



Cognitive Artifacts for Intelligent Agents in MAS: Exploiting Relevant Information Residing in Environments

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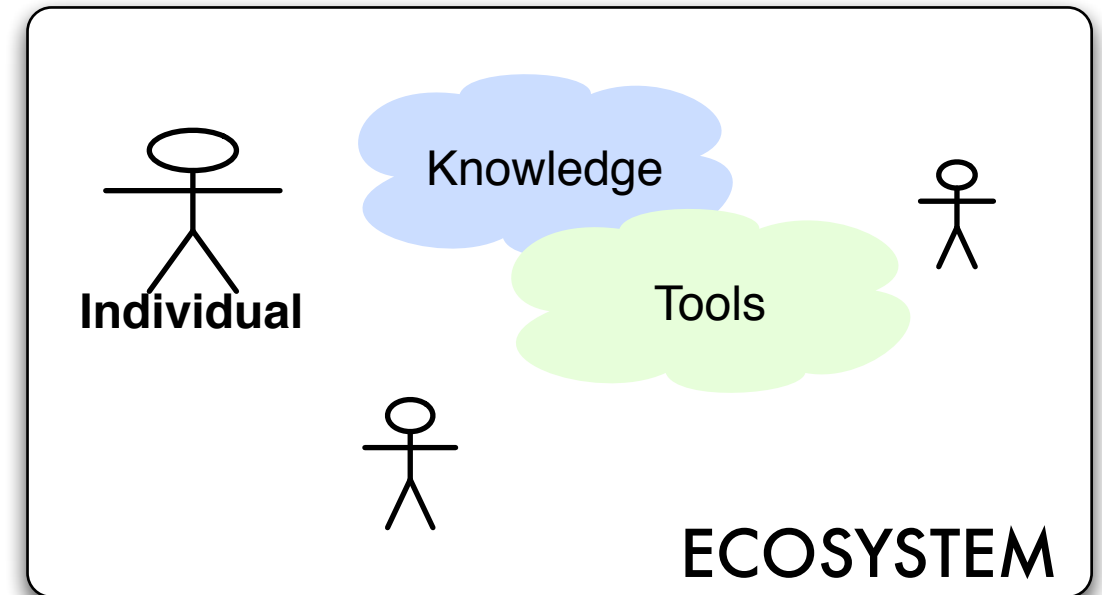
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Outline

- Agents & Artifacts
- Cognitive Artifacts
- RoomsWorld Experiment
- Conclusions

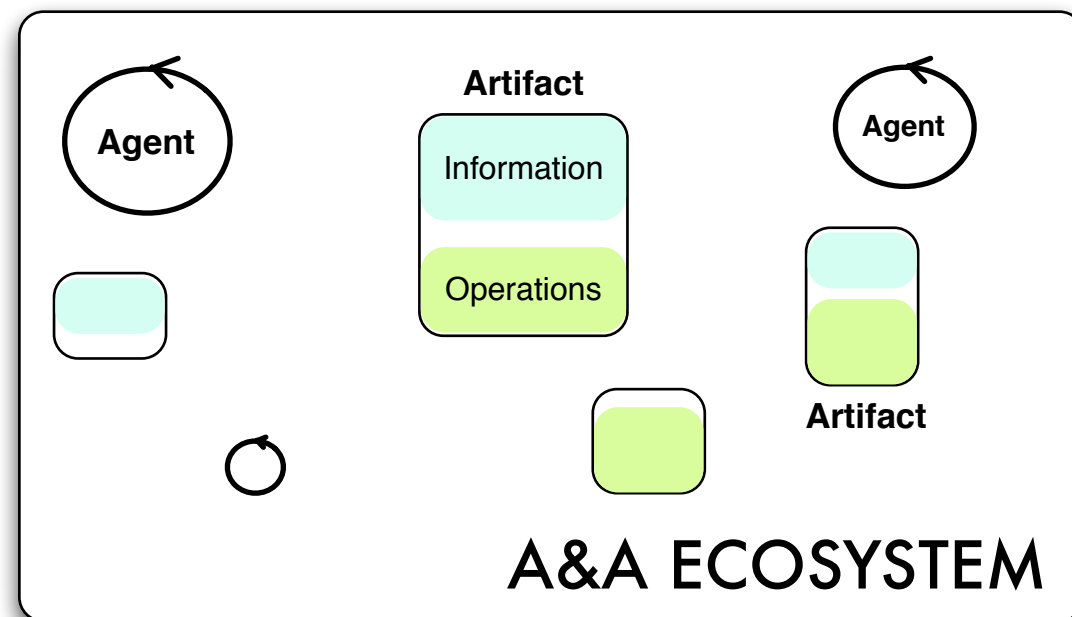
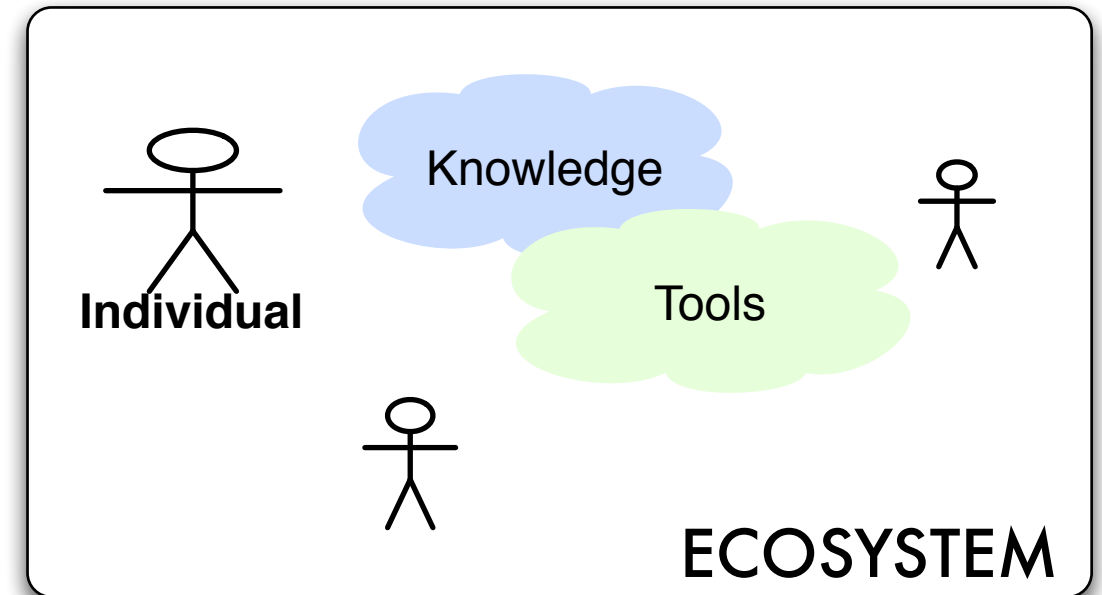
Agents & Artifacts

