

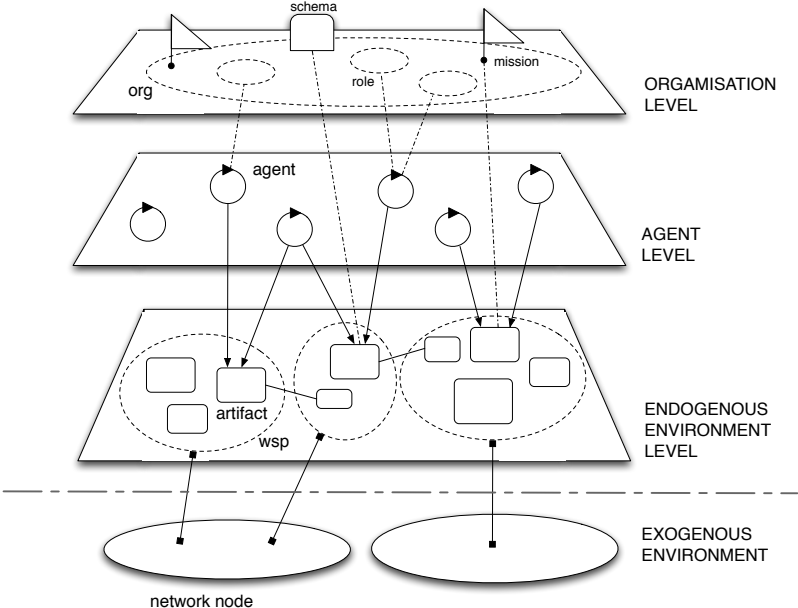
Environment Oriented Programming with CArTAgO

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Multi-Agent System (our perspective)



Outline

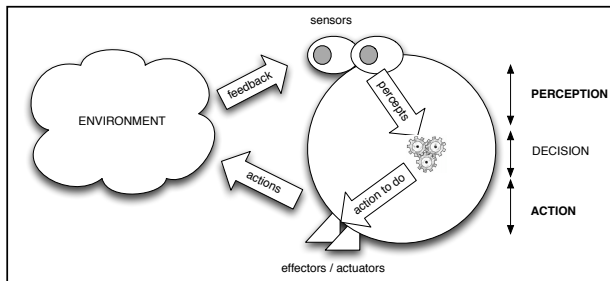
- ▶ Fundamentals
- ▶ Agent & Artifact model
- ▶ Programming the Environment
- ▶ CArtAgO (details)
- ▶ JaCa
- ▶ Conclusions

(slides written together with A. Ricci, O. Boissier, and R. Bordini)

Back to the Notion of Environment in MAS

- ▶ The notion of environment is intrinsically related to the notion of agent and multi-agent system
 - ▶ “An agent is a computer system that is situated in some environment and that is capable of autonomous action in this environment in order to meet its design objective” [Wooldridge, 2002]
 - ▶ “An agent is anything that can be viewed as perceiving its environment through sensors and acting upon the environment through effectors. ” [Russell and Norvig, 2003]
- ▶ Including both physical and software environments

Single Agent Perspective



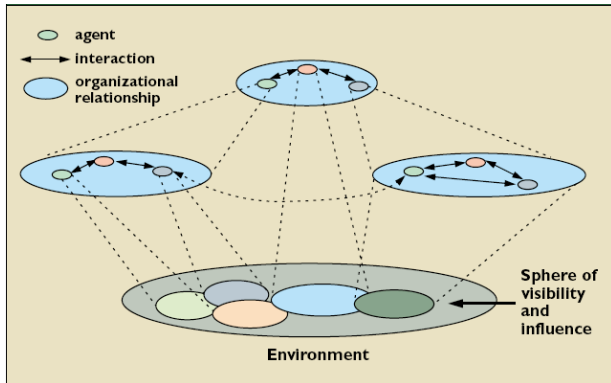
▶ Perception

- ▶ process inside agent inside of attaining awareness or understanding sensory information, creating percepts perceived form of external stimuli or their absence

▶ Actions

- ▶ the means to affect, change or inspect the environment

Multi-Agent Perspective



- ▶ In evidence
 - ▶ overlapping spheres of visibility and influence
 - ▶ ..which means: **interaction**

