Multi-Agent Oriented Programming
– Environment Oriented Programming –
The CArtAgO Platform

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Outline

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" [Wooldrige and Jennings, 1995]
  - "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

Classic Properties of Environment in MAS

- Basic classification [Russell and Norvig, 2003]
  - *Accessible* versus *inaccessible*: indicates whether the agents have access to the complete state of the environment or not
  - *Deterministic* versus *non deterministic*: indicates whether a stage change of the environment is uniquely determined by its current state and the actions selected by the agents or not
  - *Static* versus *Dynamic*: indicates whether the environment can change while an agent deliberates or not
  - *Discrete* versus *Continuous*: indicates whether the number or percepts and actions are limited or not
- Further classification [Ferber, 1999]
  - *Centralized* versus *Distributed*: indicates whether the environment is a single monolithic system or a set of cells or places assembled in a network
  - *Generalized* versus *Specialized*: indicates whether the environment is independent of the kind of actions that can be performed by agents or not.

Action Models

- Action defined as a transition of the environment state:
  - from an observational point of view, the result of the behavior of an agent -its action- is directly modelled by modifying the environmental state variables
  - ⇝ not fully adequate for modelling Multi-Agent Systems: several agents are acting concurrently on a shared environment (concurrent actions)
- Influence & reactions [Ferber and Muller, 1996]: clear distinction between the products of the agents behavior and the reaction of the environment
  - *influences* come from inside the agents and are attempts to modify the course of events in the world
  - *reactions* are produced by the environment by combining influences of all agents, given the local state of the environment and the laws of the world

⇝ handling simultaneous activity in the MAS

Example of "Agents in Environment" Approach

```
procedure RUN-ENVIRONMENT(state, UPDATE-FN, agents, termination)
  inputs: state, the initial state of the environment
          UPDATE-FN, function to modify the environment
          agents, a set of agents
          termination, a predicate to test when we are done

  repeat
     for each agent in agents do
        PERCEPT[agent] ← GET-PERCEPT(agent, state)
     end
     for each agent in agents do
        ACTION[agent] ← PROGRAM[agent](PERCEPT[agent])
     end
     state ← UPDATE-FN(actions, agents, state)
  until termination(state)
```

[Russell and Norvig, 2003]

Example of "Environment in Agents" Approach

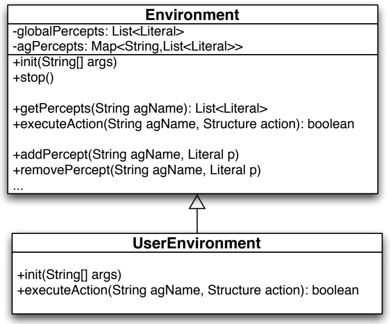
```
MOVINGBEHAVIOR METHODSFOR: PRIVATE-PRIMITIVES
PRIMCHOOSEARANDOMPLACE
| PLACES <COLLECTION> P <AGENTSPLACE> NOPLACES |
P:=SELF PLACE.
P ISNIL IFTRUE: [^NIL].
NOPLACES:=P NONOBSTACLENEIGHBOURS.
PLACES:=NOPLACES SELECT: [:PP | SELF CANHEADTO: PP].
PLACES ISEMPTY IFTRUE: [PLACES := NOPLACES].
^PLACES AT: ((RND NEXT) * (PLACES SIZE - 1)) ROUNDED + 1
...
```

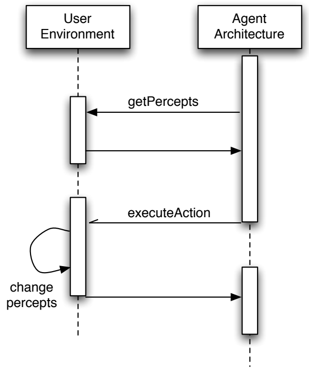
Example of MANTA Programming [Drogoul, 2003]

Environment along Agent Perspective

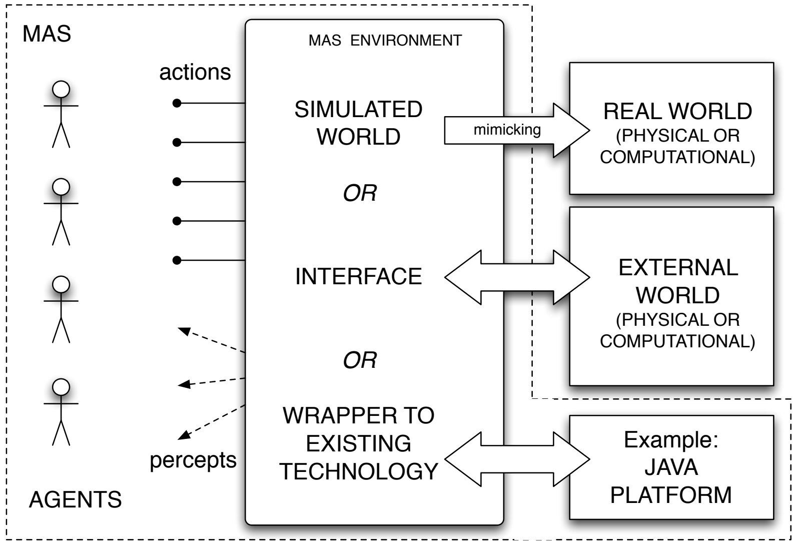
- Agent-Oriented Programming perspective
  - languages / platforms for programming agents and MAS
    - Agent-0, Placa, April, Concurrent Metatem, ConGolog / IndiGolog, AgentSpeak, AgentSpeak(L) / Jason, 3APL, IMPACT, Claim/Sympa, 2APL, GOAL, Dribble, etc
    - Jack, JADE, JADEX, AgentFactory, Brahms, JIAC, etc
- Environment support
  - typically minimal: most of the focus is on agent architecture & agent communication
  - in some cases: basic environment API: for customising the MAS with a specific kind of environment

