ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
SEDE DI CESENA

aliCE

WOA, Palermo Novembre 2008

From Agents to Artifacts Back and Forth *Operational and Doxastic Use of Artifacts in MAS*

Michele Piunti(1,2), Alessandro Ricci (1)

(1) aliCE group at DEIS, Università di Bologna, Cesena

(2) Istituto Scienze e Tecnologie della Cognizione, ISTC-CNR, Roma

[michele.piunti, alessandro.ricci]@unibo.it

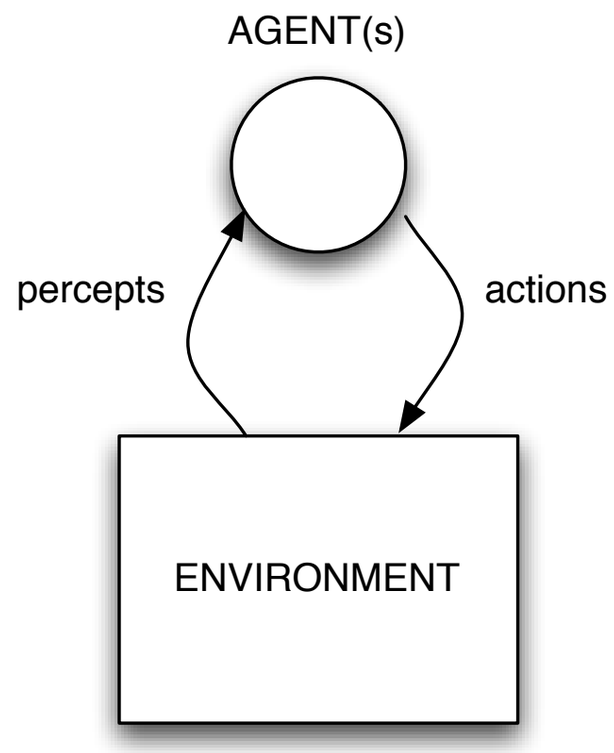
presented by

Andrea Omicini

OUTLINE

- Rationale of Agents and Artifacts (A&A) approach
- CArtAgO and Artifact programming model
- Agents and Artifacts in the Loop of Cognitive Interactions
- Example: Producers-Consumers
- Conclusions

THE ROLE OF ENVIRONMENT IN MAS



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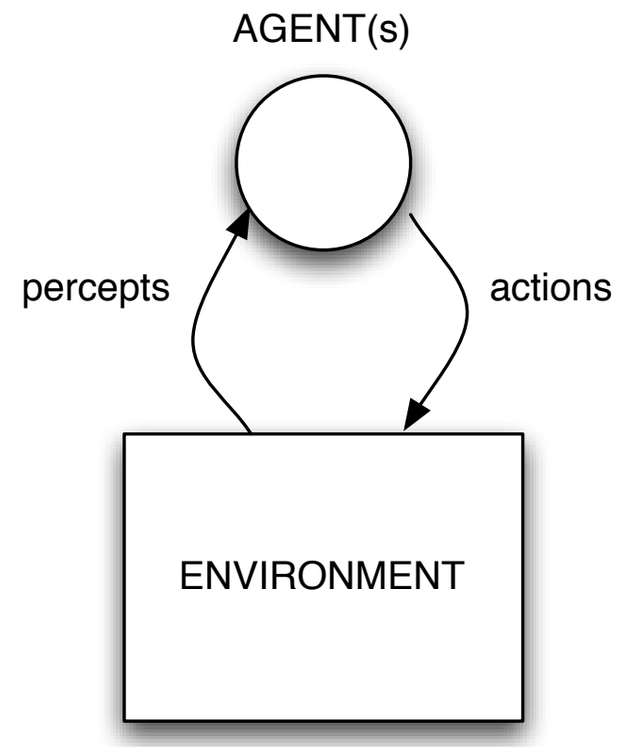
- "Traditional" (D)AI / agent / MAS view
  - the target of agent actions and source of agents perception
  - something out of MAS design / engineering



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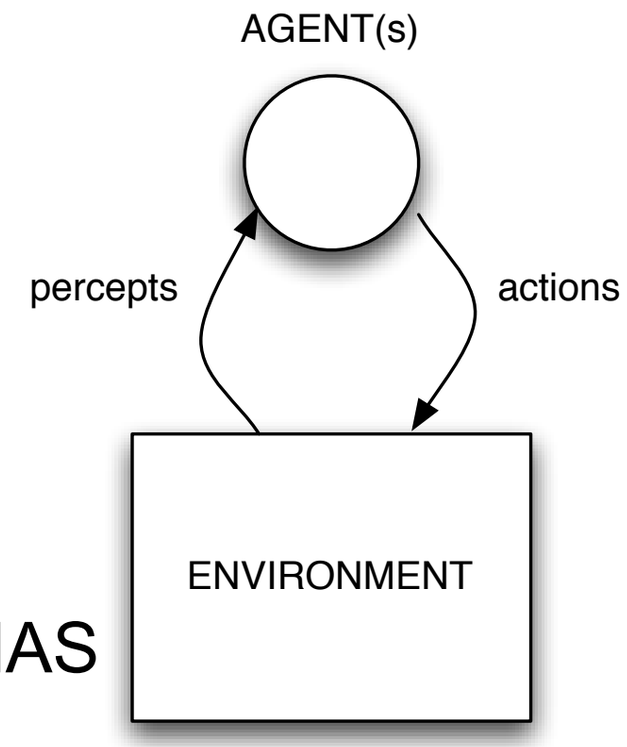
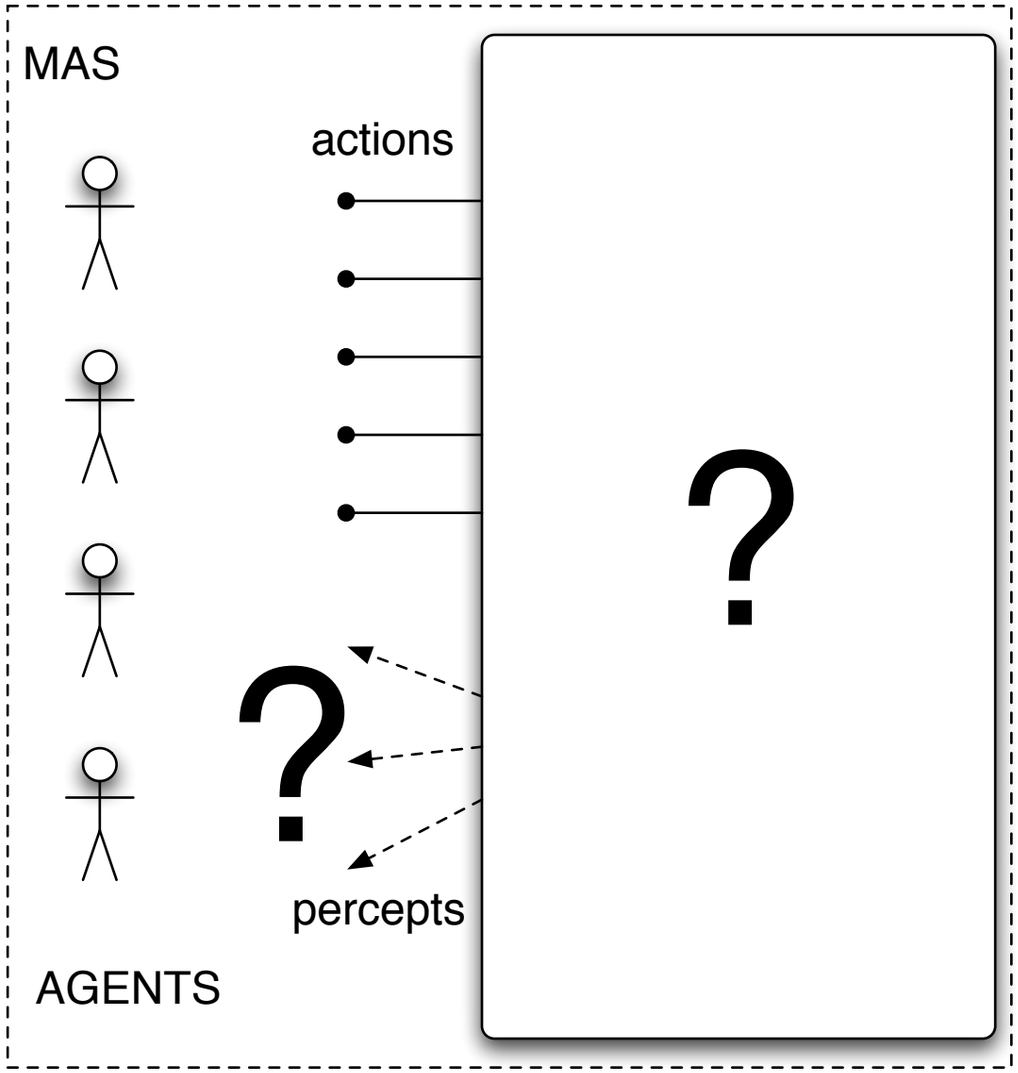


- New perspective in recent works
  - environment as a first-class issue in engineering MAS
    - mediating interaction among agents
    - encapsulating functionalities and services for enabling/ managing such interactions
      - coordination, organisation, security,...

ENVIRONMENT IN MAS PROGRAMMING ?

PERCEPTION IN AUTONOMOUS AGENTS ?



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  - defining agent (external) actions
    - typically a static list of actions, shared by all the agents
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- No support for interoperability across platforms

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- MAS: Great attention for message exchange and ACL
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  - Protocols, Ontologies = Computational load on Agents
- In general, for other kinds of percepts:
  - Information flow is shaped based on the format provided by the adopted environment
  - No clear distinction, at a reasoning level, between practical and perceptive activities

JASON ENVIRONMENT

- GOLD-MINER DEMO -

```
public class MiningPlanet extends jason.environment.Environment {
  ...
  public void init(String[] args) {...}

  public boolean executeAction(String ag, Structure action) {
      boolean result = false;
      int agId = getAgIdBasedOnName(ag);
      if (action.equals(up)) {
        result = model.move(Move.UP, agId);
      } else if (action.equals(down)) {
        result = model.move(Move.DOWN, agId);
      } else if (action.equals(right)) {
        ...
      }
      return result;
  }

  private void updateAgPercept(String agName, int ag) {clearPercepts(agName);
    // its location
    Location l = model.getAgPos(ag);
    addPercept(agName, Literal.parseLiteral("pos(" + l.x + "," + l.y + ")"));
    if (model.isCarryingGold(ag)) {
      addPercept(agName, Literal.parseLiteral("carrying_gold"));
    }
    // what's around
    updateAgPercept(agName, l.x - 1, l.y - 1);
    updateAgPercept(agName, l.x - 1, l.y);
    ...
  }
}
```

ENRICHING THE VIEW: WORK ENVIRONMENTS

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  - designing good and effective place for agents to live and work in
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  - beyond simulated worlds

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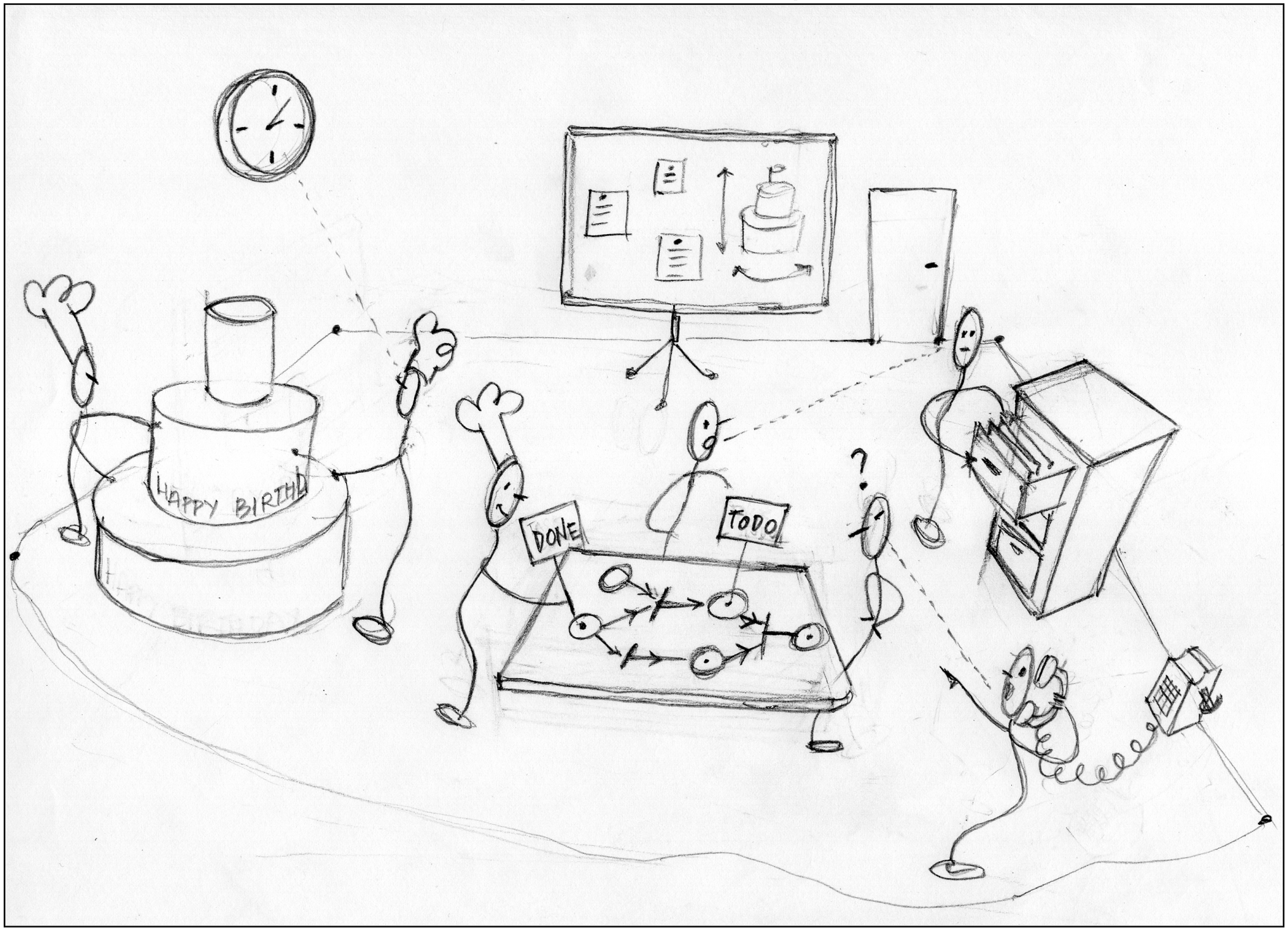
- "**Work environment**" notion
  - that *part of the MAS* that is *designed* and *programmed* so as to ease agent activities and work
    - first-class entity of the agent world
- as pivotal element of MAS design and programming

