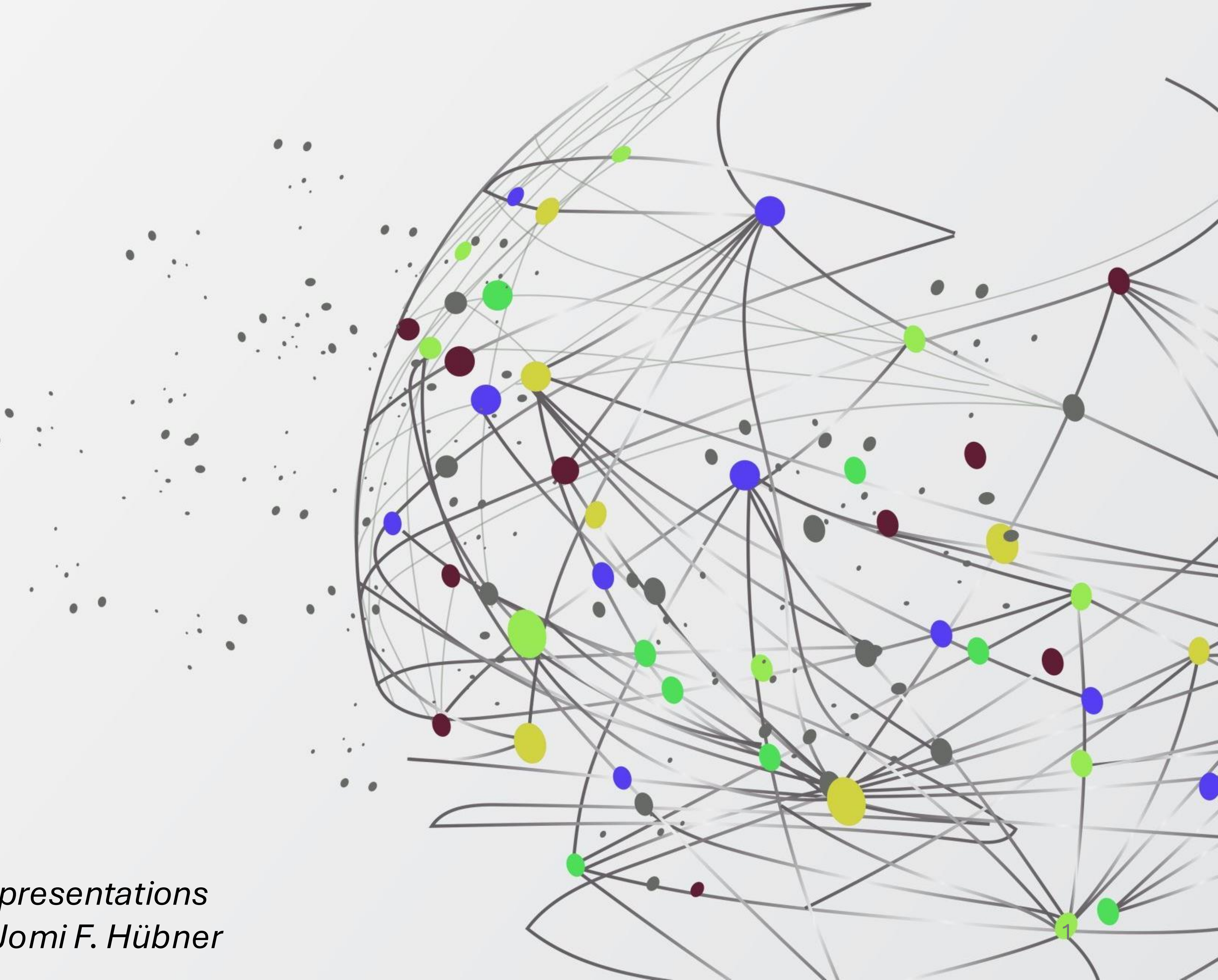
