Multi-Agent Coordination

– Introduction to Multi-Agent Oriented Coordination –

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CPS2 M2 – Fall 2023

Outline

Multi-Agent System (Reminder)

Motivations

> An **organisation** of **autonomous agents interacting** with each other within a shared **environment**

▶ **Agents**: autonomous entities able to react to events while pro-actively defining goals and directing actions to achieve them
  ↝ (soft/hard)ware, (coarse/small)-grain, (hetero/homo)geneous,

▶ **Environment**: shared medium providing the surrounding conditions for agents to exist and act (e.g. comm. and coord. infra., topology of spatial domain, support of an action model)
  ↝ virtual/physical, passive/active, deterministic or not, …

▶ **Interaction**: motor of dynamic and interoperability in the MAS
  ↝ direct communicative / indirect actions through the environment

▶ **Organisation**: abstractions to declare and make accessible to agents their expected collective structure and functioning in a shared environment (e.g. coordination and regulation activities)
  ↝ pre-defined/emergent, static/adaptive, open/closed, …
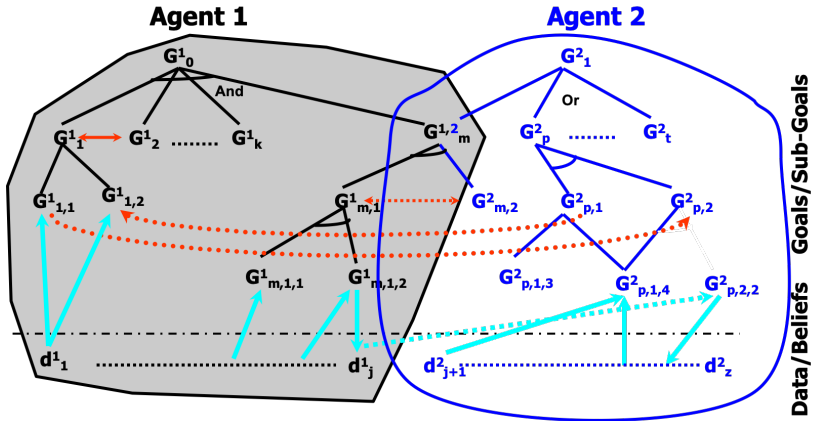
Autonomous Agent Behaviour

Motivations

Internal Perspective on the Agent: autonomous agent's behavior arise from internal goal reasoning, planning, action selection and execution, resource allocation and use.
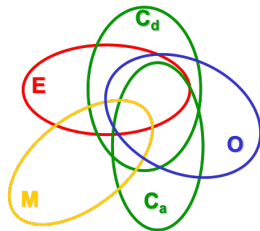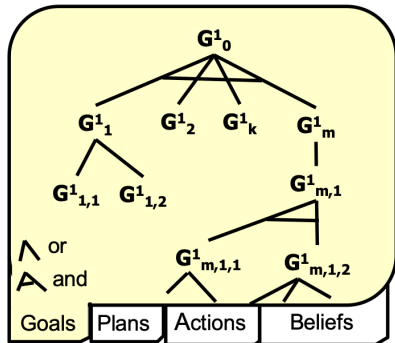
Possible behaviour are computed from the state of: the environment E, the agent's motivation M, the organisation O, the requests of adoption from other agents C_a, the requests of delegation to other agents C_d

Interacting Autonomous Agents

Motivations

- ▶ Agents autonomously execute their behaviour or interact with other agents
- ▶ **Dependencies** exist and **conflicts** may arise among the agents' behaviour

Dependencies

- ▶ Dependencies among actions, plans, goals may arise from:
    - ▶ Shared resources
    - ▶ Producers/Consumers
   - ▶ Simultaneous actions
    - ▶ Goals / Sub-Goals

    possibly leading to **conflicts**

- ▶ Distribution and non availability of information, skills or resources
    - ▶ In a multi-agent world, agents cannot be omniscient
    - ▶ Complete and up-to-date knowledge is not possible

- ▶ Global constraints to be considered (e.g. cost, time, space, laws)

- ▶ Efficiency burden
    - ▶ To not do the same action several times
    - ▶ Compute locally instead of communicating
    - ▶ ...

