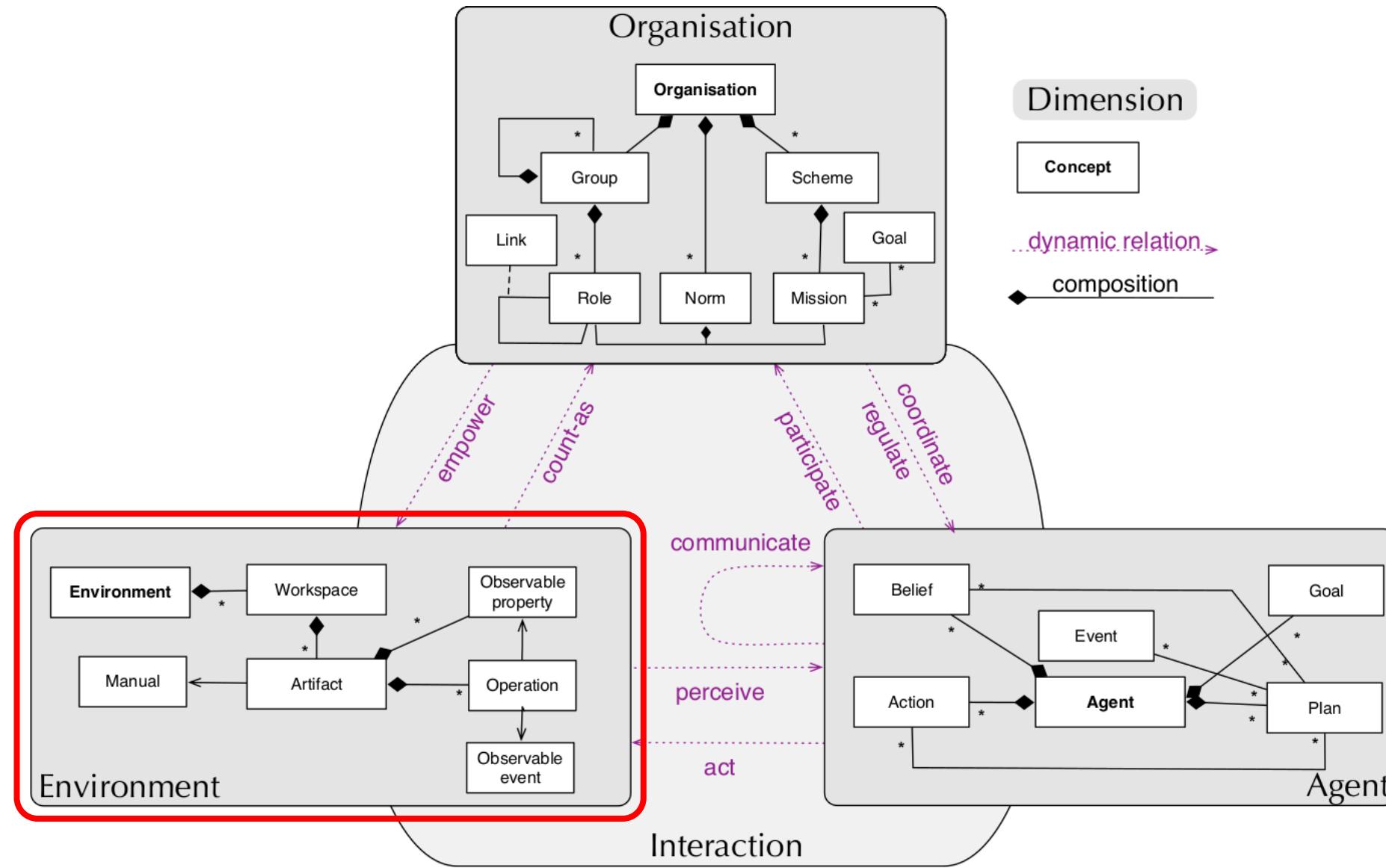


Multi-Agent Oriented Programming Tutorial

The Environment Dimension

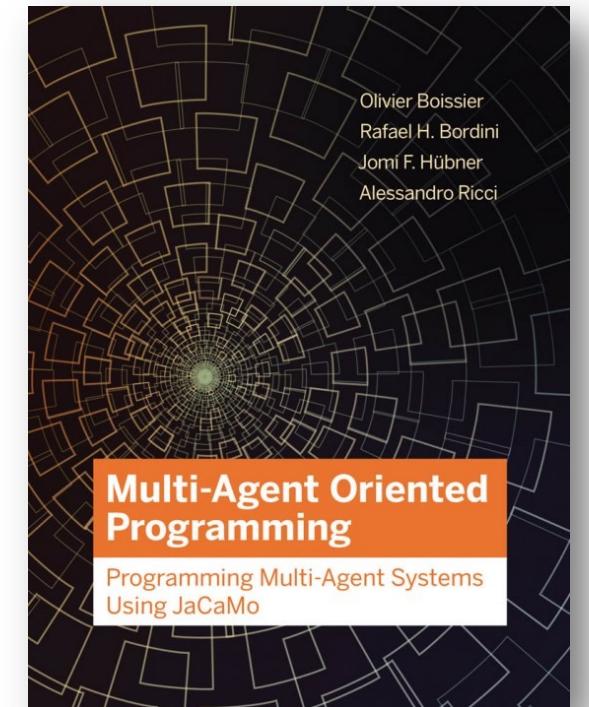
23rd European Agent Systems Summer School (EASSS 2023) — Prague, 18 July 2023

JaCaMo Metamodel – Multi-Agent Concepts

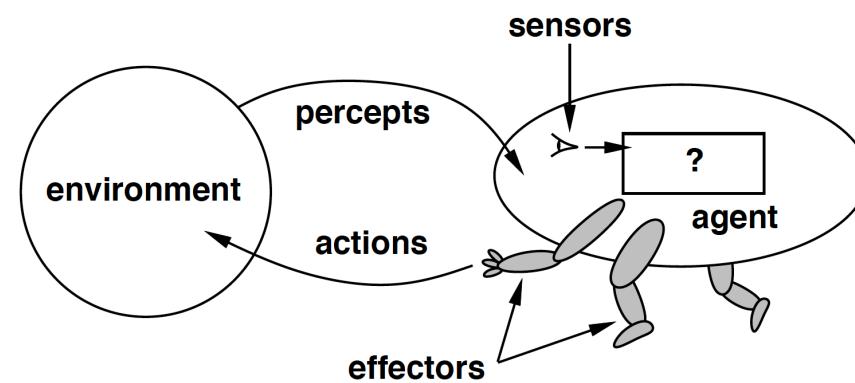


This Session's Agenda

- Environment as a First-Class Abstraction
- The Agents & Artifacts Metamodel
- Hands-on: The Smart Room Scenario (Revisited)

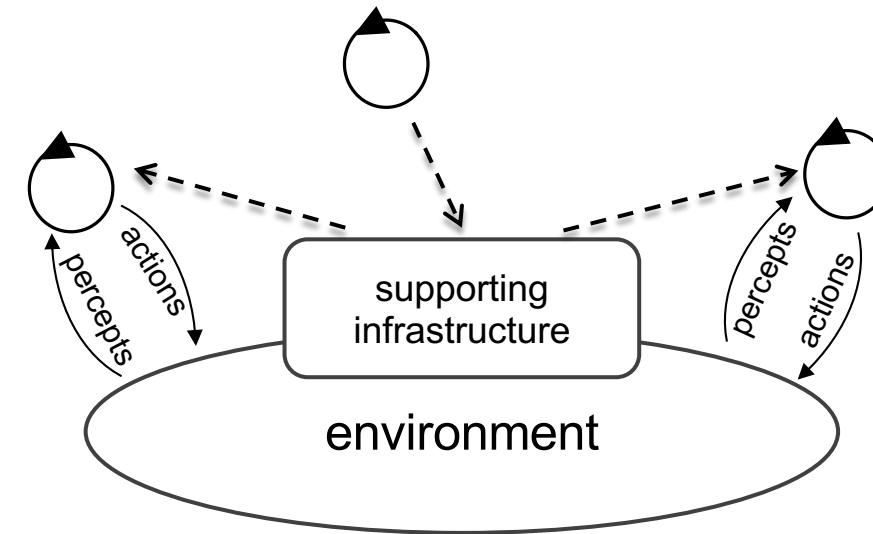


The Environment Dimension



Single-agent system perspective
[Russell & Norvig, 2020]

The Environment as the world
external to the system



Multi-agent system perspective

The Environment becomes
part of the system
(e.g.: communication and interaction infra.)

Stuart Russell and Peter Norvig (2020) Artificial Intelligence: A Modern Approach (Fourth Edition).

D. Weyns, A. Omicini, and J. Odell. Environment as a first class abstraction in multiagent systems. JAAMAS 14, 5–30, 2007.

