Introduction to Multi-Agent Programming

1. Agent Communication

Speech Acts, KIF, KQML, FIPA, JADE, IPC

Alexander Kleiner, Bernhard Nebel

Contents

Introduction

- Communication in concurrent systems:
  - Synchronization of multiple processes
    - E.g., solving the “lost update scenario”:
      - Two processes p_1 and p_2 access the shared variable *v*
      - During modifying of v by p_1, p_2 reads v and writes back the old value
      - Update from p_1 is lost
- Communication in OOP
  - Method invocation between different modules
    - E.g., object o1 invokes method m1 in m2: o1. m1(arg)
    - Which objects makes the decision about the execution of m1?
- Communication in MAS?
  - Autonomous agents have control over both state and behavior
  - Methods are executed according to the agent’s self-interest
  - However, agents can perform communicative actions, i.e. attempt to influence other agents
  - Agent communication implies interaction, i.e. agents perform communication acts

Speech Acts I

- Most treatment of communication in MAS is inspired from speech act theory
- *Speech act theory* treats communication as action.
  - speech actions are performed by agents just like other actions, in the furtherance of their intentions
- 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 theory of speech acts is generally recognized to have begun with the work of the philosopher John Austin: “How to Do Things with Words” (Austin, 1962).

Speech Acts II

- Austin noticed that some utterances are rather like ‘physical actions’ that appear to *change the state of the world*
- For example:
  - declaring war
  - ‘I now pronounce you man and wife’
- Austin identified a number of performative verbs, which correspond to various different types of speech acts
  - Examples of performative verbs are *request*, *inform*, and *promise*

Speech Acts III

- Searle (1969) identified the following five key classes of possible types of speech acts:
  - *Representatives:* commits the speaker to the truth of an expression, e.g., ‘It is raining’ (*informing*)
  - *Directives:* attempts to get the hearer to do something e.g., ‘please make the tea’ (*requesting*)
  - *Commissives:* which commit the speaker to do something, e.g., ‘I promise to... ’ (*promising*)
  - *Expressives:* whereby a speaker expresses a mental state, e.g., ‘thank you!’ (*thanking*)
  - *Declarations:* effect change of state, such as “declaring war” (*declaring*)

Agent Communication Languages I

KQML and KIF

- *Agent communication languages* (ACLs) are standard formats for the exchange of messages
- KSE (Knowledge Sharing Effort) in early 1990s designed two ACLs with different purpose
  - The Knowledge Query and Manipulation Language (KQML), which is an 'outer' language for agent communication
  - The Knowledge Interchange Format (KIF), a language for expressing content, closely based on First Order Logic

Knowledge Interchange Format (KIF)

- KIF allows agents to express
  - properties of things in a domain, e.g., “Michael is a vegetarian”
  - relationships between things in a domain, e.g., “Michael and Janine are married”
  - general properties of a domain, e.g., “All students are registered for at least one course”
- Examples:
  - “The temperature of m1 is 83 Celsius”:
    `(= (temperature m1) (scalar 83 Celsius))`
  - “An object is a bachelor if the object is a man and is not married”:
    ```
    (defrelation bachelor (?x) :=
      (and (man ?x) (not (married ?x))))
    ```
  - “Any individual with the property of being a person also has the property of being a mammal”:
    `(defrelation person (?x) :=> (mammal ?x))`

Knowledge Query and Manipulation Language (KQML) I

- KQML defines *communicative verbs*, or *performatives*, for example:
  - `ask-if` (‘is it true that. . . ’)
  - `perform` (‘please perform the following action. . . ’)
  - `tell` (‘it is true that. . . ’)
  - `reply` (‘the answer is . . . ’)
- Each message has performative („class“ of message) and a number of parameters

```
(ask-one
    :content (PRICE IBM ?PRICE)
    :receiver stockServer
    :language LPROLOG
    :ontology NYSE-TICKS
)
```

Asking about the price of IBM stock

Terminology

KQML II

Parameters of messages

Parameter	Meaning
`:content`	content of message
`:language`	formal language message is in
`:ontology`	terminology message is based on
`:force`	will sender ever deny content of message?
`:reply-with`	reply expected? identifier of reply?
`:in-reply-to`	id of reply
`:sender`	sender
`:receiver`	receiver

KQML III

Example dialogs

Dialogue (a)

```
(evaluate
  :sender A :receiver B
  :language KIF :ontology motors
  :reply-with q1 :content (val (torque m1)))
(reply
  :sender B :receiver A
  :language KIF :ontology motors
  :in-reply-to q1 :content (= (torque m1) (scalar 12 kgf)))
```

Talking about motors

Query reference q1

Asking about torque of motor 1

Answer: “It is 12kgf”

Dialogue (b)

```
(stream-about
  :sender A :receiver B
  :language KIF :ontology motors
  :reply-with q1 :content m1)
(tell
  :sender B :receiver A
  :in-reply-to q1 :content (= (torque m1) (scalar 12 kgf)))
(tell
  :sender B :receiver A
  :in-reply-to q1 :content (= (status m1) normal))
(eos
  :sender B :receiver A
  :in-reply-to q1)
```

Streaming of messages, e.g. request all available knowledge

Indication of “End of Stream”

KQML IV
Criticisms

- The basic KQML performative set was overly large and not standardized
  - different implementations of KQML were developed that could not, in fact, interoperate
- The language was missing the performative *commissives*
  - Commissives are crucial for agents coordinating their actions.
- These criticisms - amongst others - led to the development of a new language by the FIPA consortium

Agent Communication Languages II

Foundation for Intelligent Physical Agents (FIPA)

- FIPA is the standards organization for agents and multi-agent systems. It was officially accepted by the IEEE at its eleventh standards committee in 2005
- FIPA's goal in creating agent standards is to promote inter-operable agent applications and agent systems
- FIPA ACL's syntax and basic concepts are very similar to KQML, for example:

```
(inform
   :sender agent1
   :receiver agent2
   :content (price good2 150)
   :language sl
   :ontology hpl-auction
)
```

FIPA ACL

Set of Performatives in FIPA ACL

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			

FIPA ACL Performatives
Requesting Information

`subscribe`	sender asks to be notified when statement changes
`query-if`	direct query for the truth of a statement
`query-ref`	direct query for the value of an expression

FIPA ACL Performatives

Passing Information

`inform`	together with **request** most important performative; basic mechanism for communicating information; sender wants recipient to believe info; sender believes info itself
`inform-ref`	informs other agent about value of expression (in its content parameter); typically content of **request** message (thus asking the receiver to give me value of expression)
`confirm`	confirm truth of content (recipient was unsure)
`disconfirm`	confirm falsity of content (recipient was unsure)

FIPA ACL Performatives

Negotiation

`cfp`	call for proposals; initiates negotiation between agents; content-parameter contains action (desired to be done by some other agent) (e.g.: „sell me car“) and condition (e.g.: „price < 1000$“)
`propose`	make proposal
`accept-proposal`	sender accepts proposal made by other agent
`reject-proposal`	sender does not accept proposal

