

Agents & Multi-Agent Systems with JADE

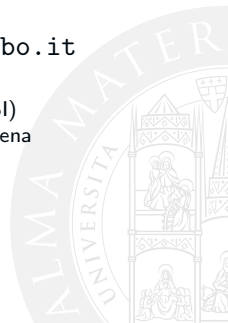
Distributed Systems / Technologies
Sistemi Distribuiti / Tecnologie

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Academic Year 2017/2018



- 1 JADE Overview
- 2 Getting Started with JADE
- 3 JADE Basics
- 4 JADE Advanced



Disclaimer

- all the material presented in these slides is rearranged by the authors starting from a collection of documents kindly made available by the JADE team
- credits for all the stuff (text & images) go to the JADE team, in particular to Giovanni Caire
- *credits for all the mistakes go to the authors of these slides*



Next in Line...

- 1 JADE Overview
- 2 Getting Started with JADE
- 3 JADE Basics
- 4 JADE Advanced



What is JADE? I

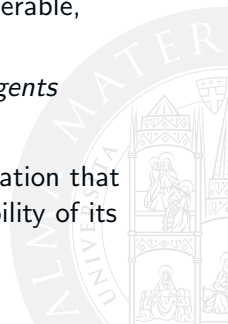
- JADE [Bellifemine et al., 2007] stands for *Java Agent DEvelopment Framework*

<http://jade.tilab.com/>

- JADE is a Java-based framework to develop agent-based applications in compliance with the **FIPA specifications** for interoperable, intelligent, multi-agent systems
- FIPA stands for *Foundation for Intelligent Physical Agents*

<http://www.fipa.org/>

- FIPA is the IEEE Computer Society standards organisation that promotes agent-based technology and the interoperability of its standards with other technologies



What is JADE? II

JADE goals

As an **agent-oriented middleware**, JADE pursues the twofold goal of being

- a full-fledged FIPA-compliant *agent platform*
 - hence, it takes charge of all those application-independent aspects – such as agent lifecycle management, communication, distribution transparency, etc. – necessary to develop a MAS
- a simple yet comprehensive *agent development framework*
 - therefore, it provides Java developers a set of APIs to build their own customisations



JADE Main Ingredients

Java

- being fully implemented in Java, JADE is a notable example of a **distributed**, **object-based**, **agent-oriented** infrastructure
- hence an interesting example about how to face a design/programming **paradigm shift**

FIPA

- being compliant to FIPA standards, JADE is a *complete* and *coherent* agent platform providing all the necessary facilities to **deploy** MAS
- promoting **interoperability**



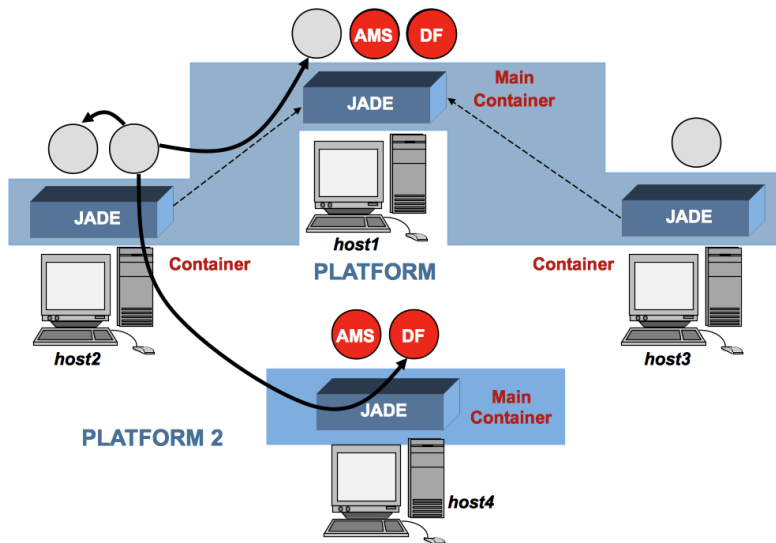
JADE Main Features

JADE offers...

- a **distributed agent platform**, where *distributed* means that a single (logical) JADE system can be split among different networked hosts
- transparent, distributed **message passing** service
- transparent, distributed **naming** service
- white pages & yellow pages **discovering** facilities
- intra-platform agent **mobility** (code & context, to some extent)
- debugging & **monitoring** graphical tools
- ... and much more



JADE Architecture Overview



Focus on. . .

- 1 JADE Overview
 - **JADE & FIPA**
 - JADE Agents
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
 - Directory Facilitator
 - FIPA Interaction Protocols in JADE
 - JADE Agents & Java Swing
 - Agent Mobility in JADE



FIPA Architecture I

Platforms & containers

- a FIPA **agent platform** can be split onto several hosts, provided that
 - each host acts as a **container** of agents—that is, provides a complete *runtime environment* for JADE agents execution (lifecycle management, message passing facilities, etc.)
 - there is (at least) one of these containers acting as the **main container** (actually, the first started)
 - the main container is responsible to maintain a *registry* of all other containers in the same JADE platform—through which agents can discover each other

→ hence, JADE promotes a peer-to-peer interpretation of a MAS



FIPA Architecture II

Agent Management System (AMS)

- for a given JADE platform, a single **Agent Management System (AMS)** exists, which
 - keeps track of all other agents in the same JADE platform—even those living in remote containers
 - should be contacted by JADE agents prior to any other action (they do not even exist until registered by the AMS)
- hence, the AMS provides the **white pages** service—that is, a *location-transparent* naming service



FIPA Architecture III

Directory Facilitator (DF)

- a single **Directory Facilitator** (DF) exists for each JADE platform that
 - keeps track of all advertised services provided by all the agents in the same JADE platform
 - should be contacted by JADE agents who wish to publish their capabilities
- hence, the DF provides the default **yellow pages** service—according to the *publish/subscribe* paradigm



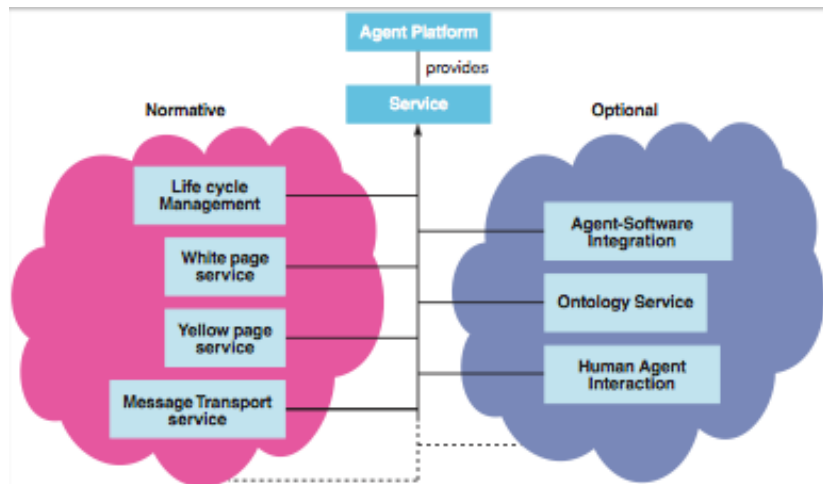
FIPA Architecture IV

Agent Communication Channel (ACC)

- for a given JADE platform, a *distributed message passing system* exists, called **Agent Communication Channel (ACC)**, which
 - controls the exchange of messages within the JADE platform, be them local or remote
 - implements all the required facilities to provide for *asynchronous* communication
 - manages all aspects regarding **FIPA ACL** (*Agent Communication Language*, [FIPA ACL, 2002]) message format, such as serialisation and deserialisation



FIPA Architecture V



FIPA required services



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- 1 JADE Overview
 - JADE & FIPA
 - **JADE Agents**
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
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Agents in JADE I

An agent is a Java object executed by a Java thread

Since JADE is an *object-based middleware*, **JADE agents** are first of all **Java objects**

- user-defined agents must extend `jade.core.Agent` class, inheriting some ready-to-use methods



Agents in JADE II

An agent is more than a Java object

Despite being Java objects, JADE agents have a wide range of features promoting their **autonomy**

- each JADE agent is executed by a single Java **thread** (with an exception, though)
- all JADE agents have a **globally unique name** (agent ID, AID), which is (by default) the concatenation – by symbol '@' – of their *local name* and of the JADE platform name
- agents *business logic* must be expressed in terms of **behaviours**
- JADE agents communicate by exchanging **FIPA ACL messages**

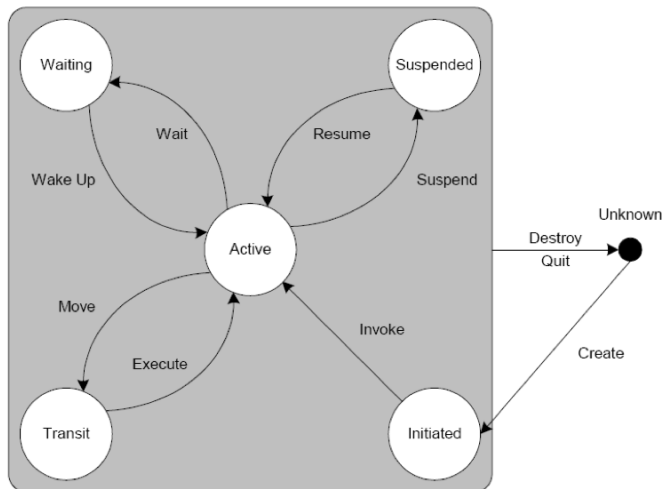


FIPA Agent's Lifecycle I

FIPA states in a JADE agent lifecycle

- Initiated** the agent object has been built, but cannot do anything since it is not registered to the AMS yet—it has no AID even
- Active** the agent is registered to the AMS and can access all JADE features—in particular, it is executing its behaviour(s)
- Waiting** the agent is blocked, waiting for something to happen (and to react to)—typically, an *ACL* message
- Suspended** the agent is stopped, therefore none of its behaviours are being executed
- Transit** the agent has started a *migration* process—it will stay in this state until migration ends
- Unknown** the agent is dead—it has been deregistered to the AMS

FIPA Agent's Lifecycle II



FIPA agent lifecycle



Agent Behaviours I

Why behaviours?