Environment in the Jason Platform





Summary (1)



Summary (2)

- ▸ In most cases, no direct support.
- ⇝ Indirectly supported by lower-level implementing technology (e.g. Java)
- ▸ In some cases, first environment API
- ⇝ useful to create simulated environments or to interface with external resources
  - simple model: a single / centralised object
  - defining agent (external) actions: typically a static list of actions, shared by all the agents
  - generator of percepts: establishing which percepts for which agents

Environment as a first-class abstraction in MAS

- considering environment as an explicit part of the MAS
- providing an exploitable design and programming abstraction to build MAS applications
- Outcome
  - distinguishing clearly between the responsibilities of agent and environment
  - separation of concerns
- improving the engineering practice with three support levels
  - basic interface support
  - abstraction support
  - interaction-mediation support

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
- e.g. sensors and actuators, a printer, a network,a database, a Web service, etc.

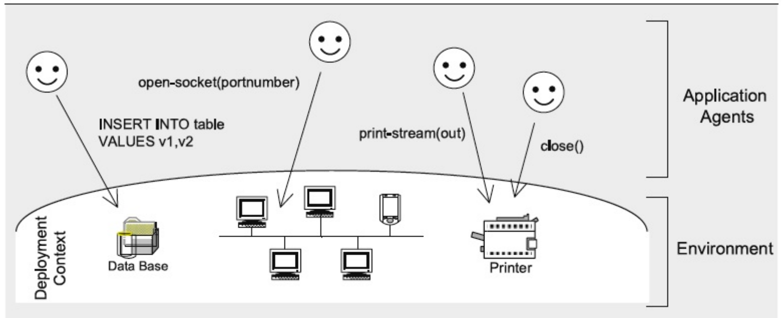


Figure from [Weyns et al., 2007]

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

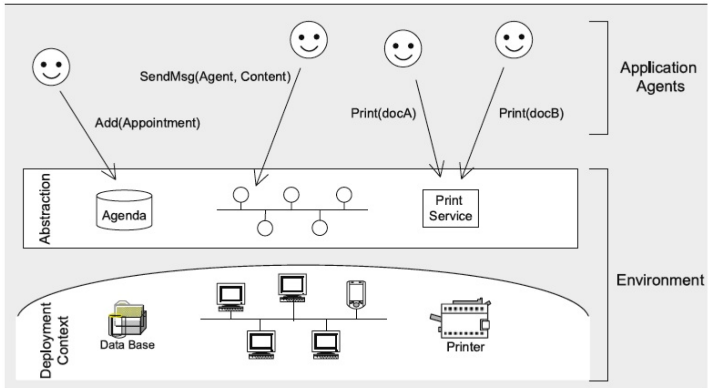


Figure from [Weyns et al., 2007]

Interaction-Mediation Support

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

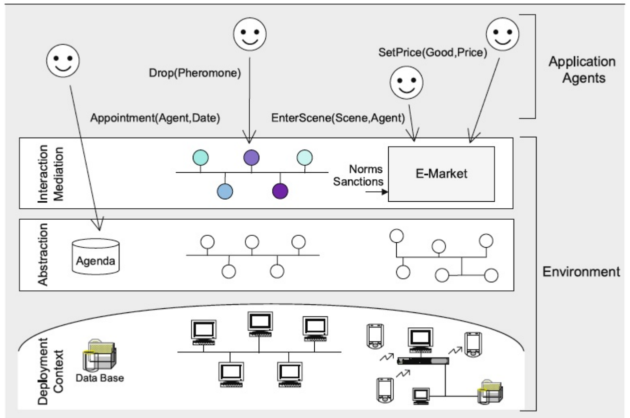


Figure from [Weyns et al., 2007]

Environment Definition Revised

Environment Definition [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

Highlights 1/2

- *First-class abstraction*
  - environment as an independent building block in the MAS
  - encapsulating its own clear-cut responsibilities, irrespective of the agents
- The environment provides the *surrounding conditions* for agents to exist
  - environment as an essential part of every MAS
  - the part of the world with which the agents interact, in which the effects of the agents will be observed and evaluated

Highlights 2/2

- Environment as a *glue*
  - on their own, agents are just individual loci of control.
  - to build a useful system out of individual agents, agents must be able to interact
  - the environment provides the glue that connects agents into a working system
- The environment *mediates* both the interaction among agents and the access to resources
  - it provides a medium for sharing information and mediating coordination among agents
    - as a mediator, the environment not only *enables interaction*, it also *constrains it*
    - as such, the environment provides a design space that can be exploited by the designer

Responsibilities 1/3

- *Structuring* the MAS
  - the environment is a shared "space" for the agents, resources, and services which structures the whole system
- Kind of structuring
  - *physical* structure
    - refers to spatial structure, topology, and possibly distribution
  - *interaction* structure
    - refers to infrastructure for message transfer, infrastructure for stigmergy, or support for implicit communication
  - *social* structure
    - refers to the embodiement of the organizational structure within the environment