FIPA ACL Performatives

Performing Actions

request	issue request for an action
request-when	issue request to do action if and when a statement is true
request-whenever	issue request to do action if and whenever a statement is true
agree	sender agrees to carry out requested action
cancel	follows request; indicates intention behind request is not valid any more
refuse	reject request

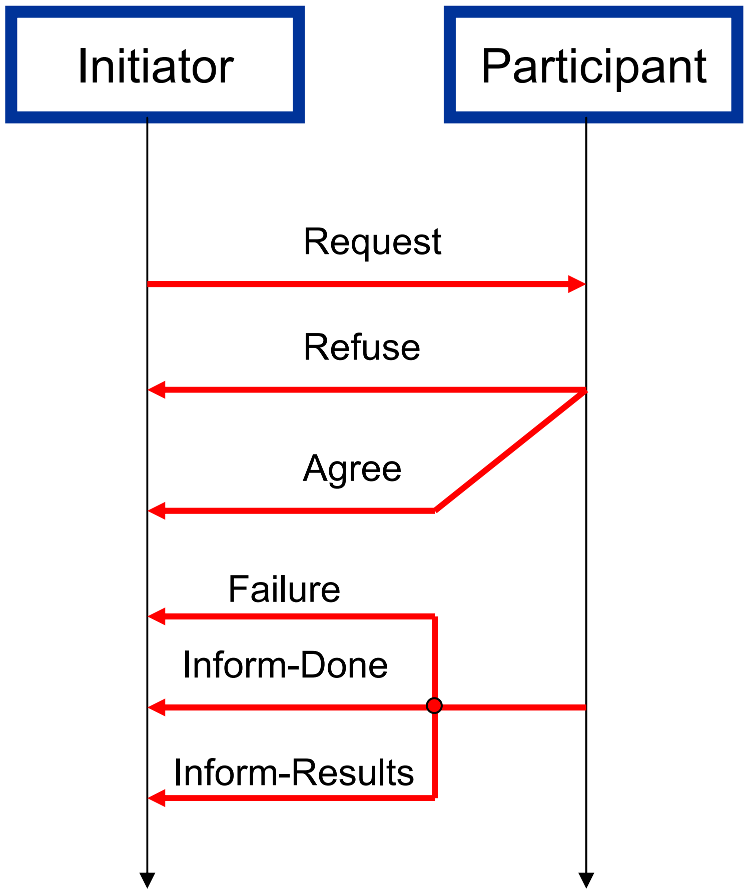
FIPA Interaction Protocols (IPs)

FIPA defined IPs are:

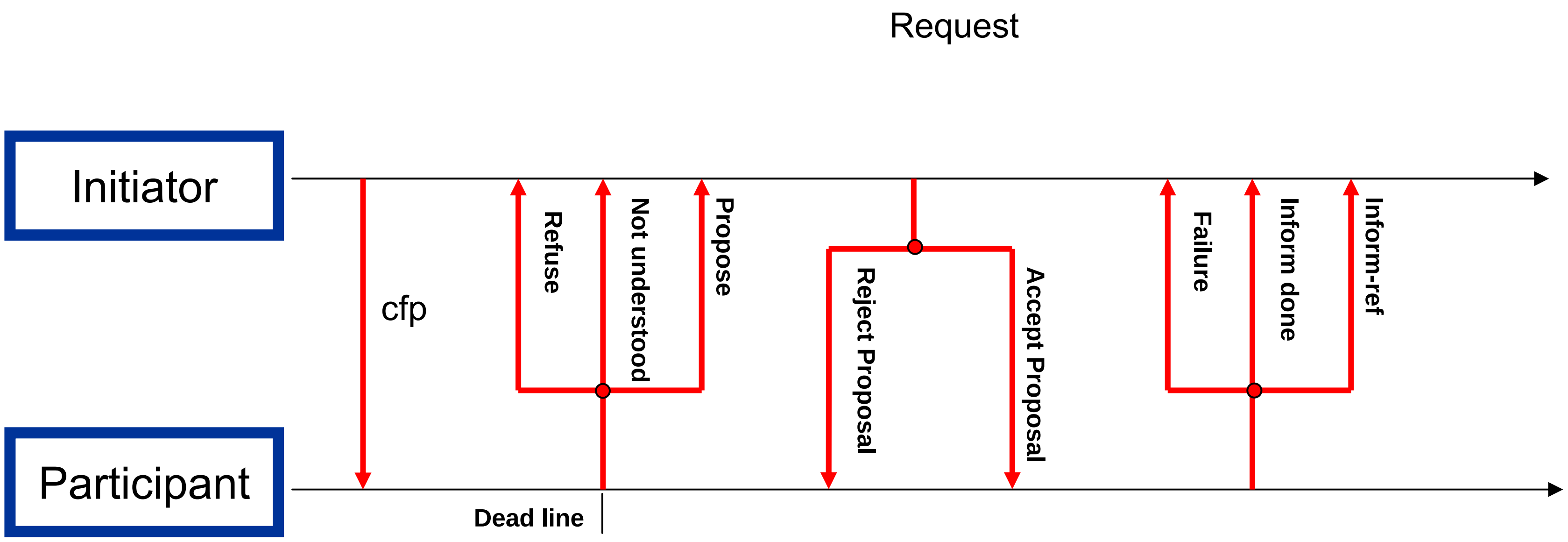
- FIPARequest
- FIPAQuery
- FIPARequestWhen
- FIPAContractNet
- FIPAIteratedContractNet
- FIPAAuctionEnglish
- FIPAAuctionDutch
- FIPABrokering
- FIPARecruiting
- FIPASubscribe
- FIPAPropose

FIPA Interaction Protocols (IPs)

FIPA IP Example: Request



FIPA Interaction Protocols (IPs)
FIPA IP Example: Contract Net



Ontologies

- Ontologies ground the terminology used by the agents
  - For example, an agent wants to buy a screw. But what means then “size”? Is it in inch or centimeter?
- Very important in the Internet, sometimes encoded by XML
  - In contrast to HTML, whose meta-language mainly describes the page layout, XML allows to tag data with semantics → semantic web

(a) Plain HTML

```
<ul>
   <li><em>Music</em>,
      <b>Madonna<b>,
      USD12<br><p>
   <li><em>Get Ready</em>,
      <b>New Order</b>,
      USD14<br><p>
</ul>
```

(b) XML

```
<catalogue>
   <product type="CD">
      <title>Music</title>
      <artist>Madonna</artist>
      <price currency="USD">12</price>
   </product>
   <product type="CD">
      <title>Get Ready</title>
      <artist>New Order</artist>
      <price currency="USD">14</price>
   </product>
</catalogue>
```

Plain HTML vs. XML

Java Agent Development Framework (JADE)

- Open Source project originated by Telecom currently governed by an International Board, e.g. Motorola, France Telecom, Whitestein, ...
- JADE allows the rapid creation of distributed, multi-agent systems in Java
- High interoperability through FIPA compliance
- JADE includes:
  - A library for developing agents (which implements message transport and parsing)
  - A runtime environment allowing multiple, parallel and concurrent agent activities
  - Graphical tools that support monitoring, logging, and debugging
  - Yellow Pages, a directory where agents can register their capabilities and search for other agents and services