The Environment as a Design Abstraction

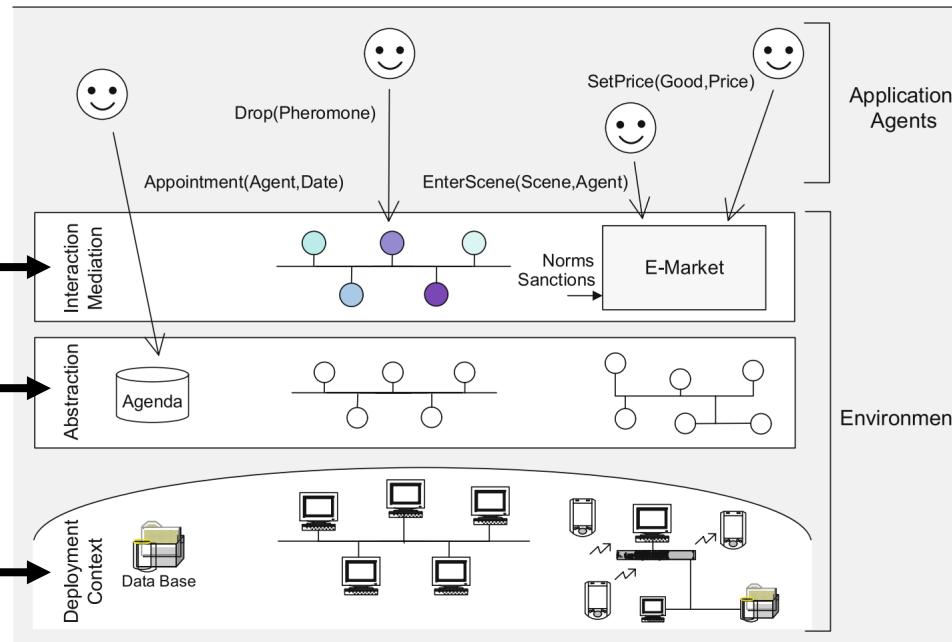
The **environment is a first-class abstraction** that provides the surrounding conditions for agents to exist and that mediates both the interaction among agents and the access to resources [Weyns et al., 2007].

3 levels of support:

Interaction-mediation

Abstraction

Basic



Engineering MAS: environment as a **first-class design abstraction** [Weyns et al., 2007].

Interaction-mediation support: mechanisms to mediate, enact, and regulate interactions

- Example: pheromone infrastructure, e-institutions, rate limiting, etc.

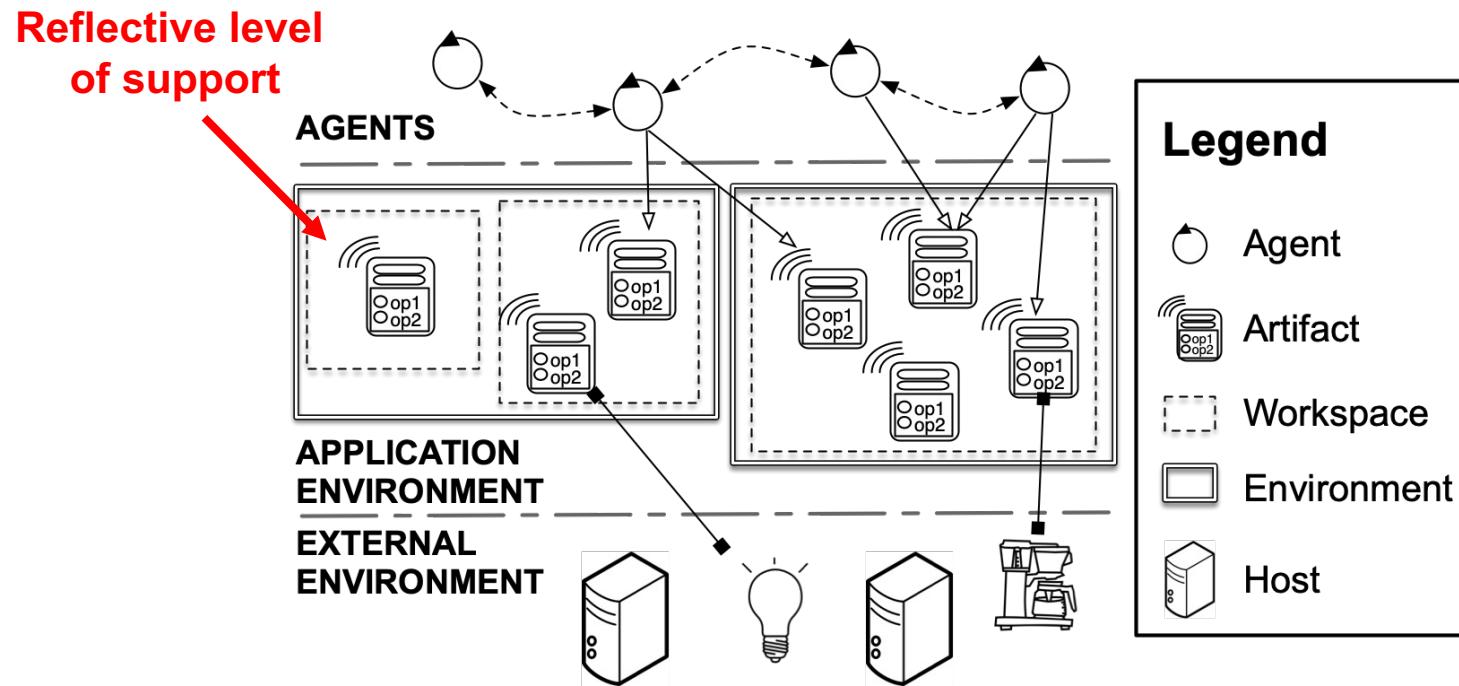
Abstraction support: conceptual bridge between abstractions used to design and program agents and the deployment context

- Example: semantic models, domain-specific abstractions, etc.

Basic interface support: raw access to the deployment context

- Example: Web APIs, device interfaces, etc.

The Environment as a Programming Abstraction



Programming MAS = Programming **Agents**
+ Programming the **Environment**

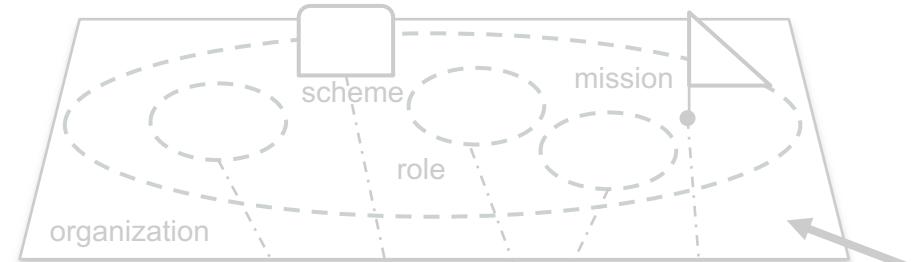
- Agents & Artifacts** [Ricci et al., 2011]:
- separation of concerns between **autonomous** vs. **non-autonomous** behavior
 - agents can **modify** the functional behavior of the environment to meet their needs

Engineering MAS: environment as a **first-class** programming abstraction [Ricci et al., 2011].

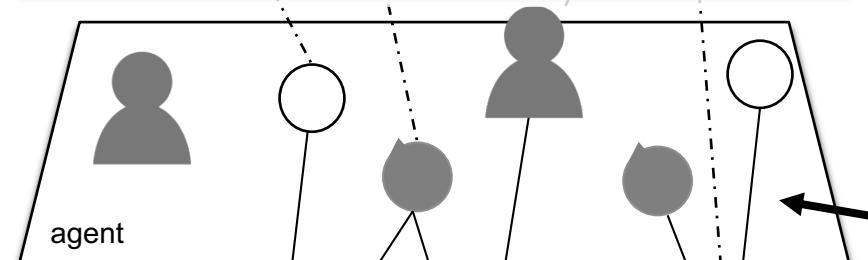
Example: Flexible Industrial Manufacturing

SIEMENS

Organizations



Agents



collectives of people and artificial agents working towards shared goals

autonomous behavior

non-autonomous behavior

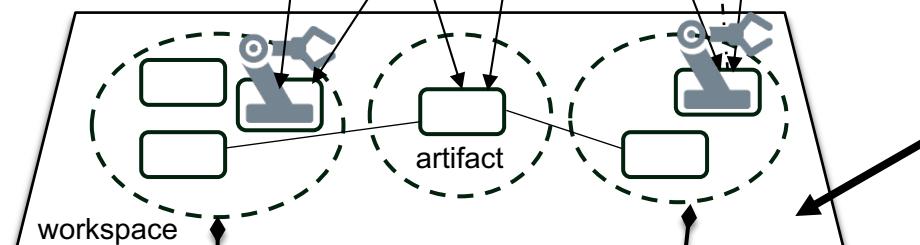
Modularity and Encapsulation

Uniformly **encapsulate** and **modularize** functionalities of the MAS outside of the agents

