MINES Saint-Étienne
Une école de l'IMT

INSPIRING INNOVATION SINCE 1816

LIMOS
LABORATOIRE D'INFORMATIQUE, DE MODÉLISATION ET D'OPTIMISATION DES SYSTÈMES

Interaction-Centric Coordination

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Multi-Agent Coordination

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Outline

Introduction

Definition

General (Morin, 1977)

Interactions are **reciprocal actions** modifying the behavior or nature of elements, bodies, objects, phenomena in **presence** or **influence**.

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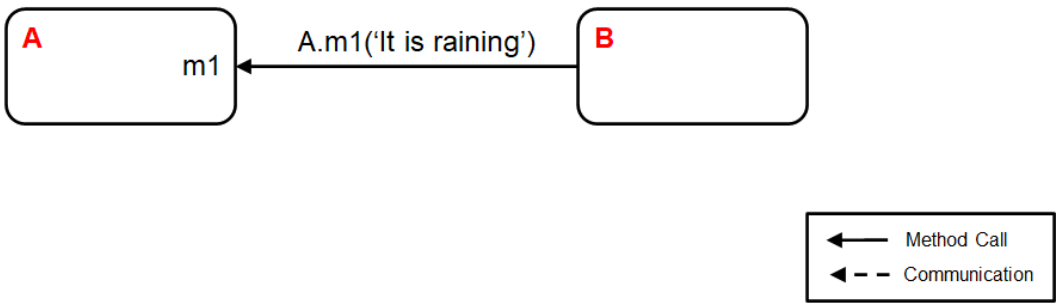

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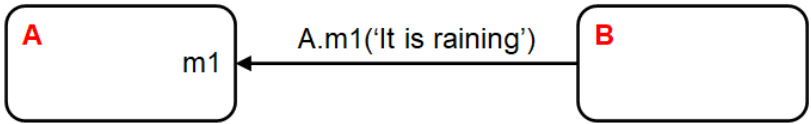
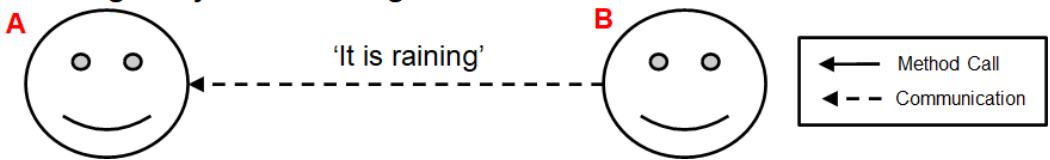


Multi-Agent Systems Paradigm



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Dynamic linking of two or more agents through **reciprocal actions**.

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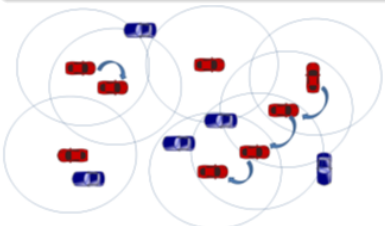

Autonomous Vehicles interact through

1. their **perceptions** of others
2. their **communications**

Definition

Four ways of interacting between agents (Werner, 1989)

- **No Communication**: agents do not communicate, they either interact by perceiving the environment or achieve their goal without any external help
- **Sending Signals**: agents synchronize by sending coded messages
- **Sending Plans**: agents transfer information concerning their tasks and beliefs
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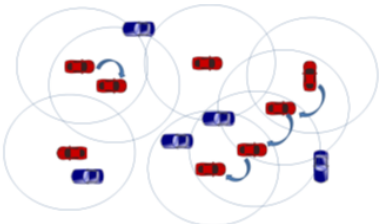

No communication: positions, movements, turn signal

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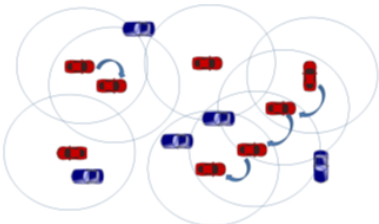