Responsibilities 2/3

- Embedding *resources* and *services*
  - resources and services can be situated either in the physical structure or in the abstraction layer introduced by the environment
  - the environment should provide support at the abstraction level shielding low-level details of resources and services to the agents
- Encapsulating a *state* and *processes*
  - besides the activity of the agents, the environment can have processes of its own, independent of agents
    - example: evaporation, aggregation, and diffusion of digital pheromones
  - It may also provide support for maintaining agent-related state
    - for example, the normative state of an electronic institution or tags for reputation mechanisms

Responsibilities 3/3

- *Ruling* and *governing* function
  - the environment can define different types of rules on all entities in the MAS.
    - constraints imposed by the domain at hand or laws imposed by the designer
    - may restrict the access of specific resources or services to particular types of agents, or determine the outcome of agent interactions
    - preserving the agent system in a consistent state according to the properties and requirements of the application domain
- Examples
  - coordination infrastructures
  - e-Institutions

Reference Abstract Architecture

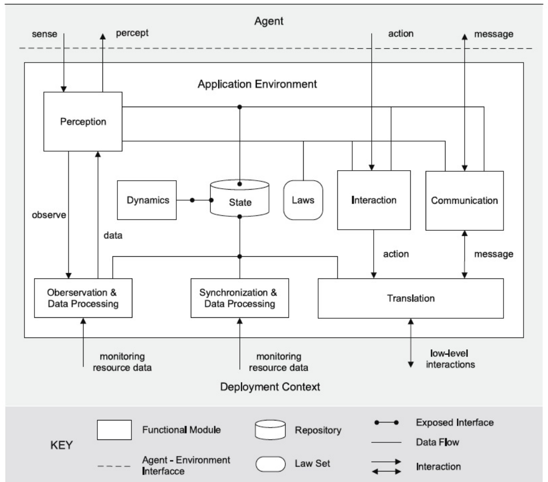
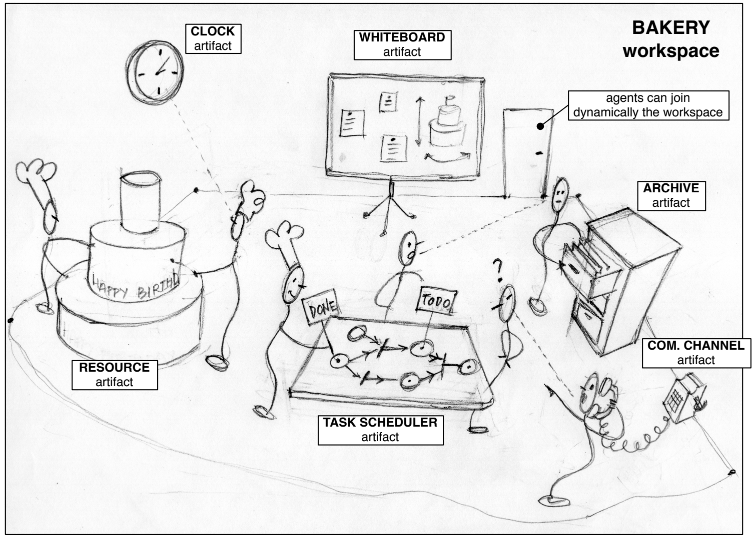


Figure from [Weyns et al., 2007]

Approaches

- Looking for general-purpose approaches for conceiving, designing, programming, executing the environment as agents' world
  - orthogonality
  - generality
  - expressiveness
- Uniformly integrating different MAS aspects
  - coordination, organisation, institutions, ...
- Examples of concrete models and technologies
  - AGRE/AGREEN/MASQ [Baez-Barranco et al., 2007]
  - GOLEM [Bromuri and Stathis, 2007]
  - A&A, CArtAgO [Ricci et al., 2007]

Background Human Metaphor



Agent & Artifacts (A&A) Basic Concepts

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

Abstraction

- artifacts as first-class resources and tools for agents

Modularisation

- artifacts as modules encapsulating functionalities, organized in workspaces

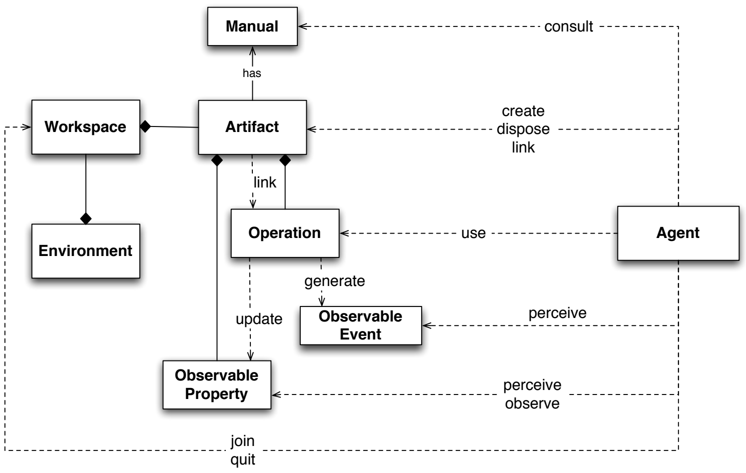
Extensibility and openness

- artifacts can be created and destroyed at runtime by agents

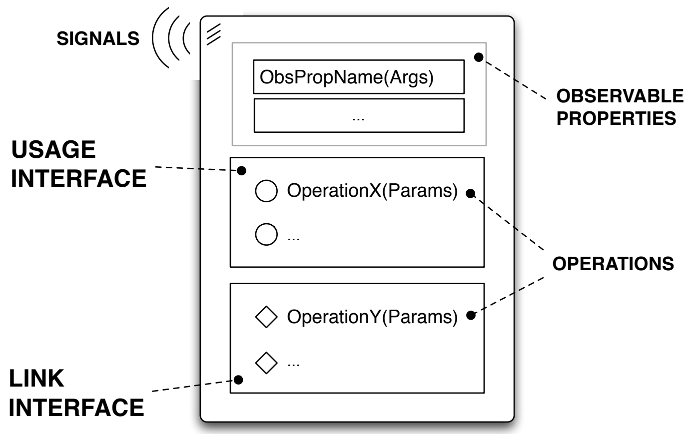
Reusability

- artifacts (types) as reusable entities, for setting up different kinds of environments

