

4. Multiagent Systems Design

Part 6: Coordination (I). Explicit Coordination

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Explicit and Implicit Coordination

- Another way to cut the cake



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Coordination

Definitions

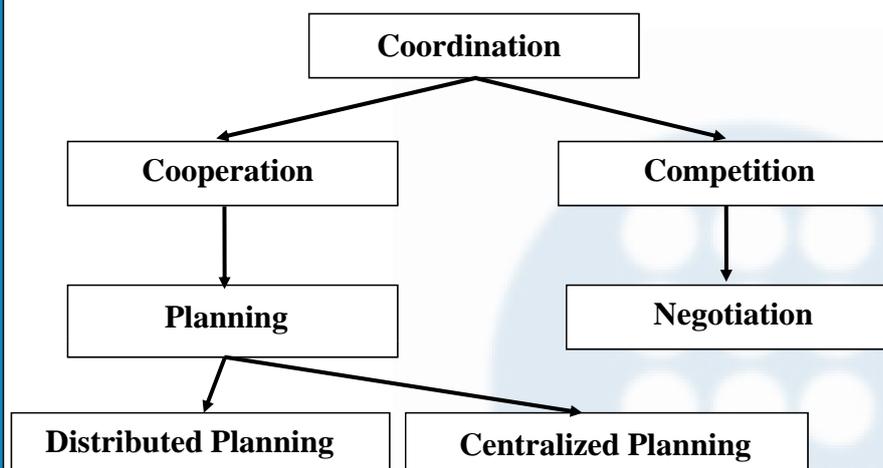
- **Coordination** could be defined as the process of managing dependencies between activities. By such process an agent reasons about its local actions and the foreseen actions that other agents may perform, with the aim to make the community to behave in a coherent manner.
- An **activity** is a set of potential operations an **actor** (enacting a role) can perform, with a given goal or set of goals.
- An **actor** can be an **agent** or an agent group
- A set of **activities** and an ordering among them is a **procedure**.

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Coordination

Types of coordination



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Coordination

Another Classification

- **Coordination** can also be divided along another dimension:
 - **Explicit Coordination:** agents communicate goals, plans, actions, state of the world with the explicit goal of acting coherently.
 - **Implicit Coordination:** no communication – the environment acts as the interaction mechanism

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Explicit Coordination for Cooperation

- Joint Intentions Theory
- Cooperative Problem Solving Process
- Teamwork
- Planning
- Negotiation
- Speech Acts
- Algorithms
- Coordination Media



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Explicit Coordination Mechanisms

Coordinating with message exchange

- Cohen and Levesque, Wooldridge and Jennings
- Agents **communicate with one another** to share:
 - Tasks
 - Task Assignments
 - Information on the State of the World
 - Motivations
 - etc.
- These communications form the basis of forming joint agreement on what to do
- This forms the basis of a “Cooperative Problem Solving Process”

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Cooperative Problem Solving Process

Four steps to (cooperation) heaven

- **4 Steps (Wooldridge and Jennings):**
 - **Problem identification:** the process begins when one or more agents identify a problem for which cooperation is needed.
 - **Team formation:** the agent (or agents) that recognised the problem solicit assistance and seek others to help with the problem. If this stage is successful a group is formed with a “joint commitment” for action.
 - **Plan formation:** the team of agents form an action plan which uses the individual skills in the team. The result of this stage is a series of individual and interdependent commitments to act.
 - **Team action:** during this phase, agents carry out the actions assigned to them.
- Followed by clean up / housekeeping

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Joint Intentions

The basis of Joint Action

- First described by Cohen and Levesque:
- Common Characteristics:
 - **Realistic**: agents must believe the state of affairs desired is achievable.
 - **Temporally Stable**: intentions should be persistent in some sense (though not completely inflexible)
- Some argue that Joint Intentions are required for Joint Action. I.e. that if you “happen” to do the right thing but didn't have a joint intention the this wasn't Joint Action.
- Jennings et. al. See **Commitments** as instantiations of Joint Intentions

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Joint Responsibility

Extending Joint Intentions

- Jennings also introduces Joint responsibility as:
 - A **joint goal** (joint intention).
 - A **recipe** (plan) for achieving that goal.
- This builds on Joint Intentions to tie a goal to concrete actions since:
 - If we have the same goal it doesn't mean we are necessarily agreed on the actions to achieve it.
 - Further, when I start to act then I need to be certain you are committed to “doing your part”.

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Criticisms of Joint Intentions Approaches

Not applicable to everything

- There are a number of well known criticism of the theories based around Joint Intentions:
 - **Failure to account for Social Structure:** what about coercion? social responsibility?
 - **Focus on internal structures:** who cares what we intended as long as we acted coherently?
 - **Limited Applicability:** the theory does not work for (e.g.) implicit coordination cases.
- However, the theory provides a strong linking point to approaches such as trust and reputation.