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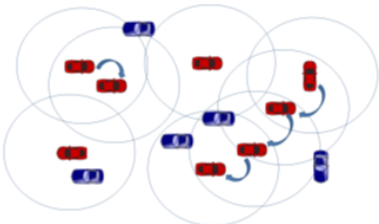

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Sending signals: honk the horn

Sending plans: send its direction at a junction

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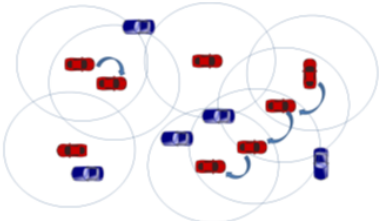

No communication: positions, movements, turn signal

Sending signals: honk the horn

Sending plans: send its direction at a junction

Sending messages: share its intention to overtake

Communication

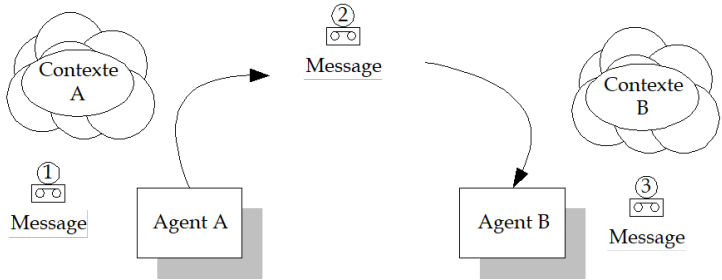

Figure: (Shannon, 1948)

Communication

The **intentional exchange of information** brought about by the **production and perception of signs** drawn from a **shared system of conventional signs** (Russel & Norvig, 2010).

Summary

- **When does an agent decide to communicate with another?**
  - Theory of Speech Act (Austin, 1962; Searle, 1969)
- **What language does the agent use to communicate?**
  - Agent communication languages like KQML (Finin et al., 1993), FIPA-ACL (FIPA, 2001)
- **What does an agent communicate about?**
  - Ontologies
- **How is the communication structured?**
  - Interaction protocols

Summary

Initial Hypothesis

A common language constitutes an interface between agents.

Syntax

How symbols are structured

Semantics

Meaning of the used symbols

Conversation

Management of message sequences

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Speech Act Theory

Introduction

- Most treatments of communication in (multi-)agent systems borrow their inspiration from the **speech act theory**
- Speech act theories are **pragmatic** theories of language, i.e., theories of language use. They attempt to account for how language is used by people every day to achieve their goals and intentions
- The origin of speech act theories are usually traced to Austin's 1962 book, *How to Do Things with Words*
- Sources of the Theory of Speech Acts (Austin, 1962; Searle, 1969; Vanderveken, 1988)

Expanded from Rosenschein's slides on Wooldridge's book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

Introduction

- Austin noticed that some utterances are rather like *physical actions* that appear to **change the state of the world**
- Examples
  - Declaring war
  - Christening
  - *I now pronounce you man and wife*
- Everything we utter is uttered with the intention of satisfying some goal

Based on Rosenschein's slides on Wooldridge's book
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Introduction

- A theory of how utterances are used to achieve goals is a **speech act theory**
- In a speech act theory, verbal actions are called **performative verbs**
- Performative verbs constitute the **building blocks** of natural language

Based on Rosenschein's slides on Wooldridge's book
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Performative Taxonomy

- **Assertives/Representatives** are used to give information about the world by asserting something. Paradigm case is *informing*.
  - 'I inform you that I'm married'
- **Directives** are used to give instructions to the recipient. Paradigm case is *requesting*.
  - 'I request you to come to my wedding'
- **Commissives** commit speakers to perform certain acts. Paradigm case is *promising*.
  - 'I promise to be faithful'
- **Expressives** are used to give the addressee information about the speaker's mental state. Paradigm case is *thanking*.
  - 'I apologize to miss your wedding'
- **Declarations** perform an act by the very fact of pronouncing the utterance. Paradigm case is *declaring*.
  - 'I marry you'

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Performatives

- The same content may have different interpretations according to the used speech act
- A says to B “go to the position p1”

Assertion	B knows that A goes to the position p1
Directive	A asks B to go to position p1
Commissive	A goes to p1
Expressive	A thinks going to p1
Declarations	???

