# JADE: Java Agent DEvelopment Framework Advanced 2.0

Stefano Mariani
s.mariani@unibo.it

Dipartimento di Informatica – Scienza e Ingegneria (DISI)
ALMA MATER STUDIORUM – Università di Bologna a Cesena

Academic Year 2015/2016

1. Directory Facilitator
2. FIPA Interaction Protocols in JADE
3. JADE Agents & Java Swing
4. JADE Agents Mobility

# Disclaimer

All the material presented in these slides is rearranged by the author 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 author.

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# 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
- can support the publish/subscribe pattern by offering a *notification service*
- can be *federated* with other DFs to implement a *truly distributed* yellow pages service

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# DF API I

## What's new

The DF service is implemented as a JADE agent – pretty much as the AMS is – 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`
  - → $\mathcal{ACL}$ messages must adhere to the `FIPAManagementVocabulary` (ontology) in package `jade.domain.FIPAAgentManagement`
  - → $\mathcal{ACL}$ messages content must adhere to the `SL0Vocabulary` in package `jade.content.lang.sl`

...

# DF API II

## JADE helps us

...

- static methods are provided to automatically build *semantically-correct* $\mathcal{ACL}$ 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

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# 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

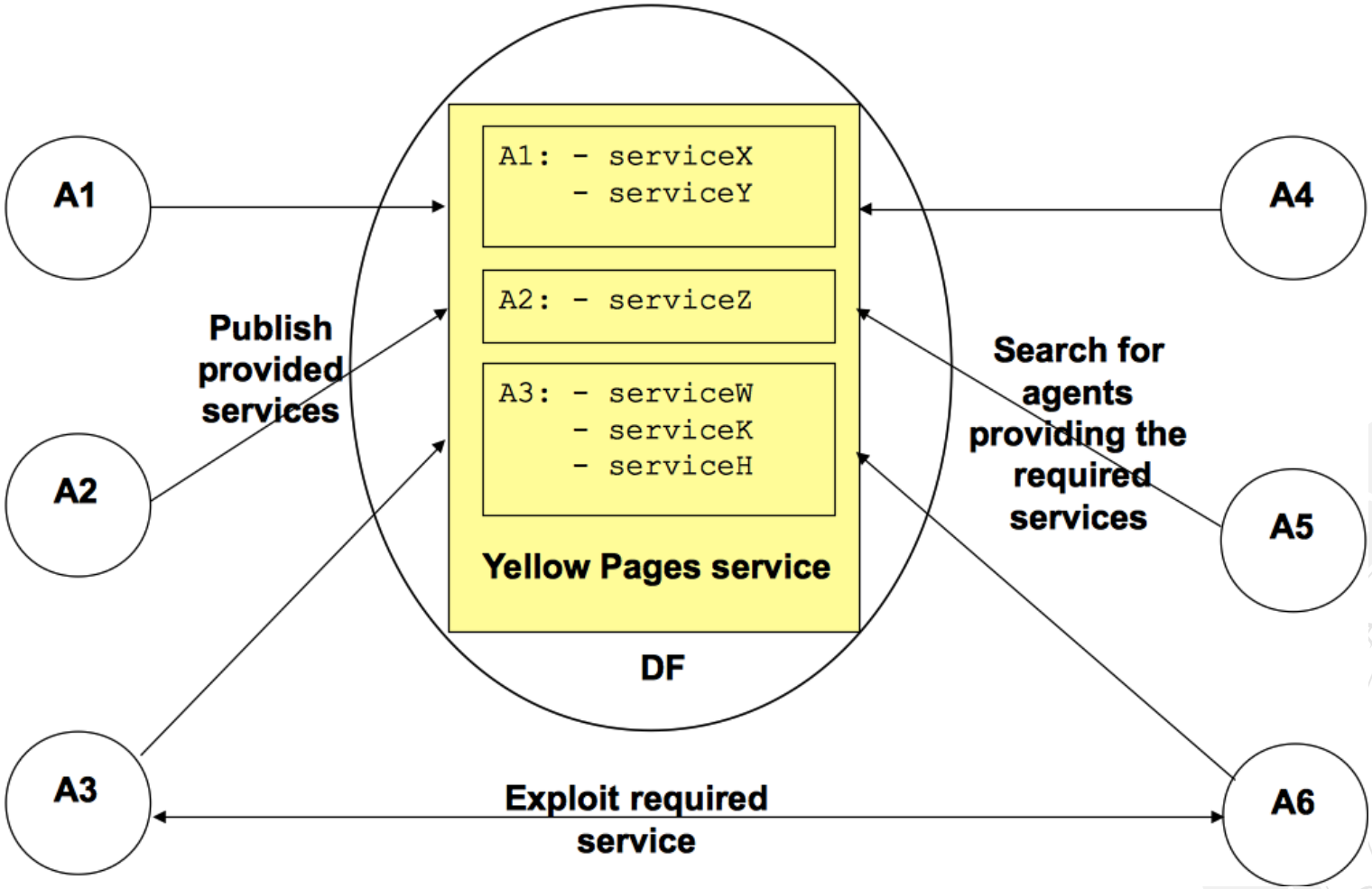
```
DFAgentDescription {
    Name: AID (mandatory)
    Protocols: set of strings
    Ontologies: set of strings
    Languages: set of strings
    Services {
        Name: String (mandatory)
        Type: String (mandatory)
        Protocols: set of strings
        Ontologies: set of strings
        Languages: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

Figure: Pseudo-code view of a DF entry

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# DF APIs Usage I



# DF APIs Usage II

## Registering to the DF

1. instantiate a DFAgentDescription object
   → `DFAgentDescription dfd = new DFAgentDescription();`
2. fill in (at least) its Name field with the advertising agent AID
   → `dfd.setName(getAID());`
3. instantiate a ServiceDescription object
   → `ServiceDescription sd = new ServiceDescription();`
4. fill in (at least) its Name and Type fields with meaningful strings
   → `sd.setType("buyer");`
   `sd.setName("online trad");`
5. add the ServiceDescription to the DFAgentDescription
   → `dfd.addServices(sd);`
6. call `DFService.register(this, dfd);`

# DF APIs Usage 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 ti is in `takeDown()` callback method
  - → `DFService.deregister(this);`

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

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

# DF APIs Usage IV

## Browsing the DF I

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

1. 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);
```
2. 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));
```

...

# DF APIs Usage V

## Browsing the DF II

...

1. launch the searching process (skip last parameter if skipped previous point)
   → `DFAgentDescription[] result = DFService.search(this, dfd, all);`
2. 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();
}
```