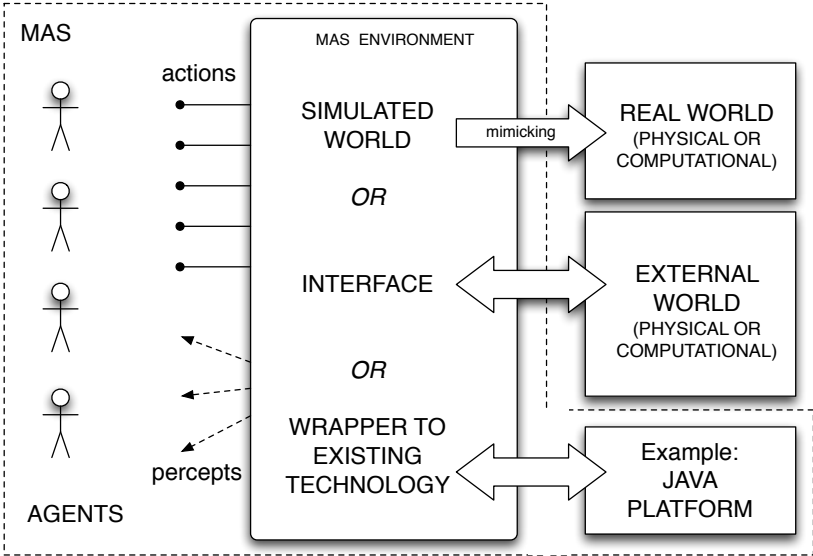
Why Environment Programming

- ▶ Basic level
 - ▶ to create testbeds for real/external environments
 - ▶ to ease the interface/interaction with existing software environments
- ▶ Advanced level
 - ▶ to uniformly **encapsulate** and **modularise** functionalities of the MAS out of the agents
 - ▶ typically related to interaction, coordination, organisation, security
 - ▶ **externalisation**
 - ▶ this implies changing the perspective on the environment
 - ▶ environment as a **first-class abstraction** of the MAS
 - ▶ **endogenous** environments (vs. exogenous ones)
 - ▶ **programmable** environments

Environment Programming: General Issues

- ▶ Defining the interface
 - ▶ actions, perceptions
 - ▶ data-model
- ▶ Defining the environment computational model & architecture
 - ▶ how the environment works
 - ▶ structure, behaviour, topology
 - ▶ core aspects to face: concurrency, distribution
- ▶ Defining the environment programming model
 - ▶ how to program the environment

Basic Level Overview

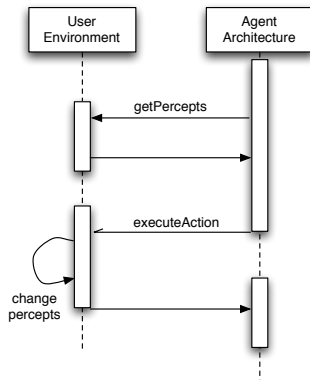
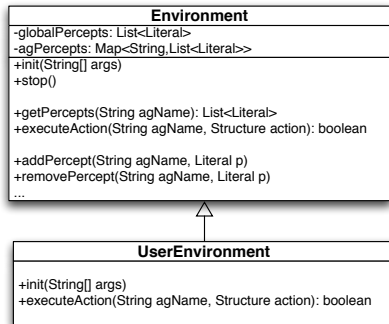


Basic Level: Features

- ▶ Environment conceptually conceived as a single monolithic block
 - ▶ providing actions, generating percepts
- ▶ Environment API
 - ▶ to define the set of actions and program actions computational behaviour
 - ▶ which include the generation of percepts
 - ▶ typically implemented using as single object/class in OO such as Java
 - ▶ method to execute actions
 - ▶ fields to store the environment state
 - ▶ available in many agent programming languages/frameworks
 - ▶ e.g., Jason, 2APL, GOAL, JADEX

An Example: *Jason* [Bordini et al., 2007] (without JaCaMo)

- ▶ Flexible Java-based Environment API
 - ▶ Environment base class to be specialised
 - ▶ executeAction method to specify action semantics
 - ▶ addPercept to generate percepts



Example (continued): MARS Environment in *Jason*

```
public class MarsEnv extends Environment {
    private MarsModel model;
    private MarsView view;

    public void init(String[] args) {
        model = new MarsModel();
        view = new MarsView(model);
        model.setView(view);
        updatePercepts();
    }

    public boolean executeAction(String ag, Structure action) {
        String func = action.getFunctor();
        if (func.equals("next")) {
            model.nextSlot();
        } else if (func.equals("move_towards")) {
            int x = (int)((NumberTerm)action.getTerm(0)).solve();
            int y = (int)((NumberTerm)action.getTerm(1)).solve();
            model.moveTowards(x,y);
        } else if (func.equals("pick")) {
            model.pickGarb();
        } else if (func.equals("drop")) {
            model.dropGarb();
        } else if (func.equals("burn")) {
            model.burnGarb();
        } else {
            return false;
        }
    }

    updatePercepts();
    return true;
}
...

...

/* creates the agents perception
 * based on the MarsModel */
void updatePercepts() {

    clearPercepts();

    Location r1Loc = model.getAgPos(0);
    Location r2Loc = model.getAgPos(1);

    Literal pos1 = Literal.parseLiteral
        ("pos(r1," + r1Loc.x + "," + r1Loc.y + ")");
    Literal pos2 = Literal.parseLiteral
        ("pos(r2," + r2Loc.x + "," + r2Loc.y + ")");

    addPercept(pos1);
    addPercept(pos2);

    if (model.hasGarbage(r1Loc)) {
        addPercept(Literal.parseLiteral("garbage(r1)"));
    }

    if (model.hasGarbage(r2Loc)) {
        addPercept(Literal.parseLiteral("garbage(r2)"));
    }
}

class MarsModel extends GridWorldModel { ... }

class MarsView extends GridWorldView { ... }
}
```

Example (continued): *Jason* Agents Playing on Mars

```
// mars robot 1

/* Initial beliefs */

at(P) :- pos(P,X,Y) & pos(r1,X,Y).

/* Initial goal */

!check(slots).

/* Plans */

+!check(slots) : not garbage(r1)
  <- next(slot);
  !!check(slots).
+!check(slots).

+garbage(r1) : not .desire(carry_to(r2))
  <- !carry_to(r2).

+!carry_to(R)
  <- // remember where to go back
  ?pos(r1,X,Y);
  -+pos(last,X,Y);

  // carry garbage to r2
  !take(garb,R);

  // goes back and continue to check
  !at(last);
  !!check(slots).

...