Performative Components

- **Locutionary Component**: Production of a sentence using a given grammar and lexicon
- **Illocutionary Component**: Effect that the sender of the message wants to produce on the recipient
- **Perlocutionary Component**: Effect of the message on the recipient

Locutionary Component

Locutionary Act

The simple speech act of generating sounds that are linked together by grammatical conventions so as to say something meaningful. Among speakers of English, for example, ‘It is raining’ performs the locutionary act of saying that it is raining, as ‘Grablistrod zetagflx dapu’ would not.

Example

Act of making an utterance, e.g., ‘Please make some tea’

Illocutionary Component

Illocutionary Act

The speech act of doing something else – offering advice or taking a vow, for example – in the process of uttering meaningful language. Thus, for example, in saying 'I will repay you this money next week,' one typically performs the illocutionary act of making a promise.

Example

Action performed in saying something, e.g., 'He requested me to make some tea'

Perlocutionary Component

Perlocutionary Act

The speech act of having an effect on those who hear a meaningful utterance. By telling a ghost story late at night, for example, one may accomplish the cruel perlocutionary act of frightening a child.

Example

Effect of the act, e.g., ‘He got me to make the tea’

Example

Agent A sends the message "please, close the window, I'm cold" to the agent B

- **Locutionary Component**: Production of a sentence using a given grammar and lexicon
  - A writes the message
- **Illocutionary Component**: Effect that the sender of the message wants to produce on the recipient
  - A wants B to close the window, the strength of the message is enforced by "please"
- **Perlocutionary Component**: Effect of the message on the recipient
  - B should close the window or propose an alternative to the justification of the demand "I'm cold" for instance B could give a coat to A

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General Perspective

A speech act can be seen to have two components

- **performative verb** (e.g., request, inform, promise, . . .)
- **propositional content** (e.g., 'the door is closed')

Examples

performative = request
content = "the door is closed"
speech act = "please close the door"

performative = inform
content = "the door is closed"
speech act = "the door is closed!"

performative = inquire
content = "the door is closed"
speech act = "is the door closed?"

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Agent Communication Language

Introduction

- **Message** is the most used form of interaction among agents
- Message is a **performative** combined with a **data structure**
- Agent Communication Languages (ACLs) are standard formats for the exchange of messages
  - the definition of a **set of performatives**
  - the **data structure of the message**
- Data structures are composed of at least the following fields
  - Sender, Receiver, Language of the content, Ontology, Message content
- Most well known ACLs are
  - KQML, FIPA-ACL

KQML

Introduction

- KQML is an ‘outer’ language, that defines various acceptable ‘communicative verbs’ or performatives
  - `ask-if (‘is it true that ...’)`
  - `perform (‘please perform the action ...’)`
  - `tell (‘it is true that ...’)`
  - `reply (‘the answer is ...’)`
- KIF is a language for expressing message **content**

Performatives

Category	Name
Simple request	`evaluate`, `ask-if`, `ask-about`, `ask-one`, `ask-all`
Request with several answer	`stream-about`, `stream-all`, `eos`
Response	`reply`, `sorry`
Generic Information	`tell`, `achieve`, `cancel`, `untell`, `unachieve`
Generator	`standby`, `ready`, `next`, `rest`, `discard`, `generator`
Skill definition	`advertise`, `subscribe`, `monitor`, `import`, `export`
Network Management	`register`, `unregister`, `forward`, `broadcast`, `route`

See https://jmvidal.cse.sc.edu/talks/agentcommunication/kqmlperformatives.html for the complete list of performatives and their meanings.