An ecosystem is a natural unit consisting of all **plants, animals and micro-organisms (biotic factors)** in an area functioning together with all of the **non-living physical (abiotic) factors** of the environment.
[Christopherson, RW (1996)]



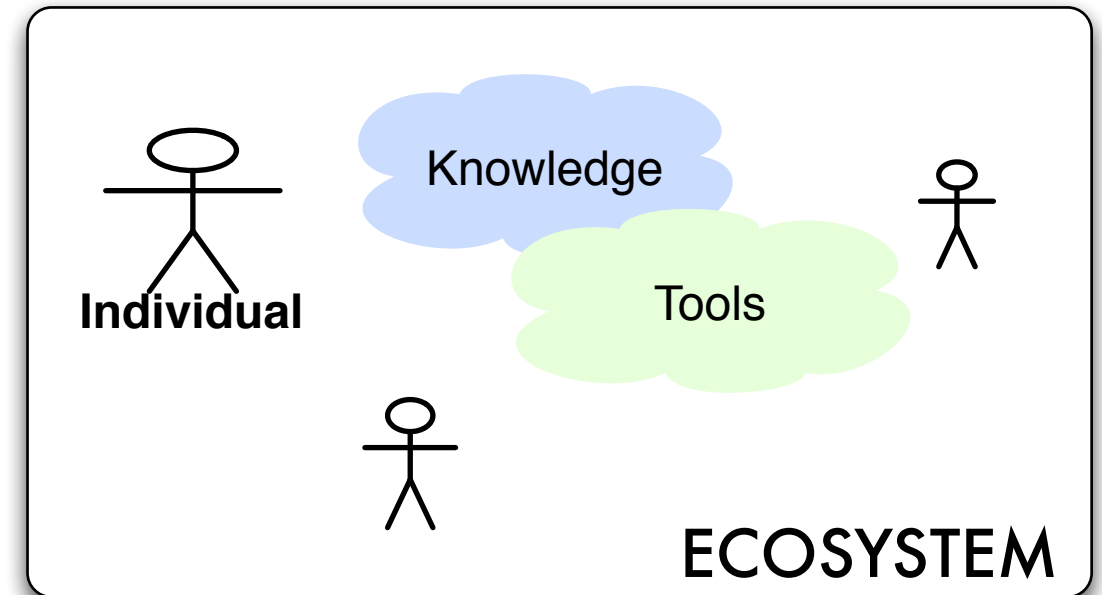
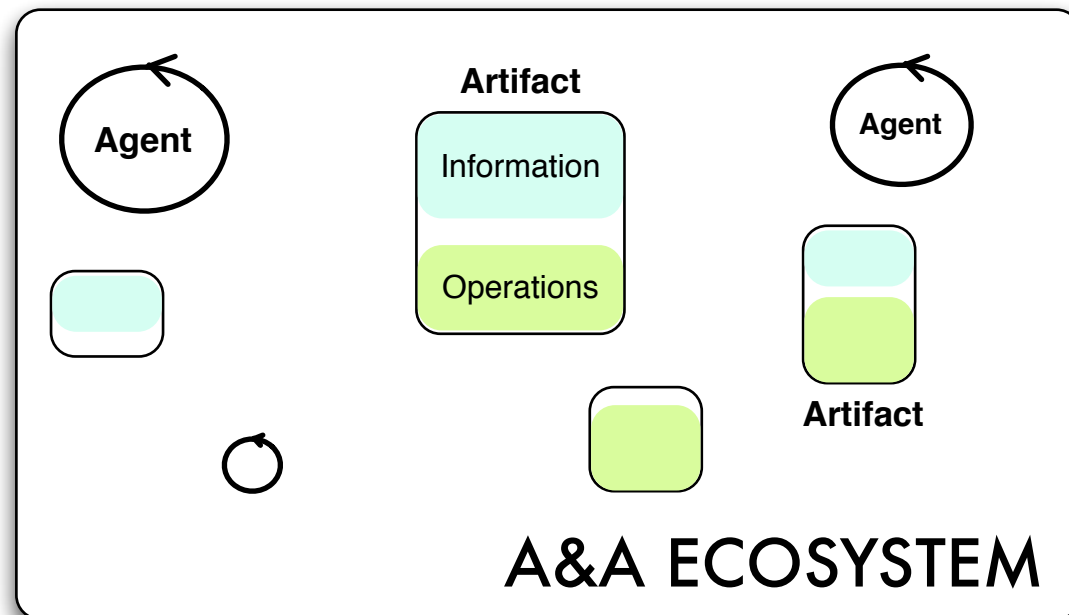
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Agents as *intentional systems*