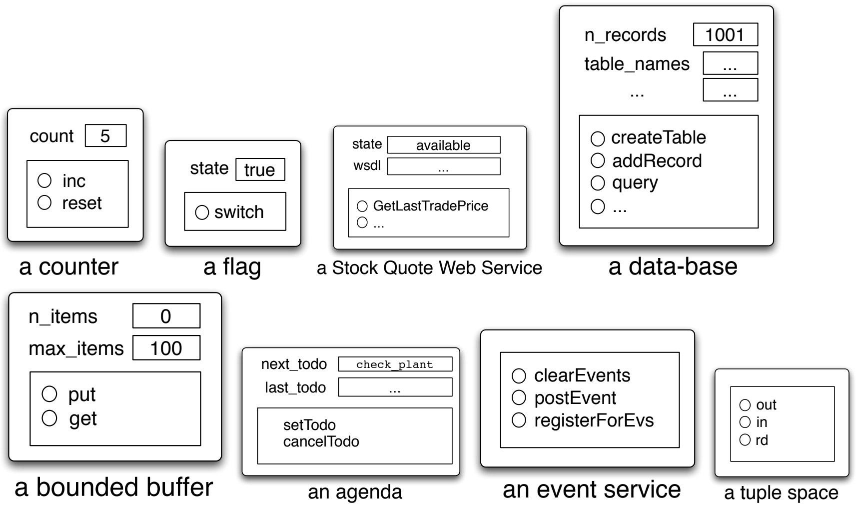
A&A Meta-Model in more Details



Artifact Abstract Representation



A World of Artifacts



Simple Artifacts Taxonomy

Individual or Personal Artifacts

- designed to provide functionalities for a single agent use
- e.g. agenda for managing deadlines, a library, ...

Social Artifacts

- designed to provide functionalities for structuring and managing the interaction in a MAS
- coordination artifacts, organisation artifacts, ...
- e.g. blackboard, 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/Percepts in Artifact-Based Environments

Actions and Percepts constitute the *Contract* provided by the environment

Action Repertoire

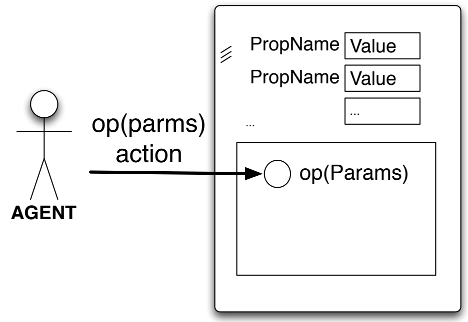
- is given by the dynamic set of operations provided by the overall set of artifacts available in the workspace
- can be changed by creating/disposing artifacts.

Action success/failure semantics is defined by operation semantics

Percept Repertoire

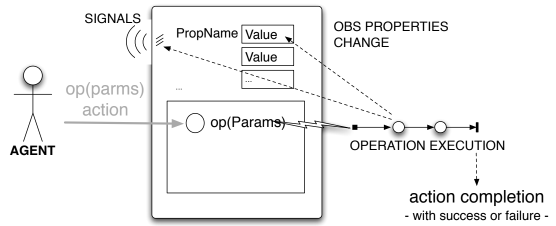
- is given by the dynamic set of *properties* representing the state of the environment and by the *signals* concerning events signalled by the environment
- can be changed by creating/disposing artifacts.

Interaction Model: Operation Execution (1)



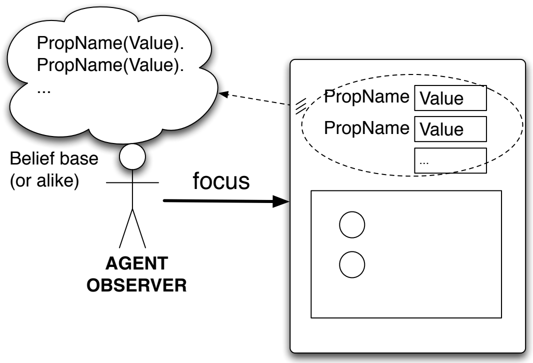
- Performing an action corresponds to triggering the execution of an operation
  - ⇝ acting on artifact's usage interface

Interaction Model: Operation Execution (2)



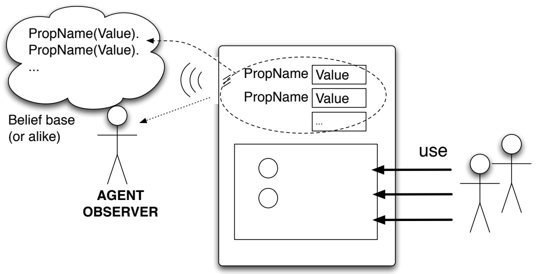
- Operation execution is:
  - a process structured in one or multiple transactional steps
  - asynchronous with respect to agent *...which can proceed possibly reacting to percepts and executing actions of other plans/activities*
- Operation completion causes action completion, generating events with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

Interaction Model: Observation (1)