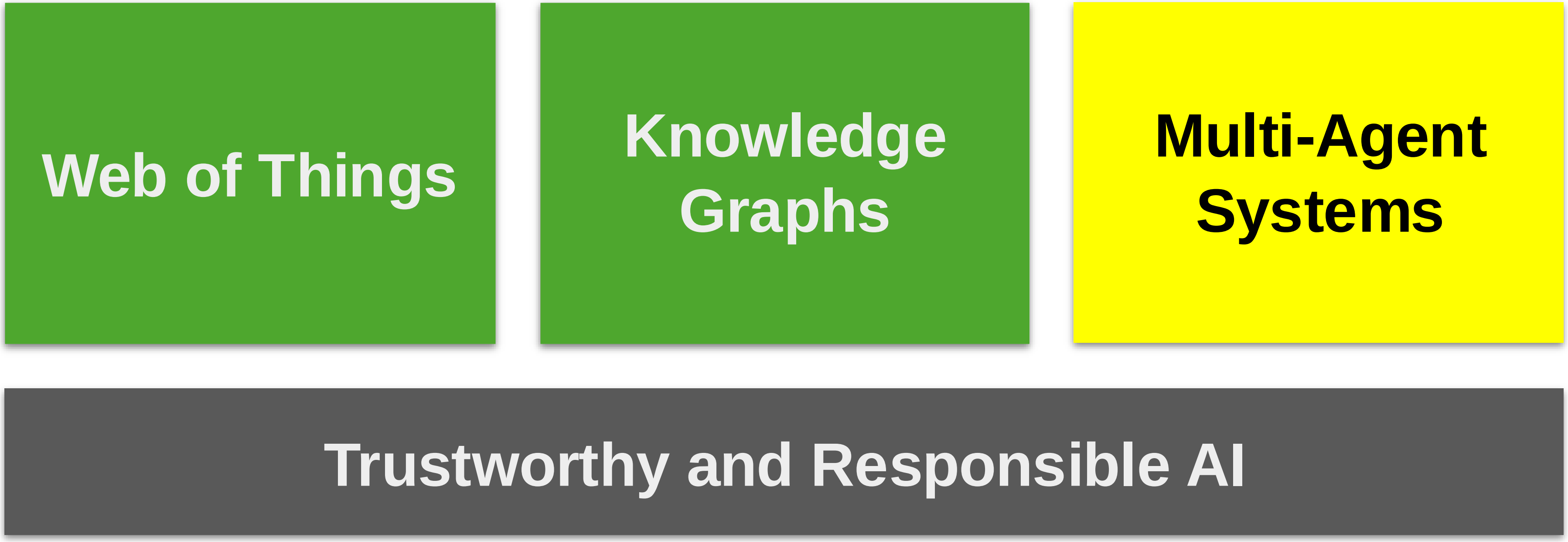
Multi-Agent Oriented Programming