JADE II
Connectivity

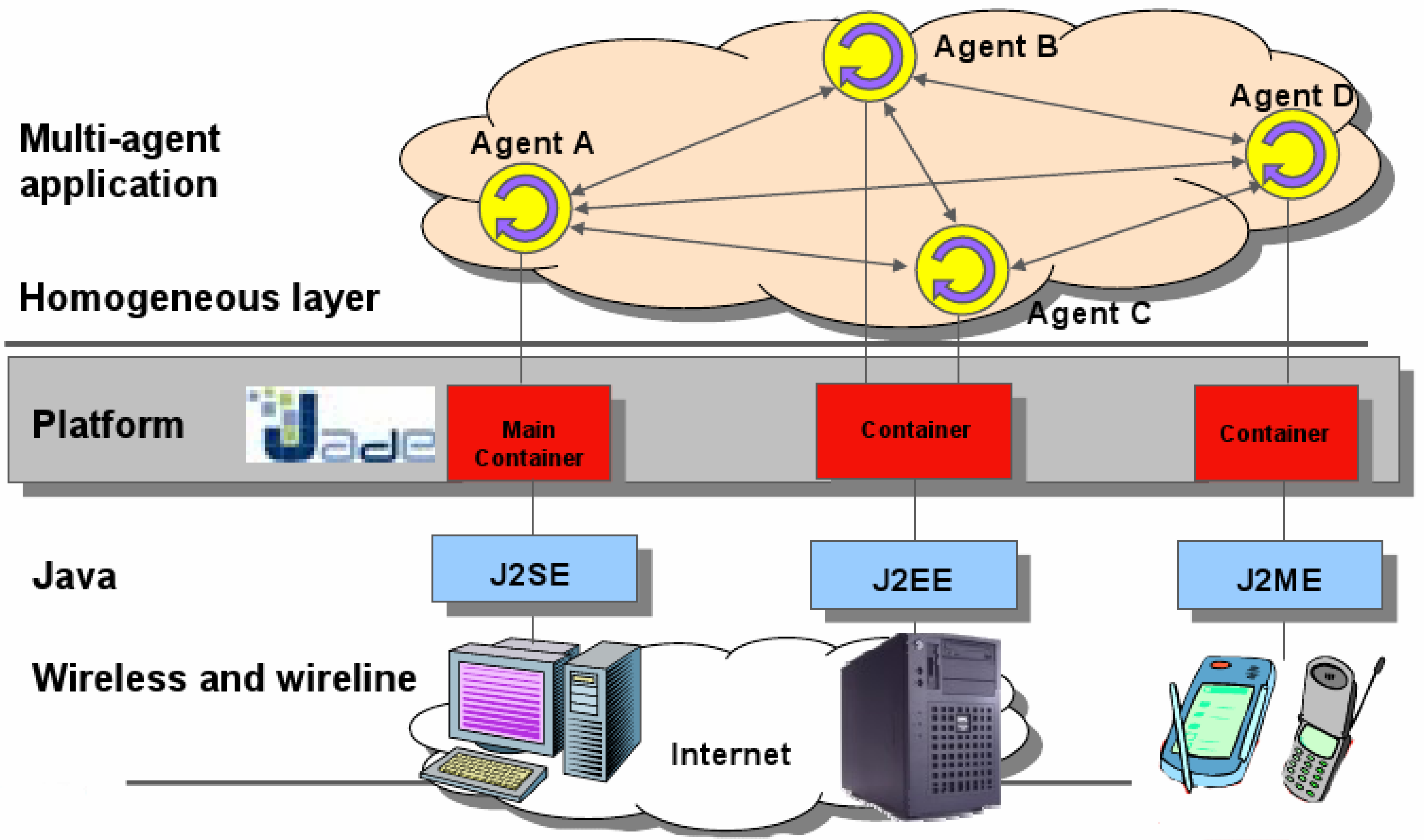


Image taken from the Jade Tutorial

JADE III
Code Example

```
public class AgentThatSearchesAndUseAService
    extends jade.core.Agent
{
    public void setup()
    {
        DFAgentDescription dfd = new DFAgentDescription();
        dfd.setType(“SearchedService");
        DFAgentDescription[] agents = DFService.search(this,dfd);
        ACLMessage msg = new ACLMessage(ACLMessage.REQUEST);
        msg.addReceiver(agents[0].getAID();
        msg.setContent(“execute service");
        send(msg);
        System.out.println(blockingReceive());
    }
}
```

Note DF means “Directory Faciliator”, an agent for accessing the yellow pages

JADE IV
Behaviors

- JADE Behaviors
  - A behavior is basically an event handler, a method which describes how an agent reacts to an event: the reception of a message or a Timer interrupt
  - The Event Handler code is placed in a method called action. Every behavior is scheduled following a round robin algorithm.
- Methods of the agents involving behaviors:
  - *addBehaviour & removeBehaviour*
- Examples of Behaviors already included in JADE:
  - SimpleBehavior - CyclicBehavior
  - TickerBehavior - WakerBehavior
  - ReceiverBehavior - SequentialBehavior
  - ParallelBehavior - FSMBehavior

JADE V

Debugging: "Dummy Agent"

- Functionalities:
  - compose and send a custom messages
  - load/save the queue of messages from/to a file

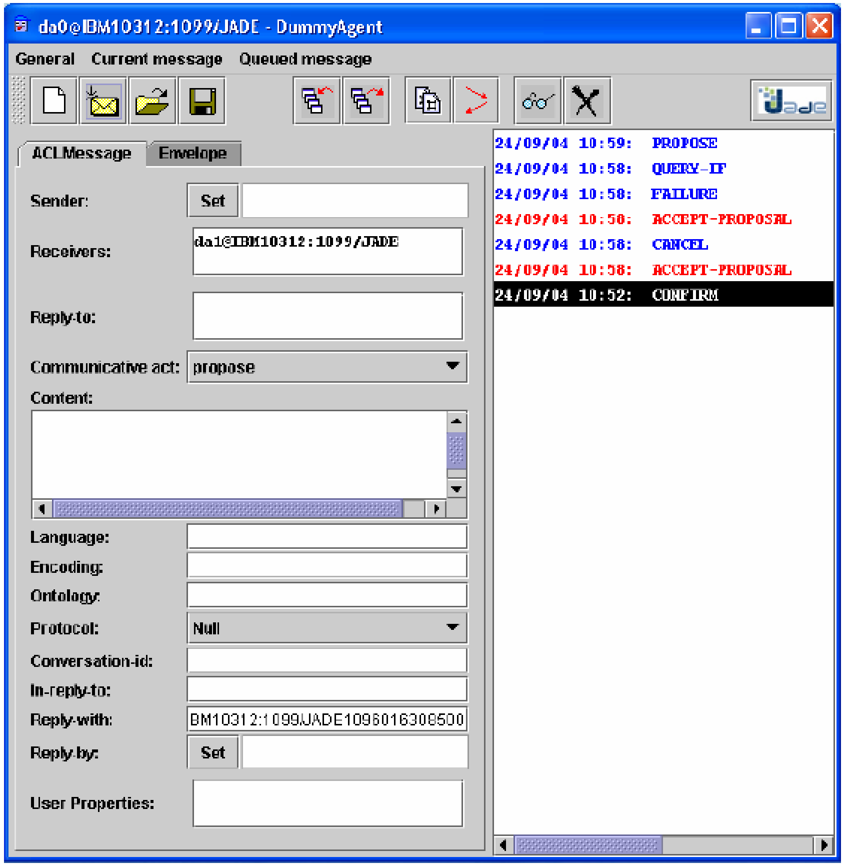


Image taken from the Jade Tutorial

JADE VI

Debugging: “Sniffer Agent”