- by definition, agents are **autonomous** entities, therefore they should act independently and concurrently w.r.t. one another
- the need for *efficiency* drives toward the execution of JADE agents as a single Java thread each
- ! however, agents need to perform complex activities, possibly composed by multiple tasks—even concurrently
- ? how can such contrasting requirements be satisfied altogether?



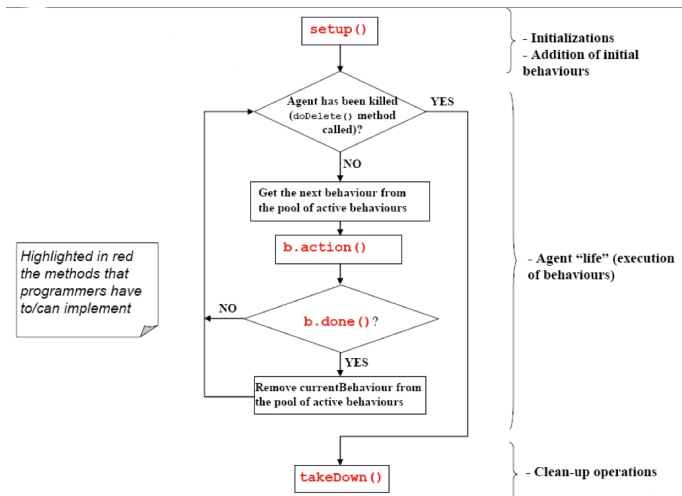
Agent Behaviours II

Concurrent agent activities with behaviours

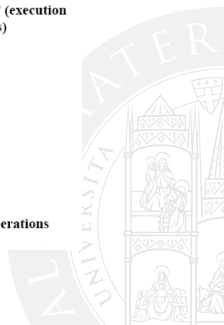
- a **behaviour** can be seen as *an activity to perform with the goal of completing a task*
- a behavior can represent a *proactive* activity – started by the agent on its own – as well as a *reactive* activity—performed in response to some events (timeouts, messages, etc.)
- ! JADE implements behaviours as Java objects, which are executed concurrently (still by a single Java thread) using a **non-preemptive, round-robin scheduler** (internal to the agent class but hidden to the programmer)



Agent Behaviours III



JADE non-preemptive scheduling policy



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- 1 JADE Overview
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 - JADE Tools
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- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
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The Agent Communication Channel (ACC) I

JADE messaging runtime

Following the FIPA specification, JADE agents communicate via **asynchronous** message passing

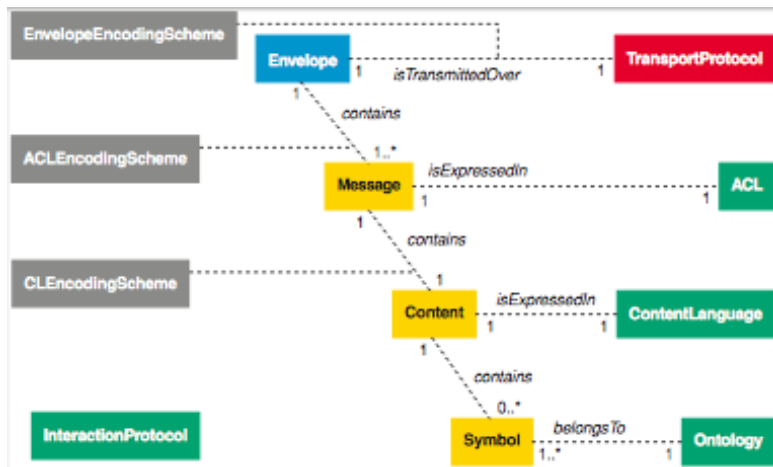
- each agent has a *message queue* (a sort of mailbox) where the JADE ACC delivers $\mathcal{ACL}$ messages sent by other agents
- whenever a new entry is added to the mailbox, the receiving agent is *notified*—it does not need to block nor to continuously ask either
 - ! *if* and *when* the agent actually processes a message is up to the agent itself (or the programmer)—for the sake of agents **autonomy**



- to understand each other

- `:sender` who sends the message—automatically set
- `:receiver` who the message targets—may be many
- `:performative` the name of the `communication act` the agents want to carry out—constrained by a FIPA ontology
- `:content` the actual information conveyed by the message
- `:language` the syntax used to encode the `:content`
- `:ontology` the semantics upon which the `:content` relies
- `:`
- `:`
- `others` fields...

The Agent Communication Channel (ACC) III



FIPA communication model abstractions



The Agent Communication Channel (ACC) IV

JADE communication primitives

- to interact, JADE agents have a number of ready-to-use methods
 - `send` to send a message to a recipient agent
 - `receive` to *asynchronously* retrieve the first message in the mailbox (if any)
 - `timed receive` to perform a *timed*, *synchronous* receive on the mailbox—timeout causes agent to resume execution
 - `selective receive` to retrieve a message from the mailbox which *matches* a given *message template*—message queue order is bypassed
- ! all the above methods are *distribution-transparent*, that is, they choose the proper address and transport mechanism based upon sender and receiver locations



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- 1 JADE Overview
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- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
 - Directory Facilitator
 - FIPA Interaction Protocols in JADE
 - JADE Agents & Java Swing
 - Agent Mobility in JADE



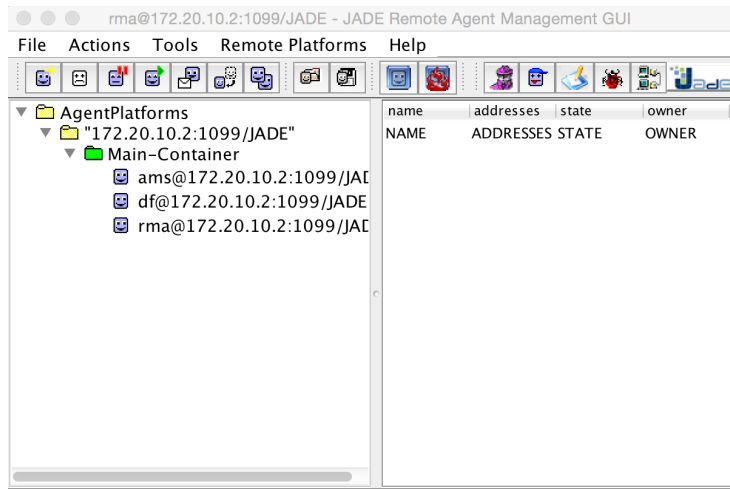
JADE Management Tools I

Remote Monitoring Agent (RMA)

- the **Remote Monitoring Agent** (RMA) enables the control of the life cycle of the agent platform and of all the registered (possibly, remote) agents
- in particular, the RMA makes it possible to
 - start, stop, kill agents
 - send them messages
 - clone and/or migrate agents
 - add, remove, shutdown (remote) platforms
 - ... and much more



JADE Management Tools II

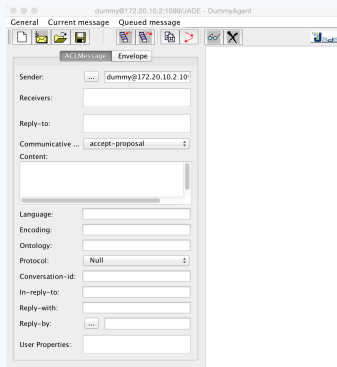


JADE RMA GUI

JADE Management Tools III

Dummy Agent

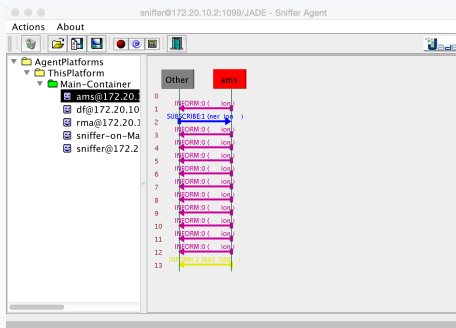
The **Dummy Agent** allows a human user to interact with JADE agents by sending, inspecting, recording custom *ACL* messages



JADE Management Tools IV

Sniffer Agent

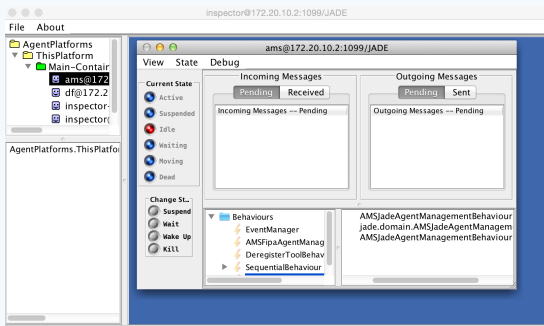
The **Sniffer Agent** allows a user to *sniff* an agent or a group of agents, which means that every message directed to/from that agent / agent group is tracked and displayed



JADE Management Tools V

Introspector Agent

The **Introspector Agent** allows to monitor and control both the queue of sent and received messages as well as the queue of behaviours—including executing them step-by-step



Next in Line...