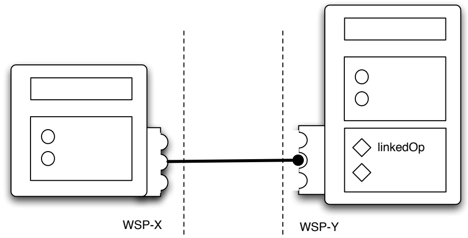
- Agents can dynamically select which artifacts to observe
  - predefined `focus`/`stopFocus` actions

Interaction Model: Observation (2)



- 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 into 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

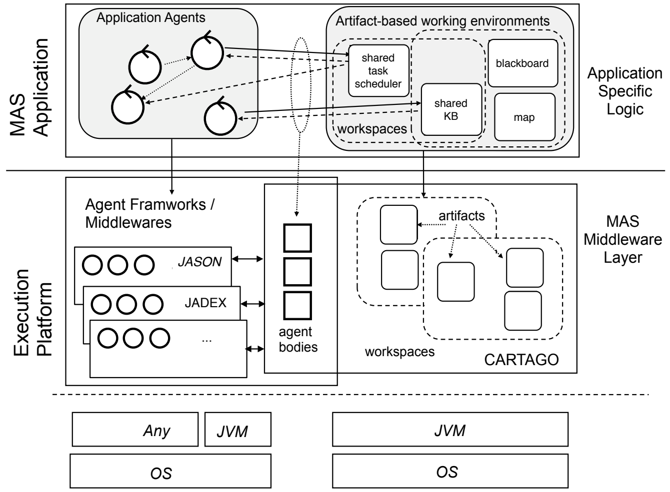
Artifact Manual

- 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
  - 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

- CArtAgO framework / infrastructure
  1. environment for programming and executing artifact based environments
  2. Java-based programming model for defining artifacts
  3. set of basic API for agent platforms to work within artifact-based environment
- integration with agent programming platforms: available bridges for Jason, Jadex, AgentFactory, simpA, ongoing for 2APL and Jade
- 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 http://cartago.sourceforge.net

CArtAgO Architecture



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`, ...
  - ....

Defining an Artifact

- An artifact type extends the cartago.Artifact class
- An artifact is composed of:
  - *state variables*: class instance fields
  - *observable properties* with a set of primitives to define/update/.. them
  - *signal* primitive to generate signals
  - *operation controls*: methods annotated with @OPERATION
    - The operation init is the operation which is automatically executed when the artifact is created (analogous to constructor in objects).
  - *internal operations*: operations triggered by other operations, methods annotated with @INTERNAL_OPERATION
  - *await* primitive to define the operation steps
  - *guards* - both for operation controls and operation steps -: methods annotated with @GUARD

Observable property

- Observable property is defined by a name and a value.
- The value can change dynamically according to artifact behaviour.
- The change is made automatically observable to all the agents focussing the artifact.
- Defined by using defineObsProperty, specifying
  - the name of the property
  - the initial value (that can be of any type, including objects)
- Accessed by
  - getObsProperty
  - updateObsProperty

Change of property

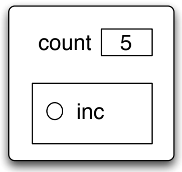
Change of the value of a property using primitive

⇝ getObsProperty(String name).updateValue(Object value)

or updateObsProperty(String name, Object value)

- the specified value must be compatible with the type of the corresponding field
- the value of the property is updated with the new value
- an event is generated (content is the value of the property) property_updated(PropertyName,NewValue,OldValue)
- the event is made observable to all the agents focussing the artifact

Example



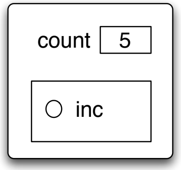
OBSERVABLE PROPERTIES:
count: int

USAGE INTERFACE:
inc: { op_exec_started(inc),
count(X),
op_exec_completed(inc) }

Example

```
public class Counter extends Artifact {
   void init() {
   defineObsProperty("count",0);
   }
   @OPERATION void inc() {
   int count = getObsProperty("count").intValue();
   updateObsProperty("count",count+1);
   }
}
```

Example (revisited)



OBSERVABLE PROPERTIES:
count: int

USAGE INTERFACE:
inc: { op_exec_started(inc),
count(X),
op_exec_completed(inc) }

Example

```
public class Counter extends Artifact {
   void init() {
   defineObsProperty("count",0);
   }
   @OPERATION void inc() {
   ObsProperty prop = getObsProperty("count");
   prop.updateValues(prop.intValue()+1);
   }
}
```


Operations

- Operation *op(param1,param2,...)* is defined as:
  - a method op, in the artifact class returning void
  - annotated with @OPERATION
- Parameters can be input and/or output operation parameters
  - Output operation parameters (OpFeedbackParam<T>) can be used to specify the operation results and related action feedback
- Operation can be composed of zero, one or multiple *atomic* computational steps

Example

```
public class Counter extends Artifact {
   int count; // state variable
   @OPERATION void init() { count = 0; }
   @OPERATION void inc() { count++; }
}
```


Observable Events

Observable events are generated by default:

- op_execution_completed, op_execution_failed, op_execution_aborted ...

Observable event can be generated explicitly, within an operation by the method

⇝ signal(String evType, Object variable params)

- Generated event is a tuple, with *evType* label, composed of the sequence of passed parameters
- Generated event can be observed by
  - the agent responsible of the execution of the operation
  - all the agents observing the artifact

⇝ signal(AgentId id, String evType, Object variable params)

- Generated event is perceivable only by the specified agent that must be observing the artifact, anyway.