```

```
...

+!take(S,L) : true
  <- !ensure_pick(S);
  !at(L);
  drop(S).

+!ensure_pick(S) : garbage(r1)
  <- pick(garb);
  !ensure_pick(S).
+!ensure_pick(_).

+!at(L) : at(L).
+!at(L) <- ?pos(L,X,Y);
  move_towards(X,Y);
  !at(L).

```

Another Example: **2APL** [Dastani, 2008]

- ▶ 2APL
 - ▶ BDI-based agent-oriented programming language integrating declarative programming constructs (beliefs, goals) and imperative style programming constructs (events, plans)
- ▶ Java-based Environment API
 - ▶ `Environment` base class
 - ▶ implementing actions as methods
 - ▶ inside action methods external events can be generated to be perceived by agents as percepts

Example: Block-world Environment in 2APL

```
package blockworld;

public class Env extends apapl.Environment {

    public void enter(String agent, Term x, Term y, Term c){...}

    public Term sensePosition(String agent){...}

    public Term pickup(String agent){...}

    public void north(String agent){...}

    ...

}
```

2APL Agents in the block-world

```
BeliefUpdates:
{ bomb(X,Y) }      RemoveBomb(X,Y){ not bomb(X,Y) }
{ true }          AddBomb(X,Y)   { bomb(X,Y) }
{ carry(bomb) }   Drop( )        { not carry(bomb)}
{ not carry(bomb) } Pickup( )    { carry(bomb) }

Beliefs:
start(0,1).
bomb(3,3).
clean( blockWorld ) :-
    not bomb(X,Y) , not carry(bomb).

Plans:
B(start(X,Y)) ;
@blockworld( enter( X, Y, blue ), L )

Goals:
clean( blockWorld )

PG-rules:
clean( blockWorld ) <- bomb( X, Y ) |
{
    goto( X, Y );
    @blockworld( pickup( ), L1 );
    Pickup( );
    RemoveBomb( X, Y );
    goto( 0, 0 );
    @blockworld( drop( ), L2 );
    Drop( )
}
...

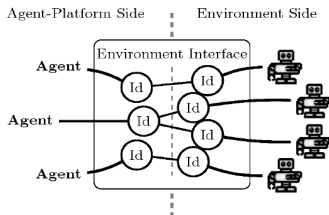
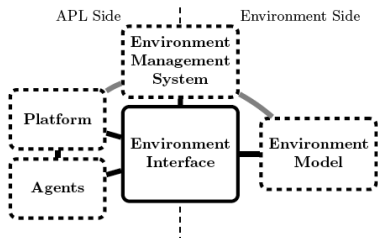
...
PC-rules:
goto( X, Y ) <- true |
{
    @blockworld( sensePosition(), POS );
    B(POS = [A,B]);
    if B(A > X) then
    { @blockworld( west(), L );
      goto( X, Y )
    }
    else if B(A < X) then
    { @blockworld( east(), L );
      goto( X, Y )
    }
    else if B(B > Y) then
    { @blockworld( north(), L );
      goto( X, Y )
    }
    else if B(B < Y) then
    { @blockworld( south(), L );
      goto( X, Y )
    }
}
...

```


Environment Interface Standard – EIS Initiative

- ▶ Initiative supported by main APL research groups [Behrens et al., 2010]
 - ▶ GOAL, 2APL, GOAL, JADDEX, JASON
- ▶ Goal: design and develop a generic environment interface standard
- ▶ Principles
 - ▶ wrapping already existing environments
 - ▶ creating new environments by connecting already existing apps
 - ▶ creating new environments from scratch
- ▶ Requirements
 - ▶ generic
 - ▶ reuse

EIS Meta-Model



- ▶ By means of the Env. Interface agents perform actions and collect percepts
 - ▶ actually actions/percepts are issued to controllable entities in environment model
 - ▶ represent the agent bodies, with effectors and sensors

Environment Interface Features

- ▶ Interface functions
 - ▶ attaching, detaching, and notifying observers (software design pattern);
 - ▶ registering and unregistering agents;
 - ▶ adding and removing entities;
 - ▶ managing the agents-entities-relation;
 - ▶ performing actions and retrieving percepts;
 - ▶ managing the environment
- ▶ Interface Intermediate language
 - ▶ to facilitate data-exchange
 - ▶ encoding percepts, actions, events

Advanced Level Overview

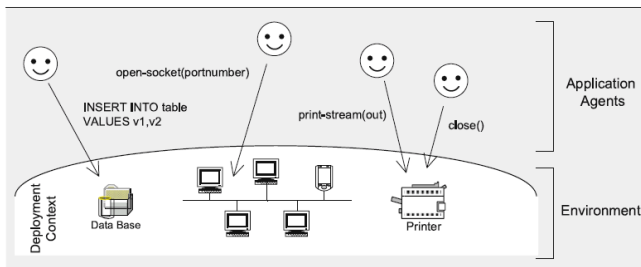
- ▶ Vision: environment as a **first-class abstraction** in MAS [Weyns et al., 2007, Ricci et al., 2010b]
 - ▶ **application** or **endogenous** environments, i.e. that environment which is an explicit part of the MAS
 - ▶ providing an exploitable **design** & **programming** abstraction to build MAS applications
- ▶ Outcome
 - ▶ distinguishing clearly between the responsibilities of agent and environment
 - ▶ separation of concerns
 - ▶ improving the engineering practice

Three Support Levels [Weyns et al., 2007]

- ▶ Basic **interface** support
- ▶ **Abstraction** support level
- ▶ **Interaction-mediation** support level