***Credits**: Slides based on previous presentations by Olivier Boissier, Andrei Ciortea, Jomi F. Hübner*

AI4Industry Summer School



Web of Things

Knowledge Graphs

Multi-Agent Systems

Trustworthy and Responsible AI

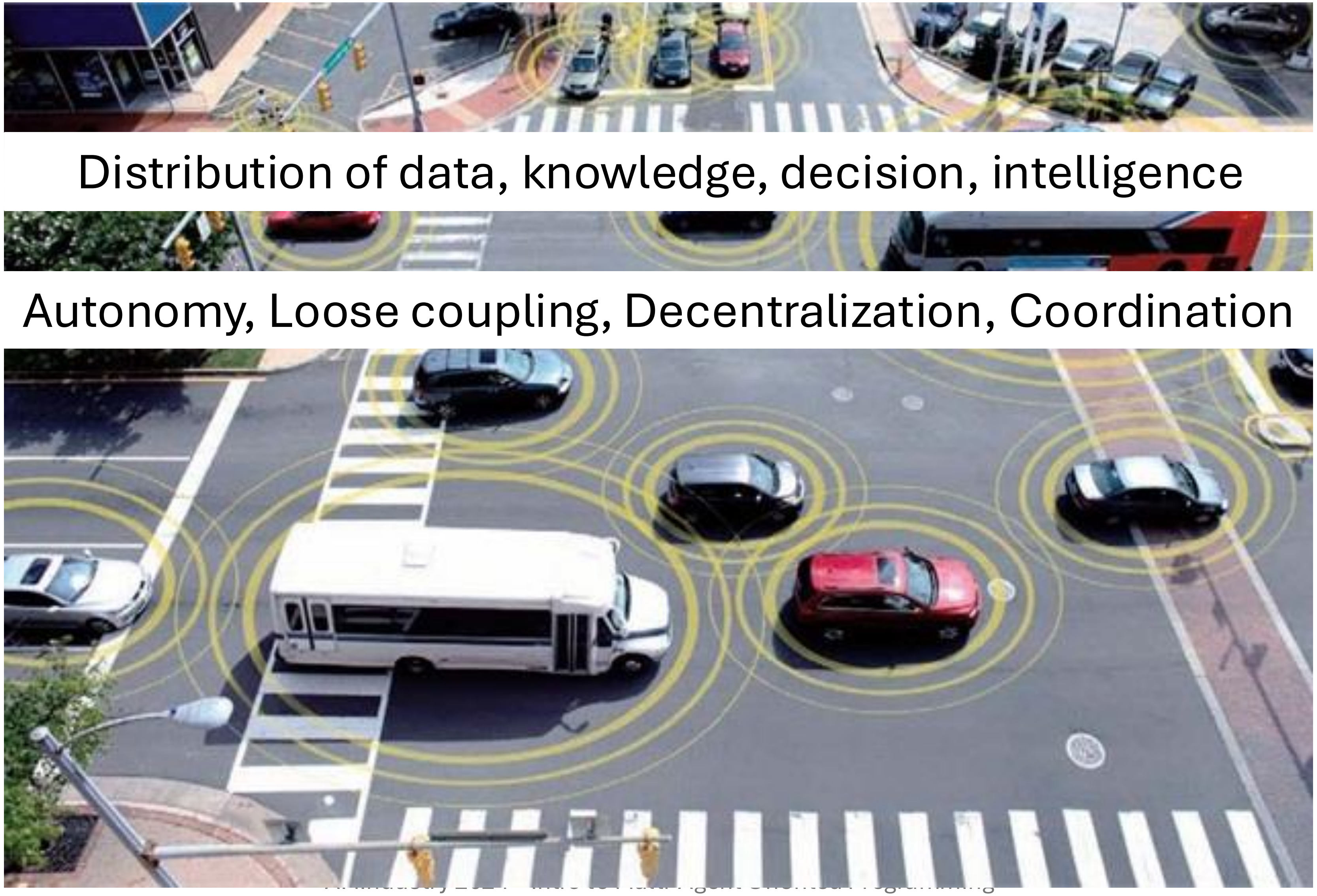
Motivation

- *Complex system* are systems composed of **many components** which may **interact with each other** and present **non-trivial relationships** between cause and effect
  - each effect > multiple causes
  - each cause > multiple effects
  - feedback loops
  - non-linear cause-effect chains
- **Complex cyber-physical social systems**
  - Smart cities
  - Smart grids
  - Manufacturing
  - Mobility systems