Example of Observable Events

Example

```
public class Count extends Artifact {
   int count;
   @OPERATION void init() { count = 0; }
   @OPERATION void inc() {
      count++;
      signal("new_value", count);
   }
}
```

Observable Events (cont'ed)

Failed primitive

- failed(String failureMsg)
- failed(String failureMsg, String descr, Object... args)

An action feedback is generated, reporting a failure msg and optionally also a tuple descr(Object...) describing the failure.

Example of Observable Events

Example

```
public class BoundedCounter extends Artifact {
   private int max;
   void init(int max) {
      defineObsProperty("count",0);
      this.max = max;
   }

   @OPERATION void inc() {
      ObsProperty prop = getObsProperty("count");
      if (prop.intValue() < max) {
          prop.updateValue(prop.intValue()+1);
          signal("tick");
      } else {
          failed("inc failed","inc_failed","max_value_reached",max);
      }
   }
}
```


Example: Bounded Buffer with Output Parameters

```
public class BBuffer extends Artifact {
   private LinkedList<Item> items;
   private int nmax;
   @OPERATION void init(int nmax) {
      items = new LinkedList<Item>();
      this.nmax = nmax;
      defineObsProperty("n_items",0);
   }

   @OPERATION(guard="bufferNotFull") void put(Item obj) {
      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 bufferNotFull(Item obj) { return items.size() < nmax; }
   @GUARD boolean itemAvailable() { return items.size() > 0; }
}
```


Operation Guards

Guard on an operation is specified as:

- a *boolean* method annotated with @GUARD, having the same number and type of parameters of the guarded operation
- Its name is included as the attribute guard of the @OPERATION annotation

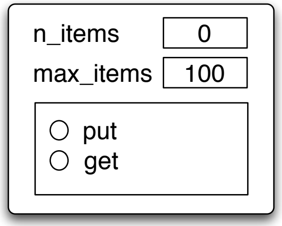
or used as parameter of the method await in the body of the operation

- The operation will be enabled only if (when) the guard is satisfied

Example

```
public class MyArtifact extends Artifact {
   int m;
   @OPERATION void init() { m=0; }
   @OPERATION(guard="canExecOp1") void op1() { ...  }
   @OPERATION void op2() { m++; }
   @GUARD boolean canExecOp1() { return m == 5; }
}
```

Example: Bounded Buffer with Guarded Operations



OBSERVABLE PROPERTIES:

n_items: int+
max_items: int

USAGE INTERFACE:

put(*item*:Item) / (n_items < max_items): {...}

get / (n_items >= 0) :
{new_item(item:Item),...}

```
public class BBuffer extends Artifact {
   private LinkedList<Item> items;
   private int nmax;
   @OPERATION void init(int nmax) {
      items = new LinkedList<Item>();
      defineObsProperty("max_items",nmax);
      defineObsProperty("n_items",0);
   }

   @OPERATION(guard="bufferNotFull") void put(Object obj) {
      items.add(obj);
      getObsProperty("n_items").updateValue(items.size());
   }
   @GUARD boolean bufferNotFull(Item obj) {
      int maxItems = getObsProperty("max_items").intValue();
      return items.size() < maxItems;
   }

   @OPERATION(guard="itemAvailable") void get() {
      Object item = items.removeFirst();
      getObsProperty("n_items").updateValue(items.size());
      signal("new_item",item);
   }
   @GUARD boolean itemAvailable() { return items.size() > 0; }
}
```


Multi-step Operation

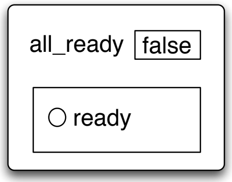
Structured (non-atomic) operations are implemented with

- one @OPERATION representing the entry point
- one or multiple transactional steps, possibly with guards
- await primitive to define the steps

Example of Multi-step Operation

```
public class MyArtifact extends Artifact {
   int internalCount;
   @OPERATION void opWithResults(double x, double y,
      OpFeedbackParam<Double> sum, OpFeedbackParam<Double> sub) {
      sum.set(x+y);
      sub.set(x-y);
   }
   @OPERATION void structureOp(int ntimes) {
      internalCount=0;
      signal("step1_completed");
      await( "canExecStep2", ntimes);
      signal("step2_completed", internalCount);
   }
   @OPERATION void update(int delta) {
      internalCount += delta;
   }
   @GUARD boolean canExecStep2(int ntimes) {
      return internalCount >= ntimes;
   }
}
```


Example: Simple synchronisation artifact



OBSERVABLE PROPERTIES:

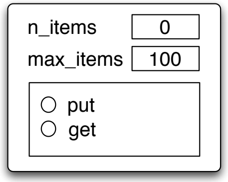
all_ready: {true,false}

USAGE INTERFACE:

ready / true: { op_exec_completed }

```
public class SimpleSynchronizer extends Artifact {
   int nReady, nParticipants;
   @OPERATION void init(int nParticipants) {
      defineObsProperty("all_ready",false);
      nReady = 0;
      this.nParticipants = nParticipants;
   }
   @OPERATION void ready() { // to synch
      nReady++;
      await("allReady");
      getObsProperty("all_ready").updateValue(true)
   }
   @GUARD booolean allReady() {
      return nReady >= nParticipants;
   }
}
```