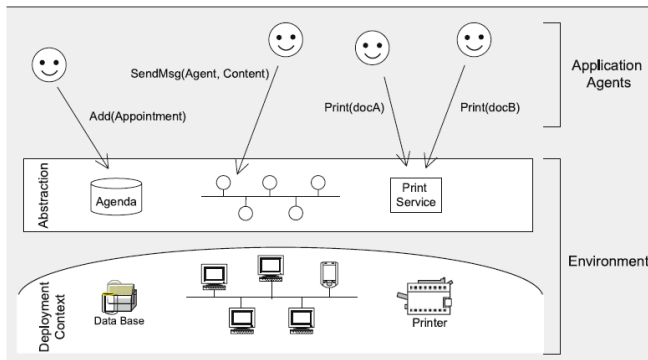
Basic Interface Support

- ▶ The environment enables agents to access the deployment context
 - ▶ i.e. the hardware and software and external resources with which the MAS interacts



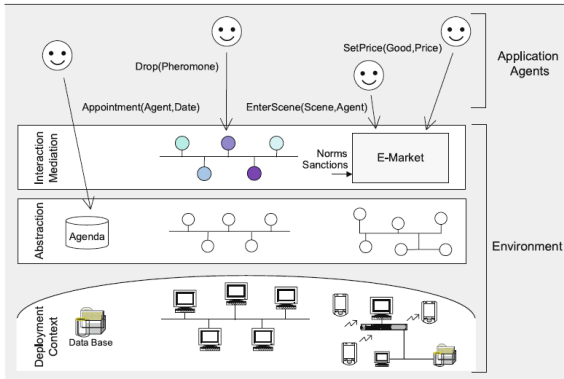
Abstraction Support

- ▶ Bridges the conceptual gap between the agent abstraction and low-level details of the deployment context
 - ▶ shields low-level details of the deployment context



Interaction-Mediation Support

- ▶ **Regulate** the access to shared resources
- ▶ **Mediate** interaction between agents



Environment Definition Revised

Environment definition revised [Weyns et al., 2007]

The environment is a first-class abstraction that provides the surrounding conditions for agents to exist and that mediates both the interaction among agents and the access to resources

Research on Environments for MAS

- ▶ Environments for Multi-Agent Systems research field / **E4MAS** workshop series [Weyns et al., 2005]
 - ▶ different themes and issues (see JAAMAS Special Issue [Weyns and Parunak, 2007] for a good survey)
 - ▶ mechanisms, architectures, infrastructures, applications [Platon et al., 2007, Weyns and Holvoet, 2007, Weyns and Holvoet, 2004, Viroli et al., 2007]
 - ▶ the main perspective is (agent-oriented) software engineering
- ▶ Focus of this tutorial: the role of the environment abstraction in **MAS programming**
 - ▶ **environment programming**

Environment Programming

- ▶ Environment as **first-class programming abstraction** [Ricci et al., 2010b]
 - ▶ software designers and engineers perspective
 - ▶ **endogenous** environments (vs. exogenous one)
 - ▶ programming MAS =
programming Agents + programming Environment
 - ▶ ..but this will be extended to include OOP in next part
- ▶ Environment as **first-class runtime abstraction** for agents
 - ▶ agent perspective
 - ▶ to be observed, used, adapted, constructed, ...
- ▶ Defining computational and programming frameworks/models also for the environment part

Computational Frameworks for Environment Programming: Issues

- ▶ Defining the environment interface
 - ▶ actions, percepts, data model
 - ▶ **contract** concept, as defined in software engineering contexts (Design by Contract)
- ▶ Defining the environment computational model
 - ▶ environment structure, behaviour
- ▶ Defining the environment distribution model
 - ▶ topology

Programming Models for the Environment: Desiderata

- ▶ **Abstraction**
 - ▶ keeping the agent abstraction level e.g. no agents sharing and calling OO objects
 - ▶ effective programming models for controllable and observable computational entities
- ▶ **Modularity**
 - ▶ away from the monolithic and centralised view
- ▶ **Orthogonality**
 - ▶ wrt agent models, architectures, platforms
 - ▶ support for heterogeneous systems

Programming Models for the Environment: Desiderata

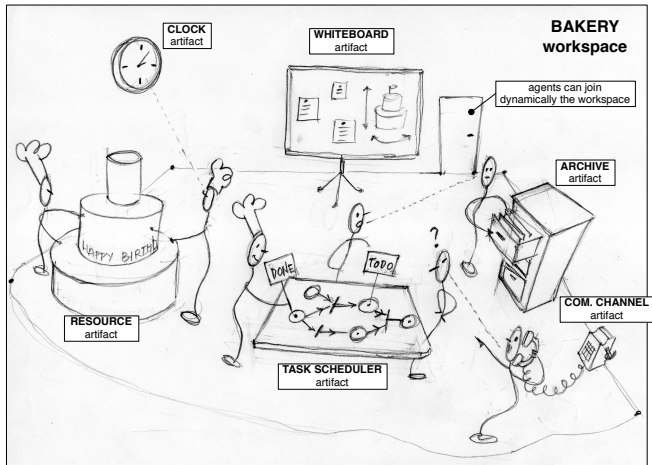
- ▶ **Dynamic extensibility**
 - ▶ dynamic construction, replacement, extension of environment parts
 - ▶ support for open systems
- ▶ **Reusability**
 - ▶ reuse of environment parts for different kinds of applications