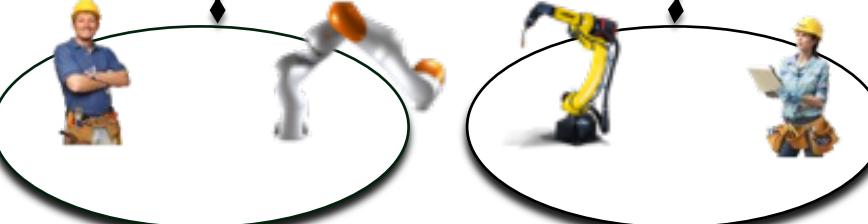
⇒ **reusability** of components

⇒ system **evolvability**: components can be developed, deployed, and can evolve independently

Application Environment



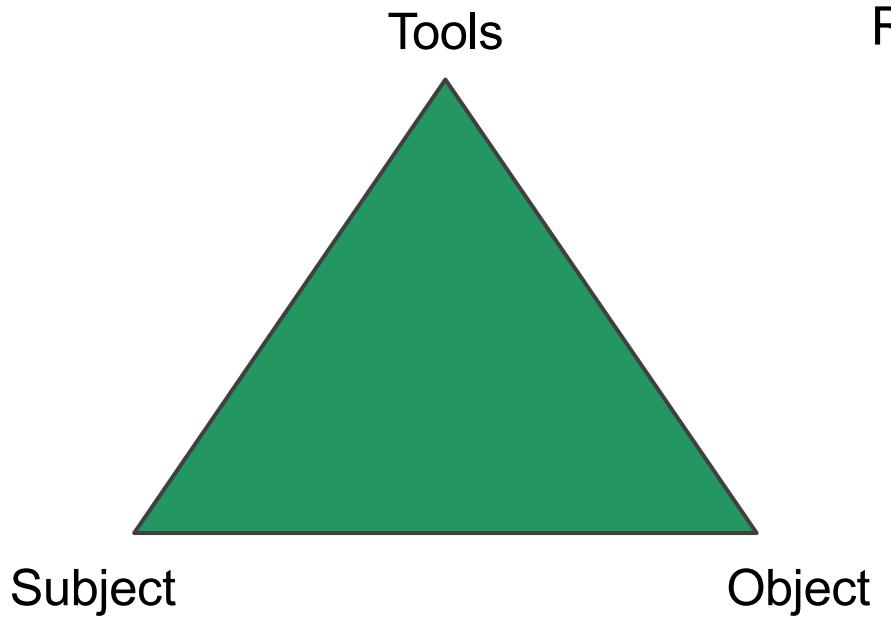
External Environment



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Activity Theory



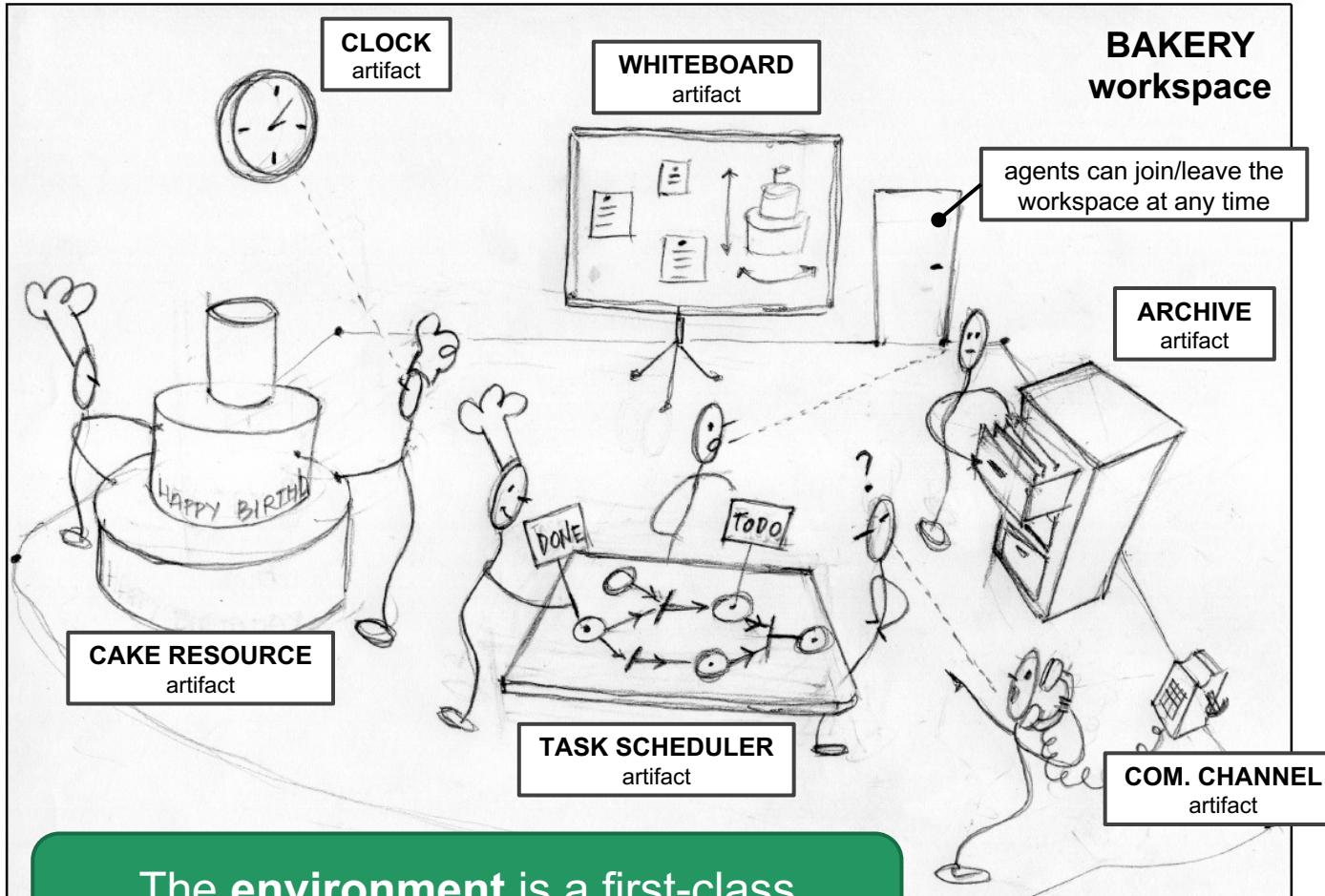
Roots in cultural-historical psychology (1920s and 1930s)



Activity (basic unit of analysis) is a **goal-directed interaction** with the world

The activity is mediated through **tools** (or **artifacts**), which evolve over time based on the experience of subjects

The Agents & Artifacts Metamodel



Key idea: **separation of concerns**

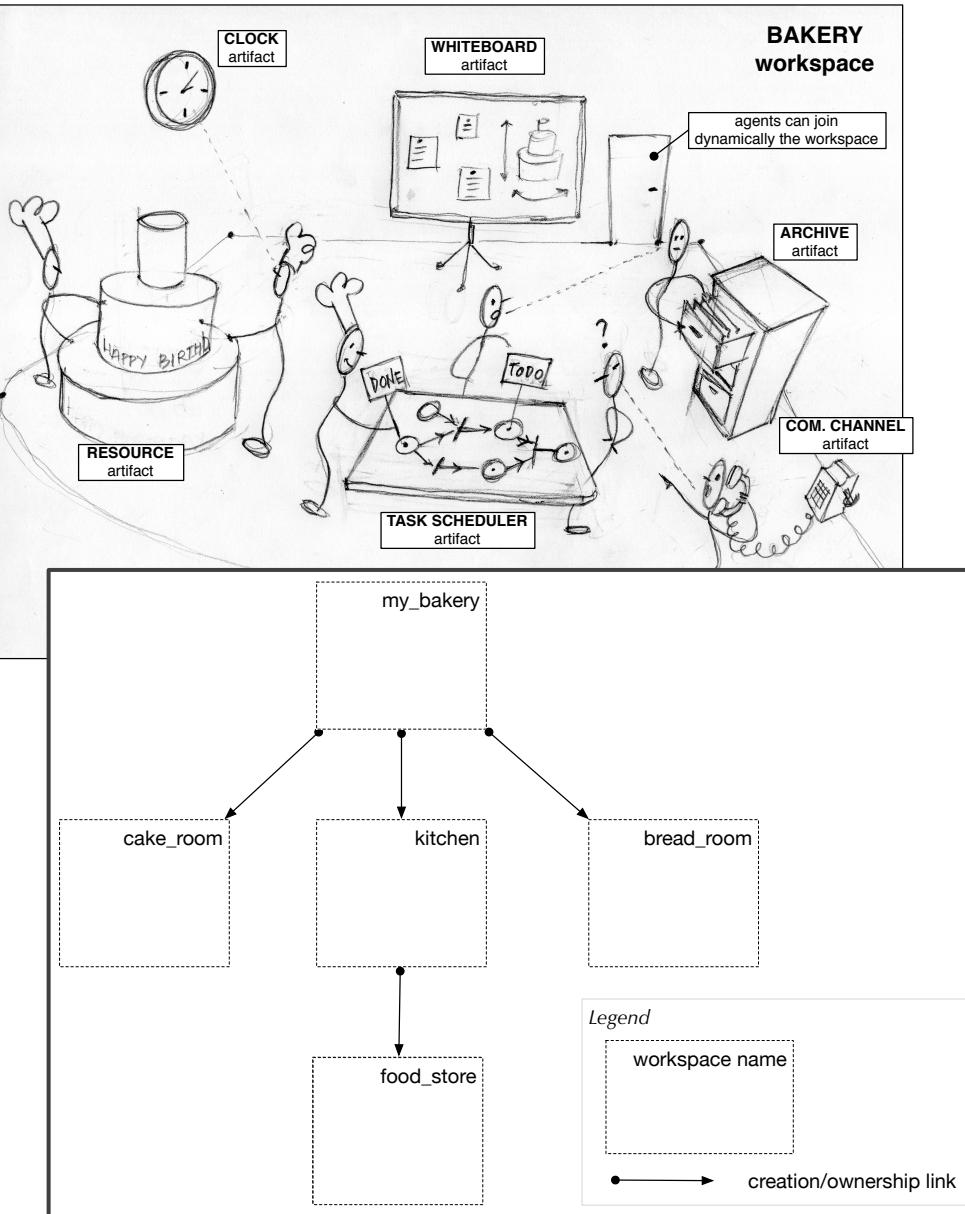
- agents encapsulate **autonomous** behavior
- artifacts encapsulate **non-autonomous** behavior