Example: Bounded Buffer with Guarded Steps



OBSERVABLE PROPERTIES:

n_items: int+
max_items: int

USAGE INTERFACE:

put(*item*:Item) / (n_items < max_items): {...}

get / (n_items >= 0) :
{ new_item(item:Item),...}

```
public class BBuffer extends Artifact {
   private LinkedList<Item> items;
   private int nmax;
   @OPERATION void init(int nmax) {
      items = new LinkedList<Item>();
      defineObsProperty("max_items",nmax);
      defineObsProperty("n_items",0);
   }
   @OPERATION void put(Object obj) {
      await("bufferNotFull", obj);
      items.add(obj);
      getObsProperty("n_items").updateValue(items.size());
   }
   @GUARD boolean bufferNotFull(Item obj) {
      int maxItems = getObsProperty("max_items").intValue();
      return items.size() < maxItems;
   }
   @OPERATION void get() {
      await("itemAvailable");
      Object item = items.removeFirst();
      getObsProperty("n_items").updateValue(items.size()-1);
      signal("new_item",item);
   }
   @GUARD boolean itemAvailable() { return items.size() > 0; }
}
```


Temporal Guards on Operation Steps

- Specified with await_time primitive
- parameter indicates the number of milliseconds that must elapse before the step could be executed, after having being triggered
- its value is a long value greater than 0

Example of Temporally Guarded Operation

```
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);
      }
   }
}
```


Link Interface

- Set of operations that can be triggered by an artifact on another artifact
- Operations are annotated with @LINK (can be composed by multiple steps, can generate events, etc.)

Example

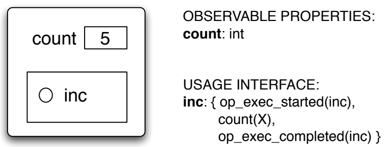
```
public class LinkableArtifact extends Artifact {
   int count;
   @OPERATION init() { count= 0; }
   @LINK void inc() {
      log("inc invoked."); count++;
      signal("new_count_value",count);
   }
}
```

- Call of the operation from the linking Artifact is done using the execLinkedOp primitive.

Linking Artifacts

- Executing execLinkedOp triggers the operation
- Once triggered, linked operation execution is the same as normal operations
- The only difference is:
  - the events that are generated by a linked operations, are made observable to the agent using or observing the artifact that triggered the execution of the link operation
  - In the case of a chain, with an agent X executing an operation on an artifact, which links the operation of an artifact B, which links an operation of an artifact C, all the observable events generated by B and C linked operations are made observable to X

The Simplest Artifact




```
public class Counter extends Artifact {
   @OPERATION void init() {
   defineObsProperty("count",0);
   }
   @OPERATION void inc() {
   int count = getObsProperty("count").intValue();
   getObsProperty("count").updateValue(count+1);
   }
}
```


Jason Agents using the Simplest Artifact (1)

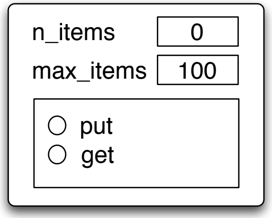
```
!create_and_use.
+!create_and_use :  true
<- !setupTool(Id);
      // first use
   inc;
      // second use specifying the id
   inc [artifact_id(Id)].
+!setupTool(C): true
<- makeArtifact("ourCount", "Counter",C).
```

Jason Agents observing the Simplest Artifact (2)

```
!observe.

+!observe :  true
<- ?myTool(C);         // query goal
   focus(C).

+count(V) : V < 10 <- println(count percept:  ,V)).

+count(V)[artifact_name(Id,'ourCount'')] :  V >= 10
<- println(stop observing.));
   stopFocus(Id).

+?myTool(CounterId):  true
<- lookupArtifact(ourCount,CounterId).

-?myTool(CounterId):  true <-.wait(10); ?myTool(CounterId).
```


Producer-Consumer Artifact

- bounded-buffer artifact for producers-consumers scenarios



OBSERVABLE PROPERTIES:

n_items: int+
max_items: int

USAGE INTERFACE:

put(*item*:Item) / (n_items < max_items): {...}

get / (n_items >= 0) :
{ new_item(item:Item),...}

```
public class BBuffer extends Artifact {
   private LinkedList<Item> items;
   private int nmax;
   @OPERATION void init(int nmax) {
      items = new LinkedList<Item>();
      defineObsProperty("max_items",nmax);
      defineObsProperty("n_items",0);
   }

   @OPERATION(guard="bufferNotFull") void put(Object obj) {
      items.add(obj);
      getObsProperty("n_items").updateValue(items.size()+1);
   }
   @GUARD boolean bufferNotFull(Item obj) {
      int maxItems = getObsProperty("max_items").intValue();
      return items.size() < maxItems;
   }

   @OPERATION(guard="itemAvailable") void get() {
      Object item = items.removeFirst();
      getObsProperty("n_items").updateValue(items.size()-1);
      signal("new_item",item);
   }
   @GUARD boolean itemAvailable() { return items.size() > 0; }
}
```

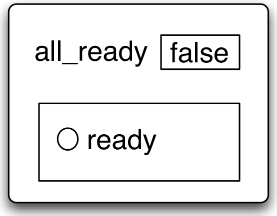

Producer Jason Agent

```
item_to_produce(0).
!produce.

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

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

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

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

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


Consumer Jason Agent

```
!consume.

+!consume:  true
<- ?bufferToUse(Buffer);
   .print("Going to use ",Buffer);
   !consumeItems.

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

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

+?bufferToUse(BufferId) :  true
<- lookupArtifact("myBuffer",BufferId).