A HUMAN WORK ENVIRONMENT

(~BAKERY)



ARTIFACTS ARE IN THE AGENT MAINSTREAM

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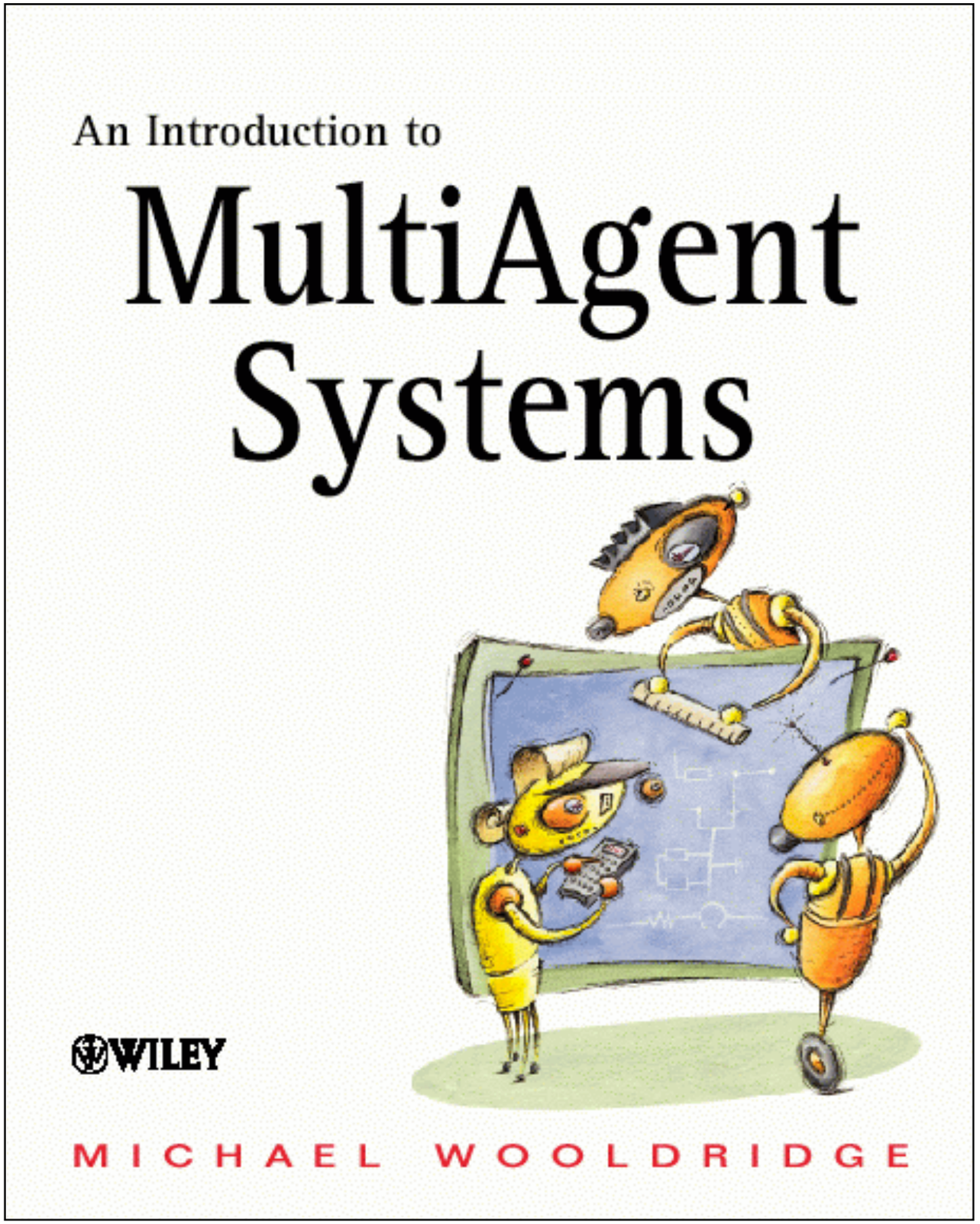

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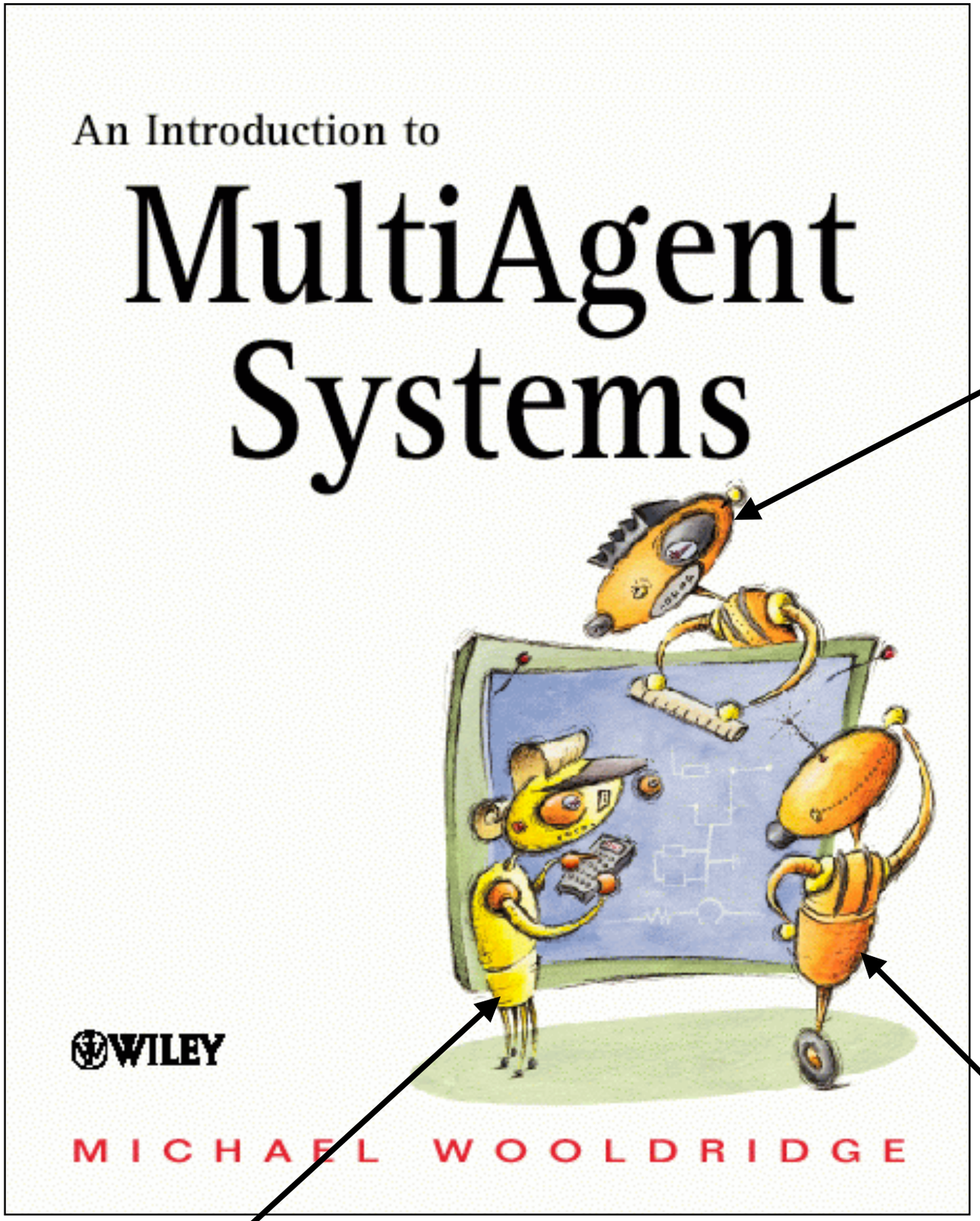

agent

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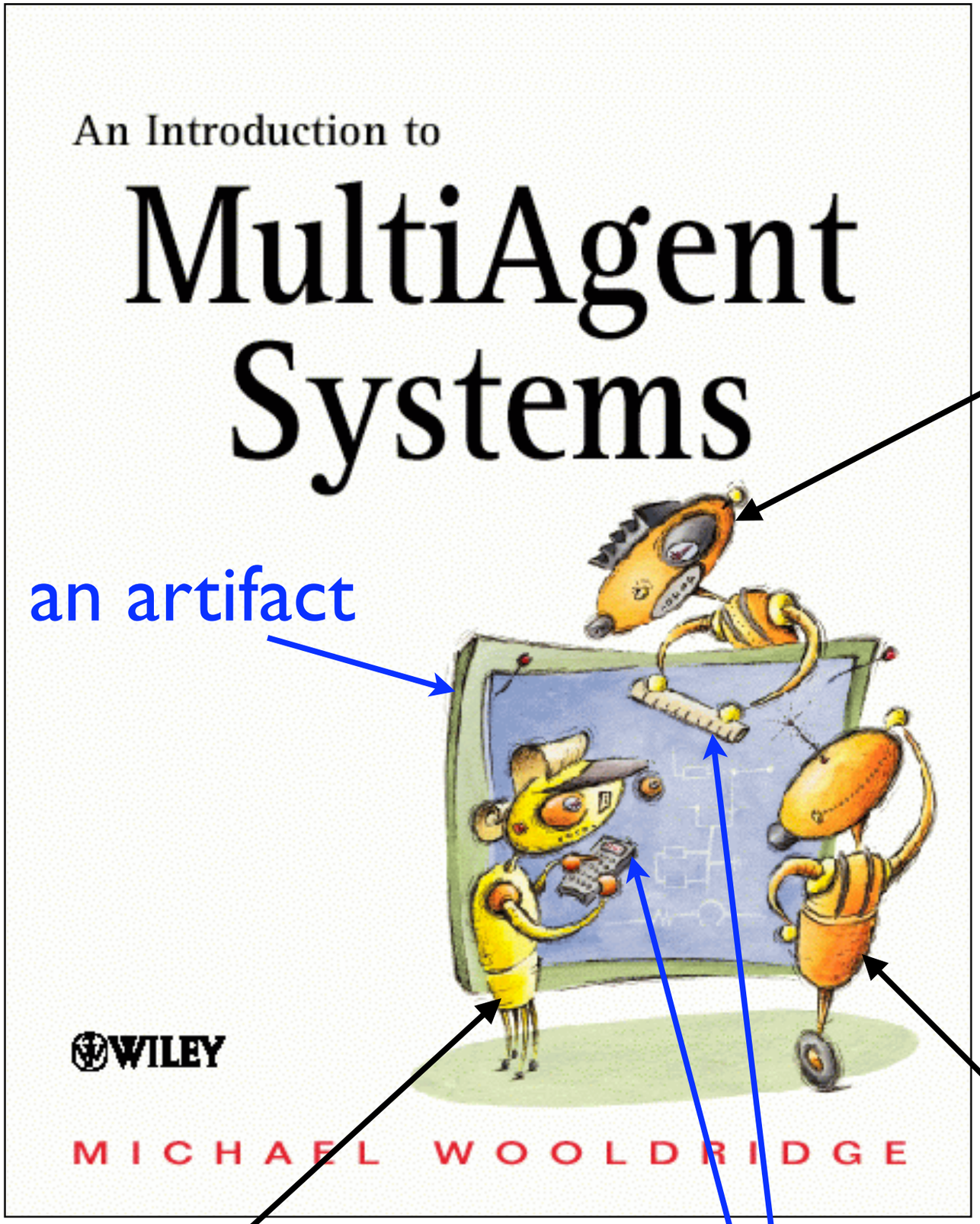