- Functionalities:
  - display the flow of interactions between selected agents
  - display the content of each exchanged message
  - save/load the data flow

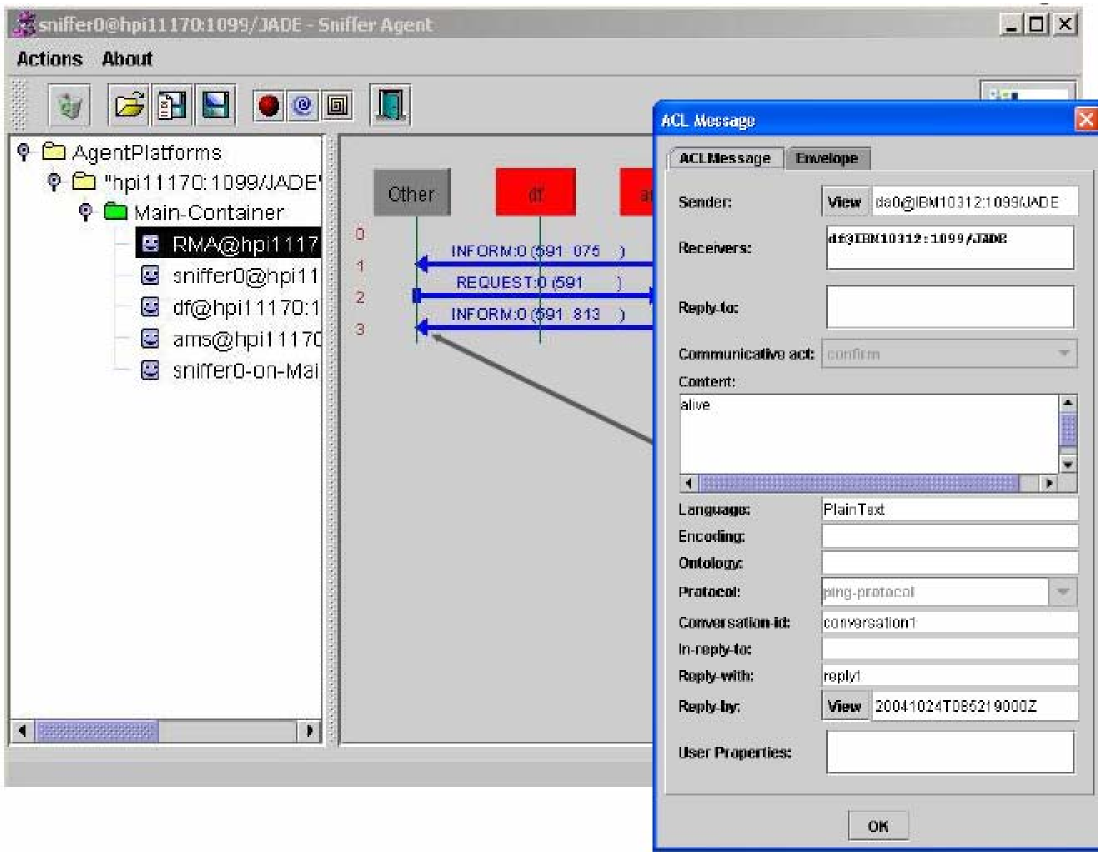


Image taken from the Jade Tutorial

JADE VII

Debugging: “Log Manager Agent”

- Functionalities:
  - browse all Logger objects on its container (both JADE-specific and application-specific)
  - modify the logging level
  - add new logging handlers (e.g. files)