Motivation

Distribution of data, knowledge, decision, intelligence

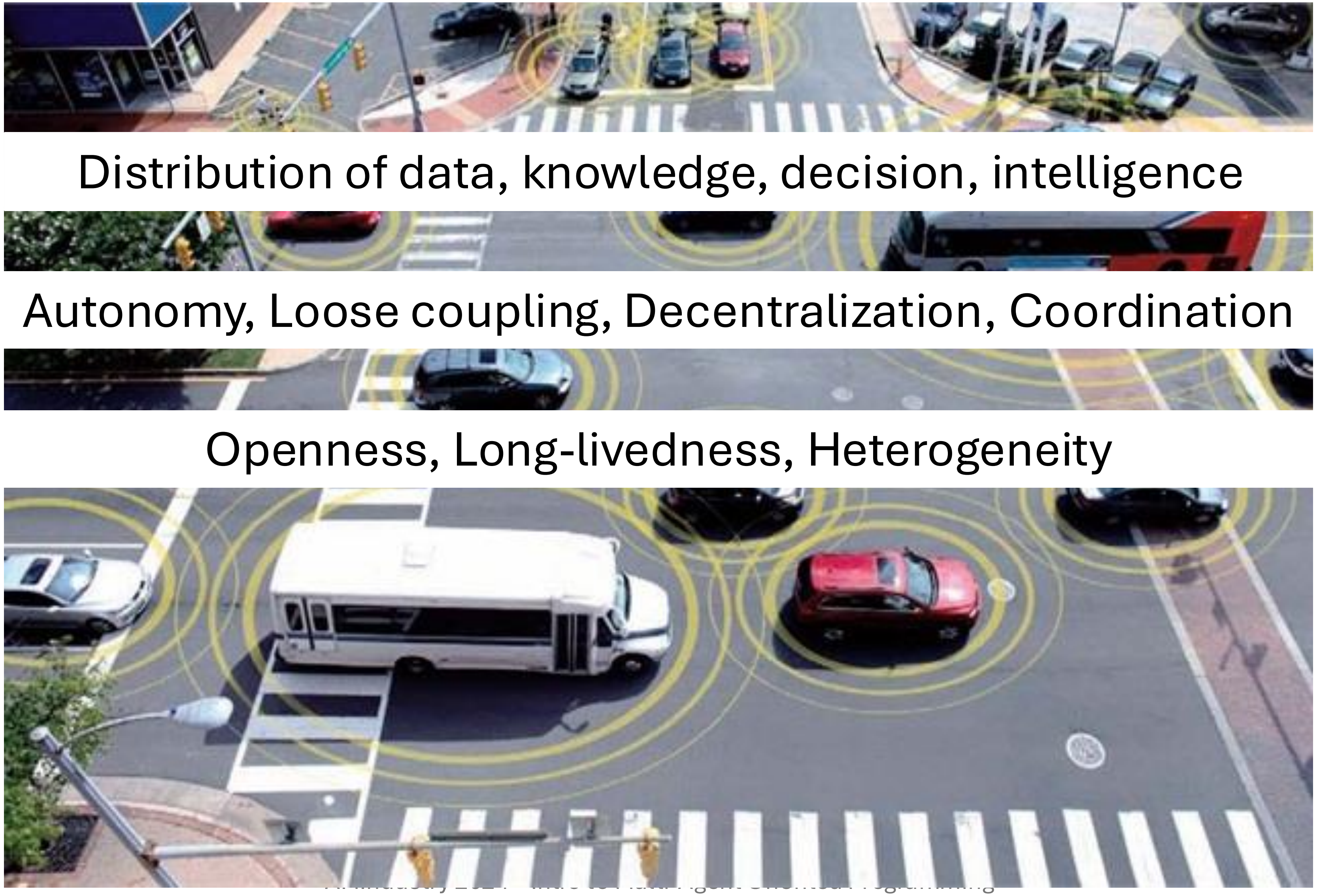
Motivation



Distribution of data, knowledge, decision, intelligence

Autonomy, Loose coupling, Decentralization, Coordination

Motivation



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Autonomy, Loose coupling, Decentralization, Coordination