- 1 JADE Overview
- 2 Getting Started with JADE**
- 3 JADE Basics
- 4 JADE Advanced



JADE: Where & What

JADE web page

Go to <http://jade.tilab.com>, then

- 1 hover over “Download” in the upper navigation bar, then click “Jade”
- 2 click “Continue”
- 3 scroll down—and yes, you agree
- 4 download (at least) [jadeBin](#) (or, `jadeAll` if you like more)



Running JADE I

Requirements

The only software requirement to execute JADE is [JRE version 6 or later](#)

Classpath yes

- add the `jade.jar` archive in `jade/lib/` to your JVM classpath
 - you are supposed to know how to do that
- open up your command prompt (wherever you can run java), and type
 - `java jade.Boot -gui &` to launch JADE main container with RMA attached
 - `java jade.Boot -container [-container-name name] &` to launch a *peripheral* (non-main) container (possibly with a given *name*) connected to the same JADE platform (previous main container)

Running JADE II

Classpath no

- open up your command prompt and navigate to jade/ folder, then type
 - `java -cp lib/jade.jar jade.Boot -gui &` to launch JADE main container with RMA attached
 - `java -cp lib/jade.jar jade.Boot -container [-container-name name] &` to launch a *peripheral* (non-main) container (possibly with a given *name*) connected to the same JADE platform (previous main container)



Running JADE III

Default ports

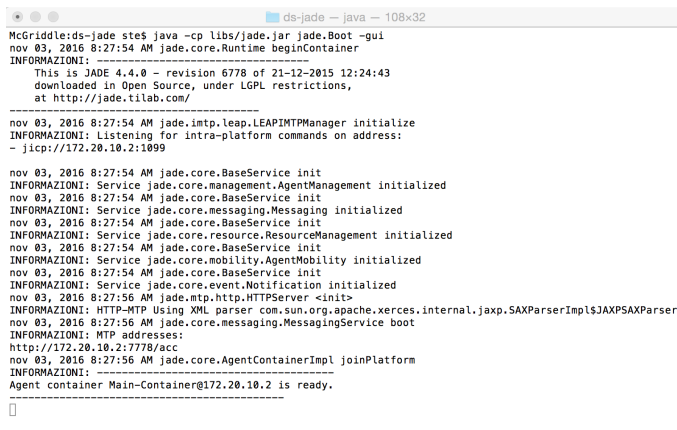
port 1099 is the default main container listening TCP port for intra-platform (remote) communications

port 7778 is the default main container listening port for inter-platform communications (HTTP is the default MTP)



What to Expect I

- if you launched the main container, the RMA GUI should show up and something like this should appear on the command prompt



```

ds-jade - java - 108x32
McGriddle:ds-jade ste$ java -cp libs/jade.jar jade.Boot -gui
nov 03, 2016 8:27:54 AM jade.core.Runtime beginContainer
INFORMAZIONI: -----
This is JADE 4.4.0 - revision 6778 of 21-12-2015 12:24:43
downloaded in Open Source, under LGPL restrictions,
at http://jade.tilab.com/
-----
nov 03, 2016 8:27:54 AM jade.imtp.leap.LEAPIMTPManager initialize
INFORMAZIONI: Listening for intra-platform commands on address:
- jicp://172.20.10.2:1099

nov 03, 2016 8:27:54 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.management.AgentManagement initialized
nov 03, 2016 8:27:54 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.messaging.Messaging initialized
nov 03, 2016 8:27:54 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.resource.ResourceManagement initialized
nov 03, 2016 8:27:54 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.mobility.AgentMobility initialized
nov 03, 2016 8:27:54 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.event.Notification initialized
nov 03, 2016 8:27:56 AM jade.mtp.http.HTTPServer <init>
INFORMAZIONI: HTTP-MTP Using XML parser com.sun.org.apache.xerces.internal.jaxp.SAXParserImpl$JAXPSAXParser
nov 03, 2016 8:27:56 AM jade.core.messaging.MessagingService boot
INFORMAZIONI: MTP addresses:
http://172.20.10.2:7778/acc
nov 03, 2016 8:27:56 AM jade.core.AgentContainerImpl joinPlatform
INFORMAZIONI: -----
Agent container Main-Container@172.20.10.2 is ready.
  
```

What to Expect II

- if you launched a peripheral container, the RMA GUI should self-update and something like this should appear on the command prompt

```

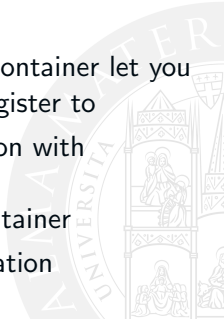
ds-jade - java - 108x32
java ... java +
McGriddle:ds-jade ste$ java -cp libs/jade.jar jade.Boot -container
nov 03, 2016 8:29:32 AM jade.core.Runtime beginContainer
INFORMAZIONI: -----
                This is JADE 4.4.0 - revision 6778 of 21-12-2015 12:24:43
                downloaded in Open Source, under LGPL restrictions,
                at http://jade.tilab.com/
                -----
nov 03, 2016 8:29:32 AM jade.imtp.leap.LEAPIMTPManager initialize
INFORMAZIONI: Listening for intra-platform commands on address:
- jicp://172.20.10.2:58263

nov 03, 2016 8:29:32 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.management.AgentManagement initialized
nov 03, 2016 8:29:32 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.messaging.Messaging initialized
nov 03, 2016 8:29:32 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.resource.ResourceManagement initialized
nov 03, 2016 8:29:32 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.mobility.AgentMobility initialized
nov 03, 2016 8:29:32 AM jade.core.BaseService init
INFORMAZIONI: Service jade.core.event.Notification initialized
nov 03, 2016 8:29:32 AM jade.core.AgentContainerImpl joinPlatform
INFORMAZIONI: -----
Agent container Container-1@172.20.10.2 is ready.
  
```

Some Notes

- option `-name` when launching the main container lets you give a name to the JADE platform
- option `-container-name` when launching a peripheral container lets you choose a name for that container
- options `-local-host` / `-local-port` when launching the main container let you choose a custom host / listening port for the JADE platform
- options `-host` / `-port` when launching a peripheral container let you specify where to find the remote main container to register to
- option `-agents` *name:full-class-name* in conjunction with `-container` launches the agent implemented in class *full-class-name* on the newly-created peripheral container
- for other options, please refer to the JADE documentation

[Bellifemine et al., 2010b]



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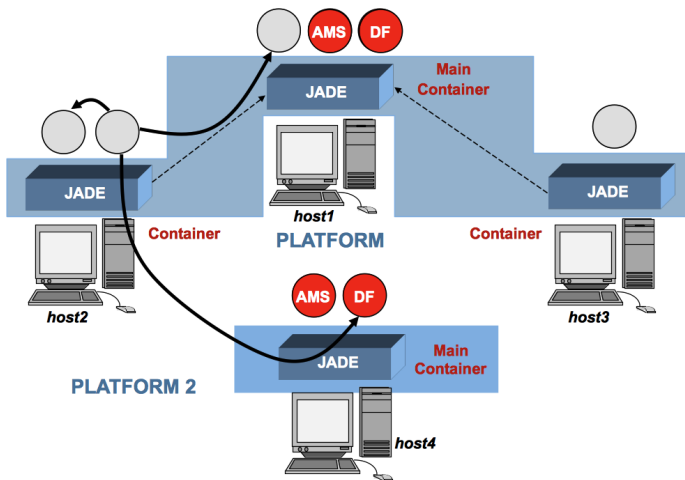


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- 1 JADE Overview
 - JADE & FIPA
 - JADE Agents
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - **JADE Architecture**
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
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JADE Architecture: Recap I



JADE Architecture: Recap II

Containers

- **agents runtimes**, the *environments* without which agents cannot exist
- *one* main container for *each* JADE platform. . .
- . . . but many peripheral containers may coexist in the same platform and in the same host too
- they automatically register themselves to the (default/given) main container
- one single JVM executed per host/platform (2 JADE on the same host are 2 JVM)



JADE Architecture: Recap III

Agent Management System (AMS)

- JADE *white pages* service
- *one* AMS service (agent) for *each* JADE platform
- always runs in the main container
- is contacted (automatically) by every JADE agent upon start...
 - AMS `register()` method called prior to agent `setup()` abstract method being called by the container
- ...and death
 - `deregister()` called after `takedown()`



JADE Architecture: Recap IV

Agent Communication Channel (ACC)

- JADE *distributed, location-transparent* **messaging service**
- **asynchronous** by default (uncoupling for agents autonomy)
- also supporting *synchronous communication*, if required
- compliant to FIPA *ACL* message format

Directory Facilitator (DF)