agent

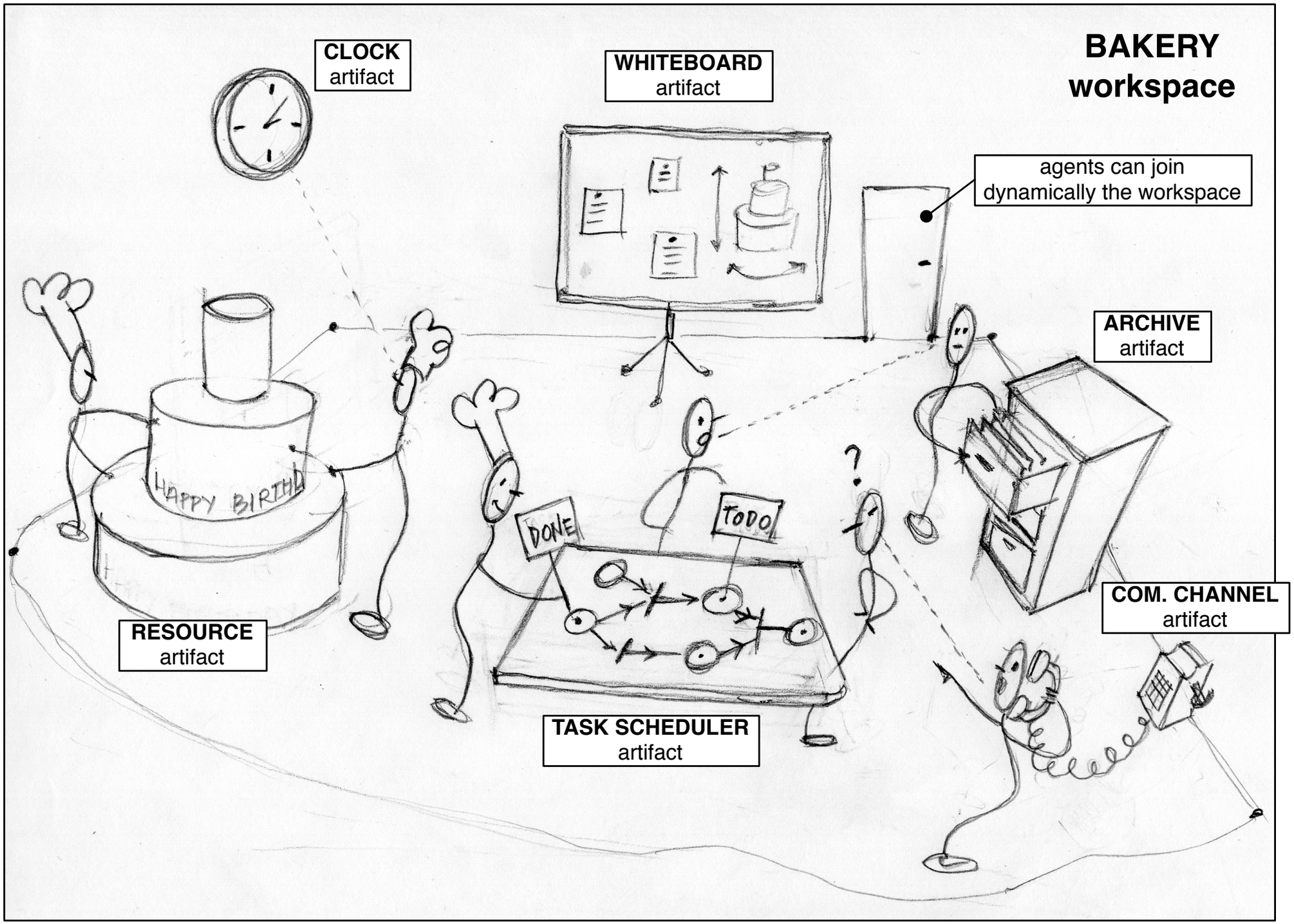
an artifact

agent

artifacts

agent

AGENTS & ARTIFACTS (A&A) MODEL: BASIC IDEA IN A PICTURE



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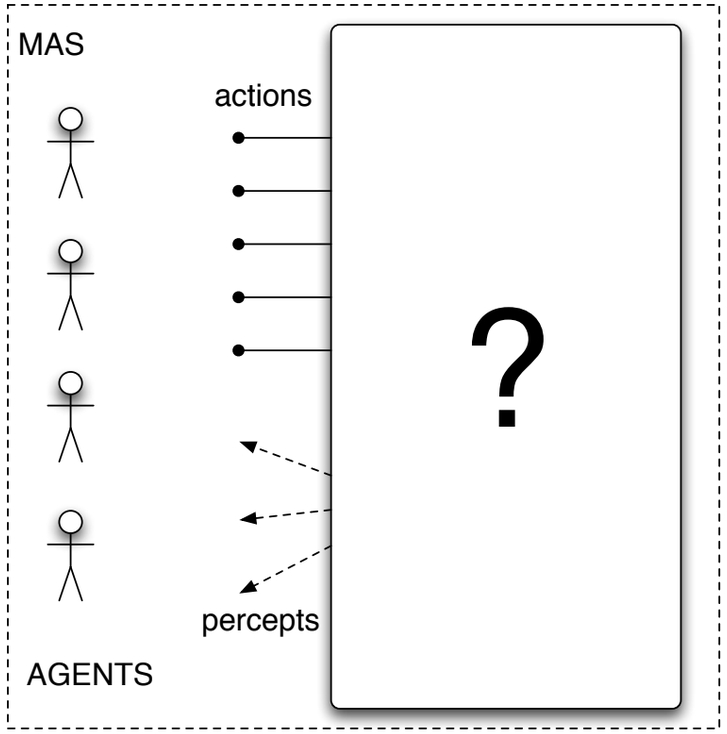

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- **Abstraction**
  - keeping the agent abstraction level
    - concepts like Action, Perception, Observation
    - i.e., no agents sharing and calling *OO objects*
  - effective programming models
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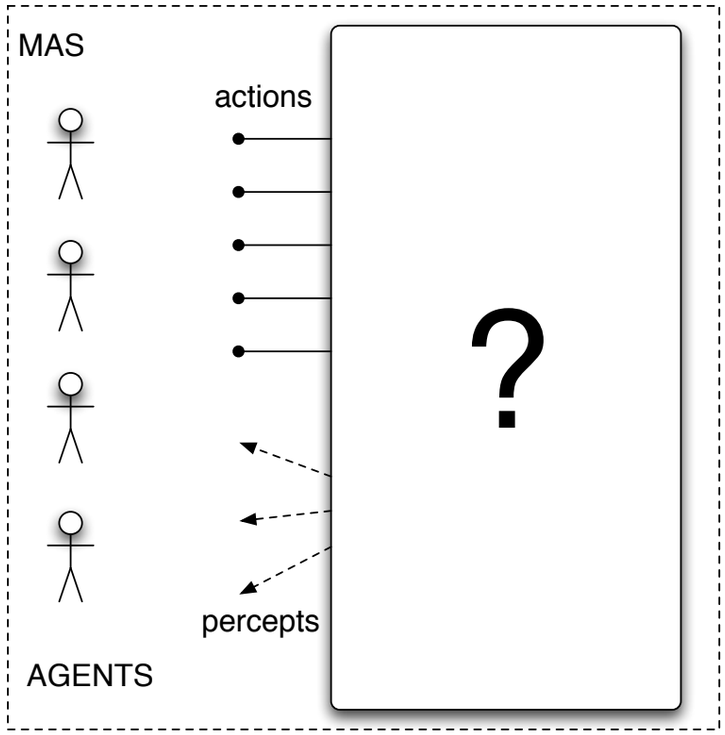

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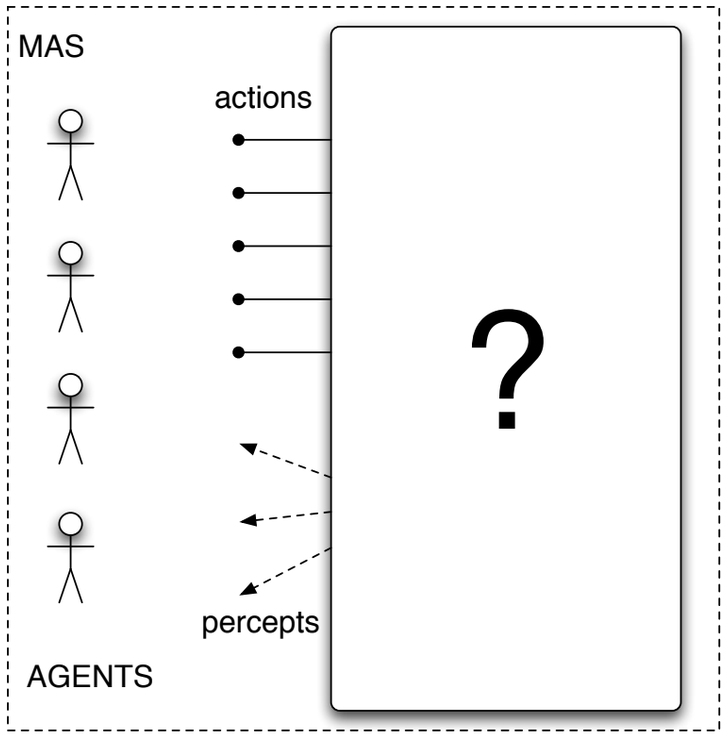
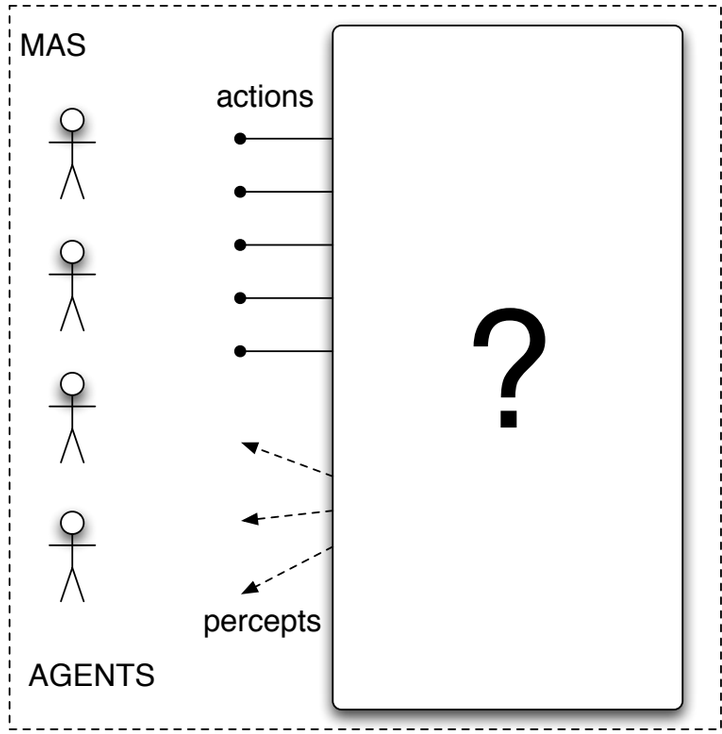


- **Orthogonality**
  - wrt agent models, architectures, platforms
  - support for heterogeneous systems

DESIDERATA FOR A WORK ENV. PROGRAMMING MODEL (2/2)



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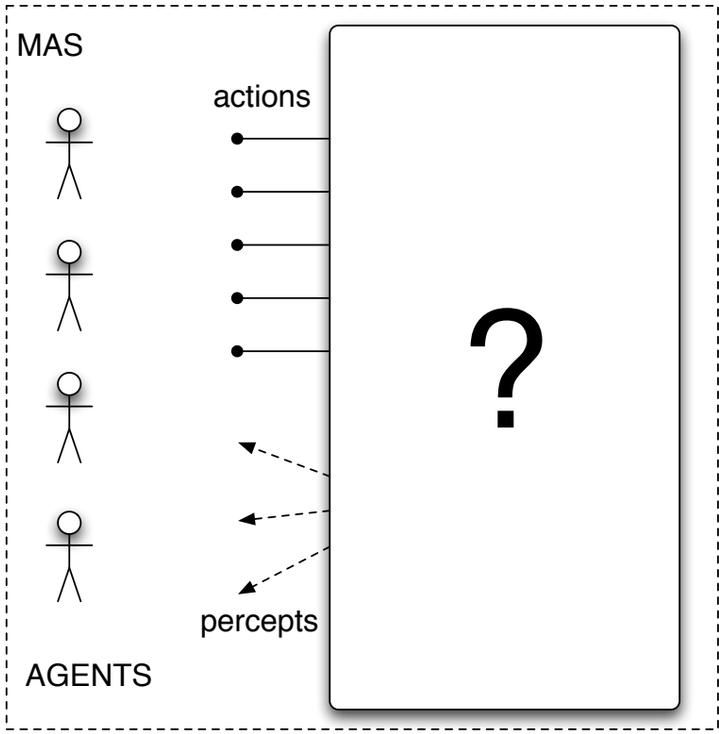
  - support for *open* systems