Openness, Long-livedness, Heterogeneity

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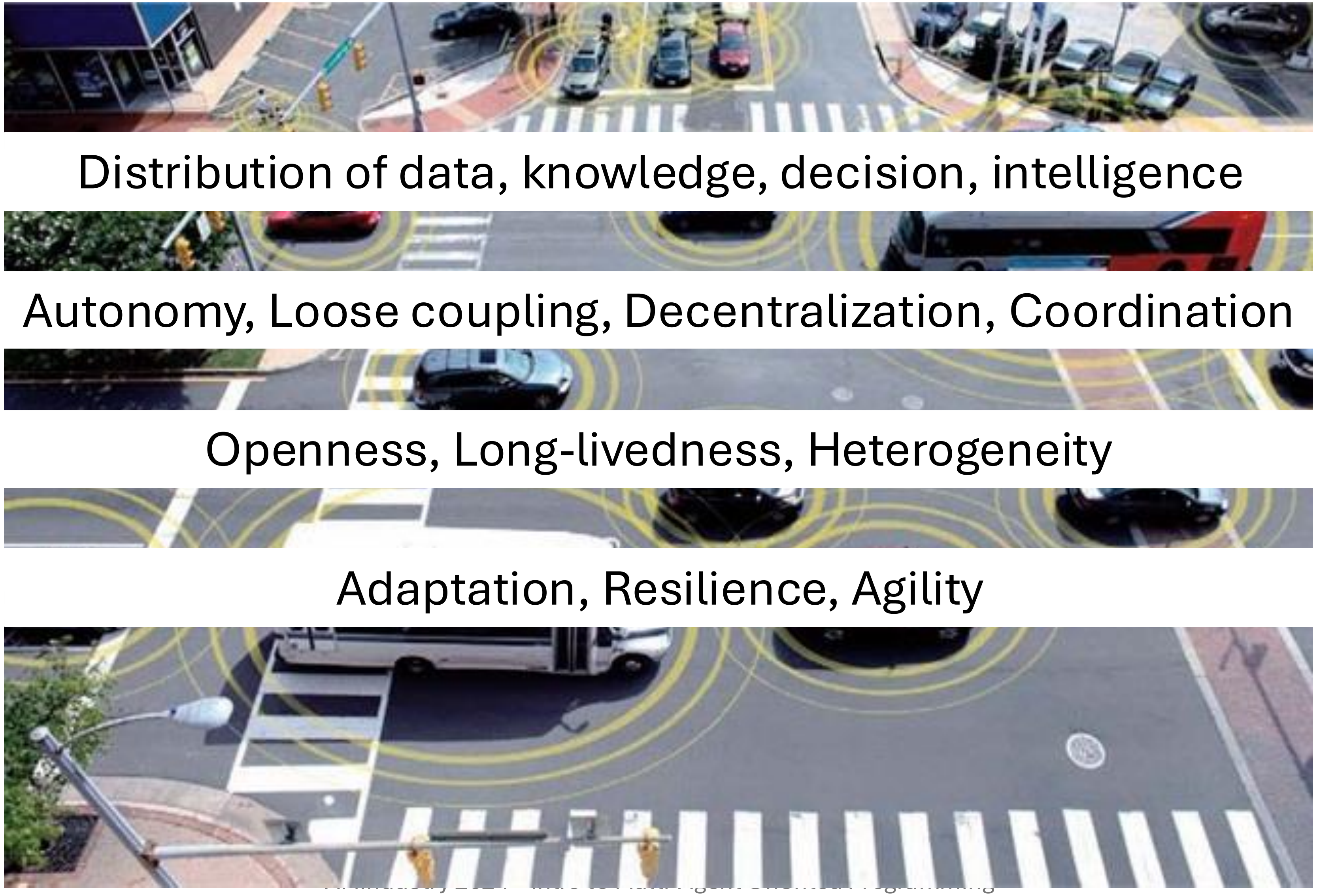