- JADE **yellow pages** service
- similar to the AMS agent
 - *one* DF service (agent) for *each* JADE platform
 - always runs in the main container
- except that it should be explicitly contacted by *advertising* and *client* agents upon need—*public/subscribe* pattern

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- 1 JADE Overview
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 - JADE ACC
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- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - **JADE Agents**
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
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JADE Agents: Recap

JADE agents

- instances of `jade.core.Agent`-derived classes
- `single-threaded`, *multitasking* computational model based on concurrent behaviours
- *asynchronous* communication model based on FIPA *ACL* messages
- FSM-like lifecycle with public methods to perform state transitions
- `jade.core.AID` class implements the globally unique naming service
 - agent name of the kind `<localname>@<platformname>`
 - pool of platform addresses, only used for *inter-platform* communications



Agents Lifecycle

Lifecycle methods

- `doActivate()` from SUSPENDED to where it was when `doSuspend()` was called
- `doDelete()` from either state to UNKNOWN
 - `doWait()` from ACTIVE to WAITING
- `doSuspend()` from ACTIVE or WAITING to SUSPENDED
 - `doWake()` from WAITING to ACTIVE
 - `doMove()` from either state to TRANSIT
 - `doClone()` same as `doMove()`



Agents Execution I

Starting agents

Agents are launched with command

```
java -cp ... jade.Boot ... -agents <name>:<class>
```

(or, from the RMA GUI)

- 1 the agent constructor is executed
- 2 the proper AID is given by the platform
- 3 registration to the AMS is done calling `register()` method
- 4 the agent is put in the ACTIVE state
- 5 `setup()` is executed
- 6 then, behaviours **scheduling** begins



Agents Execution II

Stopping agents

Agents can be stopped by any of their behaviours calling the `doDelete()` method

- 1 prior to go into UNKNOWN state, the abstract method `takeDown()` is called by the platform to allow application specific clean-up
- 2 upon its completion, the agent is deregistered from the AMS calling `deregister()` method
- 3 the agent is put into the UNKNOWN state
- 4 the thread executing the agent is destroyed



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- 1 JADE Overview
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 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - **Agent Behaviours**
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
 - Directory Facilitator
 - FIPA Interaction Protocols in JADE
 - JADE Agents & Java Swing
 - Agent Mobility in JADE



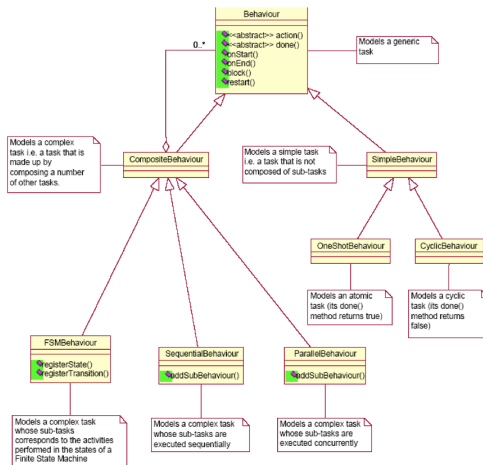
JADE Behaviours: Recap

JADE behaviours

- instances of `jade.core.behaviours.Behaviour`-derived classes
- executed concurrently according to a **round-robin, non-preemptive** scheduler internal to agents—thus, hidden to programmers
- everything is still *single-threaded*. . .
 - method `action()` should be overridden to carry out the application-specific task
 - method `done()` should be overridden too to check such task termination condition



(Simplified) Behaviours Hierarchy



Behaviour API I

```
jade.core.behaviours
```

All behaviours are in package `jade.core.behaviours`

SimpleBehaviour

- `OneShotBehaviour`

- method `action()` is executed only once...
- ...hence, method `done()` always returns `true`

- `CyclicBehaviour`

- method `done()` always returns `false`...
- ...hence, method `action()` is executed forever—until agent death



Behaviour API II

CompositeBehaviour: sequential vs. parallel

- **SequentialBehaviour**

- method `addSubBehaviour()` to add *child* behaviours...
- ...to be scheduled *sequentially*—method `done()` drives progress
- the whole behaviour ends when the last child ends

- **ParallelBehaviour**

- method `addSubBehaviour()` to add *child* behaviours...
- ...to be scheduled *concurrently*
- two termination conditions provided by default—through constants
 - `WHEN_ALL` children are done
 - `WHEN_ANY` child is done

other conditions may be implemented by the programmer exploiting JADE API—see `checkTermination()` method



Behaviour API III

CompositeBehaviour: FSM

- **FSMBehaviour**

- method `registerState()` to add a child behaviour to the FSM
 - each child represents the activity to be performed within a state of the FSM
- method `registerTransition()` to add a transition
 - the value returned by the `onEnd()` *callback* method is used to select the transition to fire
- some of the children can be registered as *final states*...
- ...hence, the whole behaviour terminates after the completion of any of them



Behaviour API IV

Other behaviours

Many other very useful abstract behaviours exist, such as

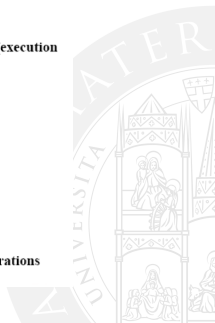
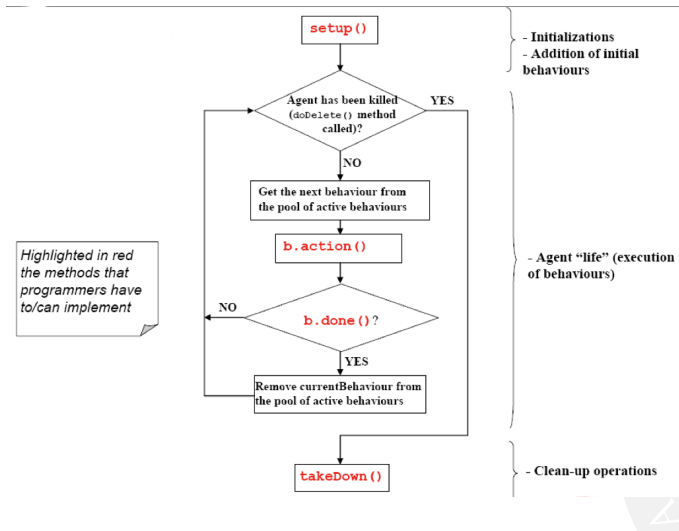
- **WakerBehaviour**
 - methods `action()` and `done()` are already implemented, so to execute abstract method `onWake()` when specified, then terminate
- **TickerBehaviour**
 - methods `action()` and `done()` are again already implemented, so to execute abstract method `onTick()` periodically as specified, then terminate when abstract method `stop()` is called
- ...

Please refer to the JADE Programmer's Guide for the others

[Bellifemine et al., 2010a]



Behaviours Scheduling: Recap



Round-Robin, Non-Preemptive Scheduling I

The `setup()` method

By overriding the `setup()` method, JADE programmers ensure their agents have an initial pool of *ready-to-schedule* behaviours

- method `addBehaviour()` to add a behaviour (also usable elsewhere)
- method `removeBehaviour()` to remove one (better use it elsewhere...)

`setup()` serves to create instances of these behaviours and *link* them to the owner agent

Round-robin

After initialisation, first behaviour from the *active behaviours* pool (*ready queue*) is scheduled for execution

Round-Robin, Non-Preemptive Scheduling II

Some remarks

- ! behaviours switch occurs only when the `action()` method of the currently scheduled behaviour returns
 - hence, when it is running *no other behaviour can execute*
- ! behaviour removal from the scheduler pool occurs only when `done()` returns `true`
 - thus, if it returns `false` the behaviour is re-scheduled for next *round*
- ! `action()` is run *from the beginning every time*: there is no way to “stop-then-resume” a behaviour
 - therefore, the computational state must be explicitly managed by the programmer in instance variables



Round-Robin, Non-Preemptive Scheduling III

One more remark

- programmers may need their agents to wait for something to happen—typically, a message to arrive
- programmers may be lured to use method `doWait()` for the purpose...

! ...don't do it!

! `doWait()` moves the agent to the WAITING state, where none of its behaviours can be executed!

- use method `block()` provided by any behaviour class instead, which allows to *suspend only the calling behaviour*
- as soon as `action()` returns, the behaviour is moved to a special queue of blocked behaviours...
 - ...from which can be restored in the ready queue *whenever any message arrives* or by explicitly calling `restart` method

Examples in `ds.lab.jade.behaviours.*`

Open a command prompt and position yourself into folder `ds-jade/`

- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents ste:ds.lab.jade.behaviours.SimpleBehavioursAgent`
- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents ste:ds.lab.jade.behaviours.CompositeBehavioursAgent`
- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents ste:ds.lab.jade.behaviours.FSMLikeAgent`

On Windows, substitute “:” with “;”, and “/” with “\”



Focus on. . .

- 1 JADE Overview
 - JADE & FIPA
 - JADE Agents
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - **JADE Messaging**
 - JADE Communication API
- 4 JADE Advanced
 - Directory Facilitator
 - FIPA Interaction Protocols in JADE
 - JADE Agents & Java Swing
 - Agent Mobility in JADE



More on *ACL* Messages I

FIPA performatives

Performatives identify the type of *communicative act* carried out by the message—thus its semantics and expected response

CFP (Call For Proposal) to obtain proposals about something

INFORM to let someone know something

PROPOSE to propose something

REQUEST to ask for a service

SUBSCRIBE to subscribe for notification about something

AGREE to express consensus about something

REFUSE to refuse a request

... ..