Check the `ds.lab.jade.bookTrading` example for the whole code.

# DF APIs Usage VI

## 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));`

...

# DF APIs Usage VII

## 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

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# Interaction Protocols I

## FIPA definition

*"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)

...

[a] such 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`

...

... please refer to JADE APIs for the others

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# AchieveRE I

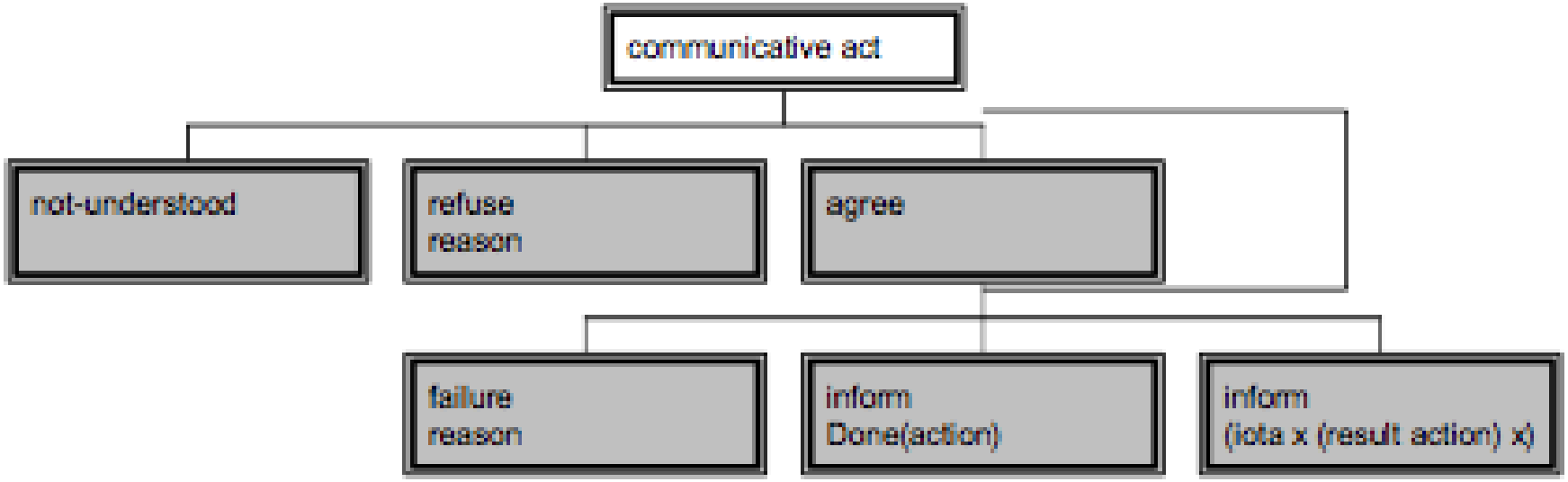



Figure: FIPA AchieveRE protocol message flow

# AchieveRE II

## AchieveREInitiator

*Initiator role* for FIPA request-like protocols

- constructed by passing the protocol-starting $\mathcal{ACL}$ 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"