Semantics

- A performative is defined with
  - **Preconditions** (Pre) define the **required states of the agents** for the creation of the message
  - **Postconditions** (Post) define the **states of the agents after** the message processing
  - **Completion** describes the expected result of the message
- Representation of the agent's knowledge
  - `Bel(A, X)`: A believes X
  - `Know(A, X)`: A knows X
  - `Intend(A, X)`: A intends to do X
  - `Want(A, X)`: A wants X

Example

Tell(A,B,X)

Pre(A): Bel(A,X) $\wedge$
Know(A,Want(B,Know(B,Bel(A,X))))

Pre(B): Intend(B, Know(B,Bel(A,X)))

Post(A): Know(A,Know(B,Bel(A,X)))

Post(B): Know(B,Bel(A,X))

Completion: Know(B,Bel(A,X))

Discussions

- Advantages
  - First agent communication “standard”
  - Several applications support KQML
  - Extensible language
    - ✓ New performatives
    - ✓ New parameters
- Limitations
  - Ambiguity and imprecision
  - Does not take into account conversation
  - Absence of performatives like Commissive performatives

FIPA

Introduction

- Foundation for Intelligent Physical Agents (FIPA)
- Benefited from the research results of KQML
- Basic structure is quite similar to KQML
  - `performative` (20 performatives)
  - `housekeeping` (e.g., sender, etc.)
  - `content` store the actual content of the message
- Explicit protocols for message exchange

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			

Message

Parameter	Category of Parameters
performative	Type of communicative acts
sender	Participant in communication
receiver	Participant in communication
reply-to	Participant in communication
content	Content of message
language	Description of Content
encoding	Description of Content
ontology	Description of Content
protocol	Control of conversation
conversation-id	Control of conversation
reply-with	Control of conversation
in-reply-to	Control of conversation
reply-by	Control of conversation

(*inform*
:sender A
:receiver B
:content (price (bid goood02) 150)
:in-reply-to round-4
:reply-with bid04
:envelope 1000
:language s1
:ontology hpl-auction
:reply-by 10
:protocol offer
:conversation-id conv02
)

Semantic Language

- Based on **mental attitudes** (beliefs, desires, etc.)
- For each act
  - **Feasibility Precondition (FP)**: Condition(s) that must be satisfied before planning to perform a speech act
  - **Rational Effect (RE)**: Effect that the agent expects, i.e., attempts to achieve with the processing of the speech act
- The use of FPs and REs implies the description of the agent's state

Receiver mental state is not taken into account as an initial condition

Semantic Language

- **Belief**: $B_i p$ "Agent i believes that the proposition p is true"
- **Uncertain**: $U_i p$ "Agent i is uncertain about the proposition p, but believes that p is more likely than non p"
- **Choice**: $C_i p$ "Agent i wishes that the proposition p is true"
- $a_1; a_2$ (Sequence), $a_1 | a_2$ (Choice)
- Feasible(a), Done(a), Agent(i, a)
- Persistent $PG_i p$, Intention $I_i p$

Semantic Language

$\langle i, \text{inform}(k, p)\rangle$

- FP: $B_i p \wedge \neg B_i(B_i \text{if}_k p \vee U_i \text{if}_k p)$
- RE: $B_k p$

$\langle i, \textit{request}(j, a)\rangle$

- FP: $B_i \text{Agent}(a, j) \wedge \neg B_i I_j \text{Done}(a)$
- RE: $\text{Done}(a)$

$\langle i, \text{query-if}(j, X)\rangle$

- FP: $\neg B_j X \wedge \neg B_j \neg X \wedge \neg U_j X \wedge \neg U_j \neg X \wedge \neg B_i I_j \text{Done}(\langle j, \text{inform-if}(i, X)\rangle)$
- RE: $\text{Done}(\langle j, \text{inform}(i, X)\rangle | \langle j, \text{inform}(i, \neg X)\rangle)$

Semantic Language

- Each performative is related to a protocol
  - Sender agent knows it has to wait an answer
  - Receiver knows how to react
- Example
  - Request
  - Auction
  - ContractNet

KQML x FIPA ACL

Comparison

- Both are identical in concepts and principles
- Both support different content languages
- Both are syntactically identical
- Both are capable of parsing messages, compose and channel them using low-level network protocol
- Both are based on the speech act theory