They are constants to be set for any *ACL* message exchanged by agents

More on $\mathcal{ACL}$ Messages II

FIPA message syntax

The syntax of an $\mathcal{ACL}$ message is defined by FIPA to enable interoperability

`addReceiver()` to add a value to the `:receiver` slot

`setContent()` to fill in the `:content` slot

`setConversationId()` to fill in the `:conversation-id` slot

`setEncoding()` to fill in the `:encoding` slot

`setInReplyTo()` to fill in the `:in-reply-to` slot

`setLanguage()` to fill in the `:language` slot

`setOntology()` to fill in the `:ontology` slot

`setSender()` to fill in the `:sender` slot

... ..

Focus on. . .

- 1 JADE Overview
 - JADE & FIPA
 - JADE Agents
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - **JADE Communication API**
- 4 JADE Advanced
 - Directory Facilitator
 - FIPA Interaction Protocols in JADE
 - JADE Agents & Java Swing
 - Agent Mobility in JADE



Agents Communication Basics I

Sending messages

In order to send a message, an agent should

- ❶ create an *ACL* message
 - `ACLMessage msg = new ACLMessage(ACLMessage.<performative>);`
- ❷ fill its (mandatory) fields
 - `msg.addReceiver(new AID(receiver));`
 - `msg.setContent("<content>");`
 - ...
- ❸ call the `send()` method
 - `send(msg);`



Agents Communication Basics II

Replying to messages

In order to simplify answering, the `ACLMessage` class provides method `createReply()` to automatically set a number of *ACL* fields

- `:receiver`
- `:language, :ontology`
- `:conversation-id, :protocol`
- `:in-reply-to, :reply-with`

Anyway, the programmer is free to overwrite such slots



Agents Communication Basics III

Who to talk with?

- ? how to find agents to talk to?
- when sending messages we must know the receiver AID
 - should we necessarily know it at compile-time?
- ! JADE provides several ways to get an agent ID:
 - by using the agent **local name** (whenever known)
 - from the RMA GUI
 - by asking to the AMS
 - by asking to the DF (we'll see how to next lesson)



Agents Communication Basics IV

JADE local names

The simplest way to identify an agent is by its local name

```
...  
msg.addReceiver(new AID("myAgent", AID.ISLOCALNAME));  
...
```

JADE ACC will automatically associate to the given agent name its AID

JADE RMA

By simply launching the RMA with

```
java -cp ... jade.Boot -gui
```

you have a GUI which displays all agents in the monitored JADE platform along with their AIDs

Agents Communication Basics V

Using the AMS

A much more comprehensive and flexible way to query JADE about existing agents is by interacting with the AMS service

- 1 prepare a placeholder for agents with
`AMSAgentDescription [] agents = null;`
- 2 configure some kind of “template” on agents with
`AMSAgentDescription template = new AMSAgentDescription (...);`
- 3 configure search parameters with
`SearchConstraints c = new SearchConstraints(...);`
- 4 launch the search process with
`agents = AMSService.search(this, template, c);`
- 5 collect AIDs with
`AID aid = agents[i].getName();`

More on Agents Communication I

JADE communication primitives

`send()` to asynchronously send a message—recipient is implicit

`receive()` to asynchronously retrieve the first message from the mailbox (if any)

`receive(MessageTemplate)` to perform a *selective receive*

`blockingReceive()` to perform a *synchronous receive*

`blockingReceive(long)` to perform a *timed synchronous receive*

`blockingReceive(MessageTemplate)` to perform a selective, synchronous receive

`blockingReceive(MessageTemplate, long)` to perform a timed, selective, synchronous receive



More on Agents Communication II

Receiving messages

One need to be careful when receiving messages

- ! method `blockingReceive()` *suspends all agent behaviours*, not only the calling one—due to synchronicity
 - call `receive()` then `block()` instead, so to resume the behaviour whenever any message arrives
 - call `blockingReceive()` only when you actually need to suspend all behaviours—e.g. during setup()
- ! method `receive()` *removes* the first message from the mailbox, therefore it may “steal” someone else’s
 - use `jade.lang.acl.MessageTemplate` within a `receive()` to get only messages *matching a given pattern*



More on Agents Communication III

Selective receive

`jade.lang.acl.MessageTemplate` allows JADE agents to perform receive operations only *on a subset of their mailbox*, which is the subset with only those messages **matching** the given template

Hint

When a JADE agent is required to have *parallel negotiations* with several other agents, one should

- create a `:conversation-id` string to *uniquely* identify messages
- by using the proper `MessageTemplate`, set up a behaviour which only responds to messages with that particular `:conversation-id`



More on Agents Communication IV

MessageTemplate API I

A set of static, *factory methods* are provided to build different kinds of template objects

`matchAll()` matches any *ACL* message

`matchContent()` match checked on :content slot

`matchCustom(ACLMessage)` template built so to match the given *ACL* message

`matchConversationId()` match checked on :conversation-id slot

`matchOntology()` match checked on :ontology slot

`matchSender()` match checked on :sender slot

... ..



More on Agents Communication V

MessageTemplate API II

... along with elementary boolean operators to combine them into more complex patterns...

`and()` to build a template which is the *intersection* of two given templates

`or()` to build a template which is the *union* of two given templates

`not()` to build a template which is the *negation* of a given template

... and a non-static method to actually check matching

`match(ACLMessage)` returns true if the given message matches the template upon which it is called

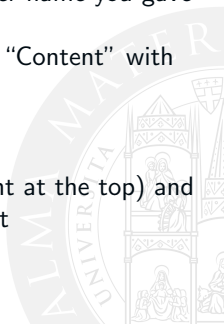


Examples in `ds.lab.jade.messaging.*` |

Open a command prompt and position yourself into folder `ds-jade/`

- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents ste:ds.lab.jade.messaging.PingPongAgent`
 - from RMA GUI launch the “DummyAgent”
 - right-click on blank text field next to “Receivers” and left-click “Add”
 - check “NAME” checkbox and digit “ste” (or whichever name you gave to the ping pong agent) then “Ok”
 - select “propose” as the “Communicative act” and fill “Content” with either “ping” or “pong”
 - fill “Ontology” with “ping-pong”
 - click “Send” (envelope icon)
 - select messages from the box on the right (most recent at the top) and click “View” (glasses icon) to inspect message content

On Windows, substitute “:” with “;” an “/” with “\”



Examples in `ds.lab.jade.messaging.*` II

- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents
calculator:ds.lab.jade.messaging.calculator.CalculatorAgent &
(agent name MUST BE "calculator")`
- `java -cp libs/jade.jar:bin/ jade.Boot -container -agents
ste:ds.lab.jade.messaging.calculator.ClientAgent &`

On Windows, substitute "&" with "start /B" (placed as first command)



Next in Line...

- 1 JADE Overview
- 2 Getting Started with JADE
- 3 JADE Basics
- 4 JADE Advanced**



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- 1 JADE Overview
 - JADE & FIPA
 - JADE Agents
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
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 - Agent Mobility in JADE



Directory Facilitator (DF): Recap

What we already know

By default, a singleton **Directory Facilitator** (DF) exists for each JADE platform, which

- provides the **yellow pages** service by keeping track of published services provided by advertising agents—be them local or remote
- should be *explicitly* contacted by JADE agents who wish to advertise their capabilities—both to submit an advertisement and to remove it
- supports the **publish/subscribe pattern** by offering a *notification service*
- can be *federated* with other DFs to implement a *truly distributed* yellow pages service



DF API I

What's new

The DF service is implemented as a JADE agent – as the AMS – in class `jade.domain.DFService`

! being JADE DF FIPA-compliant, *all interactions with the DF must follow FIPA's standards*:

- interaction protocols taken from package `jade.proto`
- *ACL* messages must adhere to the `FIPAMangementVocabulary` (ontology) in package `jade.domain.FIPAAgentManagement`
- *ACL* messages content must adhere to the `SLOVocabulary` in package `jade.content.lang.sl`

...



DF API II

JADE helps us

...

- static methods are provided to automatically build *semantically-correct* *ACL* messages:
 - `createRequestMessage()` to request the execution of a `fipa-agent-management` ontology action by the DF
 - `createSubscriptionMessage()` to request subscription for a given `DFAgentDescription` template
 - `decodeResult()` to process the content of the final message received as a result of `search()` operation
 - `decodeNotification()` to process the content of a notification message received as a consequence of a previous subscription

...



DF API III

JADE helps us even more

...