Programming MAS = Programming **Agents**
+ Programming the **Environment**

The agents' environment is modelled as a **dynamic** set of **artifacts** grouped into **workspaces**

- the **actions** provided to agents are determined by the artifacts **discovered at run time**
- agents **construct, share, and use** artifacts to support their working activities
 - ⇒ artifacts are **mediating tools** for goal-directed agents
 - ⇒ agents can **modify** the **functional behavior** of the environment to meet their needs

The Workspace Abstraction



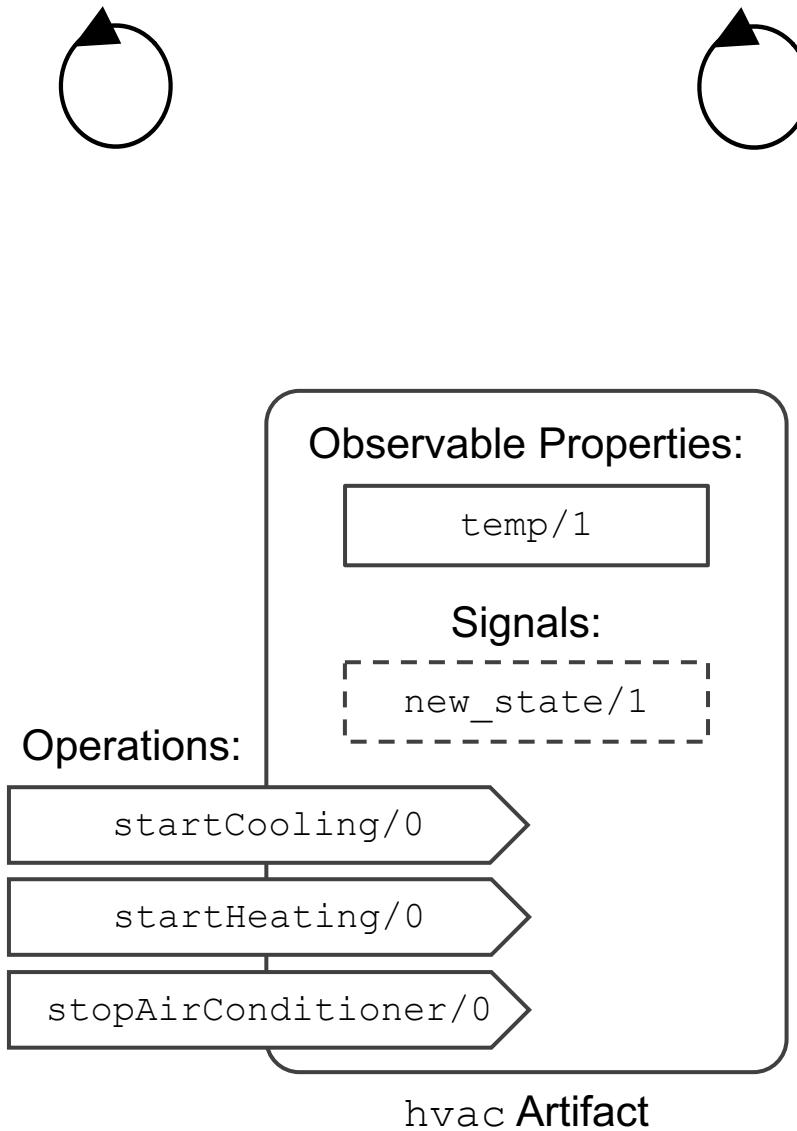
A **logical place** containing artifacts and the working context of the agents' activities

- provides a notion of **locality** and **situatedness**
- allow to **structure** complex/distributed environments

Agents can **join**, **leave**, and **work** in multiple workspaces at the same time

- agents are **embodied** and interact within the workspace through **body artifacts**
 - ⇒ separation of concerns between the **agent's mind** and the **agent's body**
 - ⇒ allows **heterogeneous agents** (implementing different architectures) to *join* and *work in* the same environment

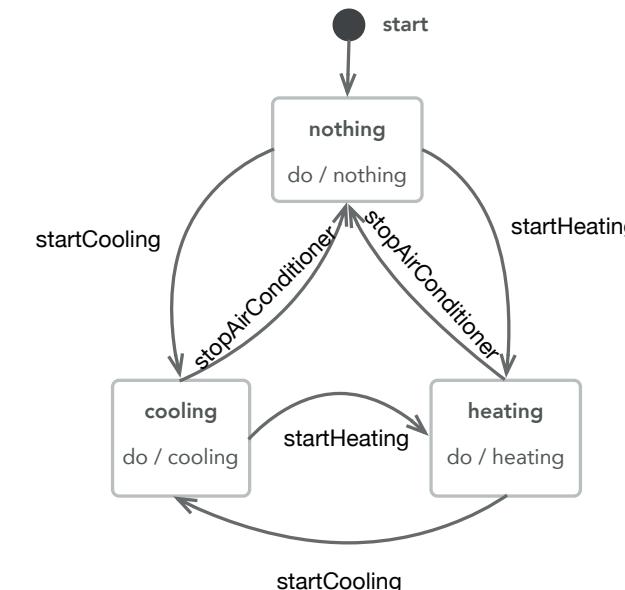
Workspaces can be distributed over a network