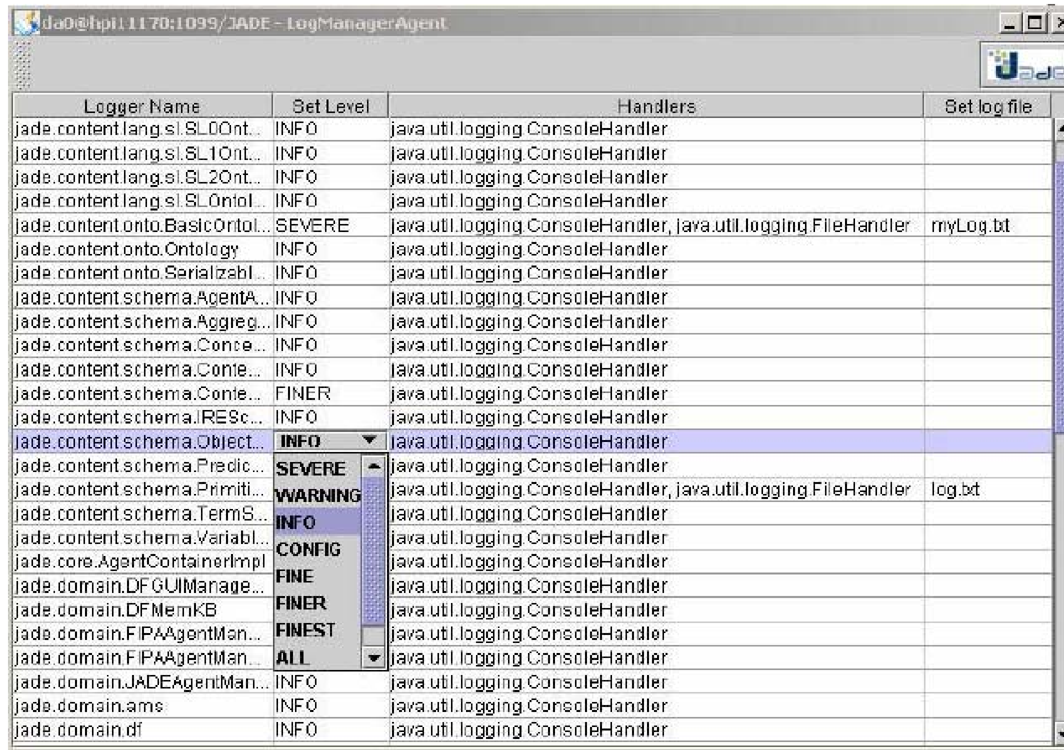


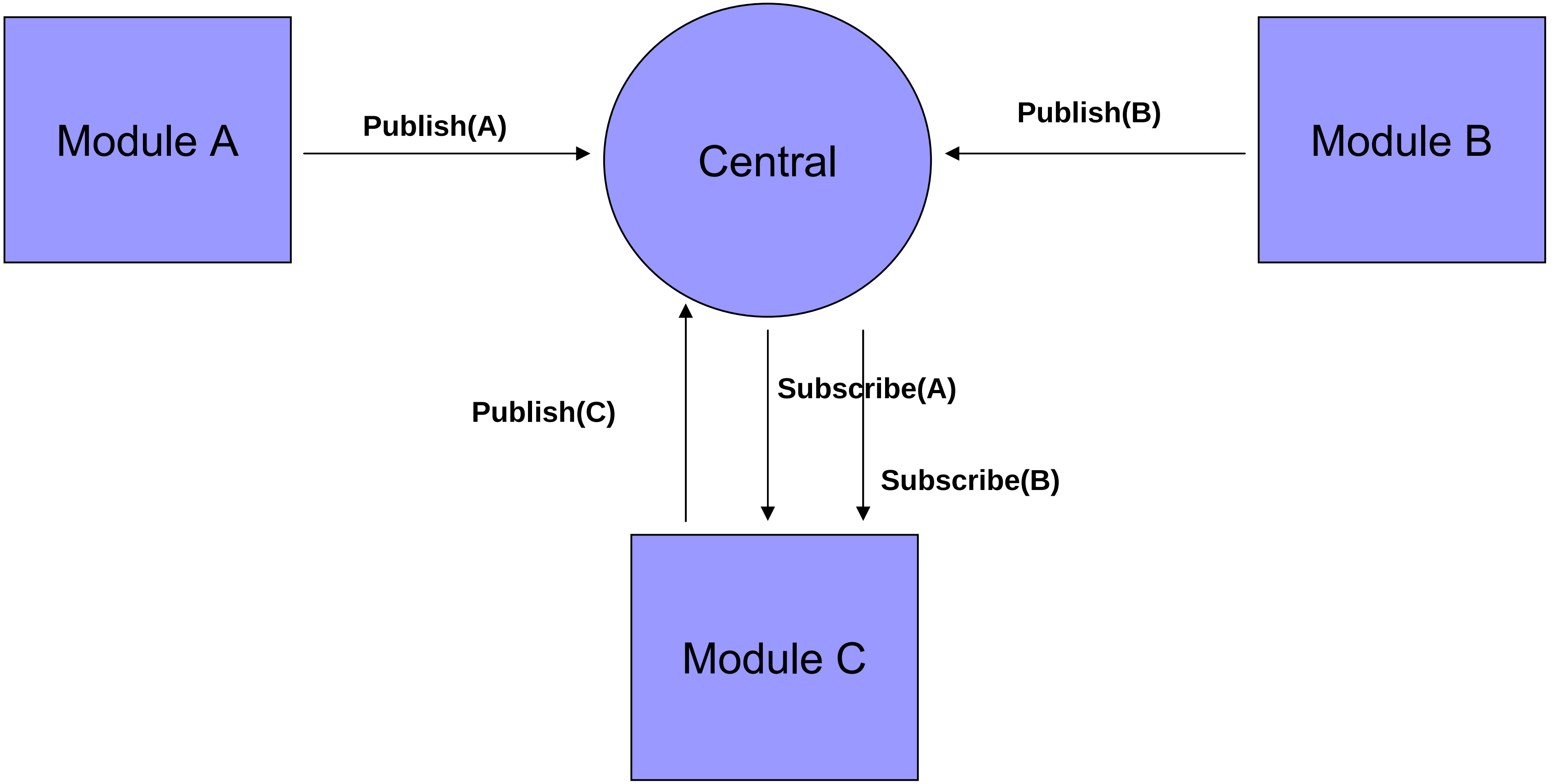
Image taken from the Jade Tutorial

Inter Process Communication (IPC)

- NOT an ACL but an efficient tool within fully cooperative & distributed environments
- Platform-independent library for distributed network-based message passing, runs with C,C++, Lisp, and JAVA
- Provided facilities for client/server and publish / subscribe communication
  - Communication takes place either point-to-point or via a "central", whereas the latter allows data logging and visualization
- Marshalling and passing of complex data structures
- Has been used by us during RoboCup, the Sick Race, and the TechX challenge