- to ease developer's work, a set of static methods embedding such interaction protocols are provided by class DFService
 - `register()` called by an agent wishing to advertise a service
 - `deregister()` called by an agent who no longer offers a previously advertised service
 - `search()` called by *client* agents looking for a service to exploit
- ! be careful 'cause all these methods are **blocking calls**, therefore *every activity of the agent is suspended* until success or failure of the call
 - if you need *asynchronous* interactions, go for the FIPA protocols approach



DF Entries Syntax I

The DFAgentDescription class (DFD)

The DFD is an entry in the DF, thus must contain (at least):

- the agent ID
- the set of services the agent wishes to advertise, in the form of `ServiceDescription`
- the set of *ontologies*, *protocols* and *languages* the agent is able to support/understand



DF Entries Syntax II

The `ServiceDescription` class (SD)

The SD is a descriptor of the service the agent wishes to publish to the DF, thus must contain (at least):

- the service *name*
- the service *type*
- the set of *ontologies* and *languages* whose knowledge is required to exploit the service
- a number of *service-specific* properties



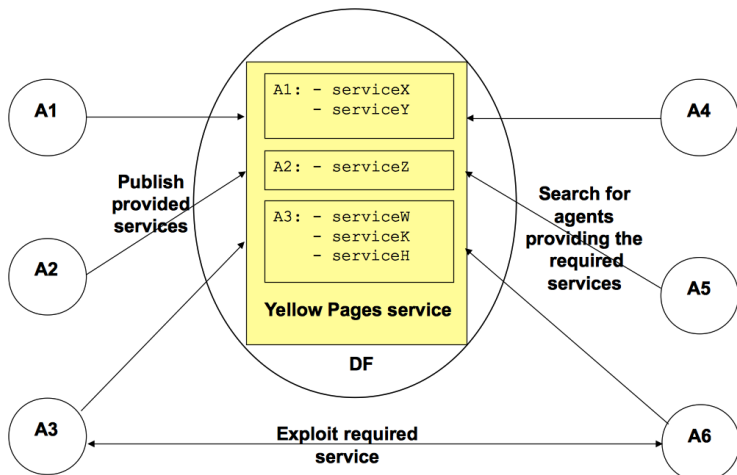
DF Entries Syntax III

```
DFAgentDescription {  
  Name: AID (mandatory)  
  Protocols: set of strings  
  Ontologies: set of strings  
  Languages: set of strings  
  Services {  
    Name: String (mandatory)  
    Type: String (mandatory)  
    Protocols: set of strings  
    Ontologies: set of strings  
    Languages: set of strings  
    Properties: {  
      Name: String  
      Value: String  
    }  
  }  
}
```

Pseudo-code view of a DF entry



Using DF API I



Using DF API II

Registering to the DF

- ❶ instantiate a `DFAgentDescription` object
→ `DFAgentDescription dfd = new DFAgentDescription();`
- ❷ fill in (at least) its `Name` field with the advertising agent AID
→ `dfd.setName(getAID());`
- ❸ instantiate a `ServiceDescription` object
→ `ServiceDescription sd = new ServiceDescription();`
- ❹ fill in (at least) its `Name` and `Type` fields with meaningful strings
→ `sd.setType("buyer");`
→ `sd.setName("online trad");`
- ❺ add the `ServiceDescription` to the `DFAgentDescription`
→ `dfd.addServices(sd);`
- ❻ call `DFService.register(this, dfd);`



Using DF API III

Deregistering from the DF

Since dead agent's AIDs are automatically removed *solely from the AMS*, it is a good practice to deregister agents upon death

- a good place where to do so is in `takeDown()` callback method
 - `DFService.deregister(this);`

! keep in mind that each agent is allowed to have *only one entry* in the DF

- each attempt to register an already registered agent throws an exception



Using DF API IV

Browsing the DF I

Client agents may query the DF to know if any agent offers the services they are looking for and then acquire their AIDs:

- ➊ create a DFD (with no AID, obviously...) filling its fields with the properties you look for
 - ```
DFAgentDescription dfd = new DFAgentDescription();
ServiceDescription sd = new ServiceDescription();
sd.setType("buyer");
dfd.addServices(sd);
```
- ➋ specify as SearchConstraints that you want to get *all* the agents offering the service (skip this if you need only one)
  - ```
SearchConstraints all = new SearchConstraints();  
all.setMaxResults(new Long(-1));
```

...



Using DF API V

Browsing the DF II

...

- ➊ launch the search process (skip last parameter if skipped previous point)

→ `DFAgentDescription[] result = DFService.search(this, dfd, all);`

- ➋ extract the AID(s) from the results set

→ `AID[] providers = new AID[result.length];
for (int i = 0; i < result.length; i++) {
 providers[i] = results[i].getName();
}`



Using DF API VI

! check the `ds.lab.jade.bookTrading` example for the whole code

Launching `ds.lab.jade.bookTrading`

Open a command prompt and position yourself into folder `ds-jade/`

- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents seller:ds.lab.jade.bookTrading.BookSellerAgent &`
- `java -cp libs/jade.jar:bin/ jade.Boot -container -agents buyer:ds.lab.jade.bookTrading.BookBuyerAgent &`

On Windows, substitute “&” with “start /B” (placed as first command)
The example should work anyway regardless of the order in which agents are launched and regardless of how many buyers and sellers you launch (at least one), provided they have different names



Using DF API VII

Subscribing to the DF I

JADE agents can ask the DF to **notify** them *as soon as* a given service is advertised

- 1 as usual, create a DFD suited for the service you wish to be notified about...

```
→ DFAgentDescription dfd = new DFAgentDescription();  
   ServiceDescription sd = new ServiceDescription();  
   sd.setType(...);  
   dfd.addServices(sd);
```

- 2 ...configure your chosen SearchConstraints (if you please)...

```
→ SearchConstraints sc = new SearchConstraints();  
   sc.setMaxResults(new Long(1));
```

...



Using DF API VIII

Subscribing to the DF II

...

- 1 ... then, perform your subscription

```
→ send(  
    DFService.createSubscriptionMessage(this, getDefaultDF(), dfd, sc)  
);
```

Now the DF will send an `ACLMessage.INFORM` to the subscribed agent *whenever* an agent matching the supplied description registers



Focus on. . .

- 1 JADE Overview
 - JADE & FIPA
 - JADE Agents
 - JADE ACC
 - JADE Tools
- 2 Getting Started with JADE
- 3 JADE Basics
 - JADE Architecture
 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
 - Directory Facilitator
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Interaction Protocols I

Protocol according to FIPA

Predefined sequences of messages that can be reused in different domains to implement a given interaction

! some kind of “design pattern” for communications

The `jade.proto` package

`jade.proto` contains behaviours implementing both the **initiator** and **responder roles** in most common interaction protocols

- managing the flow of messages and checking that it is *consistent to the protocol*
- providing *callback methods* that can be overridden to take the necessary actions when a message is received

Interaction Protocols II

(Some) Protocol classes I

AchieveRE[Initiator/Responder] factorization of all the FIPA *Request-like* interaction protocols^a, that is, those in which the initiator aims to achieve a **RE (Rational Effect)** and needs to verify if it has been achieved or not

ContractNet[Initiator/Responder] allows the initiator to send a *Call for Proposal* to a set of responders, evaluate their proposals and then accept the preferred one (or even reject all of them)

... ..

^asuch as FIPA-Request, FIPA-query, FIPA-Request-When, FIPA-recruiting, FIPA-brokering.



Interaction Protocols III

(Some) Protocol classes II

... ..

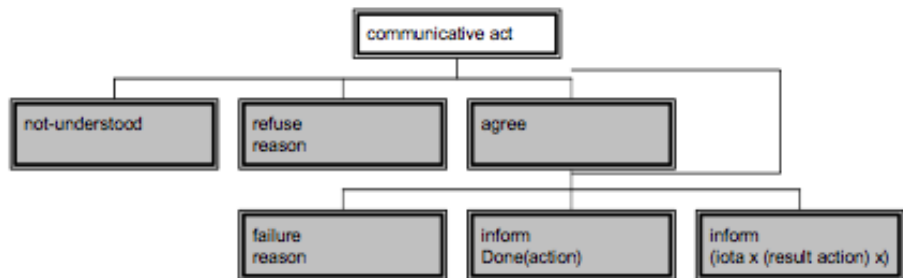
Propose[Initiator/Responder] allows the initiator to send a PROPOSE message to the participants indicating *its will to perform some action if they agrees*. The participants responds by either accepting or rejecting such proposal, then the initiator either carries out the action or not accordingly

Subscription[Initiator/Responder] allows the initiator to *subscribe* to a target agent for certain kind of events. If the participant agrees, it communicates all content *matching the subscription condition* using an INFORM-RESULT

... ..

... refer to JADE API for the others

Achieve Rational Effect (AchieveRE) I



FIPA AchieveRE protocol message flow



Achieve Rational Effect (AchieveRE) II

AchieveREInitiator

Initiator role for FIPA request-like protocols

- constructed by passing the protocol-starting *ACL* message
 - ! be sure to set the `protocol` field of the `ACLMessage` with the proper constant taken from `FIPANames.InteractionProtocols` in package `jade.domain`
- to be extended by overriding its `handle[...]` *callback* methods, which provide hooks to handle all the states of the protocol
 - e.g. `handleAgree()`, `handleInform()`, ...
 - ! be aware of the functioning of callbacks such as `handleOutOfSequence()`, `handleAllResponses()`, `handleAllResultNotifications`—refer to JADE *programmer's guide*
- manages an *expiration timeout* expressed by the value of the *reply-by* slot in `ACLMessage`
 - ! as defined by FIPA, such timeout refers to the *first response*: second response timeouts can be managed “by hand”

Achieve Rational Effect (AchieveRE) III

AchieveREResponder

Responder role for FIPA request-like protocols

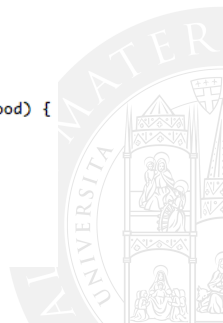
- constructed by passing the `MessageTemplate` describing *ACL* messages we'd like to manage
 - ! method `createMessageTemplate` is provided to create templates for each interaction protocol
- to be extended by overriding its `handle/prepare[...]` *callback* methods, which provide hooks to handle all the states of the protocol
 - `handleRequest()` to reply to first initiator message
 - `prepareResultNotification()` to send the final response about the RE achieved
 - ...