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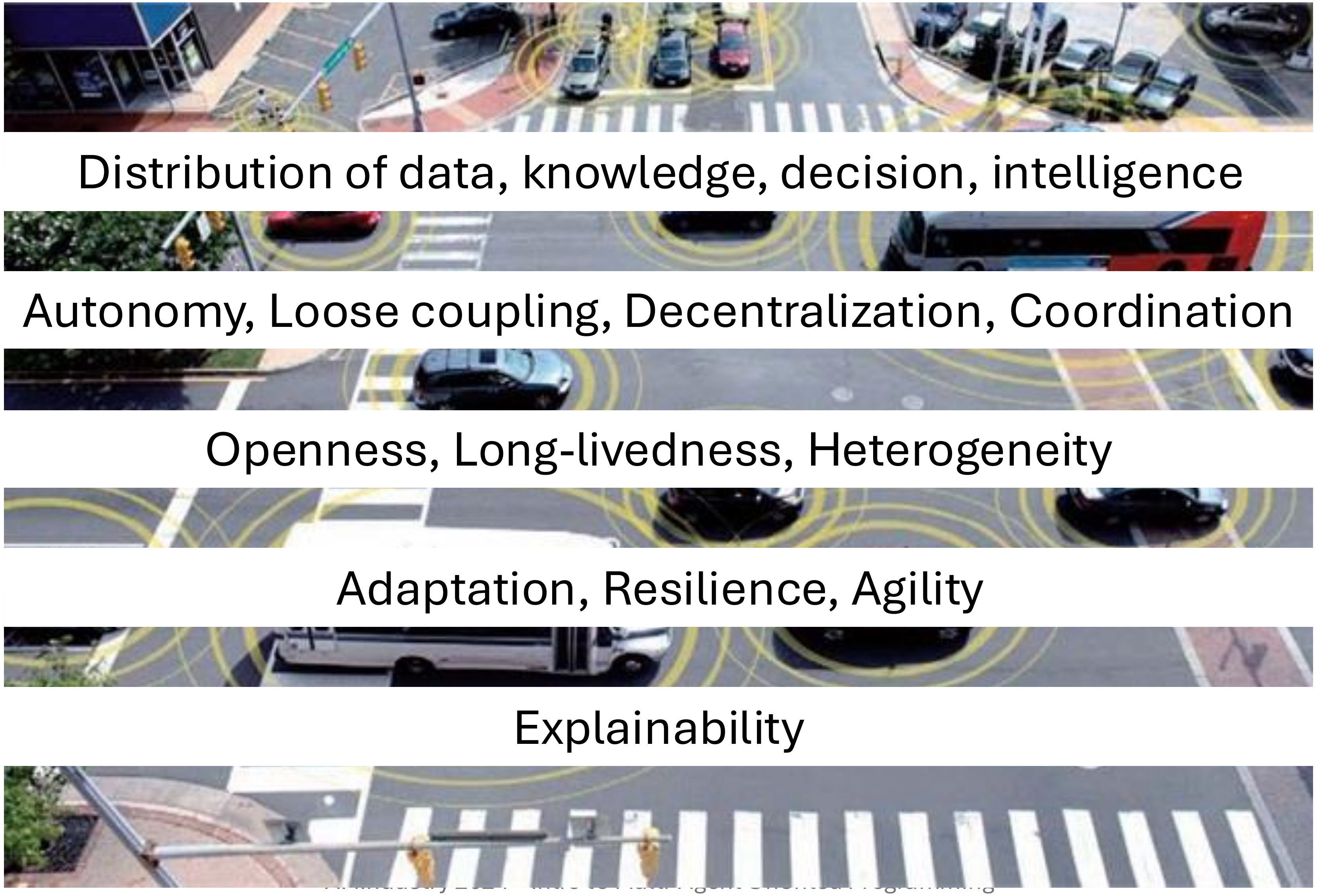

Distribution of data, knowledge, decision, intelligence

Autonomy, Loose coupling, Decentralization, Coordination

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Explainability

How can we model these complex systems?

Multi-Agent System

A set of autonomous agents interacting with each other within a shared environment, eventually under one to multiple organizations