IPC Communication Models I

Publish/Subscribe

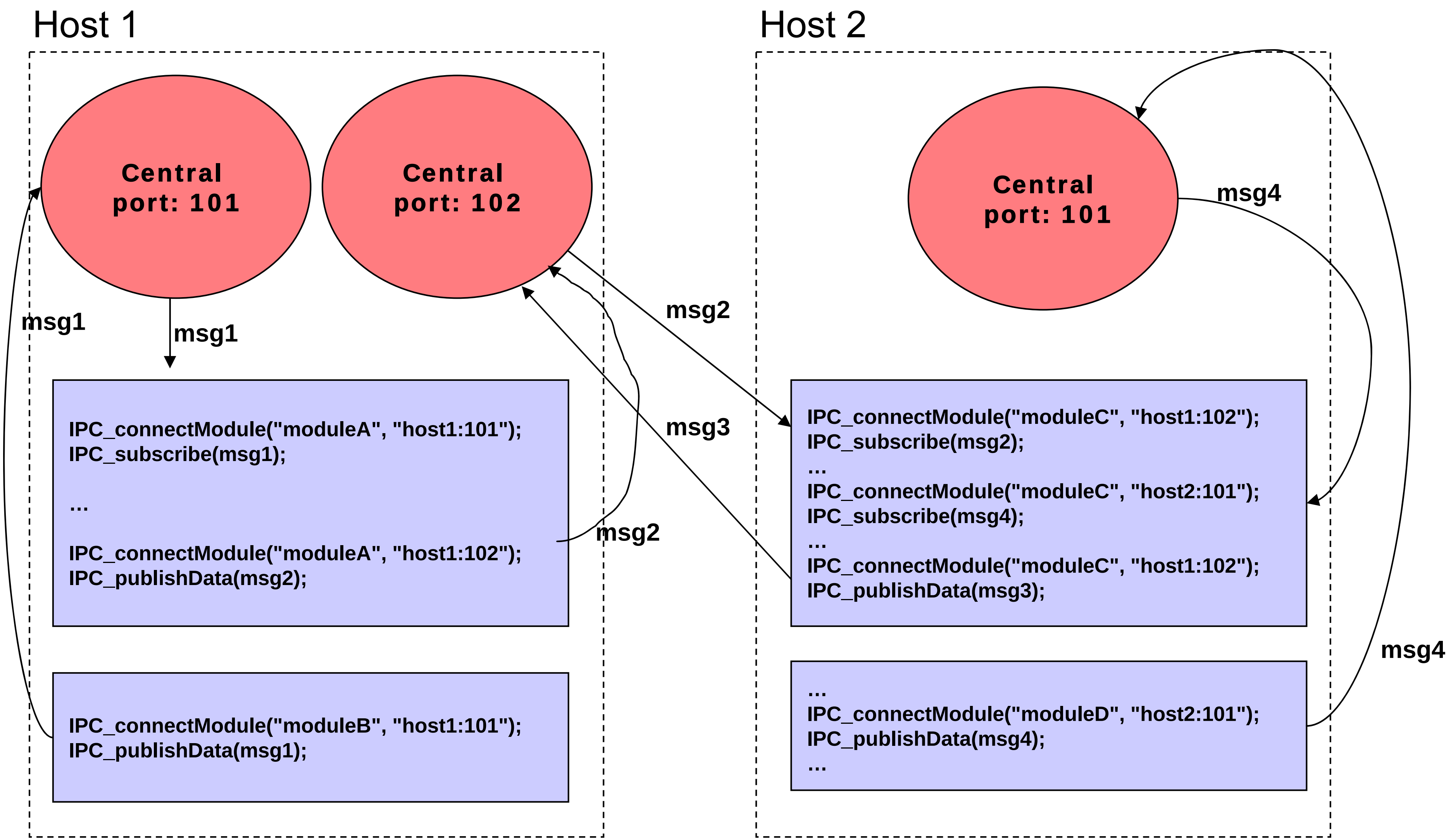


Publish / Subscribe

Module Architecture

```
module MODULE_C
static: quit, dataA, dataB
quit ← false
dataA ← NULL
dataB ← NULL

CONNECT-TO-CENTRAL()
SUBSCRIBE-HANDLER(msgHandlerA, dataA)
SUBSCRIBE-HANDLER(msgHandlerB, dataB)
DEFINE_MESSAGE(msgC)
while (not quit) do
        listen_for_messages()
        dataC ← PROCESS-DATA(dataA, dataB)
        PUBLISH-DATA(dataC)
End

Function msgHandlerA(dataA)
        UPDATE-DATA(dataA)
End

Function msgHandlerB(dataB)
        UPDATE-DATA(dataB)
End
```

Distributed execution



IPC Data Formats

Examples in C

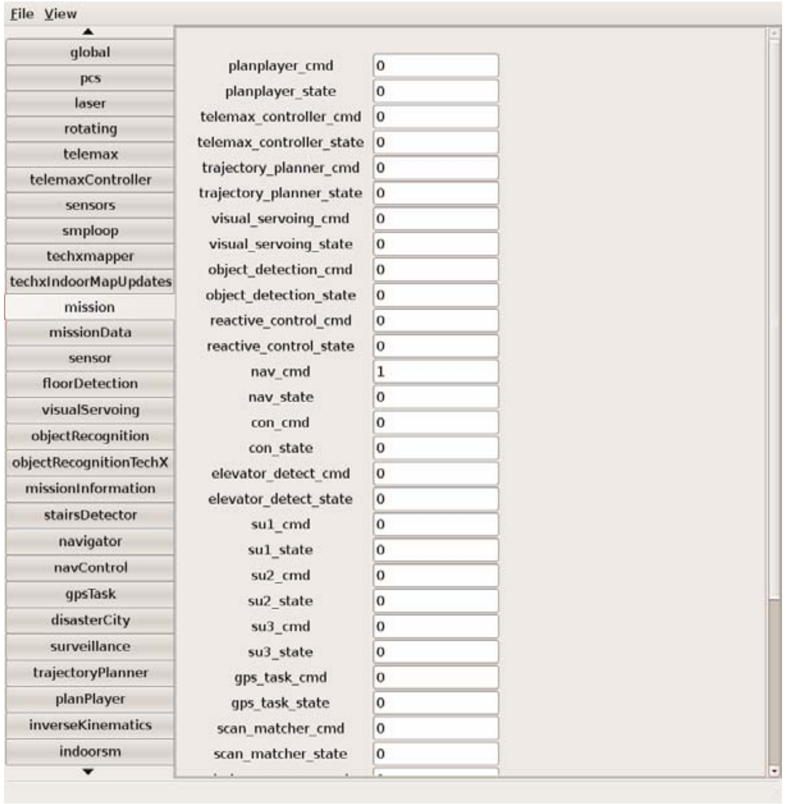
```
#define RESCUE_BATTERY_STATUS_NAME  "rescue_battery_status"
#define RESCUE_BATTERY_STATUS_FMT   "{double, double, double, string}"
typedef struct {
   double level;                ///< [V]
   double capacityLeft;         ///< [0, 1] How full is the battery (estimated)
   double timestamp;
   char* host;
} rescue_battery_status_message;


#define RESCUE_JOYPAD_BUTTON_NAME  "rescue_joypad_button"
#define RESCUE_JOYPAD_BUTTON_FMT   "{int, double, string}"
//AUTOLOGGER LOGGER_PRINTF "Jb "
typedef struct {
   int button;
   double timestamp;
   char* host;
} rescue_joypad_button_message;

...
```

IPC Communication Models II

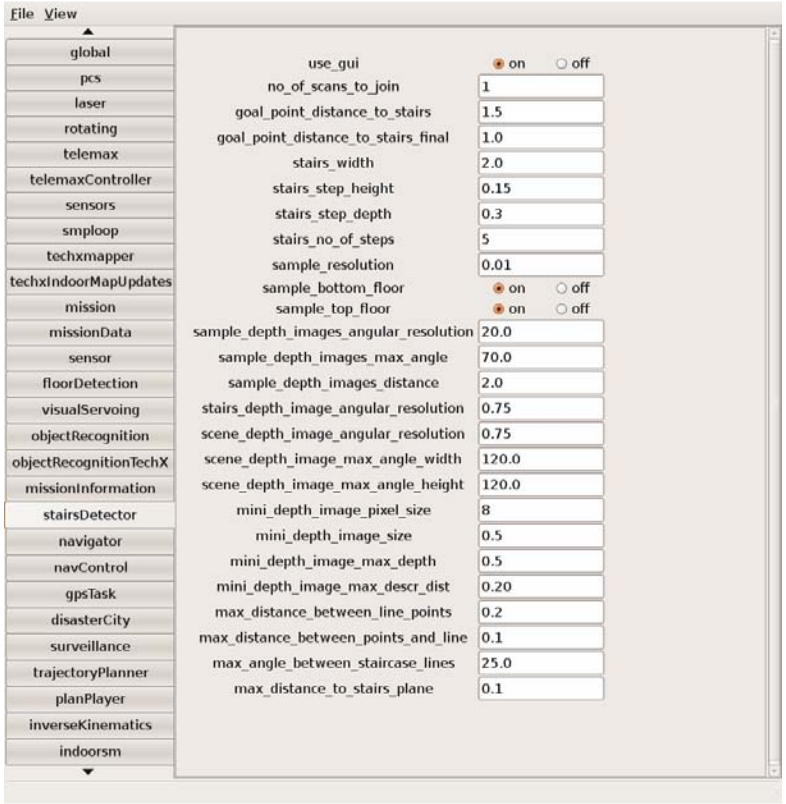
Parameter Daemon

- In a complex system composed of various modules, global parameters have to be handled somehow
- A parameter daemon is a separate module that reads parameters from a single configuration file
  - Stores specific parameters (typically fixed during runtime), but also module status information and commands (changing during runtime)
- Communication through "parameter changes"
  - Can be considered as blackboard system
  - Modules can install handler for parameter changes
- Implemented by publish/subscribe