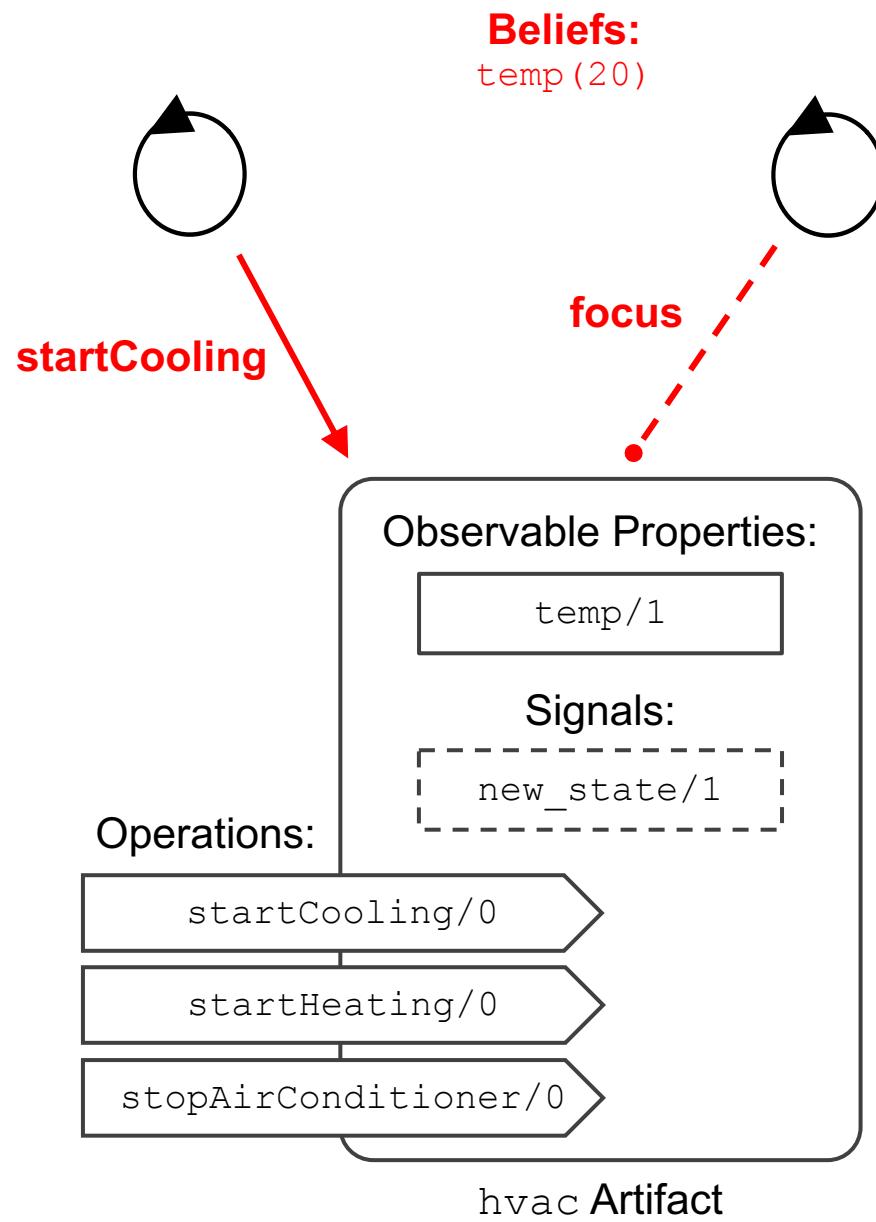


The Artifact Abstraction

Artifacts as computational objects

- *usage interface*:
- **observable properties**: state variables that can be perceived by agents
- **observable events**: non-persistent signals that carry information and can be perceived by agents
- **operations**: environmental actions provided to the agent
 - operations can update the values of observable properties or can generate signals





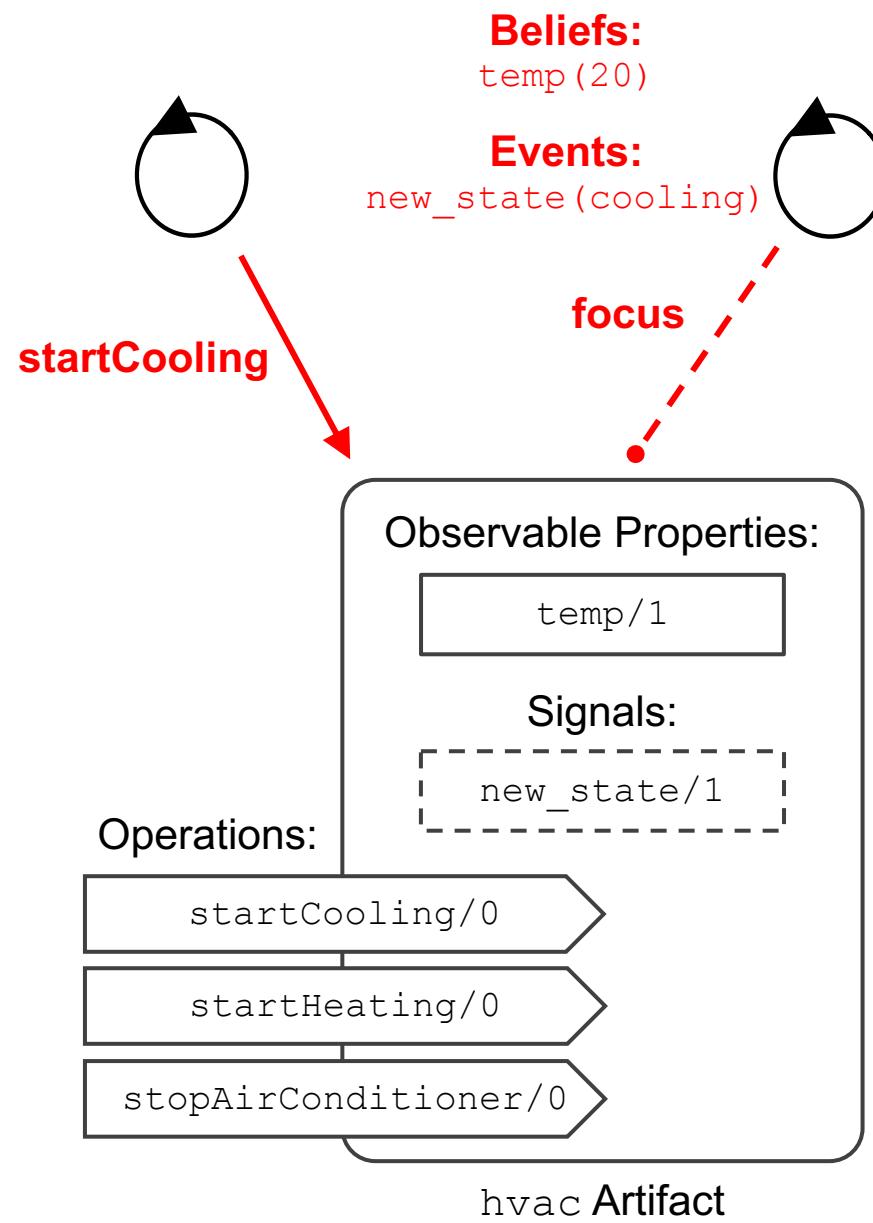
The Artifact Abstraction

Artifacts as computational objects

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Agents can **focus** on artifacts to **perceive** observable properties and signals



The Artifact Abstraction

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The Artifact Abstraction

Artifacts as computational objects

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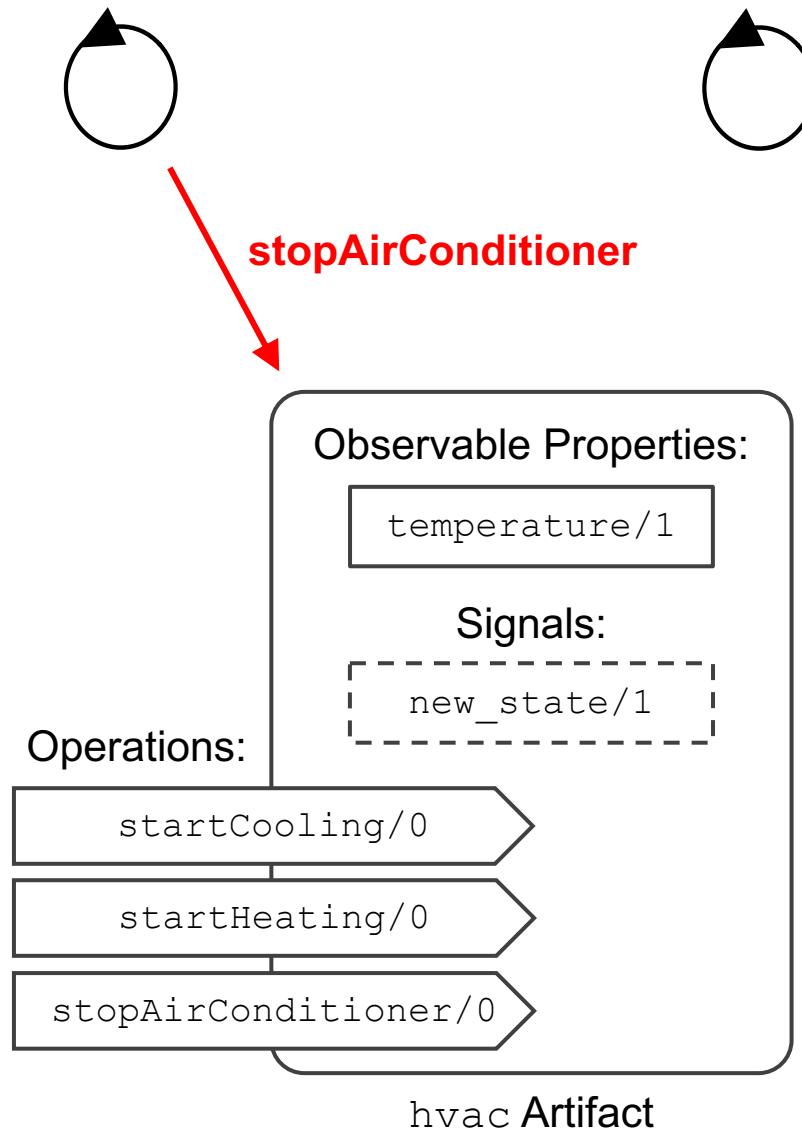
- **observable properties**: state variables that can be perceived by agents
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Why is **intentional focus** useful?