Artifact are supposed to be (not only) external component (but also) functional resources

Functional Approach

- Representational Function
- Operational Function

Operational Function

- Operations are Artifacts *intended* purposes
 - “*Intended*” is in the mind of Artifact Designers
- 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

Representational Function

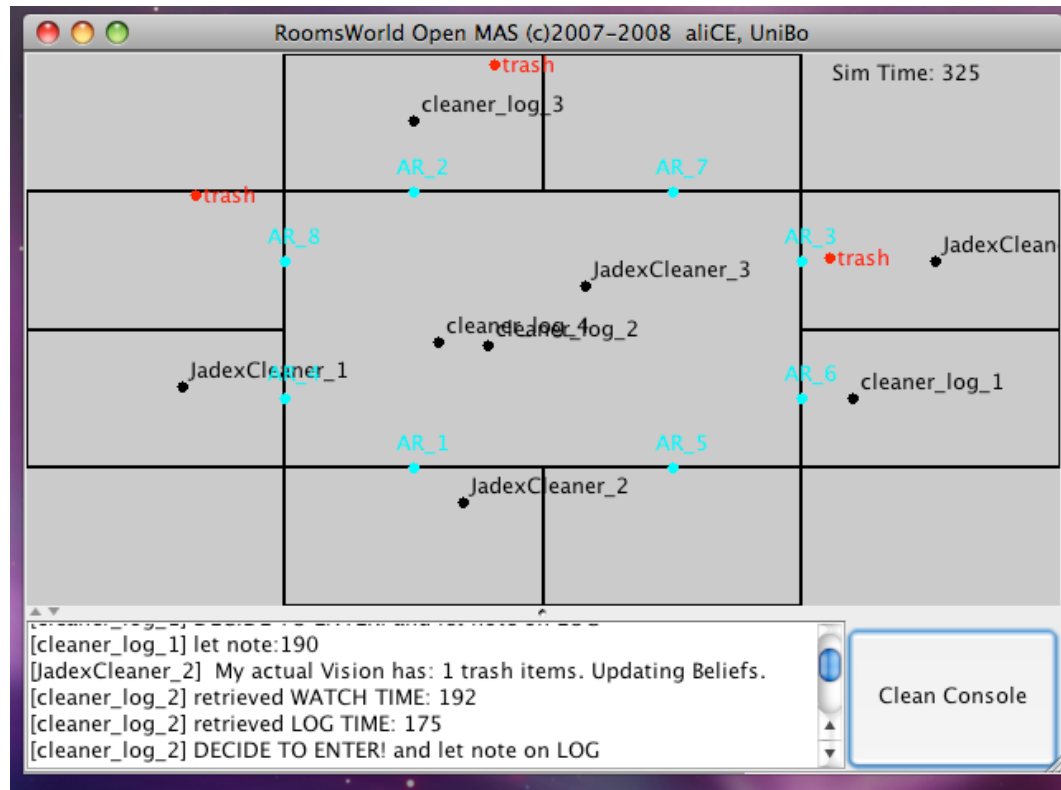
- Artifacts embed *machine-readable* Representations
 - Can maintain, make it observable, pre-process information
- From an **agent viewpoint**, Artifacts are *informational* units exploitable in a *situated* way
- Target for Agent's Epistemic Activities, i.e.:
 - External repositories, automatically collecting and providing strategic knowledge
 - Additional memory, even shared between agent groups
 -