# AchieveRE III

## AchieveREResponder

*Responder role* for FIPA request-like protocols

- constructed by passing the `MessageTemplate` describing $\mathcal{ACL}$ messages we would 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
  - ...

# 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) {

    }
});
```

Figure: JADE `AchieveREInitiator`

# AchieveRE V

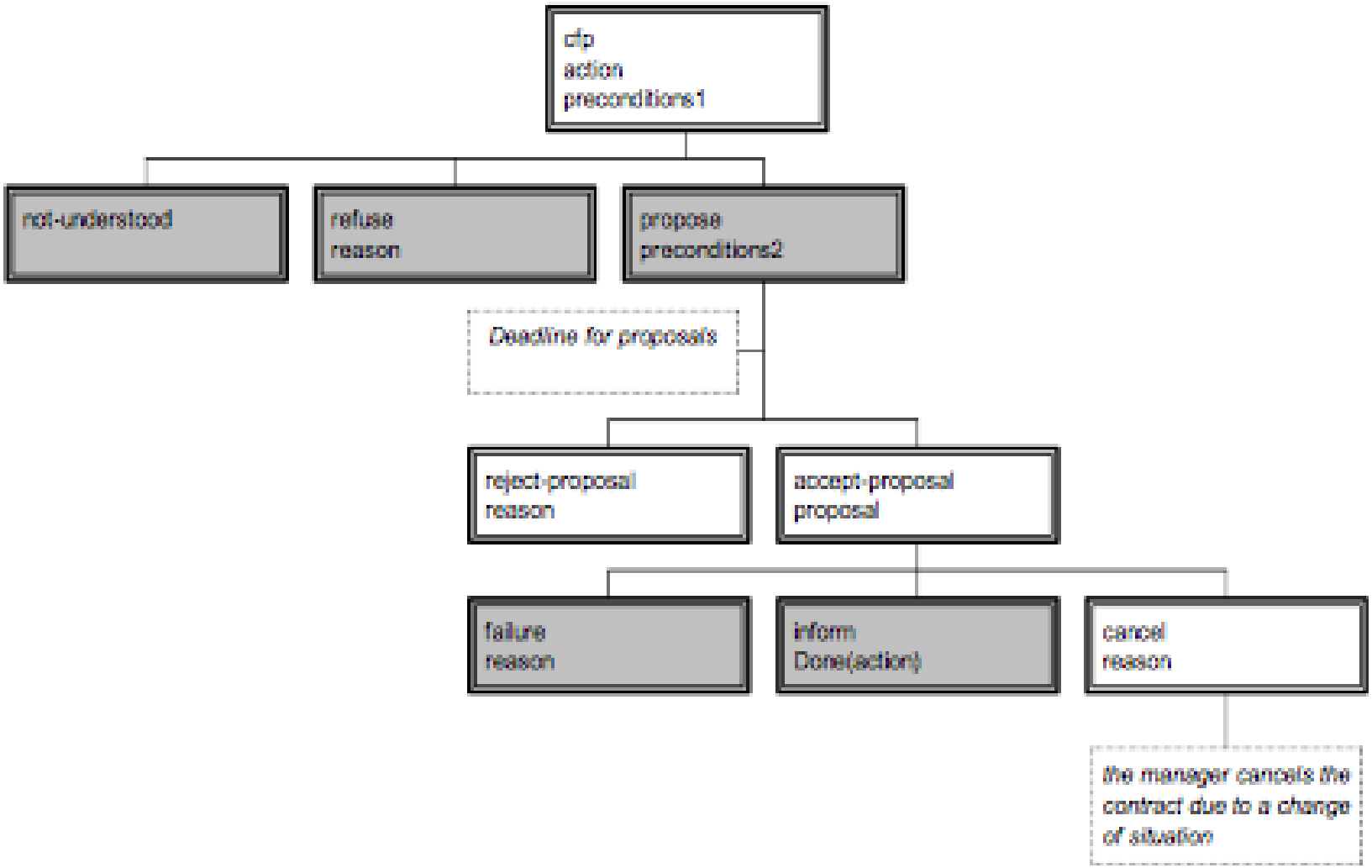
```
MessageTemplate template = AchieveREResponder.createMessageTemplate(
        FIPANames.InteractionProtocol.FIPA_REQUEST);
addBehaviour(new AchieveREResponder(this, template){
    @Override
    protected ACLMessage handleRequest(ACLMessage request)
            throws NotUnderstoodException, RefuseException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