Allows agents to **select** the parts of the environment that are relevant to their goals

- promotes **scalability**
 - agents can cope with larger environments
 - the environment infrastructure can serve more agents
- promotes **autonomy** from the environment

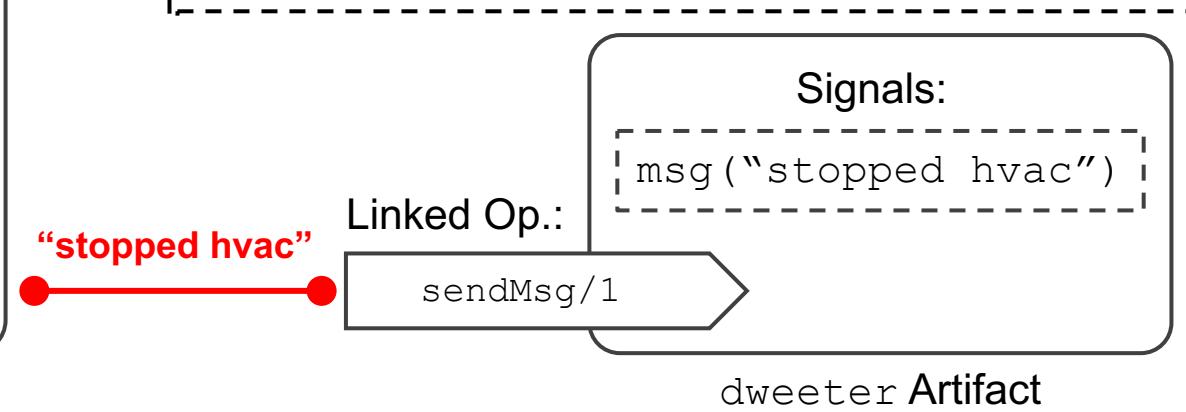
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The Artifact Abstraction

Artifacts as computational objects

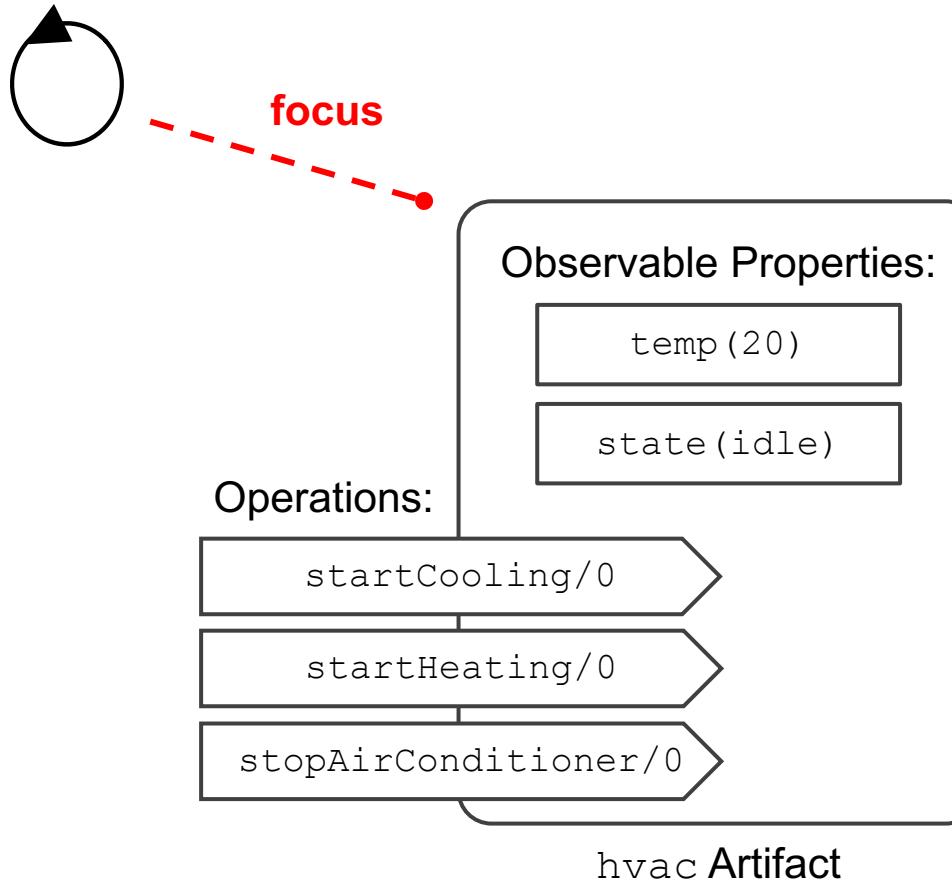
- *usage interface*:
 - **observable properties**: state variables that can be perceived by agents
 - **observable events**: non-persistent signals that carry information and can be perceived by agents
 - **operations**: environmental actions provided to the agent
 - operations can update the values of observable properties or can generate signals
- *link interface*:
 - used to connect artifacts



Proactive vs. Reactive Behavior with Artifacts

Beliefs:

```
target_temp(22)  
temp(20)  
state(idle)
```



Proactive plans: pursue (achievement) goals

Reactive plans: react to environmental changes

Proactive Plans

```
+!temp(Target) : temp(Current)  
& Target > Current  
<- startHeating.  
  
+!temp(Target) : temp(Current)  
& Target < Current  
<- startCooling.  
  
+!temp(Target)  
<- stop.
```

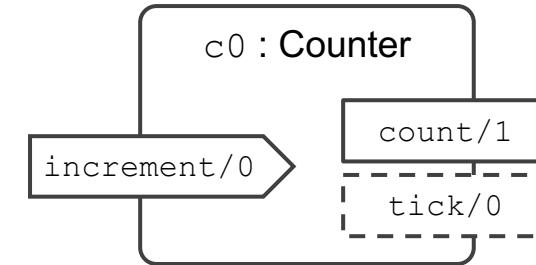
Reactive Plans

```
// maintenance task  
+temp(Current)  
: target_temp(Target)  
& Target \== Current  
<- !temp(Target).
```

A Basic Taxonomy of Artifacts

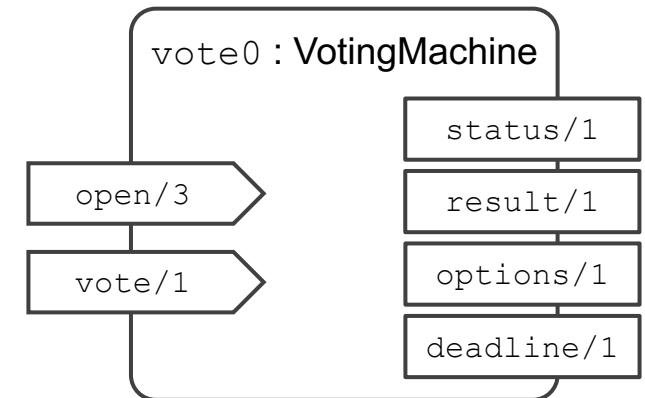
Resource Artifacts

- some specific kind of resource that can be shared by agents



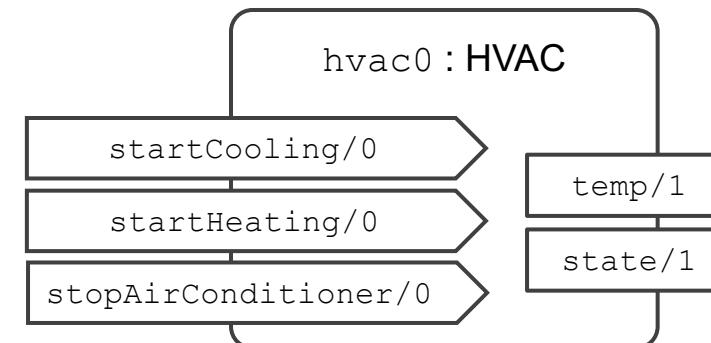
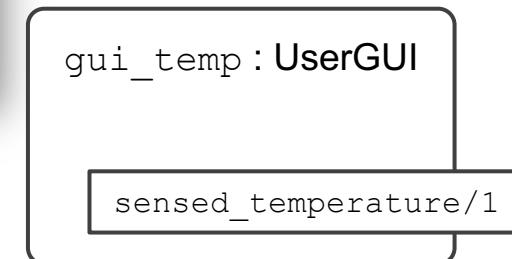
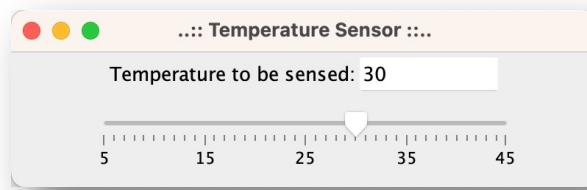
Coordination Artifacts

- artifacts specifically designed to provide coordination functionalities by enabling and managing in some way the interaction among agents



Boundary Artifacts

- artifacts that allow agents to interact with human users and, more generally, any actor or system that is external with respect to the MAS