COGNITIVE ARTIFACTS

The notion of COGNITIVE ARTIFACTS refers to agents having abilities to reason about available artifact *functions*

- Informational contents have to be included in **Epistemic Reasoning**
 - *Read, learn, and match* Representational contents
 - Observable cues in order to highlight relevant information (*situated cognition*)
- Operational contents have to be included in **Practical Reasoning**
 - By changing the actions required for achieving a goal, artifact operations change means-end reasoning (planning)

RoomsWorld



RoomsWorld

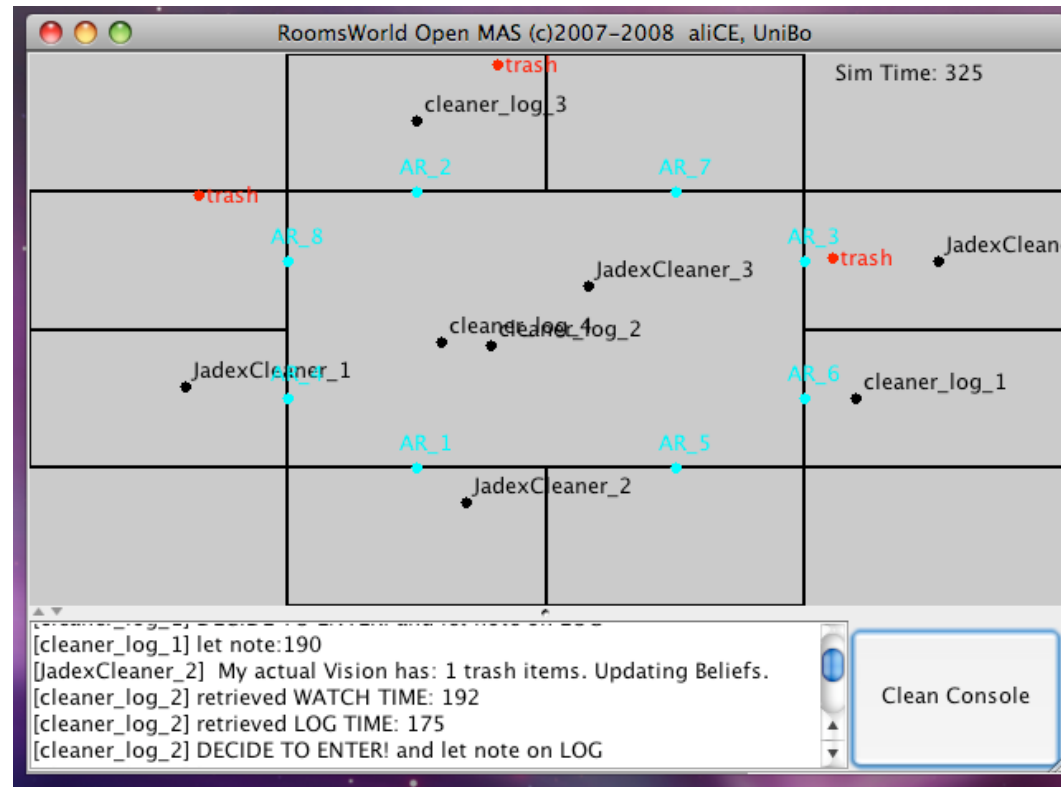
GOAL: clean rooms

BOUNDED RESOURCES

Agents have bounded range of sight
i.e., can locate trash items only entering the room

BOUNDED RATIONALITY

To prevent wasting resources (*time*) agents need a good strategy to coordinate activities