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Multi-Agent System

A Multi-Agent System **is more than** a simple set of agents

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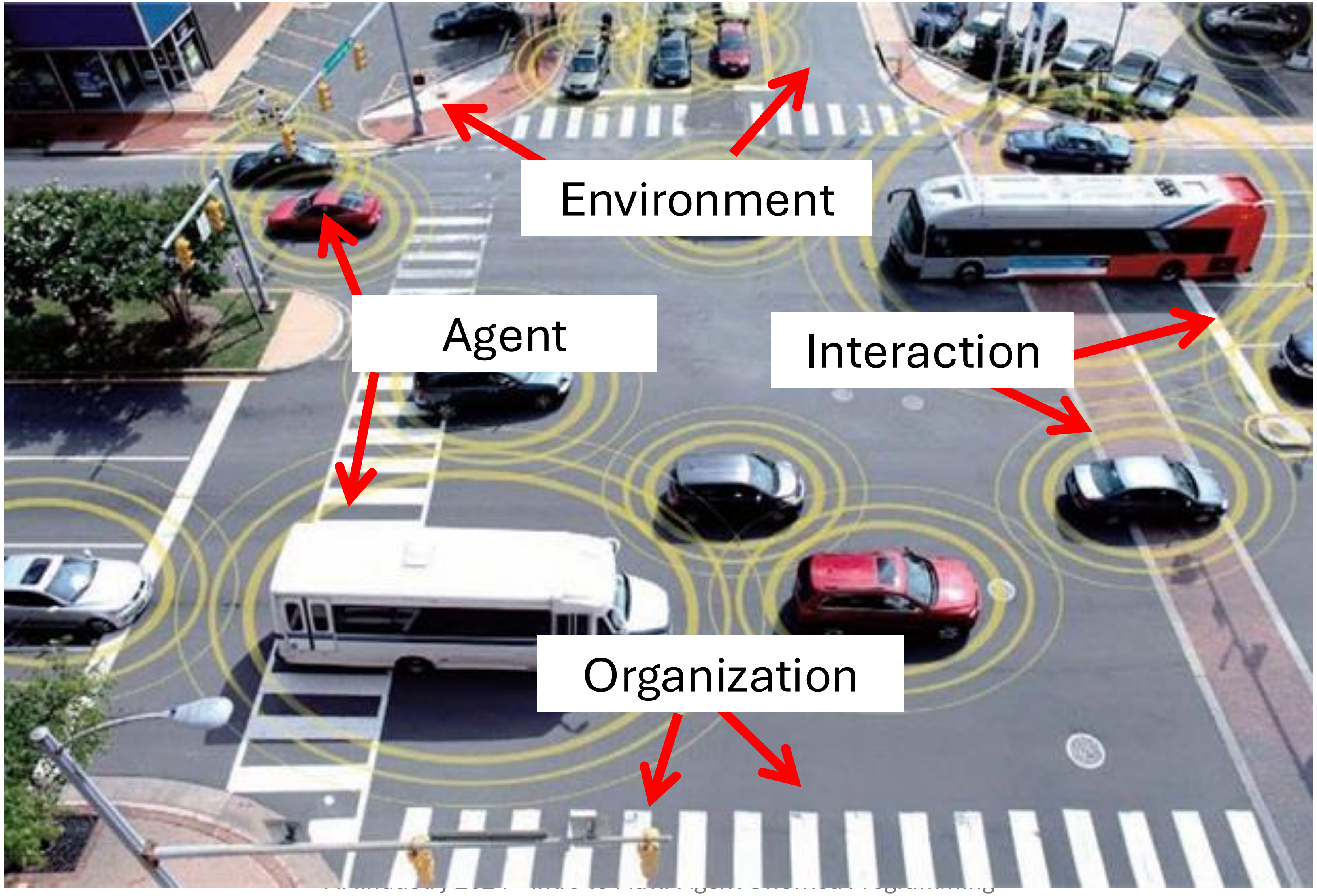