Achieve Rational Effect (AchieveRE) IV

```
ACLMessage msg = new ACLMessage(ACLMessage.REQUEST);
msg.setProtocol(FIPANames.InteractionProtocol.FIPA_REQUEST);
addBehaviour(new AchieveREInitiator(this, msg){
    @Override
    protected void handleAgree(ACLMessage agree) {
    }
    @Override
    protected void handleFailure(ACLMessage failure) {
    }
    @Override
    protected void handleInform(ACLMessage inform) {
    }
    @Override
    protected void handleNotUnderstood(ACLMessage notUnderstood) {
    }
    @Override
    protected void handleRefuse(ACLMessage refuse) {
    }
});
```

JADE AchieveREInitiator



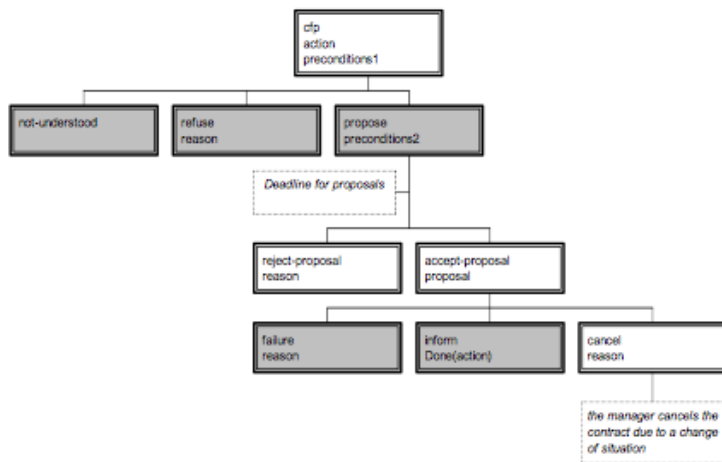
Achieve Rational Effect (AchieveRE) V

```
MessageTemplate template = AchieveREResponder.createMessageTemplate(
    FIPANames.InteractionProtocol.FIPA_REQUEST);
addBehaviour(new AchieveREResponder(this, template){
    @Override
    protected ACLMessage handleRequest(ACLMessage request)
        throws NotUnderstoodException, RefuseException {
        return new ACLMessage(ACLMessage.AGREE);
    }
    @Override
    protected ACLMessage prepareResultNotification(ACLMessage request,
        ACLMessage response) throws FailureException {
        return new ACLMessage(ACLMessage.INFORM);
    }
});
```

JADE AchieveREResponder



Contract Nets I



FIPA Contract Net protocol

Contract Nets II

ContractNetInitiator

Initiator role for FIPA contract-net protocol

- constructed by passing the protocol-starting *ACL* message
 - ! again, use `FIPANames.InteractionProtocols` to set the `protocol` field of the `ACLMessage`
- to be extended by overriding its `handle[...]` *callback* methods
 - e.g. `handlePropose()`, `handleInform()`, ...
 - ! be sure to implement `handleAllResponses()` by adding to the `acceptances` Vector all the `ACLMessage.ACCEPT_PROPOSAL` *ACL* messages to send
- manages the *expiration timeout*
 - ! again, reply-by timeout refers to the *first response*
 - ! late answers *are not consumed*, thus remain in the agent message box



Contract Nets III

ContractNetResponder

Responder role for FIPA contract-net protocol

- constructed by passing the proper `MessageTemplate`
 - ! again, use method `createMessageTemplate`
- to be extended by overriding its `handle[...]` *callback* methods
 - `handleCfp()` the initial CFP message
 - `handleAcceptProposal()` when an `ACCEPT_PROPOSAL` message is received from the initiator
 - ...



Contract Nets IV

! check the `ds.lab.jade.bookTrading.contractNet` example for the code

Launching `ds.lab.jade.bookTrading.contractNet`

Open a command prompt and position yourself into folder `ds-jade/`

- `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents seller:ds.lab.jade.bookTrading.contractNet.BookSellerAgent &`
- `java -cp libs/jade.jar:bin/ jade.Boot -container -agents buyer:ds.lab.jade.bookTrading.contractNet.BookBuyerAgent &`

On Windows, substitute “&” with “start /B” (placed as first command)
The example should work anyway regardless of the order in which agents are launched and regardless of how many buyers and sellers you launch (at least one), provided they have different names



Responder Behaviours I

Cyclic vs. single-session responders

Responder behaviours may have two forms

Cyclic Serve interactions initiated by different agents **sequentially**

- ❶ wait for the protocol initiation message
- ❷ serve the protocol
- ❸ go back waiting for a new protocol initiation message

Single-Session Serve interactions initiated by different agents **in parallel**

- ❶ get the protocol initiation message in the constructor
→ requires an external behaviour to be used
- ❷ serve the protocol
- ❸ terminate

! check the `jade.proto` package to learn more



Focus on. . .

- 1 JADE Overview
 - JADE & FIPA
 - JADE Agents
 - JADE ACC
 - JADE Tools
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 - JADE Agents
 - Agent Behaviours
 - JADE Messaging
 - JADE Communication API
- 4 JADE Advanced
 - Directory Facilitator
 - FIPA Interaction Protocols in JADE
 - **JADE Agents & Java Swing**
 - Agent Mobility in JADE



Java Swing Troubles I

What is the problem?

Whenever developing JADE agents which need to interact with a Java GUI, the *thread-per-agent* concurrency model of JADE agents must work together with the Swing **Event Dispatcher Thread (EDT)** concurrency model



Java Swing Troubles II

More in detail

- as you should know, the Swing framework *is not thread-safe*, so any code that updates the GUI elements must be executed within the EDT
 - since modifying a *model object* triggers an update of the GUI, model objects too have to be manipulated just by the EDT
- the `SwingUtilities` class exposes two *static methods* to delegate execution of `Runnable` objects to the EDT
 - `invokeLater()` puts the `Runnable` into the System Event Queue (SEQ) (accessed by the EDT only) and returns immediately—*asynchronous* call
 - `invokeAndWait()` puts the `Runnable` into the SEQ and blocks waiting its completion—*synchronous* call



JADE Solution I

GuiAgent class

To develop JADE agents interacting with a GUI, simply extend `GuiAgent` class in package `jade.gui`

`onGuiEvent(GuiEvent e)` may be viewed as the *equivalent* of the `actionPerformed()` method in Java Swing, that is, a callback invoked by JADE platform as soon as a `GuiEvent` is generated

`postGuiEvent(GuiEvent e)` used by the agent's GUI to *queue GUI events* for later processing—similar to queueing *ACL* messages in its mailbox



JADE Solution II

GuiEvent class

A GuiEvent object has

- two *mandatory* attributes
 - `source` the Object source of the event
 - `type` an integer identifying the kind of event generated
- an optional list of parameters eventually used for events processing
 - `addParameter()` takes the Object to add as a GuiEvent parameter
 - `getParameter()` gets the *i-th* parameter
 - `getAllParameter()` returns an Iterator to browse all parameters



JADE Solution III

One advice

From JADE programmer's guide

*"In general, it is not a good thing that an external software component maintains a **direct object reference** to an agent, because this component could directly call **any public method** of the agent, skipping the asynchronous message passing layer and turning an **autonomous agent** into a server object, **slave to its caller**. The correct approach is that to gather all the external methods into an **interface**, implemented by the agent class, then an object reference of that interface will be passed to the external software component (e.g., a GUI) so that only the external methods will be available from event handlers."*



JADE Solution IV

On mixing paradigms

Both the GUI and the objects reference issues raise the following warnings

- ! beware of mixing programming paradigms
 - JADE provides an agent-oriented development framework
 - JADE is implemented in Object Oriented (OO, e.g. Java)
- ! when developing agent-oriented software, stay in the agent-oriented world as much as possible
 - using OO GUIs is ok
 - using OO external references is ok (but be careful)
- ! do not think in OO terms, think in agent-oriented terms
 - e.g. no threads
 - e.g. no method calls between agents



JADE Solution V

! check the `ds.lab.jade.bookTrading.gui` example carefully

Launching `ds.lab.jade.bookTrading.gui`

- open a command prompt and position yourself into folder `ds-jade/`
 - `java -cp libs/jade.jar:bin/ jade.Boot -gui -agents seller:ds.lab.jade.bookTrading.gui.BookSellerAgent &`
 - `java -cp libs/jade.jar:bin/ jade.Boot -container -agents buyer:ds.lab.jade.bookTrading.gui.BookBuyerAgent &`
- ! on Windows, substitute “&” with “start /B” (placed as first command)
- the example should work anyway regardless of the order in which agents are launched and regardless of how many buyers and sellers you launch (at least one), provided they have different names



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JADE Mobility I

What does *mobility* mean for JADE?