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Teamwork

Another view on CPS

- Name attached to a particular flavour of cooperative problems solving which emphasises the model of the “team” (and attitudes towards the team) rather than individual mental attitudes
- Theory emphasises:
 - **Detecting Interactions:** detecting +ve and -ve interactions between subplans
 - **Monitoring plan and team progress:** are goals achieved? are team members till reachable etc.
 - **Planning and conflict resolution within the team:** contract net and other mechanisms to resolve conflicts
- Systems include: STEAM, GRATE, COLLAGEN

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Planning

Multiple Agents make planning difficult

- Traditional Artificial Intelligence Planning:
 - Is focused on planning for a single Action (what do “I” do?)
 - Often assumes the agent is the only actor in the world (who locked the door!?!)
 - Is non-trivial to generalise to multi-agent cases
- There are three key variations:
 - Planning in situations when **several friendly agents** are supposed to work together – who does what and when? However the agents are the only actors in the environment
 - Planning in situations where there are **other (neutral) agent present**.
 - Planning in situations where there are **hostile** other agents present

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Planning

Partial Global Planning

- Even the “friendly agents” cases is complex and requires:
 - Knowing the capacities of other agents
 - Sharing plan fragments
 - Coordinating individual actions
- **Partial Global Planning** (PGP and GPGP) are the most representative systems in this field:
 - Agents create plan fragments
 - Share them using a call-for-proposals style protocol
 - Agents modify their behaviour w.r.t. what they believe others are doing.

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Negotiation

Resolving conflicts

- Negotiation is the act of “**Resolving inconsistent views to reach Agreement**” (Lassri)
- Negotiation could be about many things:
 - **Costs**: a linear scale – how much to pay for a service – generally using economic mechanisms and preference evaluation.
 - **Truth**: whether something is true or not – generally using *argumentation*.
 - **Action**: on which action a group of agents should take – also often using *argumentation*.

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Negotiation

Negotiation as Coordination

- Negotiation is itself a coordination process since:
 - Agents agree to a pre-defined set of possible actions and **rules** for the negotiation process.
 - They have the **shared goal** of *reaching agreement*.
 - The information exchanged often contains details of **actions to be taken**.
- Agents however likely do not share exactly the same objective within the negotiation:
 - Buyers seek a low price
 - Seller seek a high price

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Negotiation

Methods for negotiation

- Common negotiation techniques include:
 - **(Iterative) Contract Net** (Simon and Davies): using a call-for-offers and response mechanism – in particular when counter offers are allowed.
 - **Game Theory based approaches** (Levy, Zlotkin, Roschein): sharing utility functions or seeing negotiation convergence as an iterative prisoners dilemma.
 - **Recursive and Iterative methods** (Lassri and others): convergence methods / rules for multi-round negotiations.
 - **Argumentation based methods** (Castelfranchi, Parsons, McBurney and others): using logical statements and dialogue games to force agents to reach consensus.

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Negotiation

Fatio – McBurney and Parsons

- Classification of Speech Acts (Austin, Searle, Habermas):
 - Factual
 - Expressive
 - Social Connection
 - Commissives
 - Directives
 - Inferences
 - Argumentation
 - Control
- Locutions have different effects

Locution Type	FIPA ACL Locutions
Factual Statements	confirm disc onfirm failure inform inform-if inform-ref query-if query-ref
Expressive Statements	inform
Social Connection Statements	inform
Commissives	accept-proposal agree propose refuse reject-proposal
Directives	cancel cfp request request-when request-whenever
Inferences	inform
Argumentation Statements	
Control Statements	not-understood propagate proxy subscribe

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From McBurney and Parsons 2004

Negotiation

Fatio – McBurney and Parsons

– *assert*(P_i, ϕ)

Pre-conditions: A speaker P_i desires that each participant P_j ($j \neq i$), believes that P_i believes the proposition $\phi \in \mathcal{C}$.

$((P_i, \phi, +) \notin DOS(P_i)) \wedge (\forall j \neq i)(D_i B_j B_i \phi)$.

Post-conditions: Each participant P_k ($k \neq i$), believes that participant P_i desires that each participant P_j ($j \neq i$), believe that P_i believes ϕ .

$(P_i, \phi, +) \in DOS(P_i) \wedge (\forall k \neq i)(\forall j \neq i)(B_k D_i B_j B_i \phi)$.

Dialectical Obligations: $(P_i, \phi, +)$ is added to $DOS(P_i)$, the Dialectical Obligations Store of speaker P_i .