-?bufferToUse(BufferId) :  true
<- .wait(50); ?bufferToUse(BufferId).
```

Synchronisation Artifact



OBSERVABLE PROPERTIES:

all_ready: {true,false}

USAGE INTERFACE:

ready / true: { op_exec_completed }

```
public class SimpleSynchronizer extends Artifact {
   int nReady, nParticipants;
   @OPERATION void init(int nParticipants) {
      defineObsProperty("all_ready",false);
      nReady = 0;
      this.nParticipants = nParticipants;
   }
   @OPERATION void ready() { // to synch
      nReady++;
      nextStep("setAllReady");
   }
   @OPSTEP(guard="allReady") void setAllReady() {
      getObsProperty("all_ready").updateValue(true);
   }
   @GUARD booolean allReady() {
      return nReady >= nParticipants;
   }
}
```


Jason Synch Agent - Reactive

Example

```
!work.
+!work:  true <- ...
// locate the synch tool
   lookupArtifact(mySynch,Synch);
// observe it.
   focus(Synch);
// ready for synch
   ready.
// react to all_ready(true) percept
+all_ready(true)[artifact_id(mySynch)]   :  true
<- // all ready, go on.
   ...
```


Example: A Tuple-Space Artifact

```
public class SimpleTupleSpace extends Artifact {
   TupleSet tset;

  void init(){
    tset = new TupleSet();
  }

  @OPERATION void out(String name, Object... args){
    tset.add(new Tuple(name,args));
  }

  @OPERATION void in(String name, Object... params){
    TupleTemplate tt = new TupleTemplate(name,params);
    await("foundMatch",tt);
    Tuple t = tset.removeMatching(tt);
    bind(tt,t);
  }

  @OPERATION void rd(String name, Object... params){
    TupleTemplate tt = new TupleTemplate(name,params);
    await("foundMatch",tt);
    Tuple t = tset.readMatching(tt);
    bind(tt,t);
  }

  @GUARD boolean foundMatch(TupleTemplate tt){
    return tset.hasTupleMatching(tt);
  }

  private void bind(TupleTemplate tt, Tuple t){...}
```

- Multi-step operations
  - operations composed by multiple *transactional* steps, possibly with guards
  - `await` primitive to define the steps

Remarks

- Process-based action execution semantics
  - action/operation execution can be long-term
  - action/operation execution can overlap
- Key feature for implementing coordination functionalities

Example: Dining Philosopher Agents

WAITER

```
philo(0,"philo1",0,1).
philo(1,"philo2",1,2).
philo(2,"philo3",2,3).
philo(3,"philo4",3,4).
philo(4,"philo5",4,0).

!prepare_table.

+!prepare_table
  <- for ( .range(I,0,4) ) {
       out("fork",I);
       ?philo(I,Name,Left,Right);
       out("philo_init",Name,Left,Right);
     };
     for ( .range(I,1,4) ) {
       out("ticket");
     };
     println("done.").
```

PHILOSOPHER AGENT

```
!boot.

+!boot
  <- .my_name(Me);
     in("philo_init",Me,Left,Right);
     +my_left_fork(Left); +my_right_fork(Right);
     println(Me," ready.");
     !!enjoy_life.

+!enjoy_life
 <- !thinking; !eating; !!enjoy_life.

+!eating
 <- !acquireRes; !eat; !releaseRes.

+!acquireRes : my_left_fork(F1) & my_right_fork(F2)
  <- in("ticket"); in("fork",F1); in("fork",F2).

+!releaseRes: my_left_fork(F1) & my_right_fork(F2)
 <-  out("fork",F1); out("fork",F2); out("ticket").

+!thinking <- .my_name(Me); println(Me," thinking").
+!eat <- .my_name(Me); println(Me," eating").
```


Example 4: A Clock

CLOCK

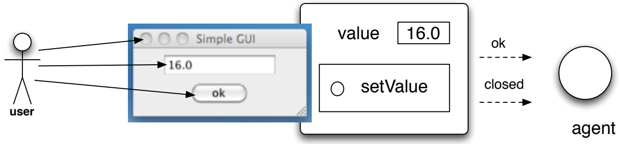
```
public class Clock extends Artifact {

  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 5: GUI Artifacts



- Exploiting artifacts to enable interaction between human users and agents

Example 5: 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).
```

Remark: 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 6: Action Execution & Blocking Behaviour

```
// agent code

@processing_stream
+!processing_stream : true
  <- makeArtifact("myStream","Stream",Id);
     focus(Id);
     +sum(0);
     generate(1000);
     ?sum(S);
     println(S).

@update [atomic]
+new_number(V) : sum(S)
  <- -+sum(S+V).
```

```
// artifact code

class Stream extends Artifact {
  ...
  @OPERATION void generate(int n){
    for (int i = 0; i < n; i++){
      signal("new_number",i);
    }
  }
}
```

- The agent perceives and processes `new_number` percepts as soon as they are generate by the `Stream`
  - even if the `processing_stream` plan execution is suspended, waiting for generate action completion
- The test goal `?sum(S)` is executed after `generate` action completion
  - so we are sure that all numbers have been generated and processed

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

- Designing and implementing artifact-based organisation Infrastructures
  - ORA4MAS infrastructure
- Cognitive stigmergy based on artifact environments
  - Cognitive artifacts for knowledge representation and coordination
- Artifact-based environments for argumentation
- Including A&A in AOSE methodology
- ...

Applying CArtAgO and JaCa

- Using CArtAgO/JaCa for building real-world applications and infrastructures
- Some examples
  - JaCa-WS / CArtAgO-WS
    - building SOA/Web Services applications using JaCa
    - `http://cartagows.sourceforge.net`
  - JaCa-Web
    - implementing Web 2.0 applications using JaCa
    - `http://jaca-web.sourceforge.net`
  - JaCa-Android
    - implementing mobile computing applications on top of the Android platform using JaCa
    - `http://jaca-android.sourceforge.net`

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