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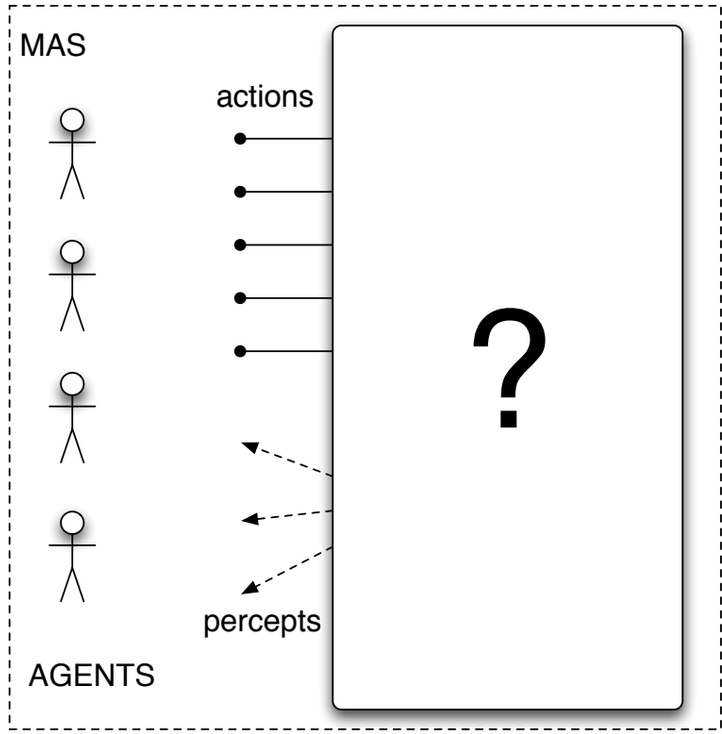

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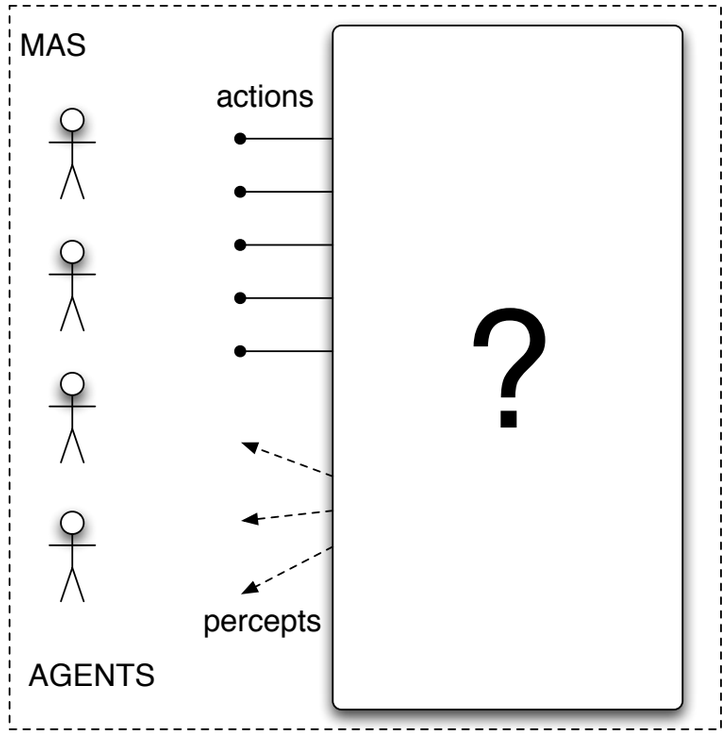


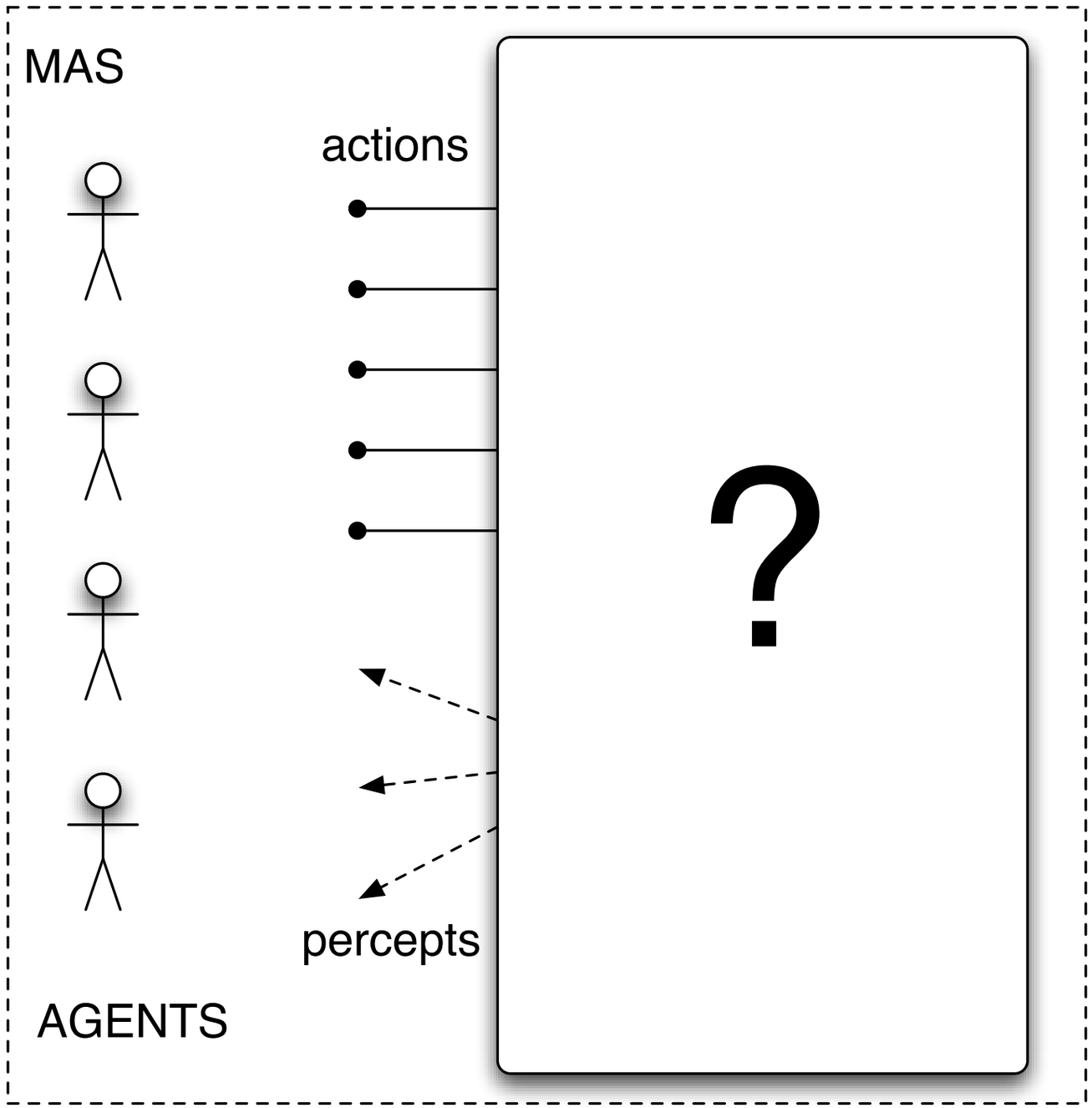
- **Modularity**
  - away from the monolithic and centralised view

- **Reusability**
  - reuse of environment parts in different application contexts / domains

A&A BASIC CONCEPTS

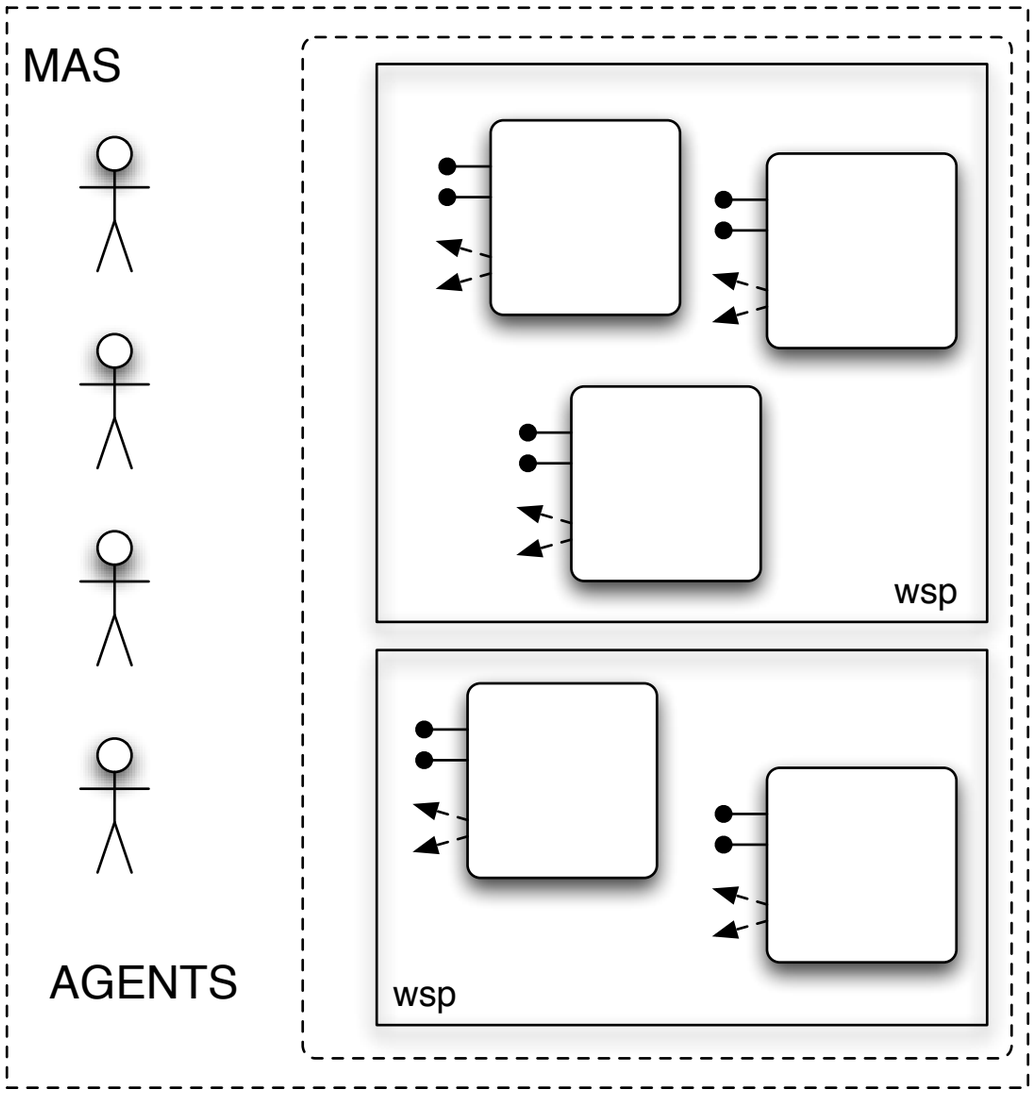
- **Agents**
  - autonomous, goal-oriented, social, pro-active entities
  - create and co-use artifacts for supporting their activities
    - besides direct communication
- **Artifacts**
  - *non-autonomous*, *authomatic, function*-oriented entities
    - controllable and observable
  - modelling the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

WORK ENVIRONMENT IN A&A



WORK ENVIRONMENT IN A&A

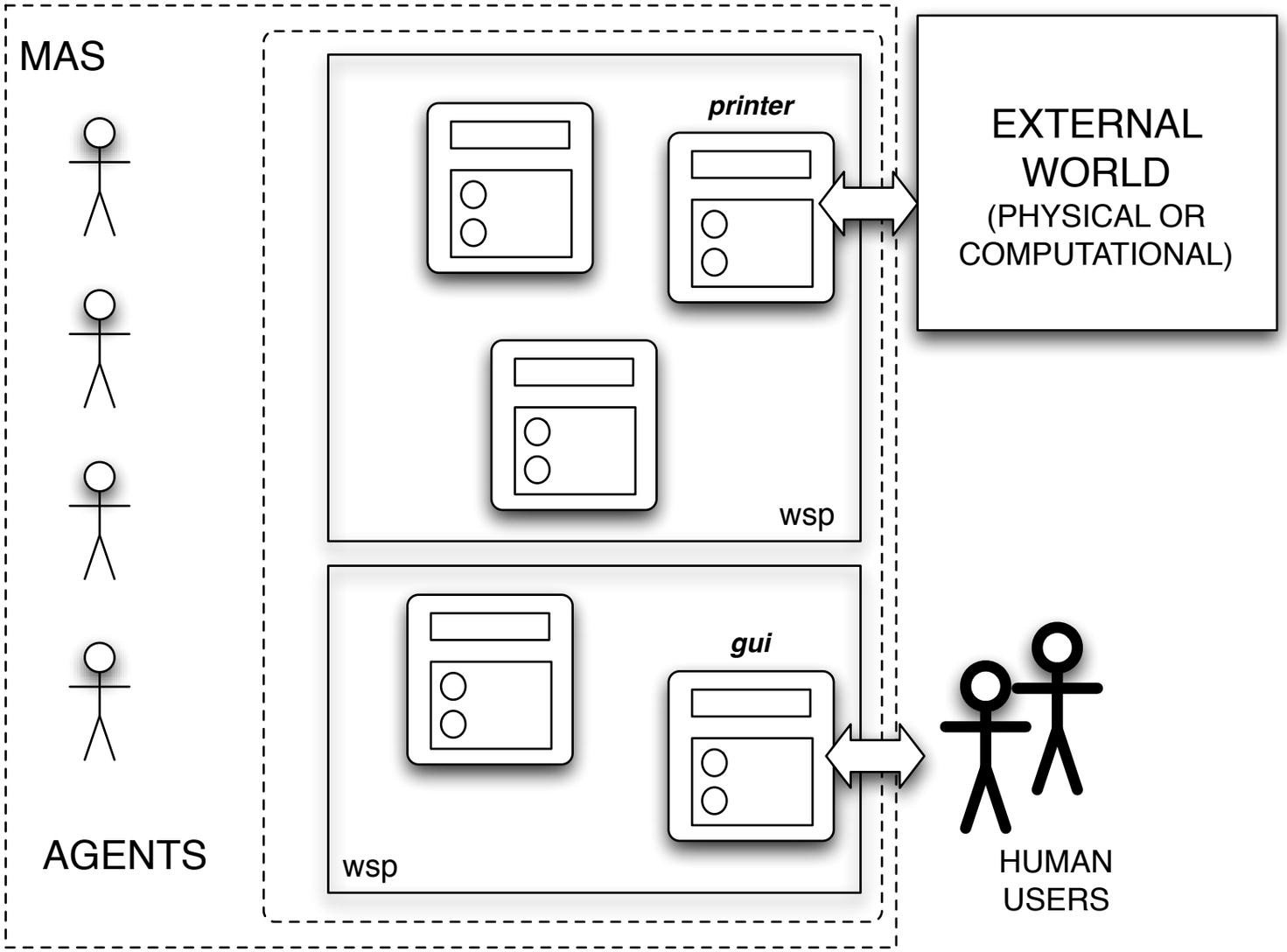
- Artifacts as building bricks to structure the (work) environment
- Workspaces as topological structure of the w.e.