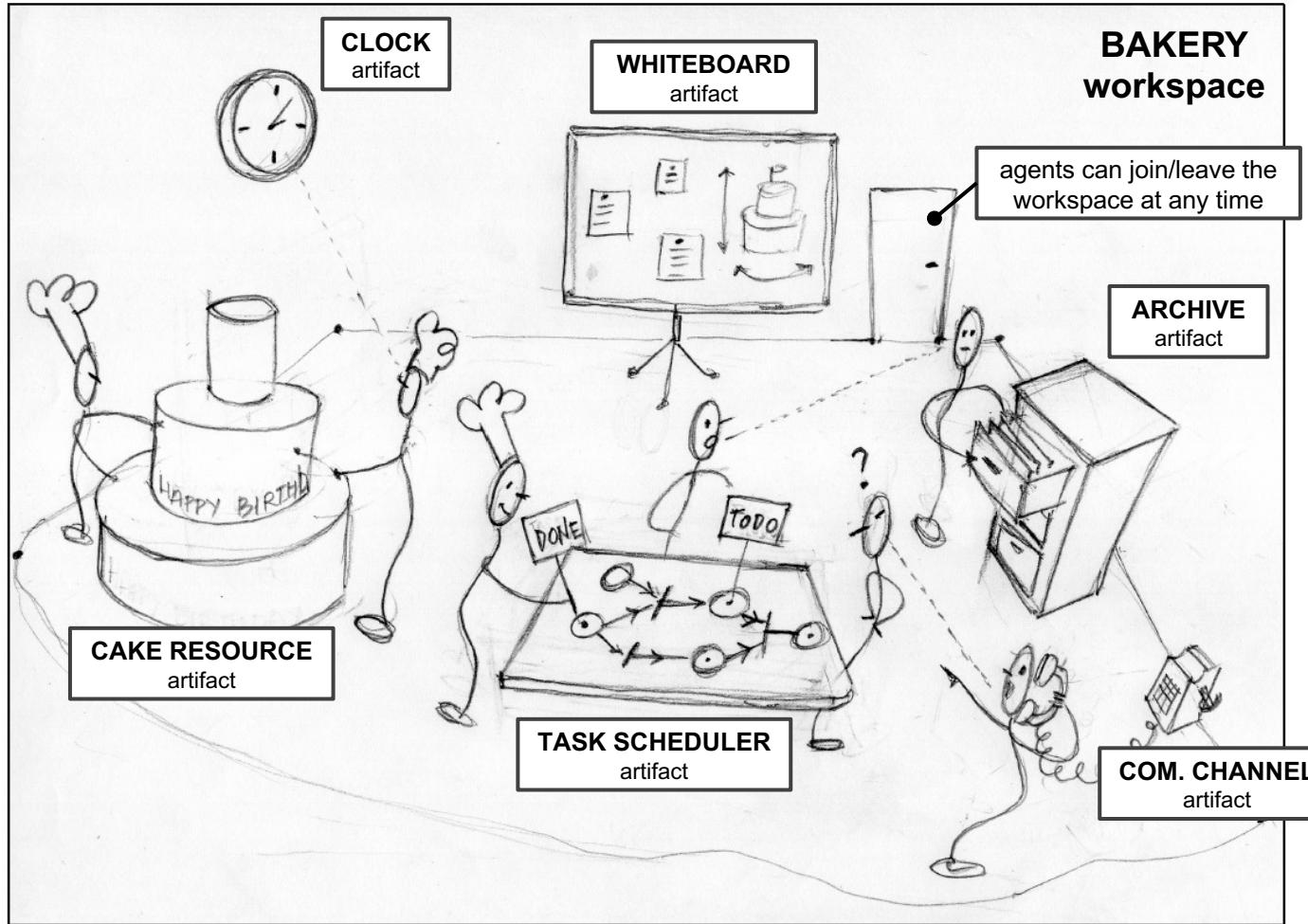
Artifacts vs. Objects

Both artifacts and objects model **nonautonomous entities** and provide a **usage interface**

But there are important differences:

- **transfer of control:**
 - in object-object interaction, a method call **implies a transfer of control** between the caller object and the callee object
 - in agent-artifact interaction, **control is encapsulated inside agents** and cannot be transferred
 - the execution of a triggered operation is carried out by another logical flow provided by the environment
 - on the agent side, the plan in execution is suspended until the action is either completed or failed (the agent can continue to pursue other intentions)
- **observable state:**
 - artifacts **have observable state** captured by observable properties
 - unlike public object instance fields, observable properties cannot be written directly (they can be updated by operations)
- **concurrency:** artifacts are **thread-safe by design**, which makes it easy to share them among agents