Existing Computational Frameworks

- ▶ AGRE / AGREEN / MASQ [Stratulat et al., 2009]
 - ▶ AGRE – integrating the AGR (Agent-Group-Role) organisation model with a notion of environment
 - ▶ Environment used to represent both the physical and social part of interaction
 - ▶ AGREEN / MASQ – extending AGRE towards a unified representation for physical, social and institutional environments
 - ▶ Based on MadKit platform [Gutknecht and Ferber, 2000]
- ▶ GOLEM [Bromuri and Stathis, 2008]
 - ▶ Logic-based framework to represent environments for situated cognitive agents
 - ▶ composite structure containing the interaction between cognitive agents and objects
- ▶ A&A and CArTAgO [Ricci et al., 2010b]
 - ▶ introducing a computational notion of artifact to design and implement agent environments

A&A and CArtAgO

Agents and Artifacts (A&A) Conceptual Model: Background Human Metaphor



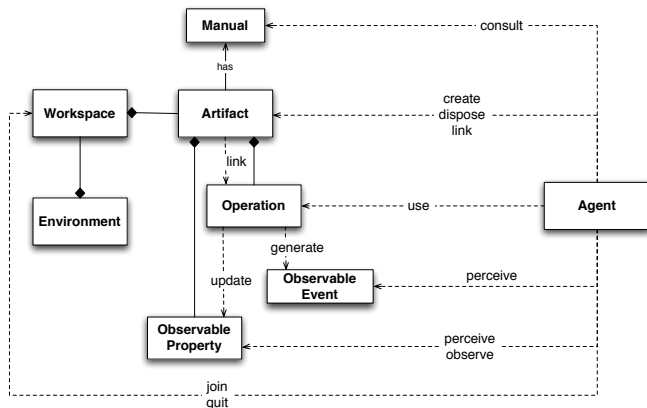
A&A Basic Concepts [Omicini et al., 2008]

- ▶ Agents
 - ▶ autonomous, goal-oriented pro-active entities
 - ▶ create and co-use artifacts for supporting their activities
 - ▶ besides direct communication
- ▶ Artifacts
 - ▶ non-autonomous, function-oriented, stateful entities
 - ▶ controllable and observable
 - ▶ modelling the tools and resources used by agents
 - ▶ designed by MAS programmers
- ▶ Workspaces
 - ▶ grouping agents & artifacts
 - ▶ defining the topology of the computational environment

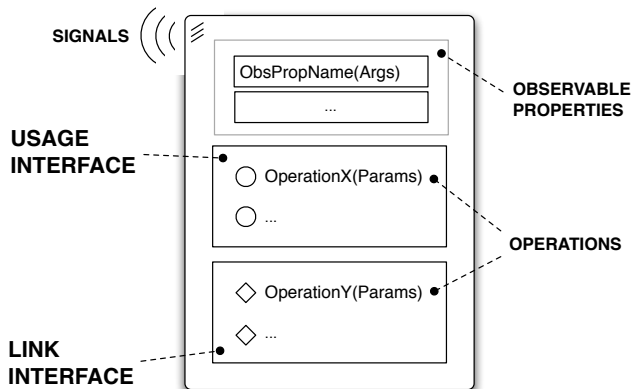
A&A Programming Model Features [Ricci et al., 2007b]

- ▶ Abstraction
 - ▶ artifacts as first-class resources and tools for agents
- ▶ Modularisation
 - ▶ artifacts as modules encapsulating functionalities, organized in workspaces
- ▶ Extensibility and openness
 - ▶ artifacts can be created and destroyed at runtime by agents
- ▶ Reusability
 - ▶ artifacts (types) as reusable entities, for setting up different kinds of environments

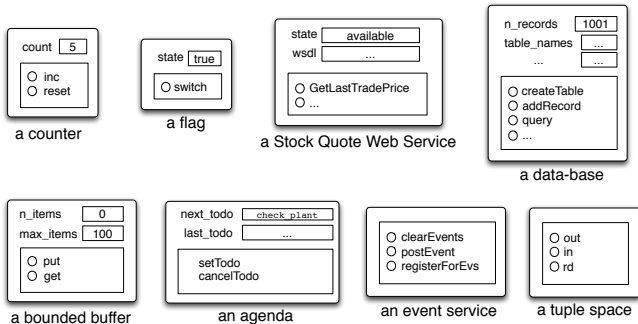
A&A Meta-Model in More Detail [Ricci et al., 2010b]



Artifact Abstract Representation



A World of Artifacts



A Simple Taxonomy

- ▶ Individual or personal artifacts
 - ▶ designed to provide functionalities for a single agent use
 - ▶ e.g. an agenda for managing deadlines, a library...
- ▶ Social artifacts
 - ▶ designed to provide functionalities for structuring and managing the interaction in a MAS
 - ▶ coordination artifacts [Omicini et al., 2004], organisation artifacts, ...
 - ▶ e.g. a blackboard, a game-board,...
- ▶ Boundary artifacts
 - ▶ to represent external resources/services
 - ▶ e.g. a printer, a Web Service
 - ▶ to represent devices enabling I/O with users
 - ▶ e.g GUI, console, etc.