Comparison

KQML	FIPA ACL
Semantic description includes preconditions, postconditions and completion conditions	Semantic description includes feasibility preconditions and rational effect
KQML has facilities for agent management and communication agent	FIPA ACL considers these as services offered by basic agents rather than message layer
KQML has facilities for multiple solutions like ask-all, stream-all, etc and goal definition like achieve and unachieve	FIPA ACL does not express these concepts in ACL, but in the context of ACL messages
KQML has facility for direct belief manipulation	FIPA ACL does not have this facility
KQML uses 'sorry' for both failure and refusal	FIPA ACL has facilities like 'failure' and 'refuse'.

https://people.ucalgary.ca/~far/Lectures/SENG697/PDF/tutorials/2002/Agent_Communication_Languages_and_Protocols.pdf

Ontologies

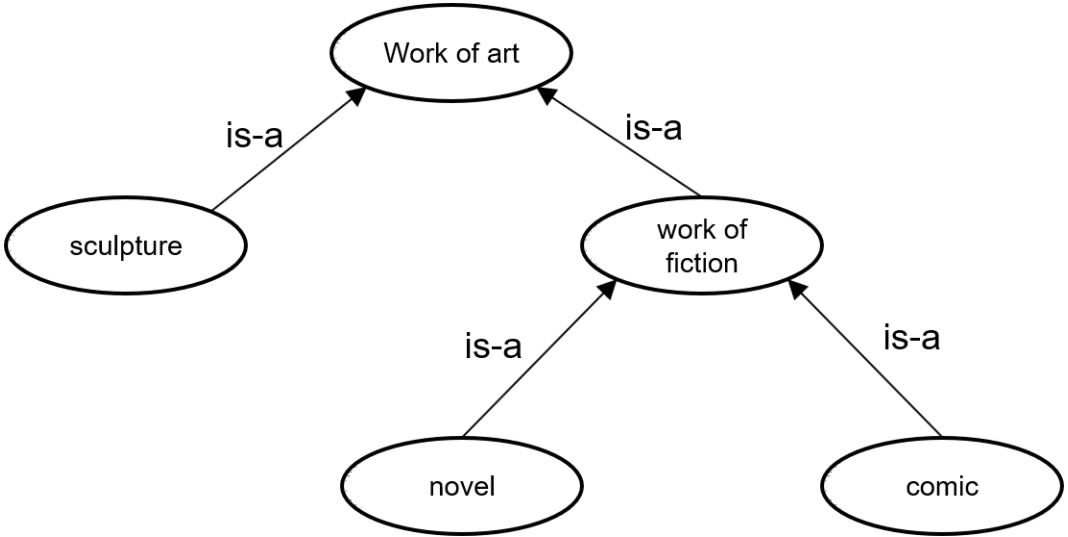
Introduction

- Agents must have agreed on a common set of terms to be able to communicate
- A **formal specification** of a **set of terms** is known as an ontology
- An ontology is intended to provide a common basis of understanding about some domain

Definition

An ontology is a **formal definition** of a **body of knowledge**. The most typical type of ontology used in building agents involves a **structural component**. Essentially a taxonomy of **class** and **subclass relations** coupled with **definitions of the relationships** between these things. (Jim Hendler) (Woodridge, 2009)

Illustration



Languages

- Traditional Ontology Languages
  - First-order predicate logic (e.g., KIF, CycL)
  - Frame-based languages (e.g., Ontolingua, F-logic, and OCML)
  - Description Logic (DL) based languages (e.g., Loom)
- Web-based Ontology Languages
  - RDF + Description Logic (e.g., OWL DL)

(Kalibatiene & Vasilecas, 2011)

Interaction Protocol

Introduction

Definition

A protocol specifies who can say what to whom and possible reactions to the message it receives

Objective

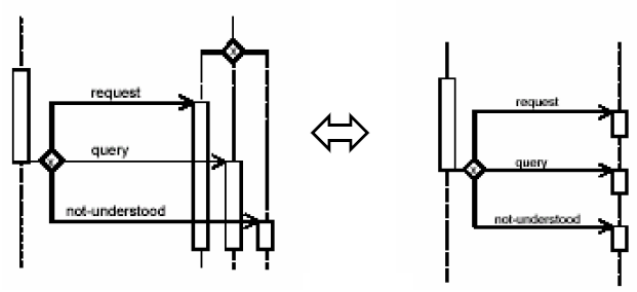
- Structure conversations
- Allow agents to know how to use speech acts