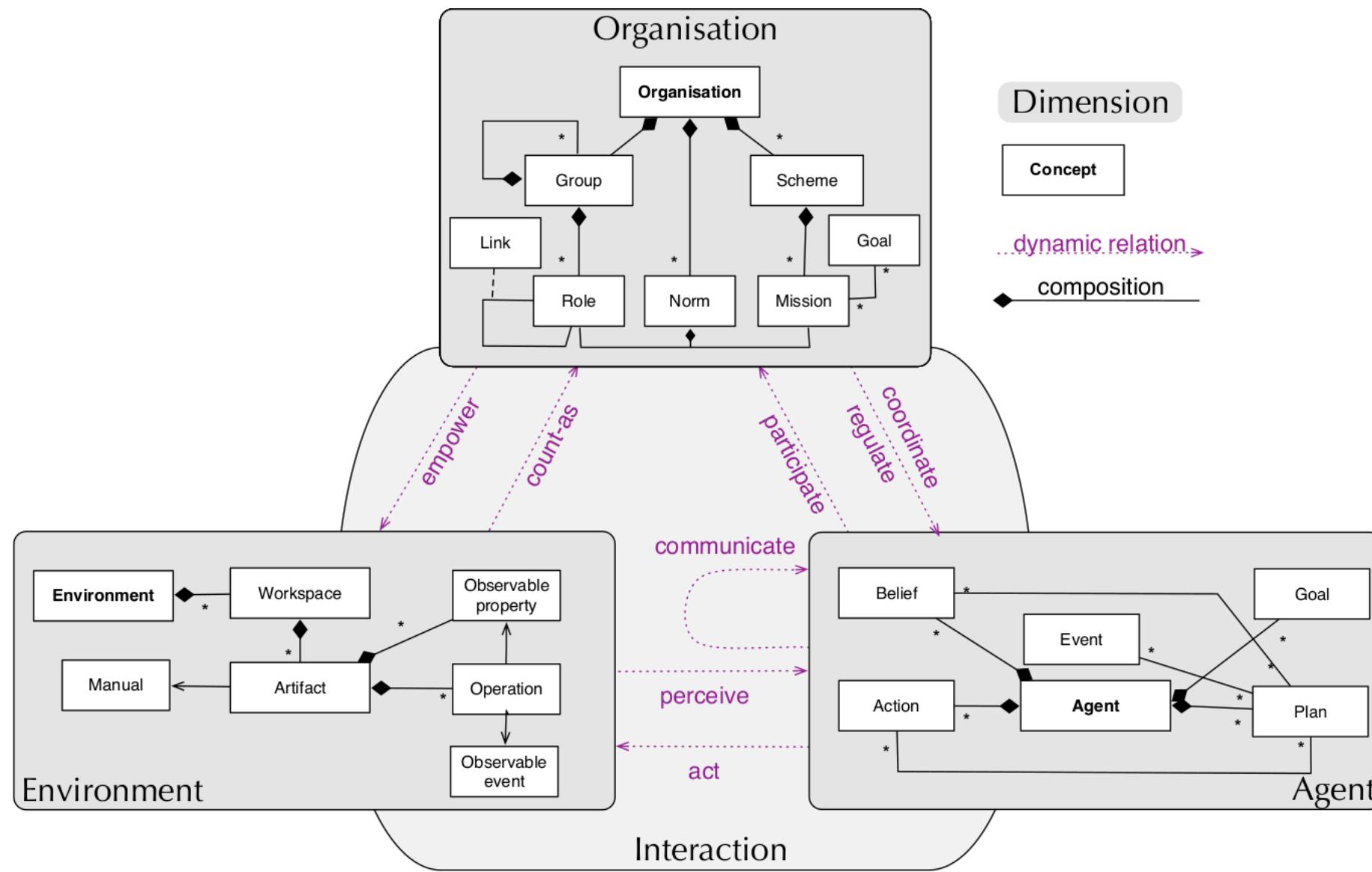
The Agents & Artifacts Metamodel



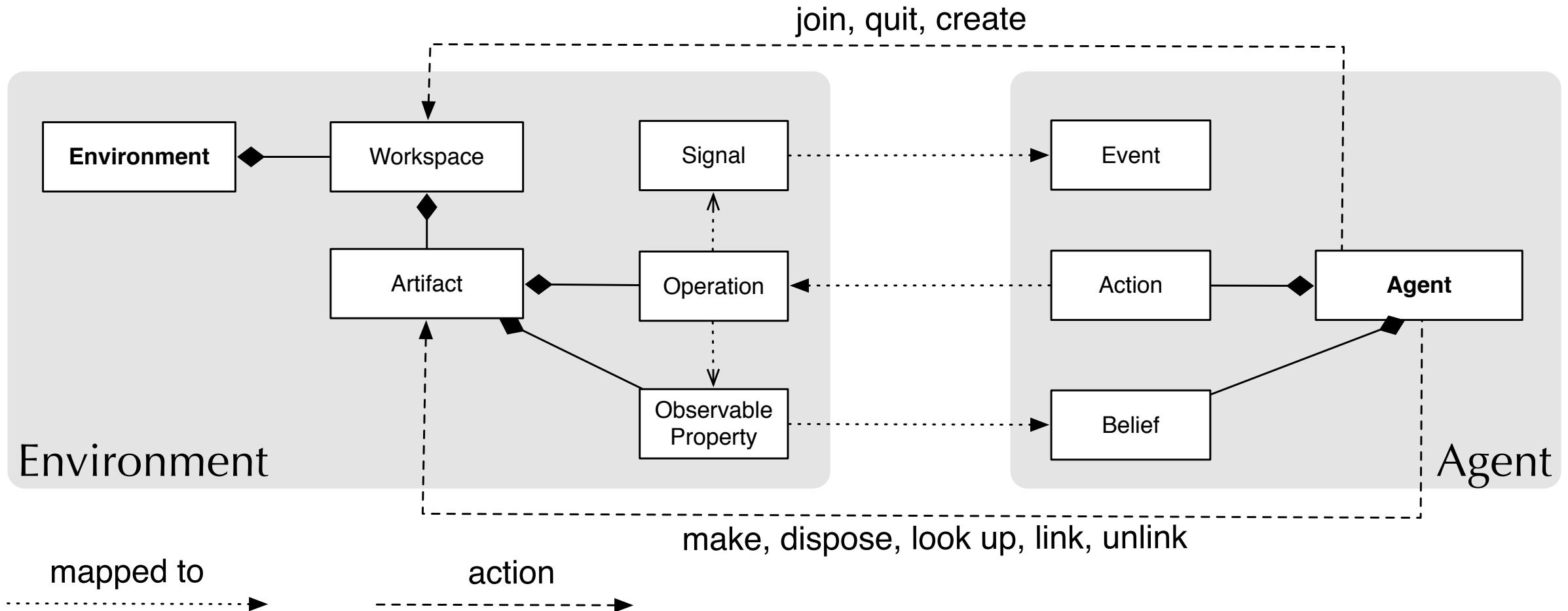
The **environment** is a first-class design and programming abstraction

Programming MAS = Programming **Agents**
+ Programming the **Environment**

JaCaMo Metamodel – Multi-Agent Concepts



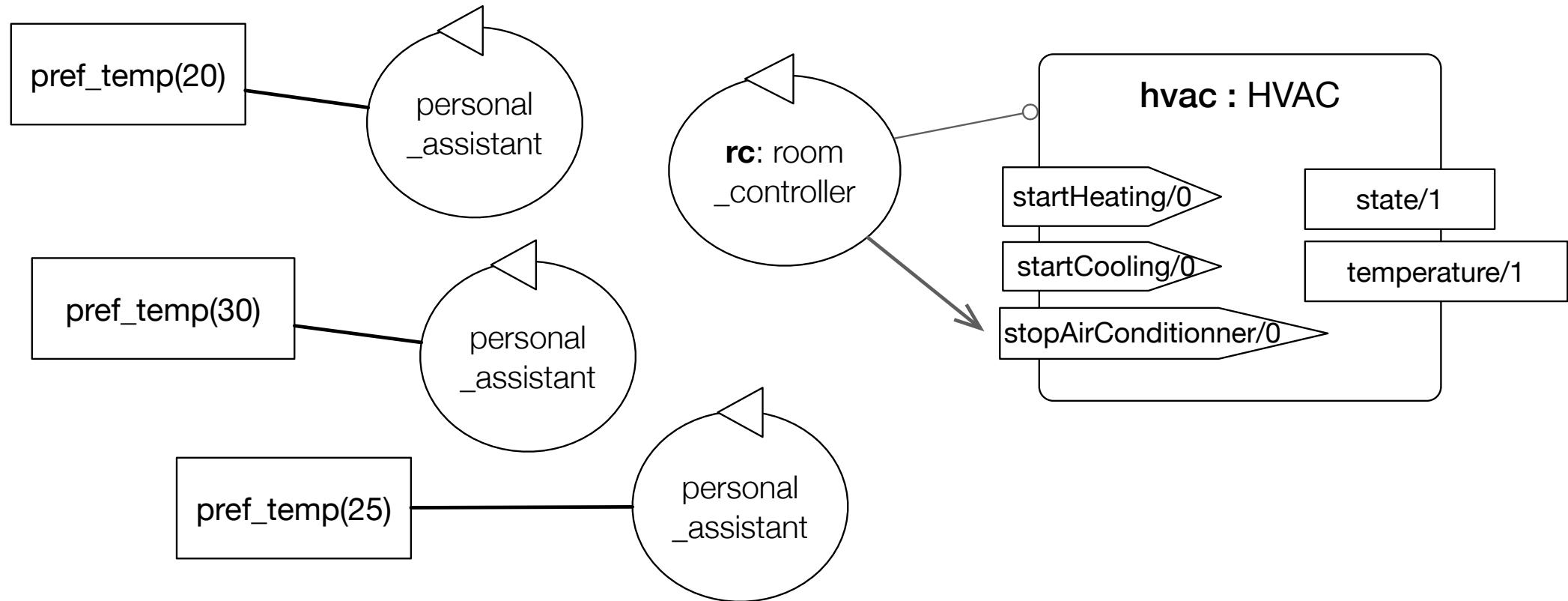
The Environment & Agent Dimensions



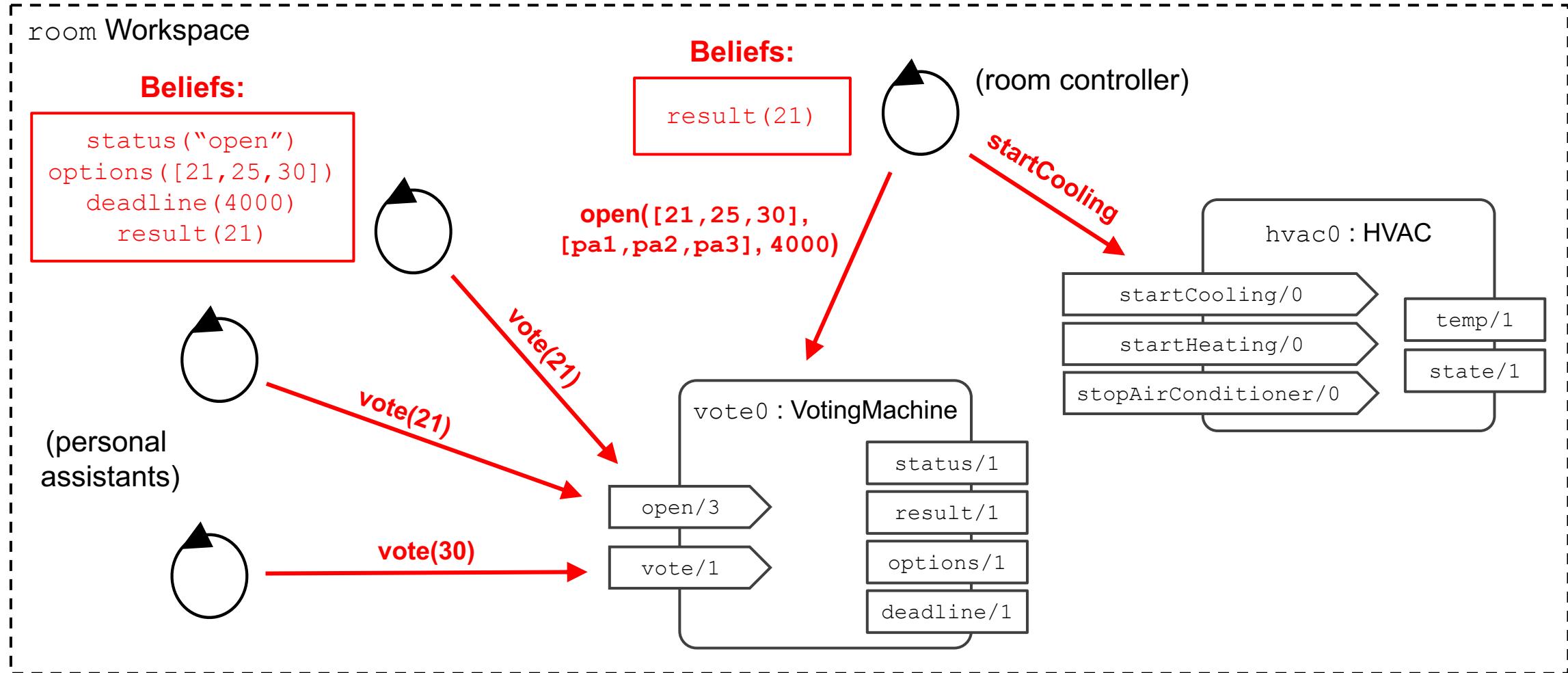
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Last Session: The Smart Room Scenario (Interaction Protocols)



This Session: The Smart Room Scenario (Voting Machines)



Any Questions / Comments / Doubts / Concerns?



Images

<https://freepik.com>