RoomsWorld

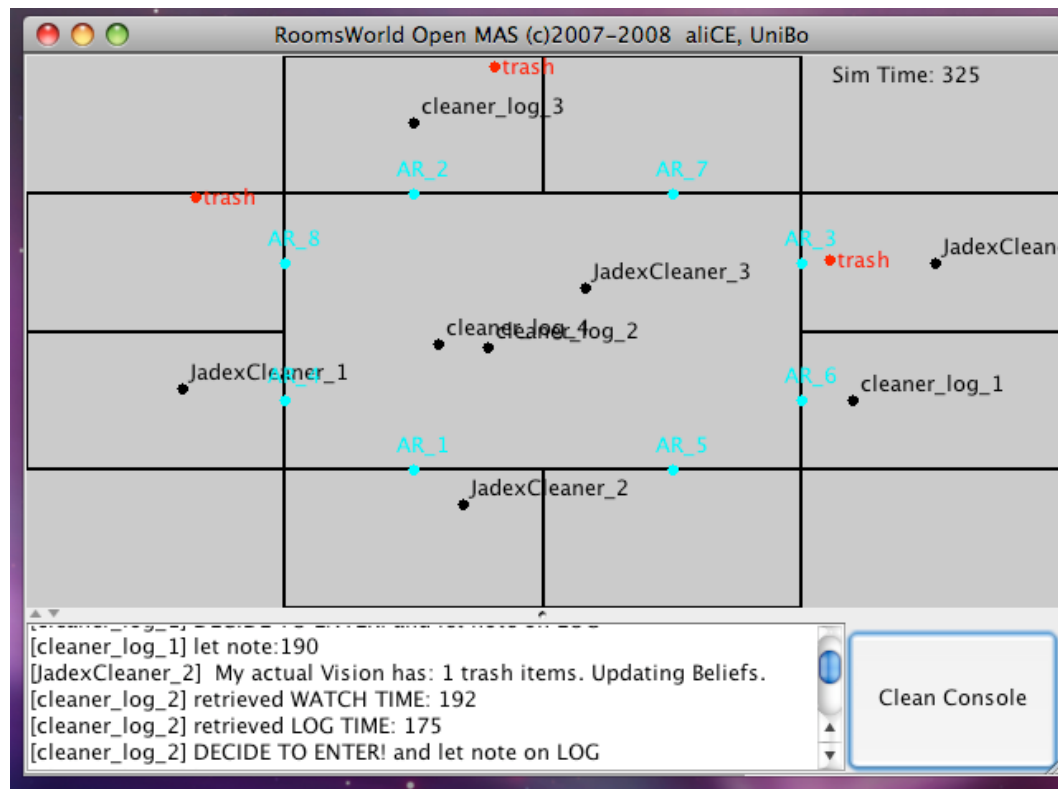
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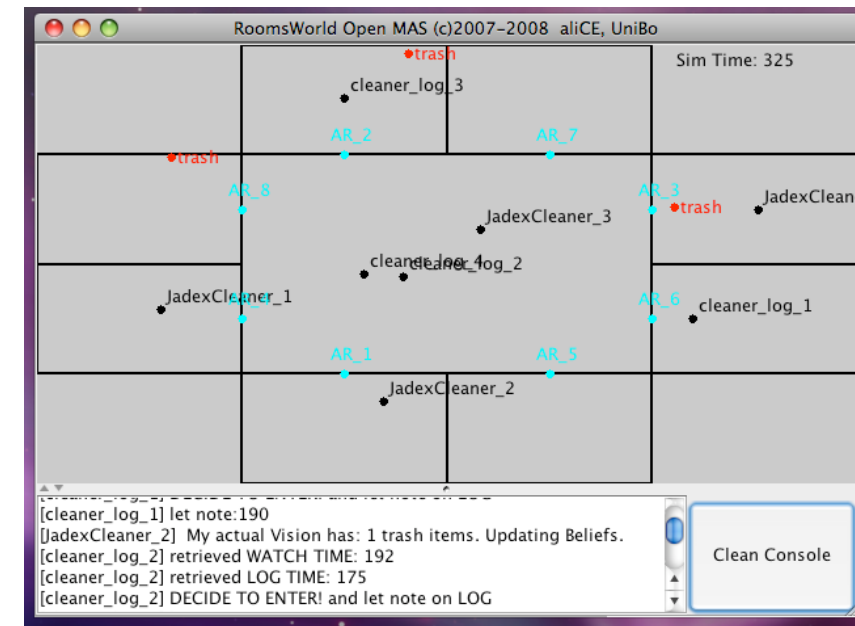
The information about which room has already been cleaned is *relevant* for deciding the next course of actions:

GOAL-SUPPORTING BELIEFS

Strategies

Each agent should deliberate the room to visit *knowing and evaluating* the activities performed **by others**

Goal-Supporting Beliefs : *targetRoom(N)*
cleaned(N,T)



WHICH STRATEGY ?

- **Normal Agents** look for trash exploring the rooms based on personal experience. Autonomously update relevant information, with no cooperation by other member of the team
- **Messaging Agents** explicit messages to coordinate activities. Once a given room has been cleaned, a messenger shares this information by broadcasting a message to the others
- **Log Strategy** exploits Cognitive Artifacts: WATCH and LOGs

Introducing Cognitive Artifacts

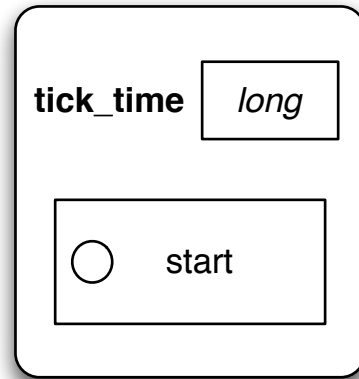
WATCH

OBSERVABLE PROPERTIES

tick_time *long*

USAGE INTERFACE

start()