Consequences

- Restriction on the use of the speech acts
- Protocol engineering
  - Predefined protocols, Protocol definition formalism, Methodology for defining protocols

Interaction Formalism – AUML

- A protocol define a set of ordered messages exchanged between roles
- Notation
  - A vertical dimension that represents time
  - A horizontal dimension that represents the different roles
  - Logical operator: and/or
    - ✓ Temporal sequence
    - ✓ Message: alternative

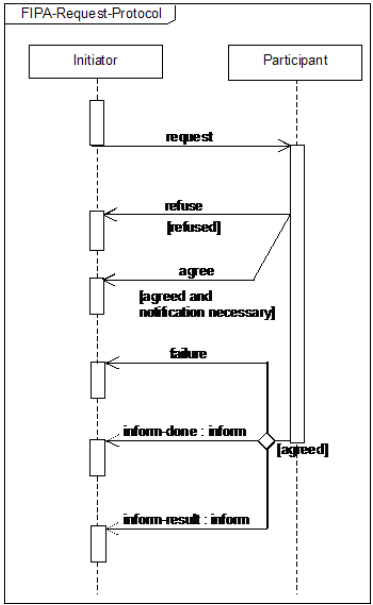


FIPA

- AUML
  (http://www.fipa.org/specs/fipa00025/XC00025E.html)
- Existing Protocols
  (http://www.fipa.org/repository/ips.php3)

Identifier	Title
SC00026	FIPA Request Interaction Protocol Specification
SC00027	FIPA Query Interaction Protocol Specification
SC00028	FIPA Request When Interaction Protocol Specification
SC00029	FIPA Contract Net Interaction Protocol Specification
SC00030	FIPA Iterated Contract Net Interaction Protocol Specification
XC00031	FIPA English Auction Interaction Protocol Specification
XC00032	FIPA Dutch Auction Interaction Protocol Specification
SC00033	FIPA Brokering Interaction Protocol Specification
SC00034	FIPA Recruiting Interaction Protocol Specification
SC00035	FIPA Subscribe Interaction Protocol Specification
SC00036	FIPA Propose Interaction Protocol Specification

FIPA – Request Protocol



FIPA – Contract Net Protocol

- How does a group of agents work together to solve a problem?
- There are two main modes of cooperative problem solving:
  - **Task Sharing**: Components of a task are distributed to component agents
  - **Result Sharing**: Information (partial results, etc.) is distributed

FIPA – Contract Net Protocol

- The **Contract Net Protocol** is a well-known task sharing protocol for task allocation
- The Contract Net Protocol is a high-level protocol for achieving efficient cooperation through task sharing (Wooldridge, 2009)
- Task distribution viewed as a kind of contract negotiation "Protocol" specifies content of communication, not just form
- Two-way transfer of information is natural extension of transfer of control mechanisms

Based on Rosenschein's slides on Wooldridge's book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

FIPA – Contract Net Protocol

- The Contract Net Protocol is carried out in 5 stages
  1. Recognize
  2. Announce
  3. Bid
  4. Award
  5. Expect

Quote from Rosenschein's slides on Wooldridge's book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

FIPA – Contract Net Protocol – Recognize

- Agent recognizes it has a problem it wants help with
- Agent has a goal, and either
  - realizes it cannot achieve the goal in isolation -— does not have capability
  - realizes it would prefer not to achieve the goal in isolation (typically because of solution quality, deadline, etc.)

