A}$
    - the states evolves accordingly to $s_{t+1}=h(s_t, a_t)$, where $s_t^i=h^i(s_t^i, a_t^i)$

- the agent i's improvement in utility at time t is defined as the **reward** r_t^i, $r_t^i = U^i(s_t^i) - U^i(s_{t-1}^i)$

$\Rightarrow$

$$r_t^1 + r_t^2 + \ldots + r_t^i = U^i(s_T^i) - U^i(s_0^i).$$

$\Rightarrow$

maximizing the utility of an agent's final state is equivalent to **maximizing the sum of received rewards** (similarity with the agent goal in RL).

Bibliography

[1] Weiss, G. (Ed.): Multiagent Systems: *A Modern Approach to Distributed Artificial Intelligence*, MIT Press, 1999 (available at www.cs.ubbcluj.ro/~gabis/weiss/Weiss.zip) [Ch. 2]
[2] Russell, J.S, Norvig, P., *Artificial Intelligence - A Modern Approach*, Prentice- Hall, Inc., New Jersey, 1995 (available at www.cs.ubbcluj.ro/~gabis/weiss) [Ch. 2, Ch. 6]
[3] https://www.slideshare.net/ToniMorenoURV/lecture-5-agent-communication