Parameter Daemon
Examples



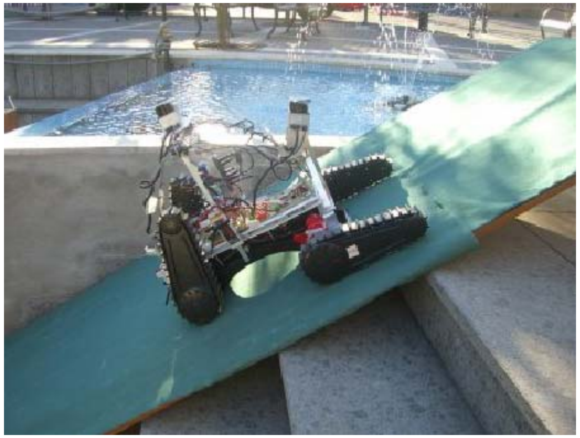
Interface for mission control: each module‘s action state can be set and the status read

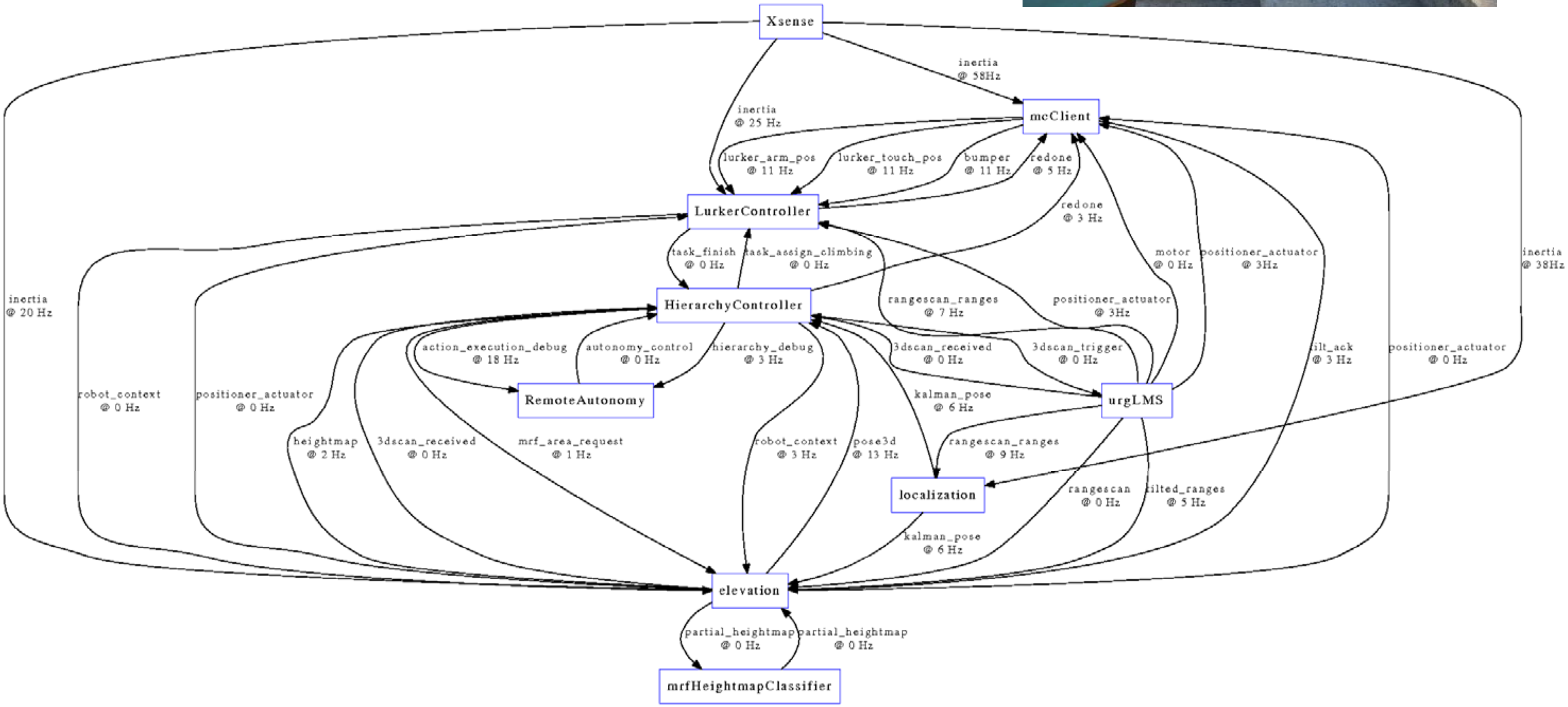


Specific parameters of “stairsDetector”