- Artifacts as Special Purpose computational ‘objects’
- Agents and Artifacts are not alternative notions, are *dual* notions

WORK ENVIRONMENT IN A&A

- Artifacts as Interfaces and Facades to external world(s)



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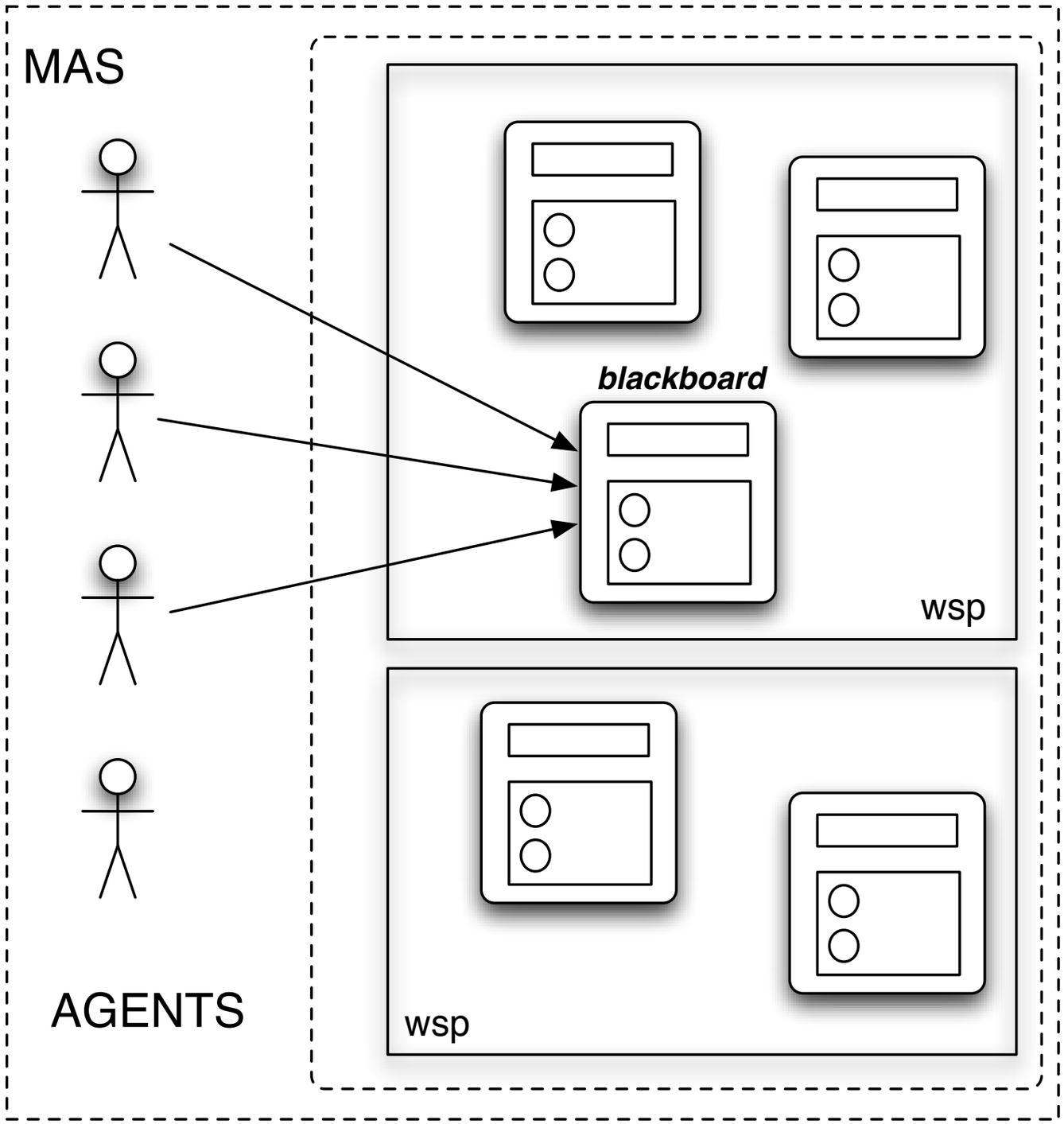
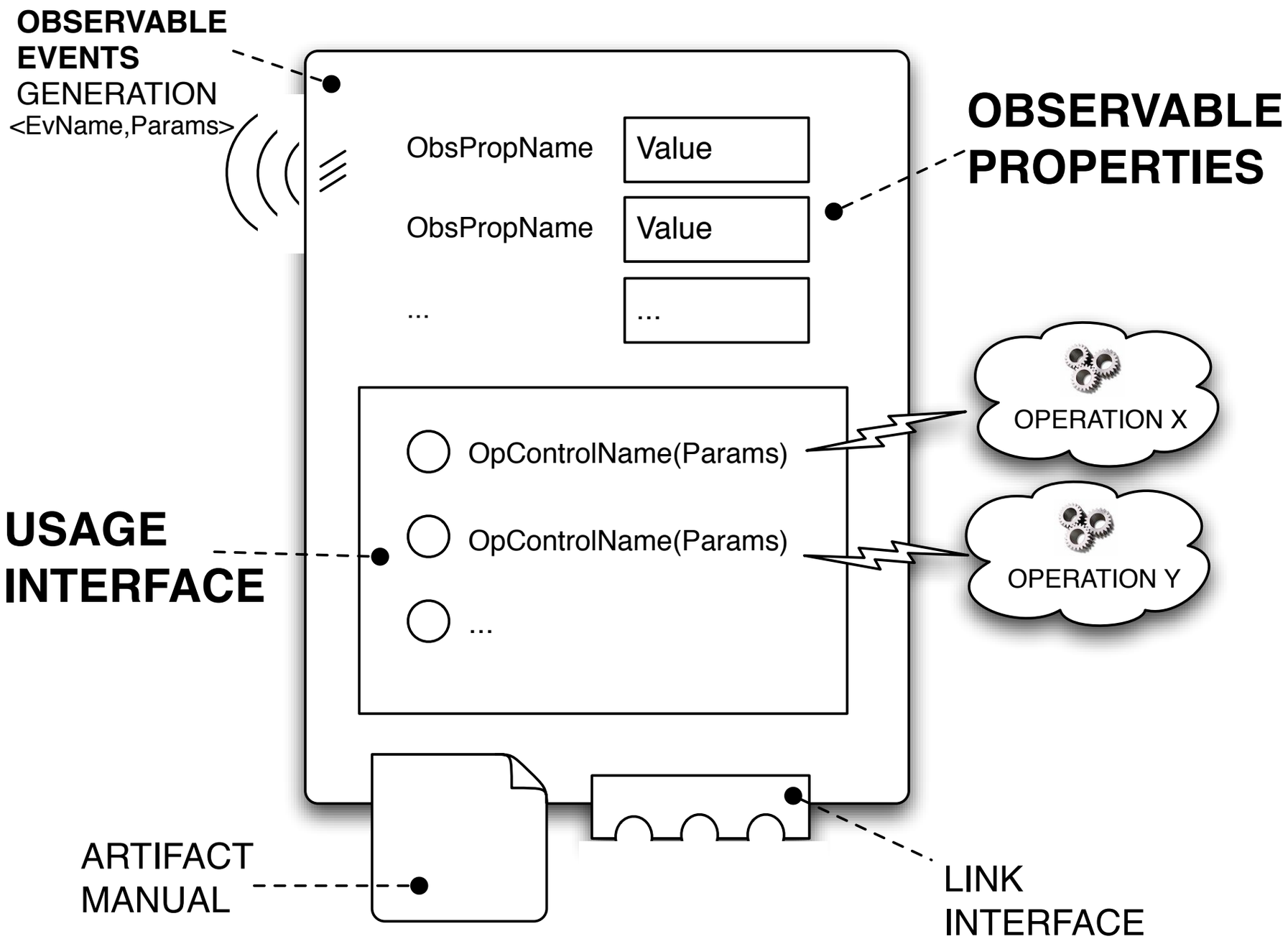


- Interaction of Ag and Art based on not ambigous notions of
  - Action
  - Perception
  - Observation

ARTIFACT COMPUTATIONAL MODEL

- “COFFEE MACHINE METAPHOR” -



CArtAgO

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- **CArtAgO** platform / infrastructure
  - runtime environment for executing (possibly distributed) artifact-based environments
  - Java-based programming model for defining artifacts
  - set of basic AGENT-API to work wihin artifact-based environment
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  - Role-Based Access Control (RBAC) security model
- Open-source technology
  - available at http://cartago.sourceforge.net

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- Integration with existing agent platforms
  - cognitive agent platforms in particular
    - ongoing cooperation with Jomi, Rafael, Alexander, Lars, Mehdi
  - available bridges: ***Jason***, **Jadex**, simpA
    - ongoing: **2APL**, Jade
  - “agent body” notion for technically realising the integration
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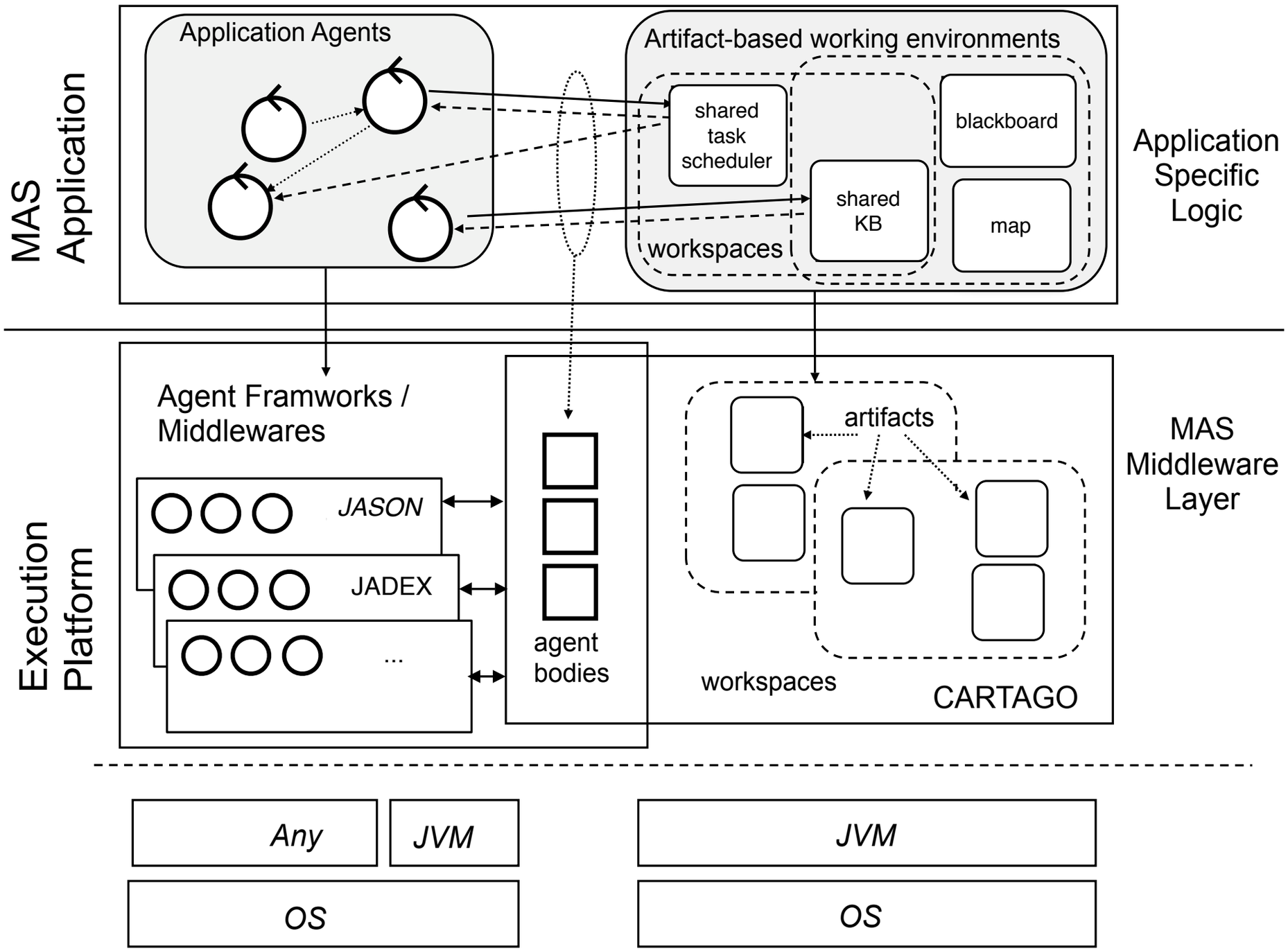
- Outcome
  - developing open and heterogenous MAS
  - different perspective on *interoperability*
    - sharing and working in a common work environment
    - common data-model based on Object-Oriented or XML-based data structures