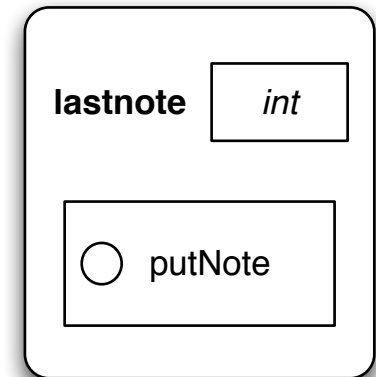
LOG

OBSERVABLE PROPERTIES

lastnote *int*

USAGE INTERFACE

putNote(Object note)



```
public class Watch extends Artifact {

    @OBSPROPERTY long tick_time;
    private final long exp_length = 2500;

    @OPERATION void init(){
        tick_time=0;
    }

    @OPERATION void start() {
        try {
            nextStep("tick");
        } catch (Exception ex) {}
    }

    @OPSTEP(tguard=1000) void tick(){
        if (tick_time<exp_length){
            try {
                updateProperty("tick_time", ++tick_time);
                // signal to synchronize dwelling agents
                signal("grig_tick", tick_time);
                outSignal("link", new Op("setSimTime", tick_time ));
                nextStep("tick");
            } catch (Exception ex){}
        } else {
            signal("exp_end");
        }
    }
}
```

```
public class Log extends Artifact {

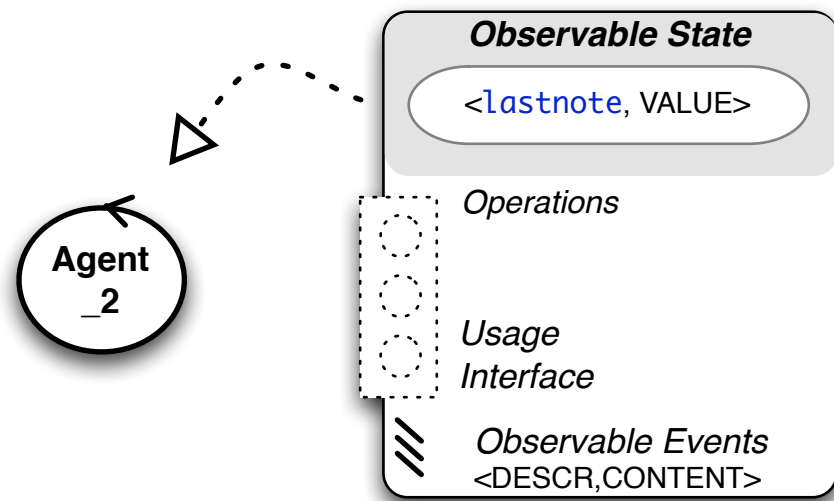
    private LinkedList<String> notes;
    ....

    @OBSPROPERTY int lastnote;

    @OPERATION void init(String n, location l){
        name=n; loc= l;
        notes = new LinkedList<String>();
    }

    @OPERATION void putNote( Object ts ){
        notes.addLast(ts.toString());
        lastnote = ((Integer)ts).intValue();
    }
}
```

Log Strategy



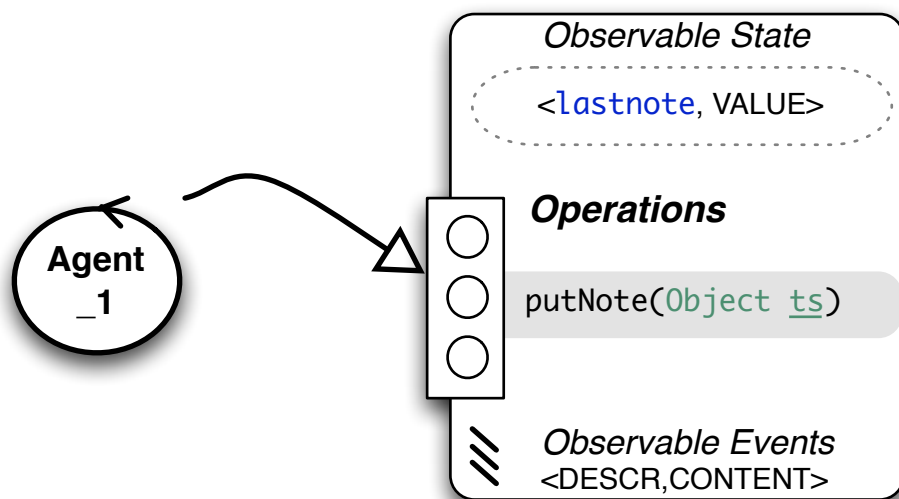
[... retrieve IDLog and IDWatch ...]

```
cartago.observeProperty(IDLog, lastnote(LogT) );
cartago.observeProperty(IDWatch, sim_time(Wt));
```

```
!decide(N, Wt, LogT).
```