Actions and Percepts in Artifact-Based Environments

- ▶ Explicit semantics defined by the (endogenous) environment [Ricci et al., 2010c]
 - ▶ success/failure semantics, execution semantics
 - ▶ defining the **contract** (in the SE acceptance) provided by the environment

actions \longleftrightarrow artifacts' operation

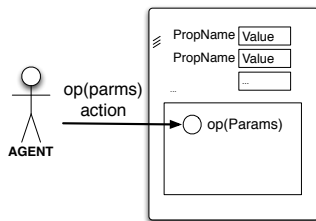
the action repertoire is given by the dynamic set of operations provided by the overall set of artifacts available in the workspace can be changed by creating/disposing artifacts

- ▶ action success/failure semantics is defined by operation semantics

percepts \longleftrightarrow artifacts' observable properties + signals

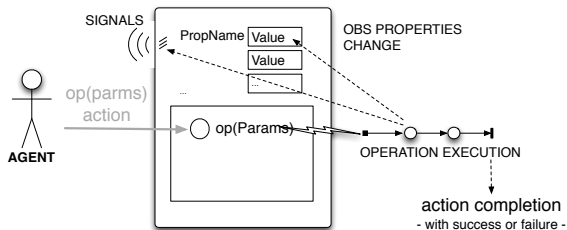
properties represent percepts about the state of the environment
signals represent percepts concerning events signalled by the environment

Interaction Model: Use



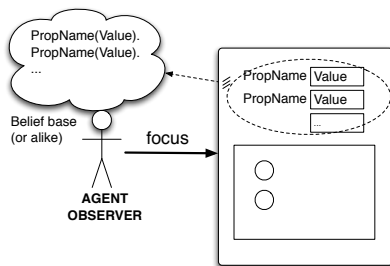
- ▶ Performing an action corresponds to triggering the execution of an operation
 - ▶ acting on artifact's usage interface

Interaction Model: Operation execution



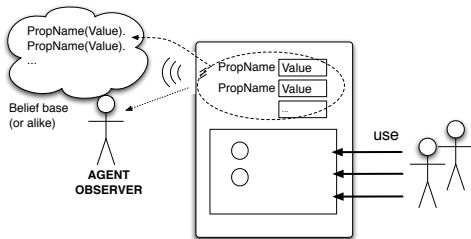
- ▶ a process structured in one or multiple transactional steps
- ▶ asynchronous with respect to agent
 - ▶ ...which can proceed possibly reacting to percepts and executing actions of other plans/activities
- ▶ operation completion causes action completion
 - ▶ action completion events with success or failure, possibly with action feedbacks

Interaction Model: Observation



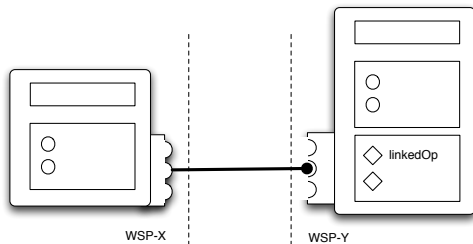
- ▶ Agents can dynamically select which artifacts to observe
 - ▶ predefined `focus/stopFocus` actions

Interaction Model: Observation



- ▶ By focussing an artifact
 - ▶ observable properties are mapped into agent dynamic knowledge about the state of the world, as percepts
 - ▶ e.g. belief base
 - ▶ signals are mapped as percepts related to observable events

Artifact Linkability



- ▶ Basic mechanism to enable inter-artifact interaction
 - ▶ **linking** artifacts through interfaces (link interfaces)
 - ▶ operations triggered by an artifact over an other artifact
 - ▶ Useful to design & program distributed environments
 - ▶ realised by set of artifacts linked together
 - ▶ possibly hosted in different workspaces

Artifact Manual

- ▶ Agent-readable description of artifact's...
 - ▶ ...**functionality**
 - ▶ **what** functions/services artifacts of that type provide
 - ▶ ...**operating instructions**
 - ▶ **how** to use artifacts of that type
- ▶ Towards advanced use of artifacts by intelligent agents [Piunti et al., 2008]
 - ▶ dynamically choosing which artifacts to use to accomplish their tasks and how to use them
 - ▶ strong link with Semantic Web research issues
- ▶ Work in progress
 - ▶ defining ontologies and languages for describing the manuals

CARTAgO

- ▶ Common ARTifact infrastructure for AGent Open environment (CARTAgO) [Ricci et al., 2009]
- ▶ Computational framework / infrastructure to implement and run artifact-based environment [Ricci et al., 2007c]
 - ▶ Java-based programming model for defining artifacts
 - ▶ set of basic API for agent platforms to work within artifact-based environment
- ▶ Distributed and open MAS
 - ▶ workspaces distributed on Internet nodes
 - ▶ agents can join and work in multiple workspace at a time
 - ▶ Role-Based Access Control (RBAC) security model
- ▶ Open-source technology
 - ▶ available at <https://github.com/CARTAgO-lang/cartago>

Integration with Agent Languages and Platforms

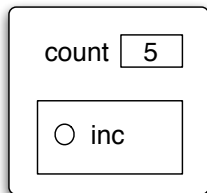
- ▶ Integration with existing agent platforms [Ricci et al., 2008]
 - ▶ by means of bridges creating an action/perception interface and doing data binding
- ▶ Outcome
 - ▶ developing open and heterogenous MAS
 - ▶ introducing a further perspective on interoperability besides the ACL's one
 - ▶ sharing and working in a common work environment
 - ▶ common object-oriented data-model

A&A in JaCaMo Platform

- ▶ Integration of CArtAgO with *Jason* language/platform
- ▶ Mapping
 - ▶ actions
 - ▶ *Jason* agent external actions are mapped onto artifacts' operations
 - ▶ percepts
 - ▶ artifacts' observable properties are mapped onto agent beliefs
 - ▶ artifacts' signals are mapped as percepts related to observable events
 - ▶ data-model
 - ▶ *Jason* data-model is extended to manage also (Java) objects