CArtAgO ARCHITECTURE



INTEGRATING HETEROGENEOUS AGENTS PLATFORMS

Extending agents repertoire with a basic set of actions enabling playing within artifact-based environment

workspace management	**joinWsp**(Name,?WspId,+Node,+Role,+Cred) **quitWsp**(Wid)
artifact use	**use**(Aid,OpCntrName(Params),+Sensor,+Timeout,+Filter) **sense**(Sensor,?Perception,+Filter,+Timeout) **grab**([Aid]) **release**([Aid])
artifact observation	**observeProperty**(Aid,PName,?PValue) **focus**(Aid,+Sensor,+Filter) **stopFocus**(Aid)
artifact instantiation, discovery, management	**makeArtifact**(Name,Template,+ArtifactConfig,?Aid) **lookupArtifact**(Name,?Aid) **disposeArtifact**(Aid)

Conceiving A&A Systems

So: artifacts provide serviceable operations, preprocessed information and coordination facilities conceived by the MAS designer for easing agents tasks

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- What's for agent architectures and systems...
  - ...When Agents are reasoning? /w mental states (Beliefs, Goals, Intentions)?
- Functional Approach to A&A design
- From an agent viewpoint, artifacts embeds:
  - **Informational (Doxastic) Function**
  - **Operational (Purposive) Function**

Operational Function

- Operations are Artifacts *intended* purposes
  - *"Intented"* is in the mind of Artifact Designers before beeing in agents intentions
- From an **agent viewpoint**, Artifacts are *non-autonomous* but *automatic* devices providing functionalities
- Exploitable as self contained operations:
  - Improving repertoire of actions, as additional means to achieve Goals
  - Externalise and distribute part of agent activities

Operational Function

- Goals can thus be achieved by the mean of operations which have been defined *by the artifact developer* within artifacts control interface.
- *Agent's Goal 'is' in Operation Outcomes*:

```
+!doAction
      : not done(myGoal) & mySensor(S) & artifactID(Aid)
      <- cartago.use(Aid, doAction(X, Y, ...), S);
         cartago.sense(S, done(Res) );
         +done(Res).  /* Res is myGoal */

+!doAction : true
      <- ?done(myGoal).
```

Doxastic Function

- Artifacts include *machine-readable* Representations
  - Can maintain, make it observable, pre-process information
- From an **agent viewpoint**, Artifacts are *informational* units, exploitable in a *situated* way:
  - As external repositories, automatically collecting and providing strategic knowledge
  - Additional memory, even shared between agent groups
  - Observable cues in order to highlight relevant information in environments (*situated cognition*)

Doxastic Function

- Artifact Observable properties can be exploited by agents to retrieve strategic information
- The mechanism of observation is conceived as a *weak* interaction
- *Strategic (Goal Supporting) knowledge 'is' in artifacts readable properties:*

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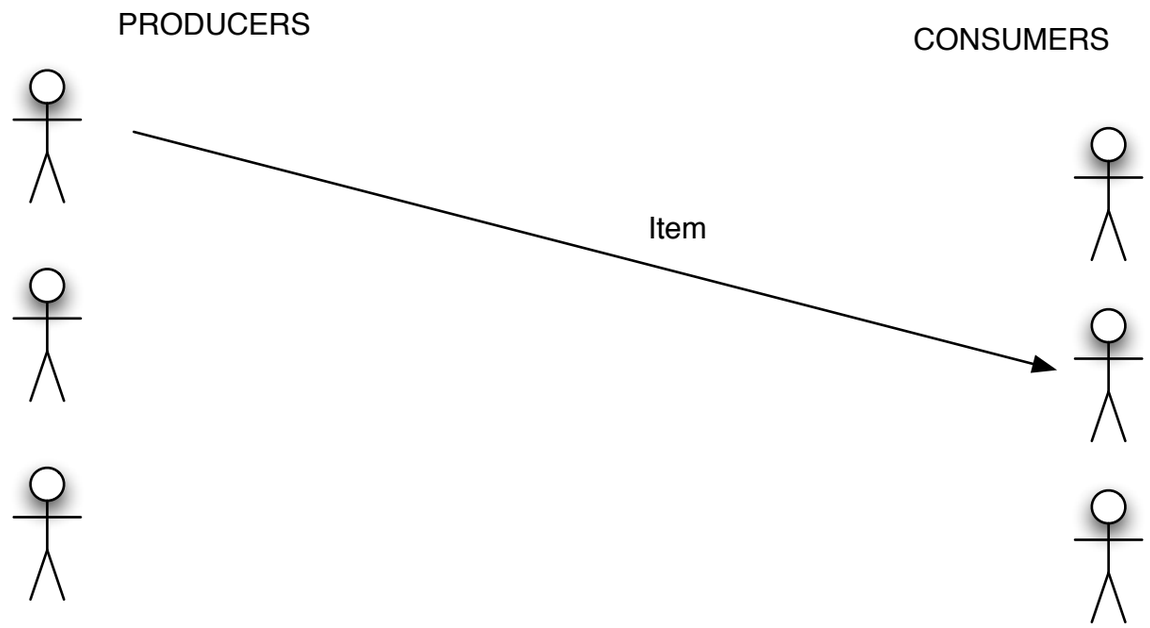
```
+!achieveGoal : artifactID(Aid)
  <-  cartago.observeProperty(Aid, propertyName(X) );
      !doAction(X).

+!doAction(X)    /* X is a Goal Supporting Belief */
  : X > 40
  <- +done(myGoal).

+!doAction(X)
  : X > 20
  <- cartago.use(Aid, doAction(X, Y), S);
     cartago.sense(S, done(Res) );
     +done(Res).  /* Res is myGoal */
```

PRODUCERS CONSUMERS

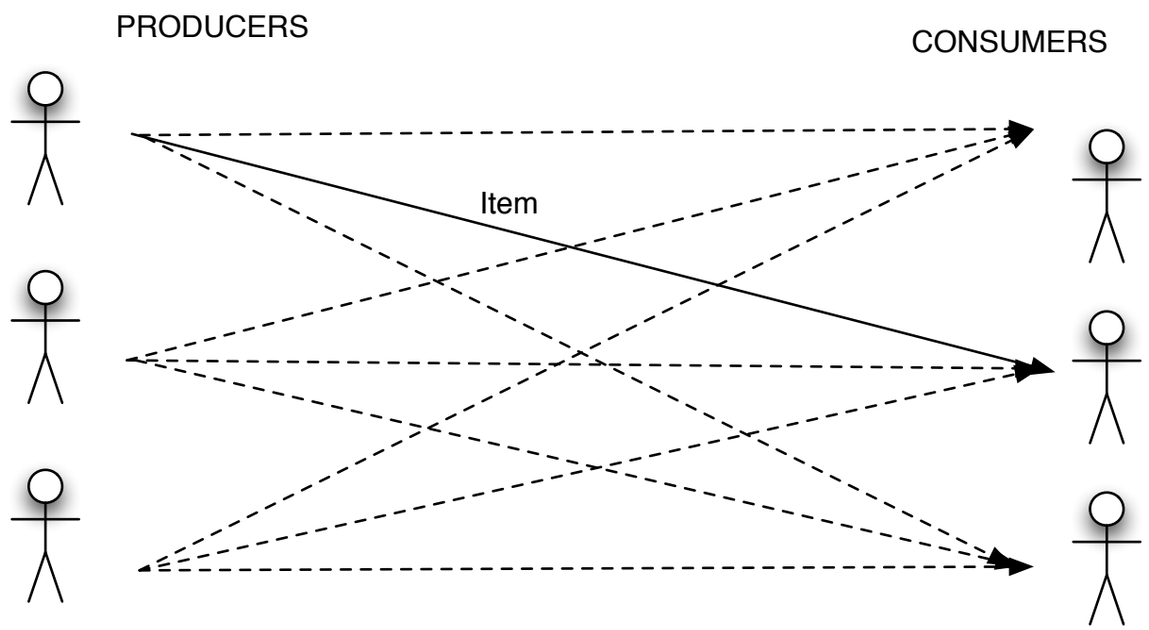
- Example: a variable number of Producer and Consumer Agents want to exchange generic Informational Items



- Agents have bounded resources: Time, Space, Memory…
  - Need for a strategy to synchronise / coordinate exchanges
  - Well known problem in concurrent systems
  - What's in MAS ?

PRODUCERS CONSUMERS IN MAS

- Direct Interaction: overload of messages and broadcasts (who may I ask for a relevant Item ?)



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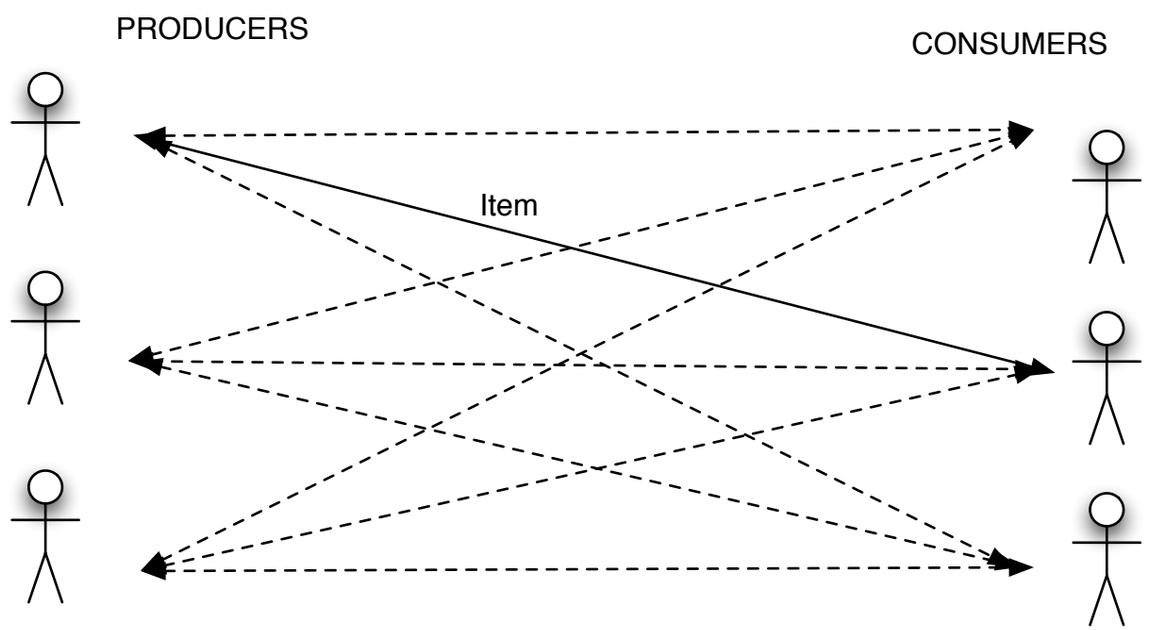
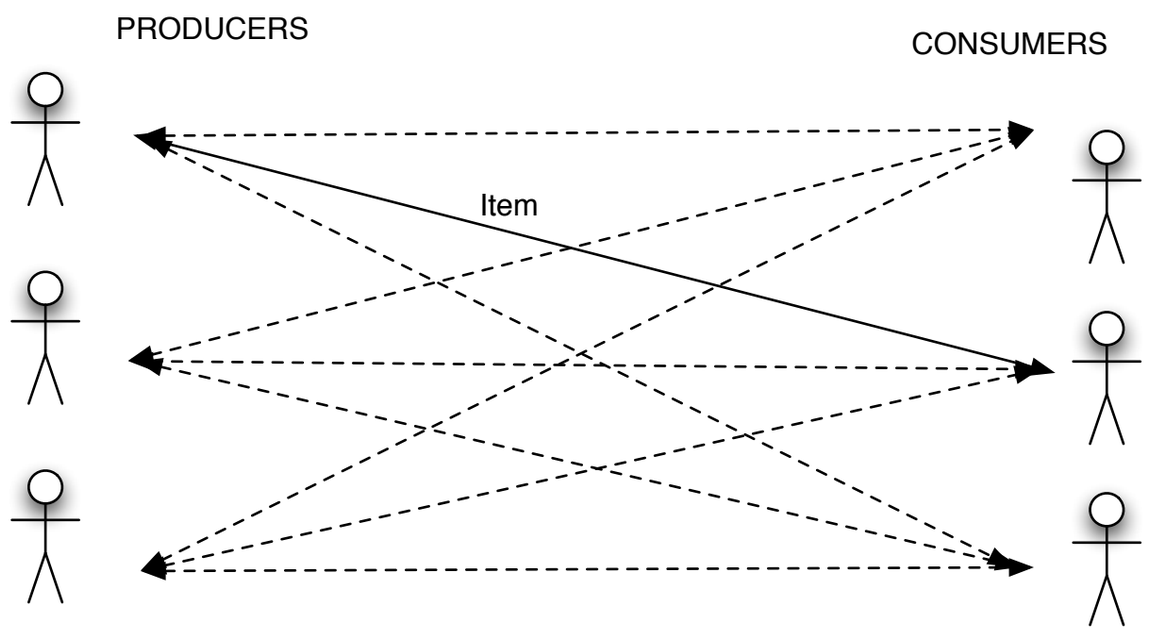