LOGs are located at the entrance of each room

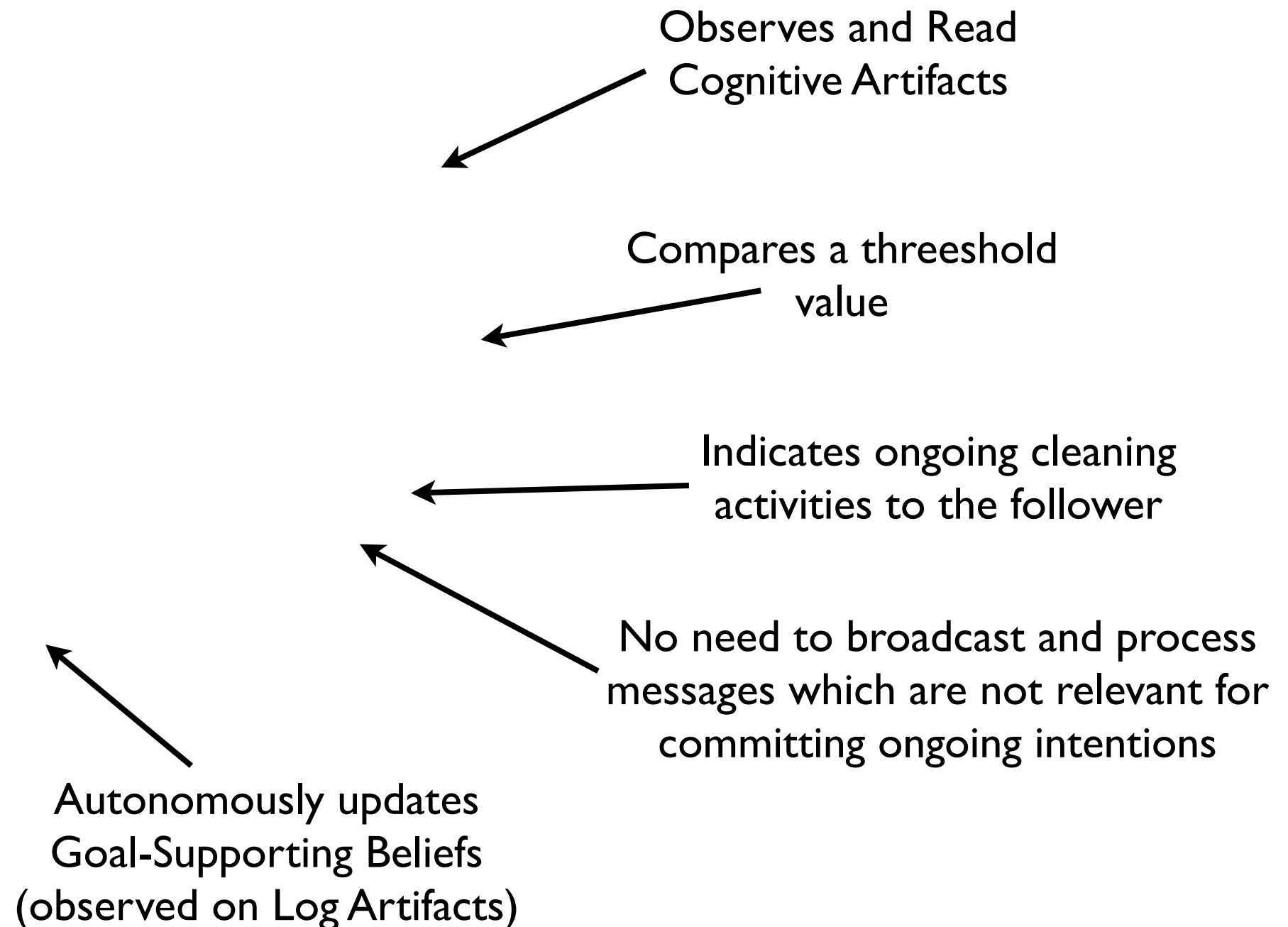
Before entering a chosen room N, an agent observes the actual time T from the *watch* and compares this information with last note observed in the *log*