Example 1: A Simple Counter Artifact

```
class Counter extends Artifact {  
  
  void init(){  
    defineObsProp("count",0);  
  }  
  
  @OPERATION void inc(){  
    ObsProperty p = getObsProperty("count");  
    p.updateValue(p.intValue() + 1);  
    signal("tick");  
  }  
}
```



- ▶ Some API spots
 - ▶ Artifact base class
 - ▶ @OPERATION annotation to mark artifact's operations
 - ▶ set of primitives to work define/update/.. observable properties
 - ▶ signal primitive to generate signals

Example 1: User and Observer Agents

USER(S)

```
!create_and_use.  
  
+!create_and_use : true  
  <- !setupTool(Id);  
      // use  
      inc;  
      // second use specifying the Id  
      inc [artifact_id(Id)].  
  
// create the tool  
+!setupTool(C): true  
  <- makeArtifact("c0", "Counter", C).
```

OBSERVER(S)

```
!observe.  
  
+!observe : true  
  <- ?myTool(C); // discover the tool  
      focus(C).  
  
+count(V)  
  <- println("observed new value: ",V).  
  
+tick [artifact_name(Id,"c0")]  
  <- println("perceived a tick").  
  
+?myTool(CounterId): true  
  <- lookupArtifact("c0",CounterId).  
  
-?myTool(CounterId): true  
  <- .wait(10);  
      ?myTool(CounterId).
```

- ▶ Working with the shared counter

Pre-defined Artifacts

- ▶ Each workspace contains by default a predefined set of artifacts
 - ▶ providing core and auxiliary functionalities
 - ▶ i.e. a pre-defined repertoire of actions available to agents...
- ▶ Among the others
 - ▶ workspace, type: `cartago.WorkspaceArtifact`
 - ▶ functionalities to manage the workspace, including security
 - ▶ operations: `makeArtifact`, `lookupArtifact`, `focus`,...
 - ▶ node, type: `cartago.NodeArtifact`
 - ▶ core functionalities related to a node
 - ▶ operations: `createWorkspace`, `joinWorkspace`, ...
 - ▶ console, type `cartago.tools.Console`
 - ▶ operations: `println`,...
 - ▶ blackboard, type `cartago.tools.TupleSpace`
 - ▶ operations: `out`, `in`, `rd`, ...
 - ▶

Example 2: Coordination Artifacts – A Bounded Buffer

```
public class BoundedBuffer extends Artifact {
    private LinkedList<Item> items;
    private int nmax;

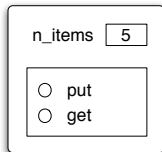
    void init(int nmax){
        items = new LinkedList<Item>();
        defineObsProperty("n_items",0);
        this.nmax = nmax;
    }

    @OPERATION void put(Item obj){
        await("bufferNotFull");
        items.add(obj);
        getObsProperty("n_items").updateValue(items.size());
    }

    @OPERATION void get(OpFeedbackParam<Item> res) {
        await("itemAvailable");
        Item item = items.removeFirst();
        res.set(item);
        getObsProperty("n_items").updateValue(items.size());
    }

    @GUARD boolean itemAvailable(){ return items.size() > 0; }

    @GUARD boolean bufferNotFull(Item obj){ return items.size() < nmax; }
}
```



- ▶ Basic operation features
 - ▶ output parameters to represent action feedbacks
 - ▶ long-term operations, with a high-level support for synchronization (await primitive, guards)

Example 2: Producers and Consumers

PRODUCERS

```
item_to_produce(0).
!produce.

+!produce: true
  <- !setupTools(Buffer);
    !produceItems.

+!produceItems : true
  <- ?nextItemToProduce(Item);
    put(Item);
    !!produceItems.

+?nextItemToProduce(N) : true
  <- -item_to_produce(N);
    +item_to_produce(N+1).

+!setupTools(Buffer) : true
  <- makeArtifact("myBuffer", "BoundedBuffer",
    [10], Buffer).

-!setupTools(Buffer) : true
  <- lookupArtifact("myBuffer", Buffer).
```

CONSUMERS

```
!consume.

+!consume: true
  <- ?bufferReady;
    !consumeItems.

+!consumeItems: true
  <- get(Item);
    !consumeItem(Item);
    !!consumeItems.

+!consumeItem(Item) : true
  <- .my_name(Me);
    println(Me, ":", Item).

+?bufferReady : true
  <- lookupArtifact("myBuffer", _).
-?bufferReady : true
  <- .wait(50);
    ?bufferReady.
```

Remarks

- ▶ Process-based operation execution semantics
 - ▶ action/operation execution can be long-term
 - ▶ action/operation execution can overlap
 - ▶ key feature for implementing coordination functionalities
- ▶ Operation with output parameters as action feedbacks

Action Execution & Blocking Behaviour

- ▶ Given the action/operation map, by executing an action the intention/activity is suspended until the corresponding operation has completed or failed
 - ▶ action completion events generated by the environment and automatically processed by the agent/environment platform bridge
 - ▶ no need of explicit observation and reasoning by agents to know if an action succeeded
- ▶ However **the agent execution cycle is not blocked!**
 - ▶ the agent can continue to process percepts and possibly execute actions of other intentions