PRODUCERS CONSUMERS IN MAS

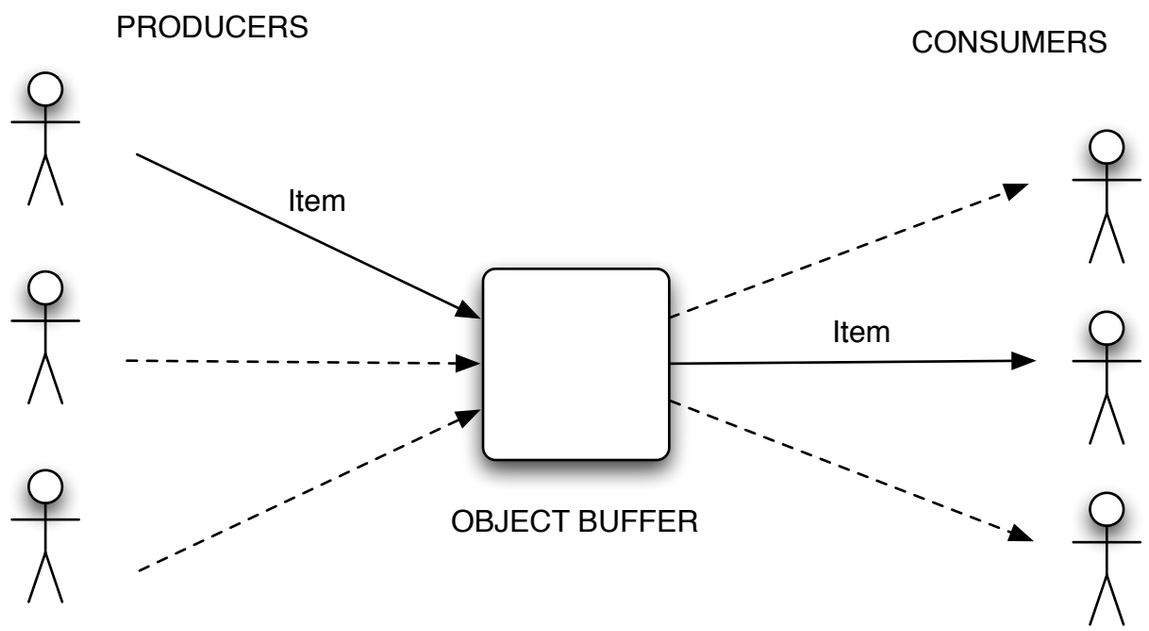
- Direct Interaction: overload of messages and broadcasts (who may I ask for a relevant Item ?)



- Which need to be typed (protocols)
- Bidirectional (Request-Response, Solicit Response...)

PRODUCERS CONSUMERS IN MAS

- Use an Object as a shared buffer reduces the number of interactions



PRODUCERS CONSUMERS IN MAS

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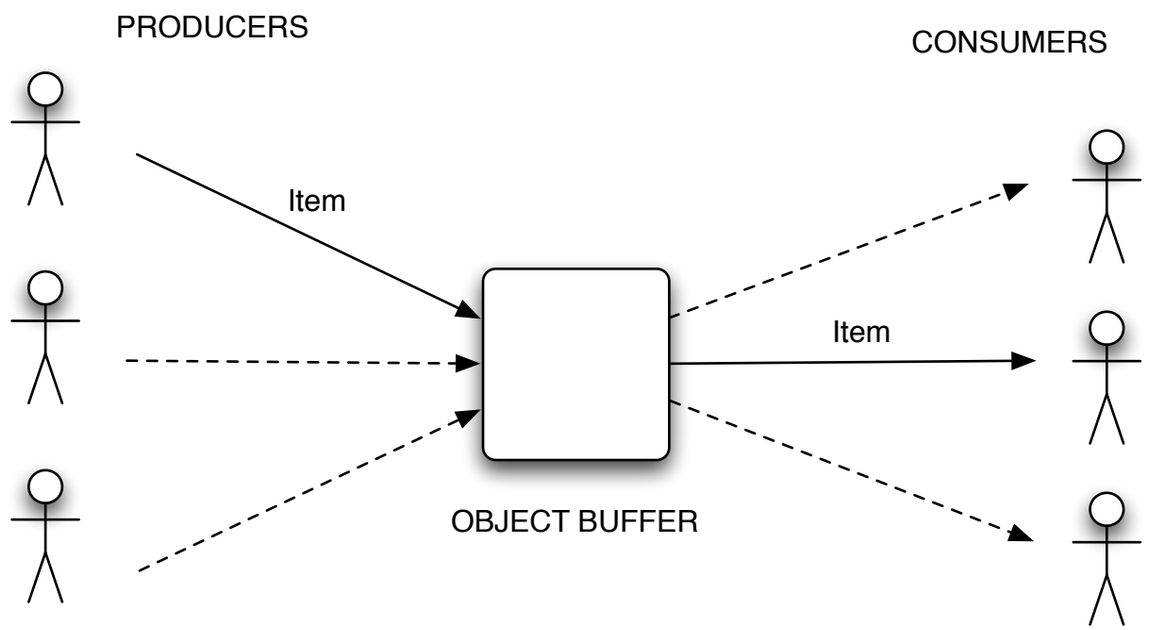
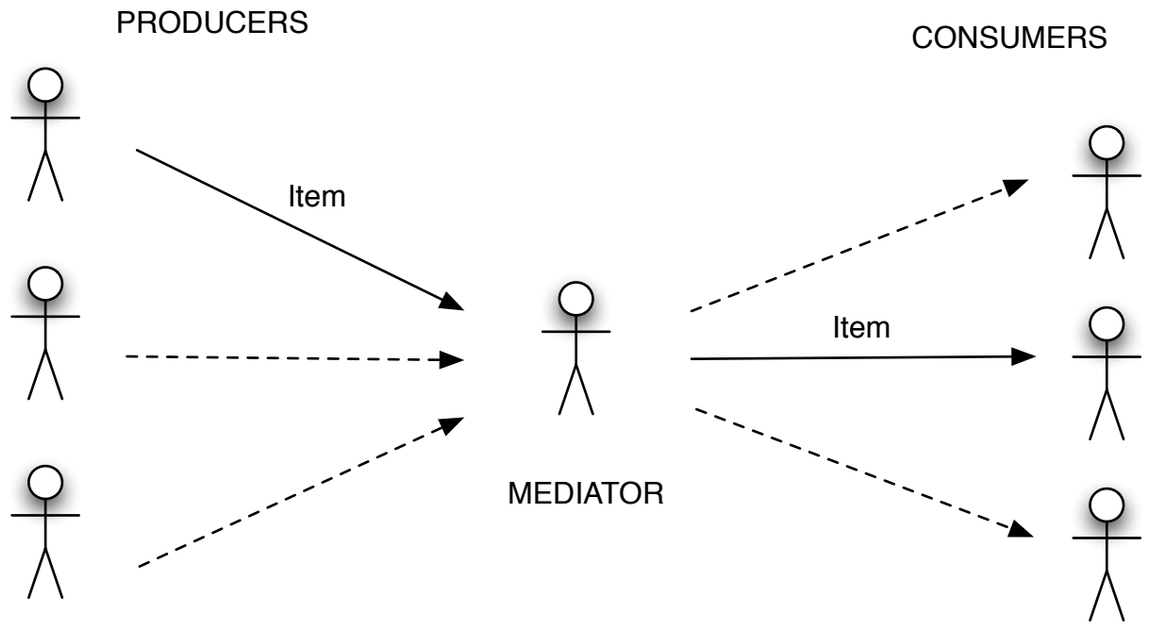


- Which kind of interaction? From Agents to (Java) Objects? RPC?
- Not the same level of abstraction for domain entities of the system

PRODUCERS CONSUMERS IN MAS

- Use a Mediator Agent to maintain the abstraction



PRODUCERS CONSUMERS IN MAS

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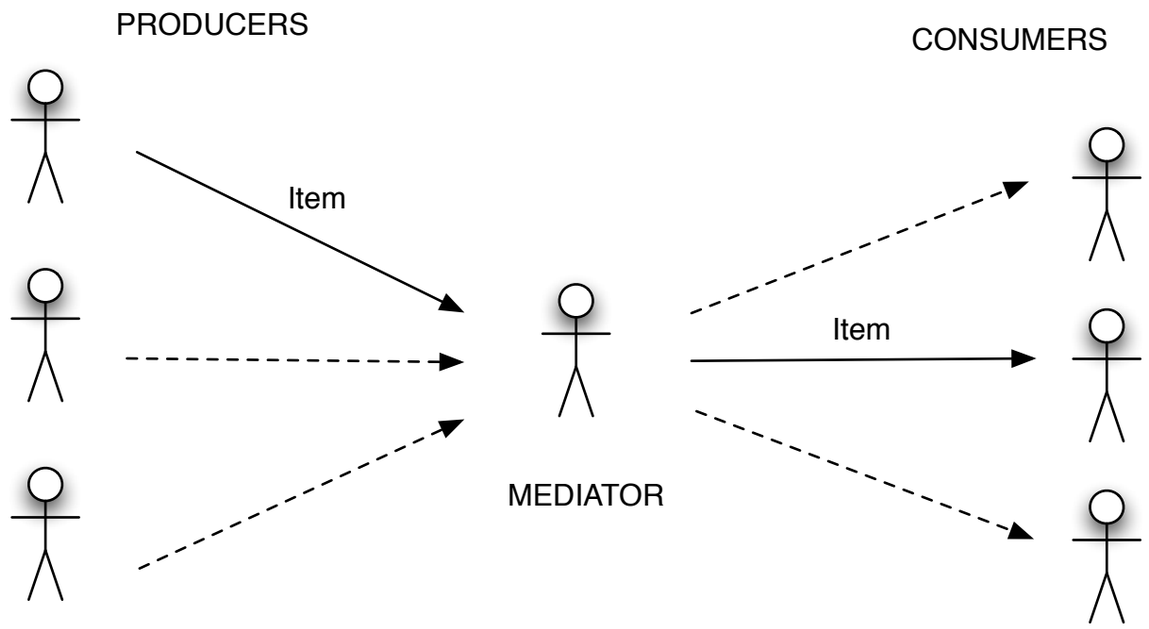
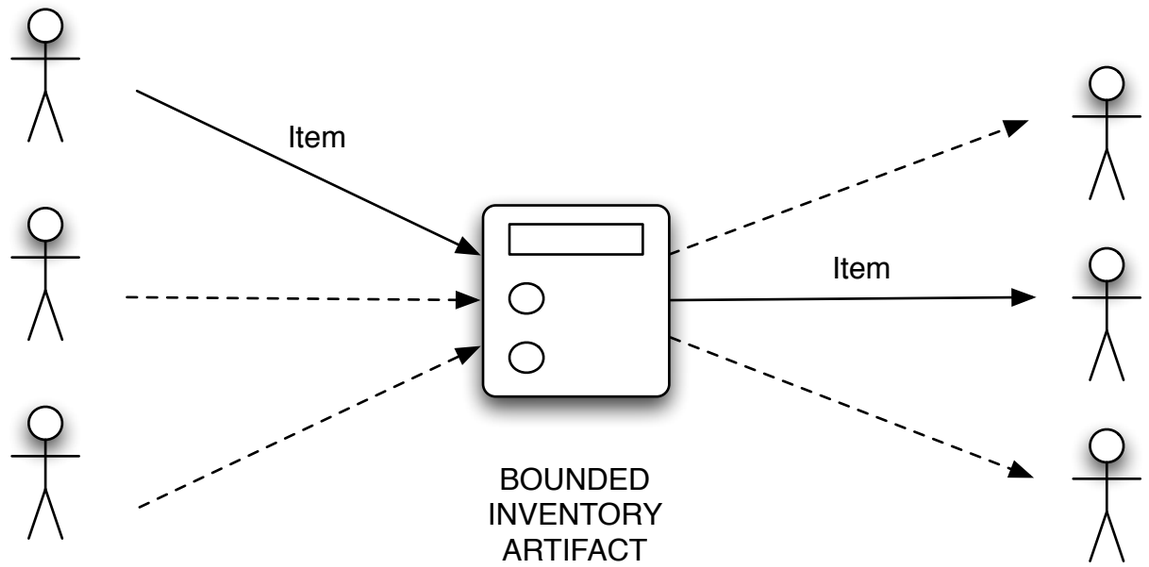


- But which kind of Agents? Reactive? Autonomous? (*can say no*?!?)
- Still need protocols and messages to exchange: opennes?

PRODUCERS CONSUMERS IN MAS

- Use an Artifact !