In JADE, *mobility* is the ability of an agent program to either **migrate** or **clone** (make a copy of) itself *across one or multiple network hosts*

Which kind of mobility?

As you may know, at least two different forms of mobility can be defined:

- weak** only the program (agent) *code* is moved/cloned

- strong** also the program (agent) *state* is moved/cloned along with its code—supposing to know what “state” means

JADE supports *some form* of strong mobility



JADE Mobility II

JADE strong mobility

A JADE agent can

- move/clone its state, which means:
 - ① **stop** its execution on the local container
 - ② **move/clone** to a remote container
 - ③ **resume** its execution there from the *exact point* where it was interrupted
- move/clone its code, which means that if its code is not available on the destination container, then it is automatically retrieved by JADE platform

Keep in mind that...

! in order to be able to move, an agent must be **Serializable**

API: Location I

Where to move/clone to?

The `jade.core.Location` *interface* represents a place where agents can move / be cloned to

- `getID()` to obtain the Location unique ID

- `getName()` to obtain the Location name

- `getAddress()` to get its address

- `getProtocol()` to know the exploited transport protocol



API: Location II

Intra- vs. inter- platform mobility

Two different classes implement the Location interface (both from its same package):

- **ContainerID** for **intra-platform** mobility
 - let cName be a container name, its ContainerID can be obtained with `new ContainerID(cName, null)`
- **PlatformID** for **inter-platform** mobility
 - requires the **migration service** add-on to be installed
 - it is developed and maintained by the Universitat Autònoma de Barcelona at tao.uab.cat/ipmp/



API: Action I

Finding destinations

To get a `Location` object, an agent must query the AMS by sending it an `ACLMMessage.REQUEST` (thus, expecting an `.INFORM` back) storing either

- a new `WhereIsAgentAction(AID aid)` object
 - to get the `Location` where the given agent is
- a new `QueryPlatformLocationsAction()` object
 - to get all the `Locations` available within the JADE platform

In both cases, what you get is a `Location` object which hides a `ContainerID`



API: Action II

What *actions*?

- `jade.content.onto.basic.Action` is the class representing a FIPA *action*, that is “an act to be carried out by an agent”
- ? do you remember we defined ACL messages as *communicative acts*?



API: Action III

Action how-to

To create and request an Action

- ❶ instantiate the Action object
→ `Action a = new Action()`
- ❷ decide who should perform the action—the AMS in our case
→ `a.setActor(getAMS())`
- ❸ choose the action to be performed
→ `a.setAction(new QueryPlatformLocationsAction())`
- ❹ *embed* the action into the request *ACL* message
→ `ACLMessage msg = new ACLMessage(ACLMessage.REQUEST)`
`Agent.getContentManager().fillContent(msg, a)`
- ❺ send the message to the receiver—again, the AMS for us
→ `msg.addReceiver(getAMS())`
`send(msg)`



API: Action IV

Collecting AMS replies I

To collect AMS replies you can do something like

- ❶ create a suitable data store for locations
 - `Map locations = new HashMap();`
- ❷ receive replies according to your preferred policy but using the correct `MessageTemplate`
 - ```
MessageTemplate mt = MessageTemplate.and(
 MessageTemplate.matchSender(getAMS()),
 MessageTemplate.matchPerformative(ACLMessage.INFORM))
ACLMessage reply = blockingReceive(mt)
```
- ❸ ...



# API: Action V

## Collecting AMS replies II

- ❶ ...
- ❷ *decode* the content of AMS reply—method dual to  
`Agent.getContentManager().fillContent(msg, a)`  
→ `Result res = (Result) getContentManager().extractContent(reply)`
- ❸ (in our case) collect all the Locations  
→ 

```
Iterator it = res.getItems().iterator()
while(it.hasNext()){
 Location l = (Location)it.next()
 locations.put(loc.getName(), l)
}
```



# doMove/doClone How-To I

## Self-motion

In the case an agent autonomously decides to move itself to another (remote) container in the same JADE platform, it simply calls the method `doMove()` passing the destination `Location` as a parameter—either discovered thanks to the AMS or a-priori known

## Self-cloning

The case of cloning is similar, except that method to call is obviously `doClone()` and that a second parameter other than the target `Location` should be passed to the call: the new name of the cloned agent (a `String`)



# doMove/doClone How-To II

## Request for movement/cloning I

Instead, if any JADE agent wishes to make another agent move, it can only perform a `[Move/Clone]Action request`, hoping the destination agent will do it—nothing more should be expected as usual

- ❶ create a `MobileAgentDescription`
  - `MobileAgentDescription mad = new MobileAgentDescription`
- ❷ fill its mandatory fields
  - `mad.setName(aid)`  
`mad.setDestination(location)`
- ❸ embed it in a `[Move/Clone]Action` object
  - `MoveAction ma = new MoveAction()`  
`ma.setMobileAgentDescription(mad)`
- ❹ ...



# doMove/doClone How-To III

## Request for movement/cloning II

- ① ...
- ② pack the  $\mathcal{ACL}$  request message encoding the [Move/Clone] Action object
  - `ACLMessage msg = new ACLMessage(ACLMessage.REQUEST)`  
`Agent.getContentManager().fillContent(msg, ma)`
- ③ send the move/clone request message
  - `msg.addReceiver(aid)`  
`send(msg)`



# doMove/doClone How-To IV

## Response for movement/cloning

The receiver agent, if agrees with the request

- ➊ decodes the content of the  $\mathcal{ACL}$  message conveying the action request
  - `ContentElement content = getContentManager().extractContent(msg)`
- ➋ gets the `[Move/Clone]Action`
  - `MoveAction ma = (MoveAction)((((Action)content).getAction()))`
- ➌ gets the destination `Location`
  - `Location loc = ma.getMobileAgentDescription().getDestination()`
- ➍ eventually, moves/clones itself
  - `if(loc != null) doMove(loc)`



## doMove/doClone How-To V

### Last note

To be able to call the above-used methods from the `ContentManager` object, the `jade.content.lang.sl.SLCodec` and the `jade.domain.mobility.MobilityOntology` must be *registered* with it.

→ to do so, write in agents `setup()` method

```
getContentManager().registerLanguage(new SLCodec())
getContentManager().registerOntology(
 MobilityOntology.getInstance()
)
```



## doMove/doClone How-To VI

### Not a FIPA standard

Please notice that such ontology is not yet a FIPA standard, hence may adapted in the future<sup>a</sup>

---

<sup>a</sup>unsure whether a standard is currently available, nor if JADE 4.4 complies to it, for we were not able to find references in documentation.



## doMove/doClone How-To VII

! check the `ds.lab.jade.mobility` example

### Launching `ds.lab.jade.mobility`: single host scenario

Open a command prompt and position yourself into folder `ds-jade/`

- `java -cp libs/jade.jar:bin/ jade.Boot -gui &`
- `java -cp libs/jade.jar:bin/ jade.Boot -container -agents ste:ds.lab.jade.mobility.MobileAgent &`

On Windows, substitute “&” with “start /B” (placed as first command)



## doMove/doClone How-To VIII

### Launching ds.lab.jade.mobility: multi host scenario

On the first host, open a command prompt and position yourself into folder ds-jade/

- `java -cp libs/jade.jar:bin/ jade.Boot -gui &`

On the second host, open a command prompt and position yourself into folder ds-jade/

- `java -cp libs/jade.jar:bin/ jade.Boot -container -host  
ip.of.first.host -agents  
ste:ds.lab.jade.mobility.MobileAgent &`

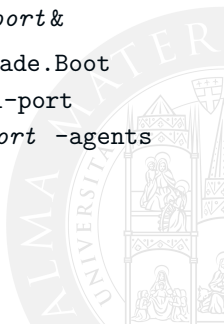
On Windows, substitute “&” with “start /B” (placed as first command)



## doMove/doClone How-To IX

If for some reason (e.g. you are in lab.) you need to bind JADE to a specific IP address and TCP port on your hosts, issue the following commands:

- on the first host: `java -cp libs/jade.jar:bin/ jade.Boot -gui -local-host ip.of.first.host -local-port firstport&`
- on the second host: `java -cp libs/jade.jar:bin/ jade.Boot -container -local-host ip.of.second.host -local-port secondport -host ip.of.first.host -port firstport -agents ste:ds.lab.jade.mobility.MobileAgent &`



# Are We Done with JADE?

In this course and lab, yes we are

The general answer, instead, is no. JADE offers many other things in addition to what we've seen during lab. lessons:

- topic-based communication
- fault tolerance service
- persistent message delivery service
- user-defined ontologies support
- ...

... feel free to experiment by yourselves, and to ask questions as well!



# References



Bellifemine, F., Caire, G., Trucco, T., and Rimassa, G. (2010a).

*JADE Programmer's Guide.*

JADE Board, JADE v. 4.0 edition.



Bellifemine, F., Caire, G., Trucco, T., Rimassa, G., and Mungenast, R. (2010b).

*JADE Administrator's Guide.*

JADE Board, JADE v. 4.0 edition.



Bellifemine, F. L., Caire, G., and Greenwood, D. (2007).

*Developing Multi-Agent Systems with JADE.*

Wiley.



FIPA ACL (2002).

*Agent Communication Language Specifications.*

Foundation for Intelligent Physical Agents (FIPA).



# Agents & Multi-Agent Systems with JADE

Distributed Systems / Technologies  
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