Example 3: Internal Processes – A Clock

CLOCK

```
public class Clock extends Artifact {  
  
    boolean working;  
    final static long TICK_TIME = 100;  
  
    void init(){ working = false; }  
  
    @OPERATION void start(){  
        if (!working){  
            working = true;  
            execInternalOp("work");  
        } else {  
            failed("already_working");  
        }  
    }  
  
    @OPERATION void stop(){ working = false; }  
  
    @INTERNAL_OPERATION void work(){  
        while (working){  
            signal("tick");  
            await_time(TICK_TIME);  
        }  
    }  
}
```

CLOCK USER AGENT

```
!test_clock.  
  
+!test_clock  
  <- makeArtifac("myClock","Clock",[],Id);  
    focus(Id);  
    +n_ticks(0);  
    start;  
    println("clock started.").  
  
@plan1  
+tick: n_ticks(10)  
  <- stop;  
    println("clock stopped.").  
  
@plan2 [atomic]  
+tick: n_ticks(N)  
  <- -+n_ticks(N+1);  
    println("tick perceived!").
```

- ▶ Internal operations
 - ▶ execution of operations triggered by other operations
 - ▶ implementing controllable processes

Example 4: Artifacts for User I/O – GUI Artifacts



- ▶ Exploiting artifacts to enable interaction between human users and agents

Example 4: Agent and User Interaction

GUI ARTIFACT

```
public class MySimpleGUI extends GUIArtifact {
    private MyFrame frame;

    public void setup() {
        frame = new MyFrame();

        linkActionEventToOp(frame.okButton,"ok");
        linkKeyStrokeToOp(frame.text,"ENTER","updateText");
        linkWindowClosingEventToOp(frame, "closed");
        defineObsProperty("value",getValue());
        frame.setVisible(true);
    }

    @INTERNAL_OPERATION void ok(ActionEvent ev){
        signal("ok");
    }

    @OPERATION void setValue(double value){
        frame.setText(""+value);
        updateObsProperty("value",value);
    }
    ...

    @INTERNAL_OPERATION
    void updateText(ActionEvent ev){
        updateObsProperty("value",getValue());
    }

    private int getValue(){
        return Integer.parseInt(frame.getText());
    }

    class MyFrame extends JFrame {...}
}
```

USER ASSISTANT AGENT

```
!test_gui.
+!test_gui
  <- makeArtifact("gui","MySimpleGUI",Id);
  focus(Id).

+value(V)
  <- println("Value updated: ",V).

+ok : value(V)
  <- setValue(V+1).

+closed
  <- .my_name(Me);
  .kill_agent(Me).
```

Other Features

- ▶ Other CArtAgO features not discussed in this lecture
 - ▶ linkability
 - ▶ executing chains of operations across multiple artifacts
 - ▶ multiple workspaces
 - ▶ agents can join and work in multiple workspaces, concurrently
 - ▶ including remote workspaces
 - ▶ RBAC security model
 - ▶ workspace artifact provides operations to set/change the access control policies of the workspace, depending on the agent role
 - ▶ ruling agents' access and use of artifacts of the workspace
 - ▶ ...
- ▶ See CArtAgO papers and manuals for more information

A&A and CArtAgO: Some Research Explorations

- ▶ Cognitive stigmergy based on artifact environments [Ricci et al., 2007a]
 - ▶ cognitive artifacts for knowledge representation and coordination [Piunti and Ricci, 2009]
- ▶ Artifact-based environments for argumentation [Oliva et al., 2010]
- ▶ Including A&A in AOSE methodology [Molesini et al., 2005]
- ▶ Defining a Semantic (OWL-based) description of artifact environments (CArtAgO-DL)
 - ▶ JaSa project = JASDL + CArtAgO-DL
- ▶ ...

Applying CArTAgO and JaCaMo

- ▶ Using JaCaMo for building real-world applications and infrastructures
- ▶ Some examples
 - ▶ JaCa-Android
 - ▶ implementing mobile computing applications on top of the Android platform using JaCa [Santi et al., 2011]
 - ▶ <http://jaca-android.sourceforge.net>
 - ▶ JaCa-WS / CArTAgO-WS
 - ▶ building SOA/Web Services applications using JaCa [Ricci et al., 2010a]
 - ▶ <http://cartagows.sourceforge.net>
 - ▶ JaCa-Web
 - ▶ implementing Web 2.0 applications using JaCa
 - ▶ <http://jaca-web.sourceforge.net>

Wrap-up

- ▶ Environment programming
 - ▶ environment as a programmable part of the MAS
 - ▶ encapsulating and modularising functionalities useful for agents' work
- ▶ Artifact-based environments
 - ▶ artifacts as first-class abstraction to design and program complex software environments
 - ▶ usage interface, observable properties / events, linkability
 - ▶ artifacts as first-order entities for agents
 - ▶ interaction based on use and observation
 - ▶ agents dynamically co-constructing, evolving, adapting their world
- ▶ CArtAgO computational framework
 - ▶ programming and executing artifact-based environments
 - ▶ integration with heterogeneous agent platforms

Summary

- ▶ environment as a **first-class abstraction** of the MAS
 - ▶ **endogenous** environments (vs. exogenous ones)
 - ▶ **programmable** environments
- ▶ **encapsulate** functionalities of the MAS out of the agents
 - ▶ externalisation

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Environment Oriented Programming

- Fundamentals

- Existing approaches

 - Basic Level

 - Advanced Level

- Artifacts and CArtAgO

- CArtAgO and Agents (E-A)

- Conclusions and wrap-up