PRODUCERS CONSUMERS IN MAS

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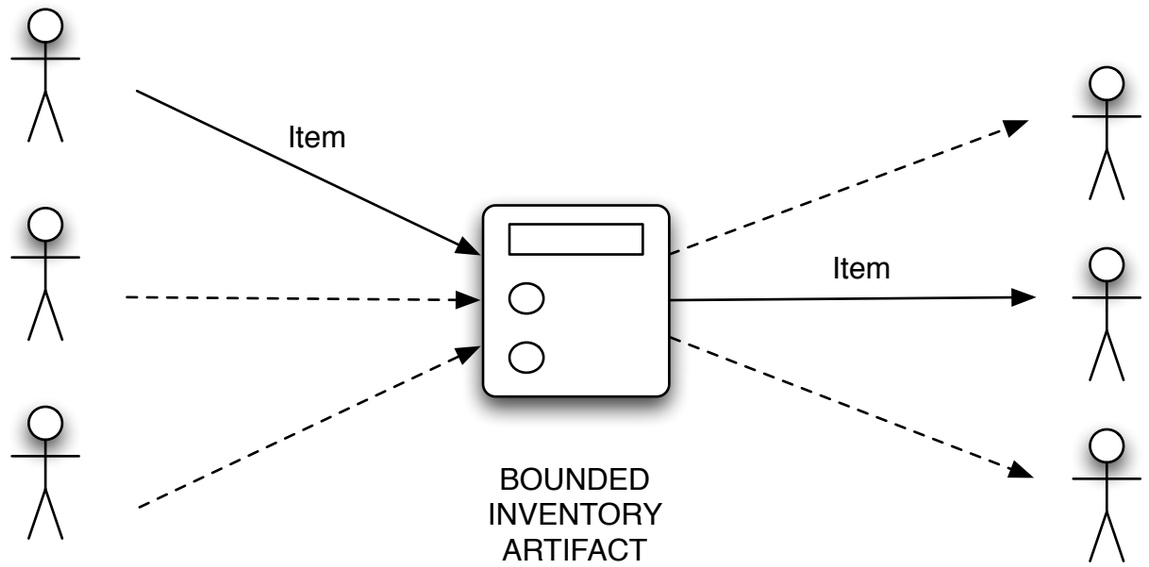
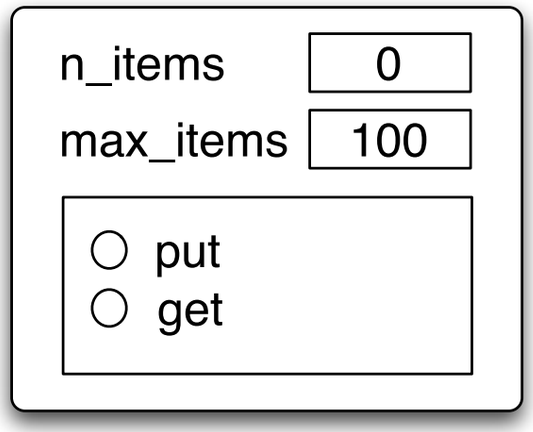


- A Bounded Inventory Artifact is designed to function as a shared Inventory mediating the activities in an authomatic fashion
  - Ruling and Enabling the exchange
- Inventory can be modified to change performance of the system (i.e. capacity, size, data preprocessing)

BOUNDED INVENTORY



OBSERVABLE PROPERTIES:

n_items: int+
max_items: int

Invariants:
n_items <= max_items

USAGE INTERFACE:

put(*item*:Item) / (n_items < max_items):
[obs_prop_updated, op_exec_completed]

get / (n_items >= 0) :
[obs_prop_updated, *new_item*(item:Item),
op_exec_completed]

```
import alice.cartago.*;
import java.util.*;

public class BoundedInventory extends Artifact {
  private LinkedList<Item> items;

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

  @OPERATION(guard="inventoryNotFull") void put(Item obj){
    items.add(obj);
    updateObsProperty("n_items",items.size()+1);
  }

  @OPERATION(guard="itemAvailable") void get(){
    Item item = items.removeFirst();
    updateObsProperty("n_items",items.size()-1);
    signal("new_item",item);
  }

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

  @GUARD boolean inventoryNotFull(Item obj){
    int maxItems = getObsProperty("max_items").intValue();
    return items.size() < maxItems;
  }
}
```

Operational Function

```
+!produceItems : nextItemToProduce(Item)
   <- cartago.lookupArtifact("my-inv", InvID);
      cartago.use(InvID, put(Item), 500).

/* Fail Event */
-!produceItems: true
   <- cartago.use(console,
      println("Insertion failed due to timeout.")).
```

```
+!consume
     : myInventory(InvID) & mySensor(S)
      <- cartago.use(InvID, get, S, 1000);
         cartago.sense(S, new_item(Item));
         !consumeItem(Item);
         !consume.

+!consumeItem(Item) : true
      <- ...
```

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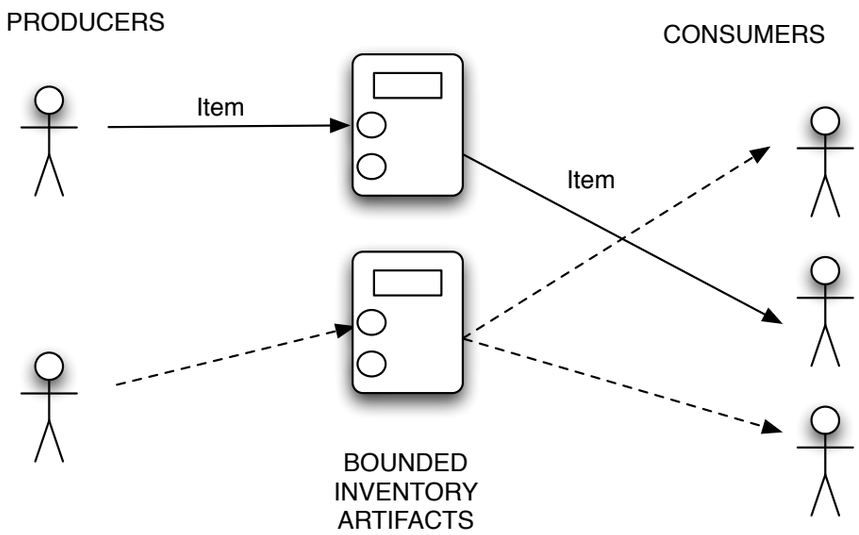
- Both Producer and Consumer Goals are in Artifact outcomes, after the use of its operations
- All the computation required to synchronise interactions is externalised in the Bounded Inventory
  - It can possibly pre-process the items, e.g. translate them to different ontologies

Doxastic Function

- Immagine now that 2 bounded buffers are in place, each with a different ‘load’



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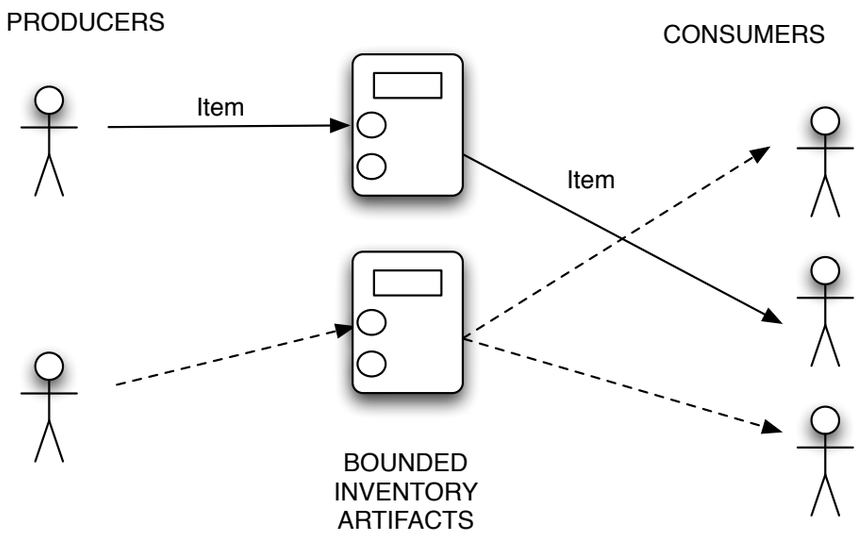


```
+!consumeActivity : true
    <- +min_items(-1);
       cartago.lookupArtifact("inventory-1", InvID1);
       cartago.focus(InvID1);
       cartago.lookupArtifact("inventory-2", InvID2);
       cartago.focus(InvID2);
       +selectedInv(InvID1,0);
       !consumeAction.

/* Updates Goal Supporting Beliefs */
+n_items(N) [source(percept), artifact(InventoryID)]
  : selectedInv(_,N1) & N > N1
    <- -+selectedInv(InventoryID,N).

+!consumeAction : selectedInv(InvID,_)
    <- cartago.use(InvID, get, mySensor);
       cartago.sense(mySensor, new_item(Item));
       cartago.use(console,println("Consumed:",Item));
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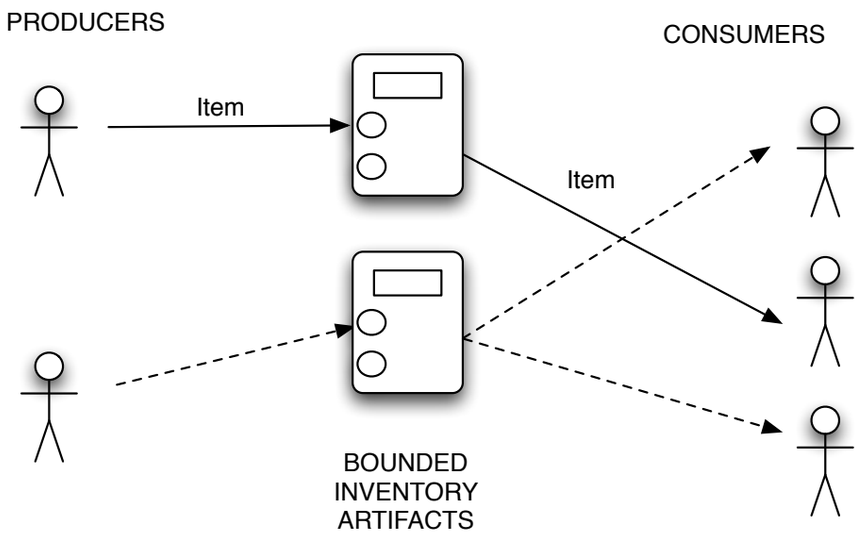


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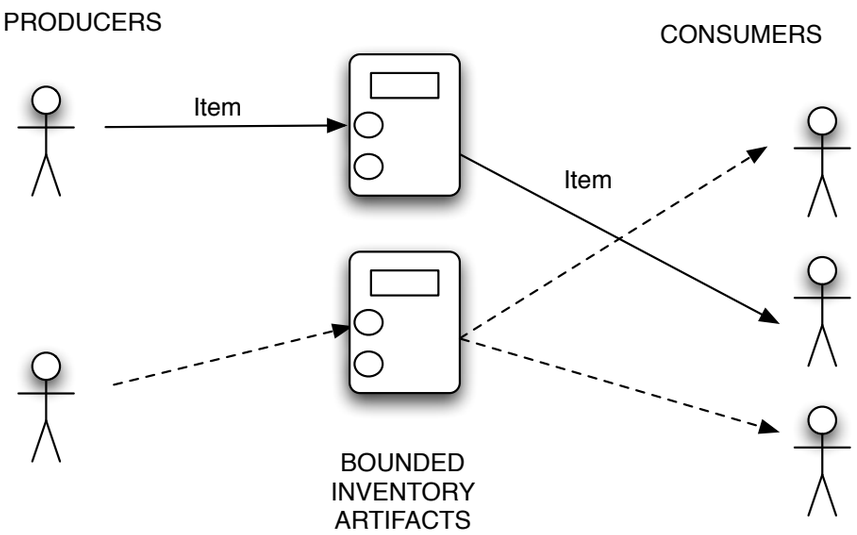


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- By focusing on artifact properties, Consumer can decide which is the most reliable one to use (Goal Supporting Beliefs)
- Update of Goal Supporting Beliefs is done automatically
  - in reaction to a property change event

Cognitive Artifacts

The notion is related to agents able to bring about artifact informational functions [Norman]

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- To provide Relevant, Strategic Information to **Single-Agent**
  - Easy reasoning about goals: *goal supporting beliefs*
  - Simplifying agent choices and easing deliberation processes

Cognitive Artifacts

The notion is related to agents able to bring about artifact informational functions [Norman]

- To provide Relevant, Strategic Information to **Single-Agent**
  - Easy reasoning about goals: *goal supporting beliefs*
  - Simplifying agent choices and easing deliberation processes
- To distribute Information in **Multi-Agent**
  1. Across *Agents*: organise and make available relevant information as permanent side-effect of artifact use (modification of artifact state)
  2. Across *Platforms*: mediated interactions
  3. Across *Time*: hold strategic information persistent over agent presence
  4. Across *Space*: no need for agents mutual presence within a location or heavy message exchange protocols

Two more Steps towards an *Extended Mind [Clarks]*

Artifacts can be *cognitively* used once their representational and operational contents are mapped into reasoning processes

- Artifact discovery as a process of **Epistemic Reasoning**
  - Agents need to *Read, learn,* and *match* Artifact Representational contents

- Operational contents has to be included in **Practical Reasoning** (to achieve goals)
  - By changing the actions required for achieving a goal, artifact operations change means-end reasoning (planning)

ONGOING EVALUATION (APPLICATIONS)

- ORA4MAS (w/ Hubner, Boissier, Kitio, Ricci)
  - exploiting artifacts to build an organisational infrastructure

- CArtAgO-WS
  - basic set of artifacts for building SOA/WS applications
    - interacting with web services
    - implementing web services

- FORMAL MODEL
  - Interactions
- ARTIFACT LIBRARIES
  - setting up a set of reusable artifacts in MAS applications

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