Multiagent Systems

6. Communication

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Agent interaction

Overview of the course

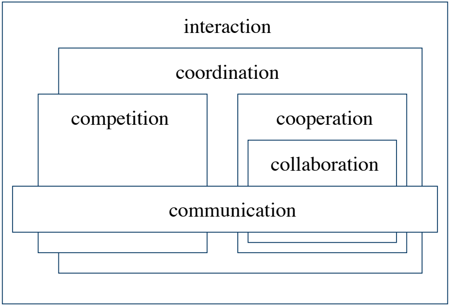
Previous contents:

- Intelligent autonomous agents
  - Abstract agent architectures
  - Deductive reasoning agents
  - Practical reasoning agents
  - Reactive and hybrid agent architectures
- Communication and cooperation
  - Agent communication
  - Methods for coordination

$\rightsquigarrow$ We will be talking about agents interacting in a common environment (focus: different forms of interaction; **macro-perspective**)

Typology of agent interaction

- Interaction does not always imply action
- Coordination does not always imply communication
- Basic typology of interaction:



Typology of agent interaction

- Non-/Quasi-communicative interaction:
  - Shared environment (interaction via resource/capability sharing)
  - "Pheromone" communication (ant algorithms)
- Communication:
  - Information exchange: sharing knowledge, exchanging views
  - Collaboration, distributed planning: optimising use of resources and distribution of tasks, coordinating execution
  - Negotiation: reaching agreement in the presence of conflict
  - Human-machine dialogue, reporting errors, etc.

Speech acts

Speech act theory

- Most multiagent approaches to communication based on **speech act theory** (started with Austin's book, *How to Do Things with Words*, 1962)
- **Basic idea**: treat communication in a similar way as non-communicative action
- Pragmatic theory of language, concerned with how communication is used in the context of agent activity
- Austin (1962): Utterances are produced, and may have effects, like "physical" actions: utterances may change the state of the world
- **Speech act theory** is a theory of how utterances are used to achieve intentions

Speech act theory

- A speech act can be conceptualised to consist of:
  1. **Locutionary act** (physical utterance)
  2. **Illocutionary act** (intended meaning)
  3. **Perlocution** (effect of the act)
- Two parts of a speech act:
  1. Performative = communicative verb used to distinguish between different "illocutionary forces"
     Examples: promise, request, purport, insist, demand, etc.
  2. Propositional content = what the speech act is about
- Example:
  - Performative: request/inform/enquire
  - Propositional content: "the window is open"

Speech act theory: Searle

- Searle (1972) identified the following categories of **performatives**, each corresponding to a different type of speech acts:
  - **assertives/representatives** (informing, making a claim)
  - **directives** (requesting, commanding)
  - **commissives** (promising, refusing)
  - **declaratives** (effecting change to state of the world)
  - **expressives** (expressing mental states)
- Ambiguity problems:
  - "Please open the window!"
  - "The window is open."
  - "I will open the window."
  - ...
- Debate as to whether this (or any!) typology is appropriate (and innate to human thinking)

Examples

- performative = request
  content = "the window is open"
  speech act = "Please open the window!"
- performative = inform
  content = "the window is open"
  speech act = "The window is open."
- performative = inquire
  content = "the window is open"
  speech act = "Is the window open?"

Speech act theory

Austin and Searle also analyzed the conditions under which speech acts can be successfully completed.

Austin's **felicity conditions**:

1. There must be an accepted conventional procedure for the performative
2. The procedure must be executed correctly and completely
3. The act must be sincere, any uptake must be completed as far as possible

Searle's properties for success of (e.g.) a request:

1. I/O conditions (ability to hear request, normal situation)
2. Preparatory conditions must hold (requested action can be performed, speaker must believe this, hearer will not perform action anyway)
3. Sincerity conditions (wanting the action to be performed)

Speech acts: Plan-based semantics

- If communication is like action, what **should** agents say?
- Cohen and Perrault (1979) proposed applying planning techniques to speech acts (STRIPS-style)
- Pre- and post-conditions describe **beliefs**, **abilities** and **wants** of participants
- Distinction between `can-do` and `want` preconditions
- Identified necessity of mediating acts, since speech acts say nothing about perlocutionary effect
- This has been the most influential approach to using communication in multiagent systems!
- Cohen and Levesque later integrated that in their model of intentions

Speech acts: Plan-based semantics

Examples of the Cohen-Perrault model

Request(s, h, α):

$$\begin{aligned}
&\texttt{pre-can} &: \; & s\,\texttt{Bel}\,(h\,\texttt{Can}\,\alpha) \wedge \; s\,\texttt{Bel}\,(h\,\texttt{Bel}\,(h\,\texttt{Can}\,\alpha)) \\
&\texttt{pre-want} &: \; & s\,\texttt{Bel}\,(s\,\texttt{Want}\,\alpha) \\
&\texttt{effect} &: \; & h\,\texttt{Bel}\,(s\,\texttt{Bel}\,(s\,\texttt{Want}\,\alpha))
\end{aligned}$$