Managing Dependencies

Motivations

Internal Perspective on MAS: MAS behaviour results from the management of dependencies between the behaviour of the autonomous agents
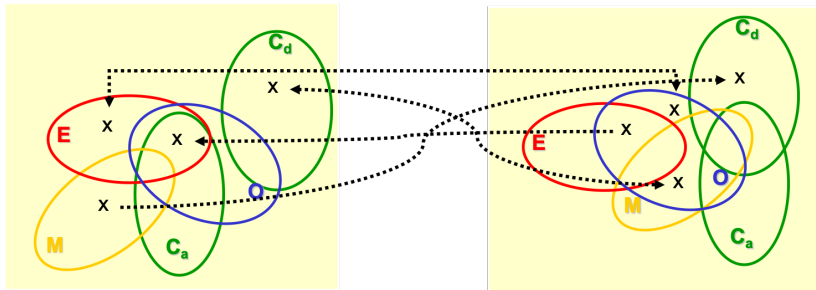
Dependencies among possible behaviour computed from the state of: the environment E, the agent's motivation M, the organisation O, the requests of adoption from other agents C_a, the requests of delegation to other agents C_d)

Outline

Coordination of Autonomous Agents

Definition

- Coordination aims at having a **global behaviour** of the autonomous agents in a shared and dynamic environment
- Coordination **manages dependencies** among agents
- Coordination operates by different **means and process**, **directly or indirectly** on one or several of the internal components of the agent:
    - goal reasoning
    - planning
    - action selection and execution
    - resource allocation and use
    - data observation and adoption

Multi-Agent Coordination & Agent Autonomy

Definition

	From open delegation …		… to executive delegation	
	Data-directed	Goal-directed	Plan-directed	Action-directed
Autonomous Agent	(i) receives data and selects them (**observation-autonomy**), (ii) generates goals from data and selects them, (iii) generates plans achieving goals and selects them, (iv) selects actions according to plans and executes them	(i) receives goals and selects them (**goal-autonomy**), (ii) generates plans achieving goals and selects them, (iii) selects actions according to plans and executes them	(i) receives plans and selects them (**plan-autonomy**), (ii) selects actions according to plans and executes them	(i) receives actions, selects them (**execution-autonomy**) and executes them
…	…	…	…	…
Executive Agent	(i) receives the selected data (**no observation autonomy**), (ii) generates goals from data and selects them, (iii) generates plans achieving goals and selects them, (iv) selects actions according to plans and executes them	(i) receives the selected goals (**no goal-autonomy**), (ii) generates plans achieving goals and selects them, (iii) selects actions according to plans and executes them	(i) receives the selected plans (**no plan-autonomy**), (ii) selects actions according to plans and executes them	(i) receives the selected actions (**no execution-autonomy**) and executes them

External Perspective on MAS

Definition

From an observer (user, agent) point of view,

- the agent behaviour can be considered as **being autonomous**

    - An agent X **is autonomous** w.r.t. Y for an entity P of Y iff X can decide locally to adopt P
        - X: agent, principal actor who is the subject of autonomy
        - Y: secondary actor or referent (user, environment, other agent, organisation, ...) that is the element w.r.t. which X is considered as autonomous for P
        - P: object (goal, plan, action, resource, data, ...) that is the element for which X is considered autonomous

- the MAS behaviour can be considered as

    - **Cooperation**: agents behave together to achieve a shared goal
    - **Collaboration**: agents behave to achieve compatible goals
    - **Competition**: agents behave to achieve incompatible goals

Outline

Coordination

Approaches for Coordination

- Coordination is used in a variety of disciplines, such as Economy, Sociology, Biology, Computer Science (even in subfields of it like robotics, concurrent programming, and mainstream software engineering): each has its own epistemological apparatus and research agenda

- Coordination is a key characteristic of MAS: the capability of autonomous agents to coordinate with others constitutes a centrepiece of this paradigm. **However** there is no agreement on what coordination means

Coordination

Approaches for Coordination

- ► In Management Science, coordination is the act of managing interdependencies between activities performed to achieve a goal[Malone and Crowston, 1994]

  e.g. resource sharing, task allocation, global constraints, co-design, multi-agent decision

- ► The process by which an agent reasons about its local actions and the (anticipated) actions of others to try and ensure the community acts in a coherent manner (Agents actions can be performed so that they do not conflict with one another), ... [Jennings, 1996]

- ► The coordination problem consists of composing (relating, harmonizing, adjusting, integrating) some coordination objects (tasks, goals, decisions, plans) with respect to some coordination process, which solves the coordination problem by composing co-ordination objects with the coordination direction (goal, function) [Ossowski, 1999]