– *question*(P_j, P_i, ϕ)

Pre-conditions: Some participant P_i ($i \neq j$) has a dialectical obligation to support ϕ and participant P_j desires that each other participant P_k ($k \neq j$), believe that P_j desires that P_i utter a *justify*(P_i, ϕ, \cdot) locution.

$\exists i (i \neq j) ((P_i, \phi, +) \in DOS(P_i)) \wedge (\forall k \neq j) D_j B_k D_j (\exists \Delta \in \mathcal{A})$

Done [*justify*($P_i, \Delta \vdash^+ \phi$), $((P_i, \phi, +) \in DOS(P_i))$]).

Post-conditions: Participant P_i must utter a *justify* locution.

$(\exists \Delta \in \mathcal{A}) \text{ Done } (\text{justify}(P_i, \Delta \vdash^+ \phi), \text{Done } [\text{question}(P_j, P_i, \phi), ((P_i, \phi, +) \in DOS(P_i))])$.

Dialectical Obligations: No effect.

From McBurney and Parsons 2004

Negotiation

Fatio – McBurney and Parsons

- Taking an approach like this:
 - Makes it possible to specify and build the agent reasoning elements
 - Makes it possible to build open-ended coordination protocols
 - Makes it possible to plug new agents (possibly built by different people) straight into the environment
- Fatio is just an example – focuses on fact / action based negotiation using argumentation.

Speech Act Based Coordination

The meaning behind explicit coordination

- Messages in a negotiation or any other explicit coordination have a meaning – they imply things such as:
 - A commitment to act
 - The acceptance of a fact
 - Information about an outcome
 - ...
- Explicit semantics are needed for agents to “understand” these messages.
- Hence explicit coordination can be seen as **language** or **interaction design**.

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Speech Act Based Coordination

Methods for speech act based coordination

- To achieve this interaction design there have been three families of approaches:
 - Definition of the semantics of **communication primitives** (Lux, Steiner, FIPA): focusing on the definition of meaning of individual speech act (inform, accept, etc.)
 - Definition of specific **coordination languages** (e.g. COOL): which focus only on the expression of joint action and specifically representing actions to be carried out.
 - Definition of **coordination protocols** (Pitt, Burmeister and others): which argues that individual speech acts have no strong semantics outside the context of a dialogue.

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Coordination Algorithms

Focusing on the nature of the distributed problem

- Coordination by “Algorithm” is somewhat controversial since some approaches do not allow for significant Agent Autonomy in the process.
- Two main approaches:
 - **Distributed Constraint Satisfaction** (DCSP): an extension of CSP solving techniques which capture several variables in each agent. Agents propagate choices for the “edge variables” which affect others.
 - **Hierarchical Authority Algorithms** (Durfee et. al.): mechanisms which enforce authority values on participation and according to these rankings drive plan interchange processes.

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Coordination Media

Artefacts for Coordination

- In addition to techniques which focus on what the agent “does” there are some which aim at providing agents themselves with “**tools to coordinate**” - coordination media.
- These systems include:
 - **Blackboard systems** (mainstream AI): which are shared spaces for interchange of information or action plans.
 - **Tuple spaces** (Bologna school): which provide shared spaces based on the idea of a “tuple” of values. Tuple spaces focus in particular on communication, allows for distributed spaces and propagation of tuples between spaces.

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Summary of Explicit Coordination Approaches

- Approaches:
 - Are based on shared **mental models** of goals to be achieved
 - Use **explicit messages** of one form or another to communicate intentions
 - Are concerned with the modelling of the **semantics** of the interactions between agents
- Mirror a lot of human processes (e.g. negotiation, argument ...)
- Some approaches focus on the effects on agents, others tackle the nature of the problem itself

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Challenge Problem

Coordination of Resource use in a Grid Environment

- You manage a “Utility Grid”
 - 20 machines
 - 1000 users
 - Average 10 jobs per min
- Each Machine:
 - Buffer – max 10 jobs in the Q
- Each Job:
 - Takes time T1 to process
- Protocols/Actions:
 - Query the Q length of a resource
 - Reply: Send a Q length message
 - Send a Job to a resource
 - Reply: job accepted
 - Reply: job rejected
- All messages take time T2

What is a good single scheduler policy?

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What if you have 5 Independent Schedulers?

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Locating Material

- Related Materials:
 - <http://www.lsi.upc.edu/~jvazquez/teaching/sma-upc/docs/willmott96coordination.pdf>
 - <http://www.lsi.upc.edu/~jvazquez/teaching/sma-upc/docs/willmott96bibliography.pdf>
- [Note that the bibliography is not only Coordination]

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