Quote from Rosenschein's slides on Wooldridge's book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

FIPA – Contract Net Protocol – Announce

- In this stage, the agent with the task sends out an **announcement** of the task which includes a **specification** of the task to be achieved
- Specification must encode
  - description of task itself (maybe executable)
  - any constraints (e.g., deadlines, quality constraints)
  - meta-task information (e.g., “bids must be submitted by . . .”)
- The announcement is then **broadcast**

Quote from Rosenschein’s slides on Wooldridge’s book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

FIPA – Contract Net Protocol – Bid

- Agents that receive the announcement decide for themselves whether they wish to **bid** for the task
- Factors
  - agent must decide whether it is capable of expediting task
  - agent must determine quality constraints and price information (if relevant)
- If they do choose to bid, then they submit a **tender**

Quote from Rosenschein's slides on Wooldridge's book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

FIPA – Contract Net Protocol – Award & Expect

- Agent that sent task announcement must choose between bids and decide who to “award the contract” to
- The result of this process is communicated to agents that submitted a bid
- The successful **contractor** then expedites the task
- May involve generating further manager-contractor relationships: **sub-contracting**

Quote from Rosenschein’s slides on Wooldridge’s book
http://www.cs.ox.ac.uk/people/michael.wooldridge/pubs/imas/distrib/powerpoint-slides/

FIPA – Contract Net Protocol – Illustration

We need to arrive as soon as possible to the company but we do not have a car?

FIPA – Contract Net Protocol – Illustration

I want a Taxi !

Taxi 1

I want a Taxi !

I want a Taxi !

Taxi 3

Taxi 2

FIPA – Contract Net Protocol – Illustration

I can be there in 12m

Taxi 1

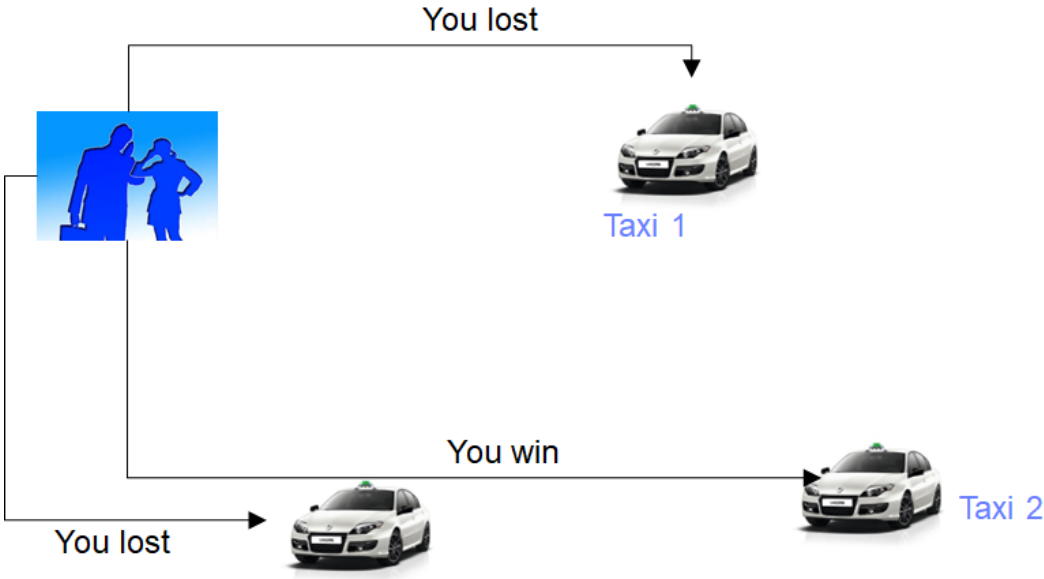
I can be there at 7m

Taxi 3

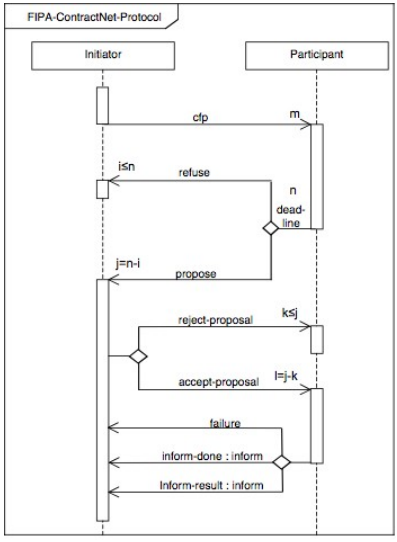
I can be there at 5m

Taxi 2

FIPA – Contract Net Protocol – Illustration



FIPA – Contract Net Protocol



http://www.fipa.org/specs/fipa00029/SC00029H.html

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