Figure: JADE AchieveREResponder

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# ContractNet I



# ContractNet II

## ContractNetInitiator

*Initiator role* for FIPA contract-net protocol

- constructed by passing the protocol-starting $\mathcal{ACL}$ 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` $\mathcal{ACL}$ 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

# ContractNet 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
  - ...

Check the `ds.lab.jade.bookTrading.contractNet` example for the code.

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# Responder Behaviours

## Cyclic vs. single-session responders

Responder behaviours may have two forms:

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

1. wait for the protocol initiation message
2. serve the protocol
3. go back waiting for a new protocol initiation message

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

1. get the protocol initiation message in the constructor
   → requires an external behaviour to be used
2. serve the protocol
3. terminate

Check the `jade.proto` package to learn more.

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# Java Swing Troubles I

## What's 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 $\mathcal{ACL}$ 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 maintain 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."*

Check the `ds.lab.jade.bookTrading.gui` example carefully.

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# JADE Mobility I

## What means "mobility" for JADE?

In JADE, *mobility* is the ability of an agent program to migrate or to 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 automagically retrieved by JADE platform

## Keep in mind that...

! In order to be able to move, an agent must be `Serializable`

# Outline

1. Directory Facilitator
   - API
   - Syntax
   - Usage
2. FIPA Interaction Protocols in JADE
   - Achieve Rational Effect
   - Contract Net
   - More On Responders
3. JADE Agents & Java Swing
4. JADE Agents Mobility
   - API

# Location API 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

# Location API 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[a]

[a] `tao.uab.cat/ipmp/`

# Action API I

## Finding destinations

To get a `Location` object, an agent must query the AMS by sending it an `ACLMessage.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`

# Action API II

## What are such "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 $\mathcal{ACL}$ messages as *communicative acts*?

# Action API III

## Action how-to

To create and request an `Action`

1. instantiate the `Action` object
   → `Action a = new Action()`
2. decide who should perform the action—the AMS in our case
   → `a.setActor(getAMS())`
3. choose the action to be performed
   → `a.setAction(new QueryPlatformLocationsAction())`
4. *embed* the action into the request $\mathcal{ACL}$ message
   → `ACLMessage msg = new ACLMessage(ACLMessage.REQUEST)`
   `Agent.getContentManager().fillContent(msg, a))`
5. send the message to the receiver—again, the AMS for us
   → `msg.addReceiver(getAMS())`
   `send(msg)`

# Action API IV

## Collecting AMS replies I

To collect AMS replies you can do something like

1. create a suitable data store for locations
   → `Map locations = new HashMap()`
2. 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)
```

3. ...

# Action API V

## Collecting AMS replies II

1. ...
2. *decode* the content of AMS reply—method dual to

   `Agent.getContentManager().fillContent(msg, a))`

   → `Result res = (Result) getContentManager().extractContent(reply)`
3. (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-movement

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

1. create a `MobileAgentDescription`
   → `MobileAgentDescription mad = new MobileAgentDescription`
2. fill its mandatory fields
   → `mad.setName(aid)`
   `mad.setDestination(location)`
3. embed it in a `[Move/Clone]Action` object
   → `MoveAction ma = new MoveAction()`
   `ma.setMobileAgentDescription(mad)`
4. ...

# 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

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

# doMove/doClone How-To V

## The 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

Notice that such ontology is not yet a FIPA standard, hence may adapted in the future[a]

[a] not sure wether at present a standard is available nor if JADE 4.4 complies to it, cannot find references in documentation.

# Are We Done with JADE?

## In our 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 ask questions!

# JADE: Java Agent DEvelopment Framework Advanced 2.0

Stefano Mariani
s.mariani@unibo.it

Dipartimento di Informatica – Scienza e Ingegneria (DISI)
ALMA MATER STUDIORUM – Università di Bologna a Cesena

Academic Year 2015/2016