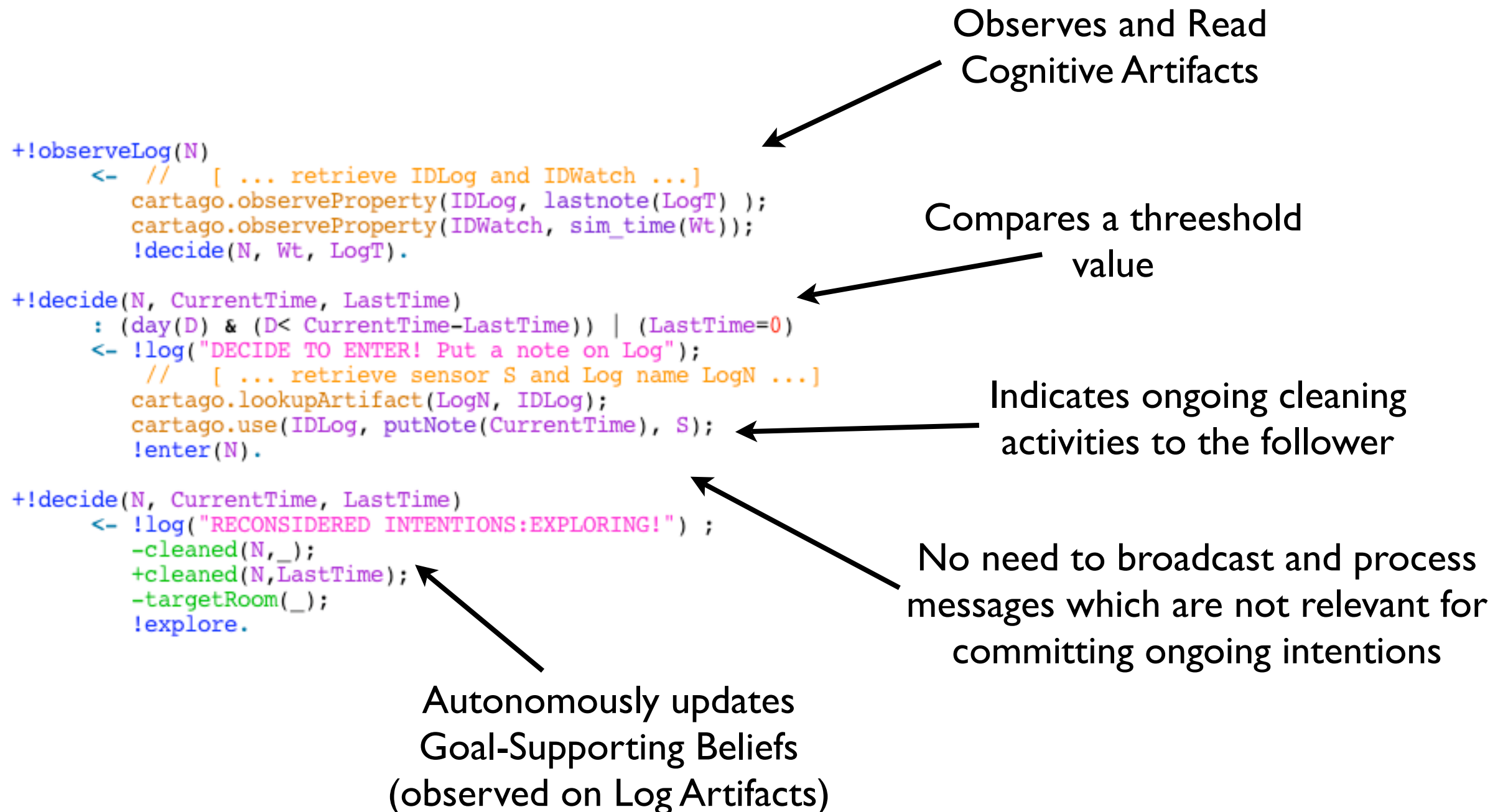
```
...
cartago.lookupArtifact(LOG, LogID);
cartago.use(LogID, putNote(CurrentTime));
...
```

Before exploring the room, the agent puts a note on the *log* indicating the time at which the room has been cleaned

Easing Means End (Jason)



Easing Means End (Jason)



Experiment

- GOAL EFFECTIVENESS cleaned items (i.e. agent's score) and in function of elapsed time
- BELIEF CHANGE COST total amount of belief change operations performed by all the agents of the team upon their *goal supporting beliefs*
- COST-EFFECTIVENESS RATIO: total amount of achieved task (score) divided by the belief change cost (unit of achieved goals for each belief change)

Discussion

- Although broadcasting messages to the overall society allows **messaging agents** to maintain an updated knowledge of the global environment, this requires to waste computational resources to process messages and update beliefs which are not relevant for the ongoing task
- On the contrary, **log agents** locally exploit information concerning their actual purposes, fully exploiting logs as suitable beliefbase enhancer
 - Logs are cooperatively updated by agents during their activities
 - Store the information which persist even beyond their use
 - Global behavior of the society smerges since informational contents of the distributed logs

Concluding Remarks

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

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

- To provide Relevant, Strategic Information (Single-Agent)
 - Easy reasoning about goals: *goal supporting beliefs*
 - Simplifying agent choices and easing Belief Update

Concluding Remarks

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

- To provide Relevant, Strategic Information (Single-Agent)
 - Easy reasoning about goals: *goal supporting beliefs*
 - Simplifying agent choices and easing Belief Update
- To distribute Information (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

Next Steps and Ongoing Works

- Autonomous selection / use / creation of artifacts which are not known at design time
 - exploiting artifact manuals and artifact interfaces
- Definition of a formal model for artifacts and A&A
 - based on I/O automata-like approaches
 - exploring impact on MAS validation
- Using the integration for tackling MAS main issues
 - e.g. Open MAS Organisation
 - ORA4MAS infrastructure [Boissier, Hübner, Kitio], EUMAS 2007

end

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