Task or Result Sharing

Approaches for Coordination

- **Task Sharing**: **Who** does **What** and **How**, given the goals and skills of the agents, given contextual constraints
  - Task decomposition
  - Task allocation
  - Task resolution and execution
  - Synthesis, Integration
- **Result Sharing**: to increase the confidence, the scope, precision, availability of results
  - Task resolution and execution
  - Synthesis, Integration

Predefined **OR** Emergent
Centralized **OR** Decentralized

Approaches
Approaches for Coordination

In real systems, coordination is addressed along different approaches [Scott, 1981]:

▶ Rational systems: normative structure supporting the coordination among autonomous entities

▶ Natural systems: coordination is the result of the actions of the agents

▶ Economic Systems: Coordination is the result of economic interest of the agents

▶ Open Systems: Coordination is the result of the evolution of the environment
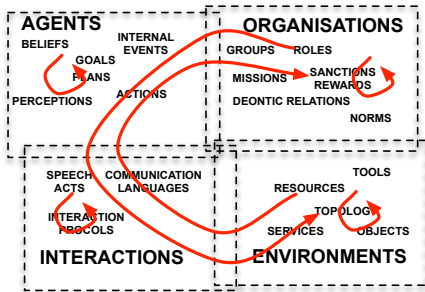
Outline

Multi-Agent Oriented Coordination

- ▶ Coordination of the system may be programmed using one or several families of concepts [Boissier, 2003]

- ↝ Interlacement of the various dynamics into bottom-up / top-down global cycles

↝ A rich palette of models to address multi-agent coordination!!

Agent Centered Coordination

Multi-Agent Oriented Coordination

- **Subjective coordination**, **Agent-centric perspective**
  - the space of interaction is considered from the subjective viewpoint of an agent.
  - Coordination is driven by the agent's own perception and understanding of the other agents' behaviour, capabilities and goals, as well as of the environment and organisation state and dynamics
  - The agent monitors all interactions that are perceivable and relevant to it, as well as their evolution over time
- Large set of approaches: from design-time/hard-coded (e.g. benevolent agents), to fully-controlled and uncontrolled coordination
  - TAEMS, Mental Constructs (Social Commitments, Joint-Intentions, ...), Epistemic Reasoning, Agent specialisation (limiting interactions and reduction of inter-dependencies), Increase of local capabilities in order to take locally better decisions, Decision theory, Multi-Agent Planning

Qualitative vs Quantitative Models

Multi-Agent Oriented Coordination– Agent Centered Coordination

- **Qualitative Models**

    - directly represent the different "reasons" for preferring or not certain objects of coordination to others
    - In cooperative environments, it is straightforward to conceive coordination as a kind of **constraint satisfaction problem**

- **Quantitative models**

    - the coordination problem is hidden in the shape of a multi-attribute utility function
    - The quantitative approach may draw upon a well developed theoretical framework for both, cooperative settings (Operations Research) and non-cooperative settings (Game Theory)
    - **optimisation problem**: to determine a local action (plan, goal, etc.), and to induce others to choose local actions (plans, goals, etc.), so as to maximise its local utility

Environment/Interaction/Organisation Centered Coordination
Multi-Agent Oriented Coordination

- **Objective Coordination**
  - The space of interaction is considered from the objective viewpoint given by an external observer not directly involved in the interaction
  - coordination means affect agent interaction so as to make the resulting MAS evolution accomplish one or more of the observer's goals. They are influenced not only by their perception and understanding of MAS agents and environment, but also by their a-priori knowledge of the agents' aims, capabilities and behaviour.
- **Macro-Centric Perspective**: coordination as-a service that exert run-time control on the agents' behaviour, instantiated in
  - environment-centric
  - interaction-centric
  - organisation-centric

  coordinations

Environment/Interaction/Organisation Centered Coordination

Multi-Agent Oriented Coordination

- **Environment-Centered Coordination**
  - Agents as situated entity in open systems
  - Engineering the environment to shape the interaction taking place between agents
  - Run-time control on the agents behaviour by affecting/regimenting agent actions or its perceptions

- **Interaction-Centered Coordination**
  - Engineering the interaction that could take place in the system to shape the interaction taking place between agents
  - Run-time control on the agents behaviour by affecting agent actions by influencing agent behaviour

- **Organization-Centered Coordination**
  - Engineering the structure, relations and plans that could take place in the system to shape the interaction taking place between agents
  - Run-time control on the agents behaviour by affecting/enforcing agent behaviour, actions, interactions

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