Agent-Based Systems

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Lecture 6 – Agent Communication

Where are we?

Last time . . .

- Reactive and hybrid agent architectures
- Criticism of symbolic AI/deliberative architectures
- Situated/embodied/behaviour-based intelligence, emergence
- Subsumption architecture
- Hybrid approaches: the best of both worlds?
- Horizontal layering: Touring Machines
- Vertical layering: InteRRaP

Today . . .

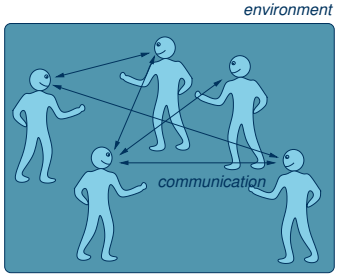
- **Agent Communication**

Overview of the course

- 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
- Multiagent decision making
  - Multiagent interactions
  - Social choice
  - Coalition formation
  - Resource allocation
  - Bargaining
  - Argumentation in multiagent systems
  - Logics for multiagent systems

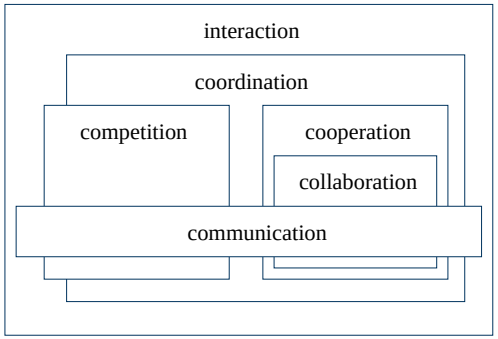
Agent interaction and communication

- So far, we have dealt exclusively with single agents
- Today's lecture marks the beginning of the second block of the course syllabus: **foundations of multiagent systems**
- We will be talking about agents interacting in a common environment
- Focus will be on different forms of interaction



Categories of agent interaction

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



Categories 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 act theory

- Most multiagent approaches to communication based on **speech act theory** (started by Austin (1962))
- Underlying 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 like “physical” actions to change the state of the world
- Speech act theory is a theory of how utterances are used to achieve one’s intentions

Speech act theory

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

Speech act theory

- Searle (1972) identified following categories of performatives:
  - 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)

Speech act theory

- Austin and Searle also analysed 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 as rational action

- 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 would 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
- Cohen and Levesque later integrated that in their model of intentions (as previously discussed)

Speech acts as rational action

- Example of the Cohen-Perrault model:

$$\begin{aligned}
&\mathit{Request}(S, H, \alpha)\\
&\quad \mathit{pre{-}can}: \ (S\ \mathit{BEL}\ (H\ \mathit{CAN}\ \alpha)) \wedge (S\ \mathit{BEL}\ (H\ \mathit{BEL}\ (H\ \mathit{CAN}\ \alpha)))\\
&\quad \mathit{pre{-}want}: \ (S\ \mathit{BEL}\ (S\ \mathit{WANT}\ \mathit{requestInstance}))\\
&\quad \mathit{effect}: \ (H\ \mathit{BEL}\ (S\ \mathit{BEL}\ (S\ \mathit{WANT}\ \alpha)))\\
&\mathit{CauseToWant}(A_1, A_2, \alpha)\\
&\quad \mathit{pre{-}can}: \ (A_1\ \mathit{BEL}\ (A_2\ \mathit{BEL}\ (A_2\ \mathit{WANT}\ \alpha)))\\
&\quad \mathit{effect}: \ (A_1\ \mathit{BEL}\ (A_1\ \mathit{WANT}\ \alpha))
\end{aligned}$$

- This has been the most influential approach to using communication in multiagent systems!

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 de-facto standard)
- FIPA=Foundation for Intelligent Physical Agents

KQML/KIF

- KQML – Knowledge Query and Manipulation Language
- An "outer" language, defines various acceptable performatives
- Example performatives:
  - `ask-if` ('is it true that...')
  - `perform` ('please perform 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
  → need content languages
- *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))`
- Can be also 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

- In recent years, FIPA started work on a program of agent standards – the centrepiece is an ACL called FIPA-ACL
- Basic structure is quite similar to KQML, but semantics expressed in a formal language called SL

```
(inform      :sender agent1 :receiver agent5
             :content (price good200 150)
             :language sl :ontology hpl-auction)
```

- ”Inform” and ”Request” basic performatives, all others (about 20) are macro definitions (defined in terms of these)
- The meaning of inform and request is defined in two parts:
  - “Feasibility precondition”, i.e. what must be true in order for the speech act to succeed
  - ”Rational effect”, i.e. what the sender of the message hopes to bring about

FIPA ACL semantics

- Assume $B_i\varphi$ means i believes φ, $Bif_i\varphi$/$Uif_i\varphi$ means i knows/is uncertain about the truth value of φ
- Basic definitions of semantics of request/inform in FIPA ACL:

  $\langle i, inform(j, \varphi)\rangle$
  feasibility precondition: $B_i\varphi \wedge \neg B_i(Bif_j\varphi \vee Uif_j\varphi)$
  rational effect: $B_j\varphi$
  $\langle i, request(j, \alpha)\rangle$
  feasibility precondition: $B_i Agent(\alpha, j) \wedge \neg B_i I_j Done(\alpha)$
  rational effect: $Done(\alpha)$

- Here, $Agent(\alpha, j)$ means that j can perform j, $Done(\alpha)$ means that the action has been done

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
- Alternative approaches use notion of **social commitments**
  - “A debtor *a* is indebted to a creditor *b* to perform action *c* (before *d*)”
  - Often public commitment stores are used to track status of generated commitments
  - At least (non)fulfilment of commitments can be verified
- This is a fundamental problem of all mentalistic approaches to communication semantics!

Ontologies

- One aspect we have not discussed so far: how can agents ensure the **terminology** they use is commonly understood?
- What are **ontologies**?
  - philosophically speaking: a theory of nature of being or existence
  - practically speaking: a formal specification of a shared conceptualisation
- Ontologies have become a prominent are of research in particular with the rise of the **Semantic Web**
- 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

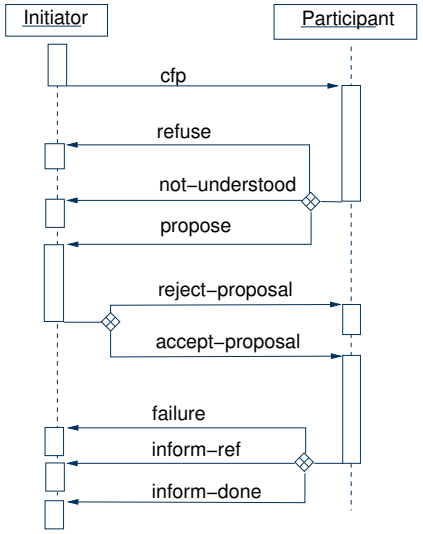
Interaction protocols

- ACLs define the syntax and semantics of individual utterances
- But they don't specify what agent *conversations* 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 constrains

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, decentralisation 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**