IPC Example I

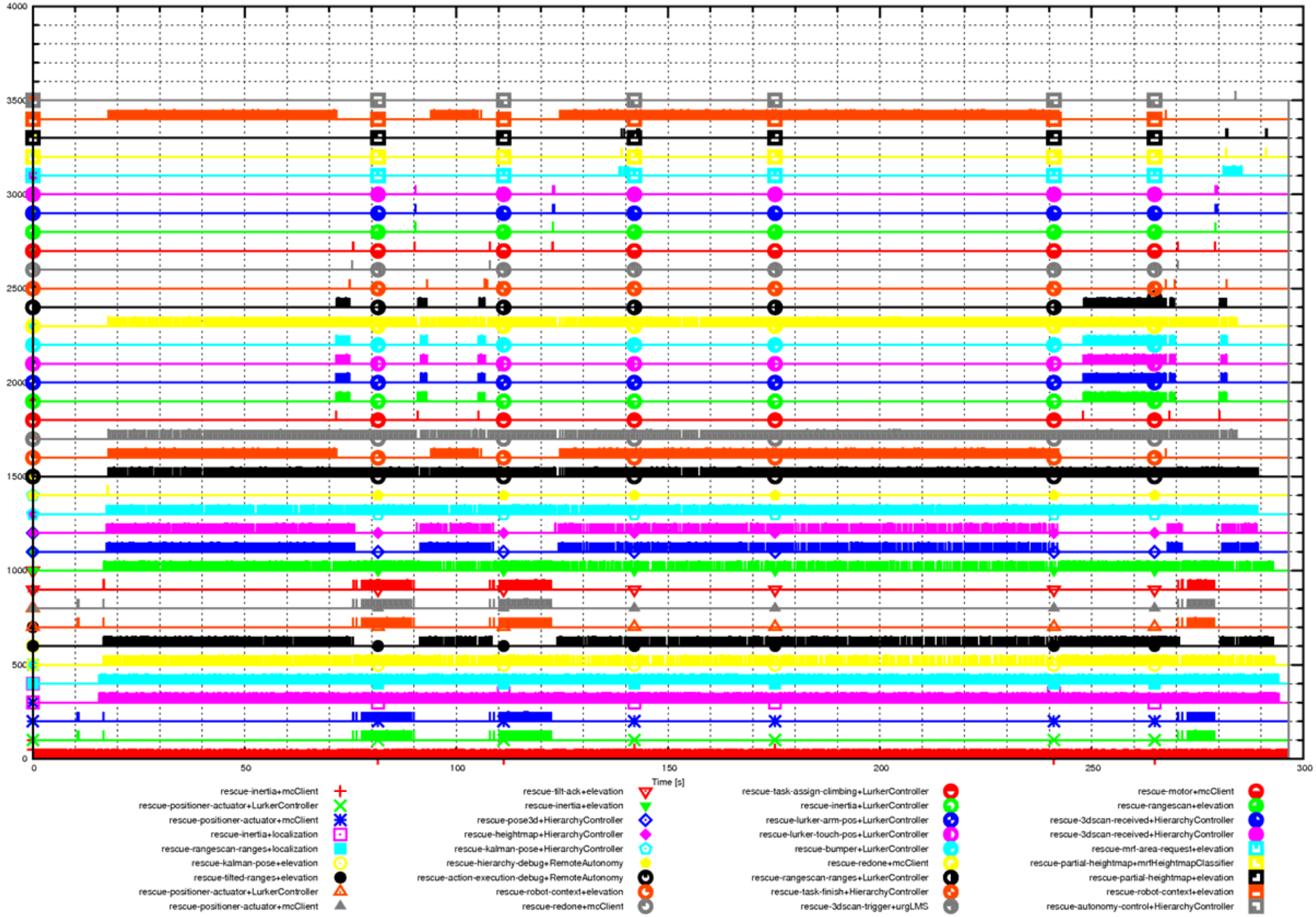
Autonomous Lurker Robot





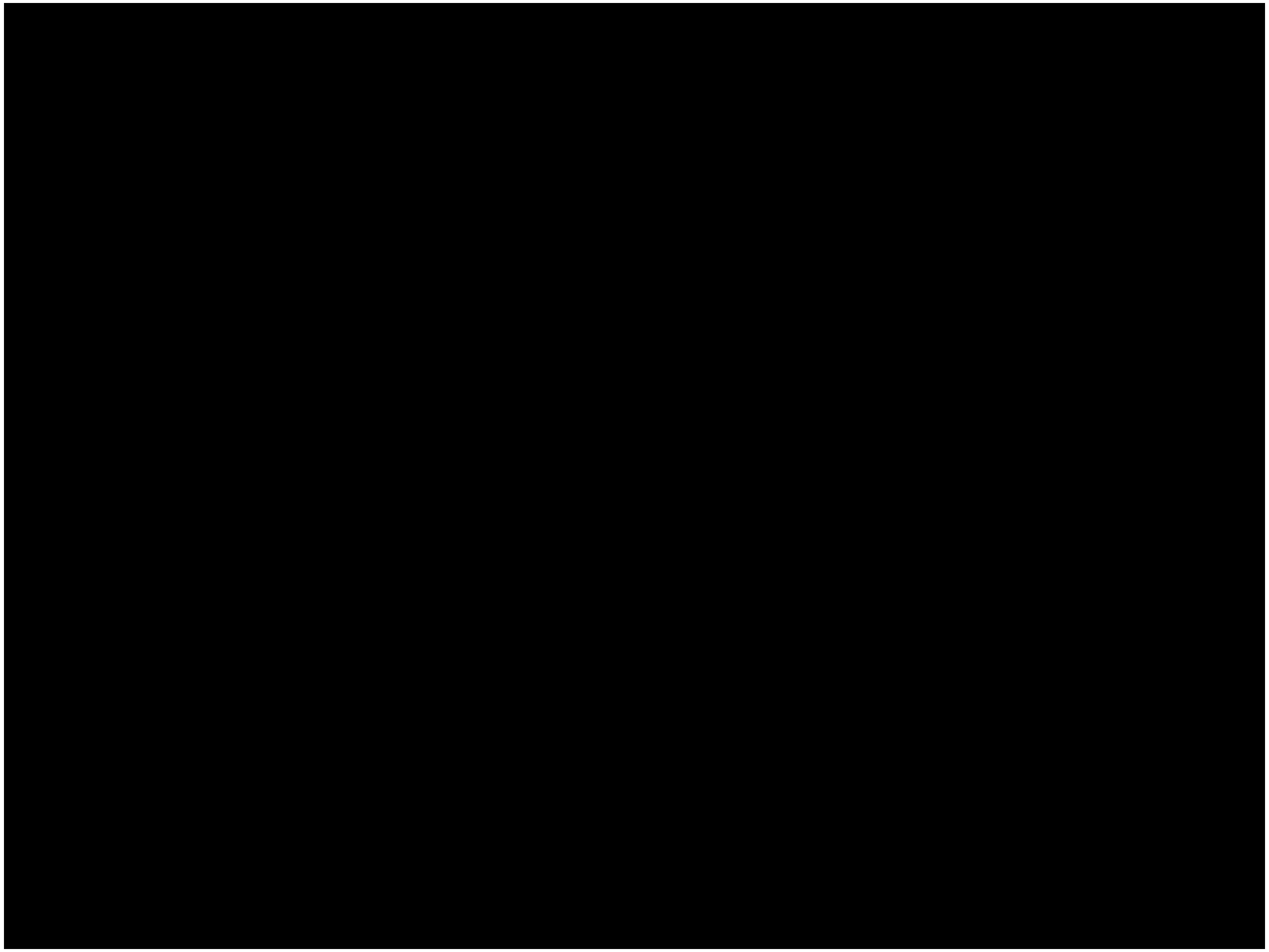
IPC Example I

Lurker Communication Graph



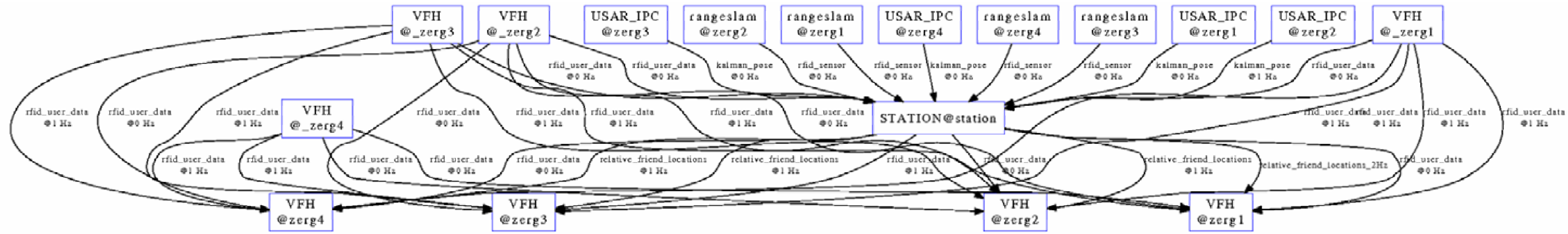
IPC Example I

Video Lurker Exploration (IROS`07)



IPC Example II

Autonomous team of Zerg Robots



Summary

- ACLs provide standards for communication among selfish agents, e.g. within an open systems
- Motivated from the theory of speech acts, communication is implemented in terms of actions
- The FIPA ACL can be considered as the de facto standard for agent communication
- IPC offers all necessary functionality within fully cooperative and distributed environments
- Although IPC is very efficient

Literature

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- Searle, J.R., **Speech Acts** *Cambridge University Press*, 1969
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  - Agent Interaction Protocols (http://www.fipa.org/repository/ips.php3)
- JADE
  - Website http://sharon.cselt.it/projects/jade/
  - Tutorial: http://www.iro.umontreal.ca/~vaucher/Agents/Jade/JadePrimer.html
- IPC:
  - Website http://www.cs.cmu.edu/afs/cs/project/TCA/www/ipc/ipc.html