CauseToWant$(a1, a2, \alpha)$:

$$\begin{aligned}
&\texttt{pre-can} &: \; & a1\,\texttt{Bel}\,(a2\,\texttt{Bel}\,(a2\,\texttt{Want}\,\alpha)) \\
&\texttt{pre-want} &: \; & \text{-} \\
&\texttt{effect} &: \; & a1\,\texttt{Bel}\,(a1\,\texttt{Want}\,\alpha)
\end{aligned}$$

Agent communication languages

Agent communication languages

- Agent communication languages (ACLs) define standards for messages exchanged among agents
- Usually based on speech act theory, messages are specified by:
  - Sender/receiver(s) of the message
  - Performative to describe intended actions
  - Propositional content in some content language
- Most commonly used languages:
  - KQML/KIF
  - FIPA-ACL (today the de-facto standard)

FIPA: Foundation for Intelligent Physical Agents
KQML: Knowledge Query and Manipulation Language
KIF: Knowledge Interchange Format

KQML/KIF

- KQML: **Knowledge Query and Manipulation Language**
- ...is an "outer" language, defines various acceptable performatives
- Example performatives:
  - `ask-if` ("is it true that ...")
  - `perform` ("please do the following action ...")
  - `tell` ("it is true that ...")
  - `reply` ("the answer is ...")
- Message format:

```
(performative
    :sender        <word>   :receiver    <word>
    :in-reply-to   <word>   :reply-with  <word>
    :language      <word>   :ontology    <word>
    :content       <expression>
    )
```

Example

```
(advertise
   :sender        Agent1
   :receiver      Agent2
   :in-reply-to   ID1
   :reply-with    ID2
   :language      KQML
   :ontology      kqml-ontology
   :content       (ask
                     :sender   Agent1
                     :receiver Agent3
                     :language Prolog
                     :ontology blocks-world
                     :content  ''on(X,Y)''
                     )
    )
```

KQML/KIF

- KQML does not say anything about content of messages, i.e., we need a **content language**
- KIF (Knowledge Interchange Format): a logical language to describe knowledge
- ... essentially first-order logic with some extensions/restrictions
- Examples:
  - ```
    (=> (and (real-num ?x) (even-num ?n))
         (> (expt ?x ?n) 0))
    ```
  - `(interested joe '(salary , ?x , ?y , ?z))`
- BTW, KIF can also be used to describe ontology referred to by interacting agents ...
    ```

KQML/KIF

- KQML/KIF were very successful, but also some problems
- List of performatives (up to 41!) not fixed (interoperability problems)
- No formal semantics, only informal descriptions of meaning
- KQML completely lacks commissives, this is a massive restriction!
- Performative set of KQML rather ad hoc, not theoretically clear or very elegant

⇝ These lead to the development of FIPA ACL

FIPA ACL

Basic structure is quite similar to KQML:

- performatives: fixed set of 20 performatives in FIPA
- housekeeping: e.g., sender, receiver, message IDs
- content: the actual content of the message

Example:

```
(inform
   :sender   agent1
   :receiver agent3
   :content  (price goodABC 125)
   :language sl
   :ontology hpl-auction
   )
```

FIPA ACL performatives

performative	passing info	requesting info	negotiation	performing actions	error handling
accept-proposal			x		
agree				x	
cancel		x		x	
cfp			x		
confirm	x				
disconfirm	x				
failure					x
inform	x				
inform-if	x				
inform-ref	x				
not-understood					x
propose			x		
query-if		x			
query-ref		x			
refuse				x	
reject-proposal			x		
request				x	
request-when				x	
request-whenever				x	
subscribe		x			

Inform and Request

"Inform" and "Request" are the two basic performatives in FIPA. All others are macro definitions, defined in terms of these.

The meaning of inform and request is defined in two parts:

- **feasibility pre-condition**: what must be true in order for the speech act to succeed
- **"rational effect"**: what the sender of the message hopes to bring about

Inform

For the "inform" performative:

- Content: a statement
- Pre-conditions for sender:
  Sender believes that the content is true
  Sender intends that the recipient believes the content
  Sender does not already believe that the recipient is aware of whether content is true or not

Request

For the “request” performative:

- Content: an action
- Pre-conditions for sender:
  Sender intends action content to be performed
  Sender believes that the recipient is capable of performing the action
  Sender does not believe that receiver already intends to perform action

Problems

- Impossible for the speaker to enforce those beliefs on the hearer!
- More generally: No way to verify mental state of agent on the grounds of its (communicative) behaviour
- This is a fundamental problem of all mentalistic approaches to communication semantics!
- Alternative approaches use the notion of **social commitments**
  - Idea: "A debtor a is indebted to a creditor b to perform action c (before t)"
  - Often public commitment stores are used to track status of generated commitments
  - Benefit: at least (non)fulfilment of commitments can be verified

Ontologies

Ontologies

- One aspect we have not discussed so far: how can agents ensure the **terminology** they use is commonly understood?
- What are ontologies?
  - In Philosophy: a theory of nature of being or existence
  - More pragmatically: a formal specification of a shared conceptualisation
- Ontologies have become a prominent area of research in particular with the rise of the Semantic Web (Web Ontology Languages OWL)
- Many interesting problems: ontology matching and mapping, ontology negotiation, ontology learning, etc.
- For our purposes sufficient to know that agreement on terminology is prerequisite for meaningful communication

The ontology spectrum

- Informal ontologies
  - Controlled vocabulary
  - Glossary
  - Thesaurus
  - Informal "is-a" taxonomies
- Formal ontologies
  - Formal "is-a" taxonomies
  - Properties
  - Value restrictions
  - Additional logical constraints

Ontology engineering

From a domain modeller's perspective, an ontology is a (terminological) knowledge base given by:

- a **vocabulary** used to describe some given domain
- a specification of the **intended meaning** of the vocabulary almost always allows for building a classification system of the concepts
- possibly, further constraints specifying additional domain knowledge

The aim is:

- to specify a common understanding of the domain
- to have a formal and machine-readable model of the domain

Ontology engineering

Design criteria for ontologies include:

- **meaningful** (e.g., all named classes can have instances)
- **correct**, in the sense that domain experts can agree on the meaning of the vocabulary as specified in the ontology
- **rich**, in the sense that the specified meaning provides a reasonable approximation of the intended meaning of the vocabulary

Existing tools and reasoners (Protege, Fact++, Racer, etc.) can help to build such ontologies, but also to solve several reasoning tasks . . .
There exists a family of well-defined ontology languages (e.g., OWL-languages) with a solid logical basis (Description Logics).

Reasoning services

Given a fixed domain ontology, there are several reasoning tasks related to its design and its usage in applications:

- **Concept satisfiability**: Can we find contradictory classes/concepts in the ontology, i.e., concepts which can not be instantiated?
- **Concept subsumption**: Does concept A subsume concept B, i.e., must each (possible) instance of concept B be an instance of concept A?
- **Subsumption hierarchy**: Compute the subsumption relations between all pairs of named concepts mentioned in the ontology
- **Instance queries**: Given a knowledge base of the individuals of the domain, retrieve all instances that math a given query
- **Ontology mapping/alignment**: Given two ontologies of the same domain, map/align the concepts specified in both

Communication protocols

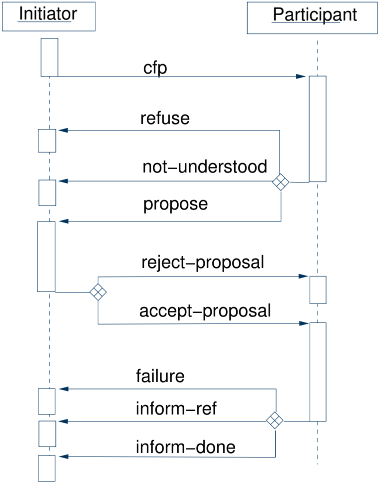
Interaction protocols

- ACLs define the syntax and semantics of individual utterances
- But they don't specify how agent conversations should look like
- This is done by **interaction protocols** for different types of agent dialogues
- Interaction protocols govern the exchange of a series of messages among agents
- Restrict the range and ordering of possible messages (effectively define patterns of admissible sequences of messages)
- Often formalised using finite-state diagrams or "interaction diagrams" in FIPA-AgentUML:
  define agent roles, message patterns, semantic constraints

Example: Contract-net protocol

- One of the oldest, most widely used agent interaction protocols
- A manager agent announces one or several tasks, agents place bids for performing them
- Task is assigned by manager according to evaluation function applied to agents' bids (e.g., choose cheapest agent)
- Idea of exploiting local cost function (agents' private knowledge) for distributed optimal task allocation
- Even in purely cooperative settings, decentralization can improve global performance
- A typical example of "how it can make sense to agentify a system"
- Successfully applied to different domains (e.g. transport logistics)

Contract-net protocol



Summary

- Different kinds of interaction and communication
- Focus on agent-to-agent communication
- Speech act theory – theoretical foundation for ACLs
- Agent communication languages & their semantics
- Interaction protocols
- But how about agent strategies in interaction and their global effects?
- Next time: **Methods for Coordination**

Acknowledgments

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- Dr. Michael Rovatsos, The University of Edinburgh
  `http://www.inf.ed.ac.uk/teaching/courses/abs/abs-timetable.html`
- Michael Wooldridge: **An Introduction to MultiAgent Systems**, John Wiley & Sons, 2nd edition 2009 and 1st edition 2002.