Multi-Agent System

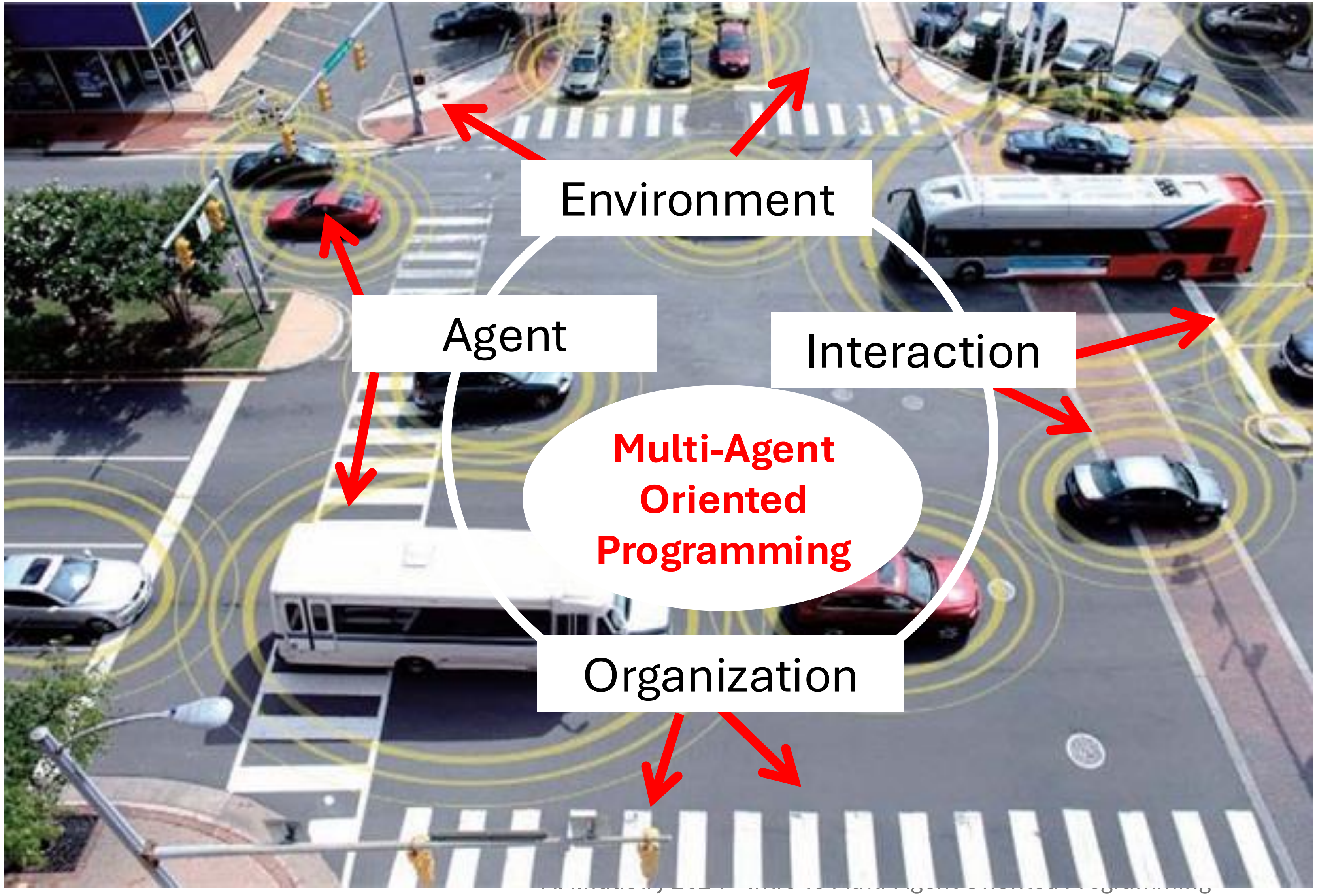
Multi-Agent-Based Simulation models used to describe and simulate complex systems, either natural or artificial, to analyze their properties

- Local representations of different points of view, decisions, goals, motivations, behaviors, etc.
- Interaction between local strategies, behaviors and global and common strategies of control
- Continuous operation and evolution
- Solution is the result of interaction between local processes

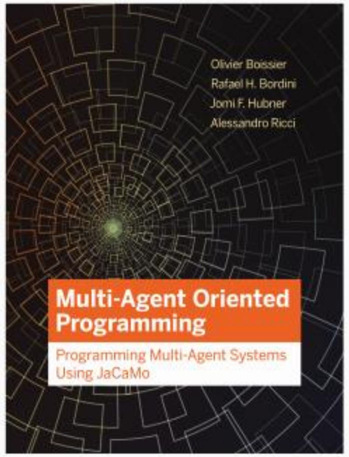
Multi-Agent-Based System Engineering models used to design and develop systems and applications

- Multi-* (sites, expertise, domains, points of view, decisions, goals, motivations, …)
- Incremental and collaborative development
- Continuous execution and adaptation
- Increasingly user-centric

Multi-Agent Oriented Programming (MAOP)



- Aim at **Engineering Systems**
- Provide **first-class abstractions** to model and implement **Agents**, **Environments**, **Interactions** and **Organization**
- Integrate
  - AOP (Shoham, 1993)
  - EOP (Ricci et al., 2010)
  - IOP (Huhns, 2001)
  - OOP (Pynadath et al., 1999)


Olivier Boissier
Rafael H. Bordini
Jomi F. Hubner
Alessandro Ricci

Multi-Agent Oriented Programming

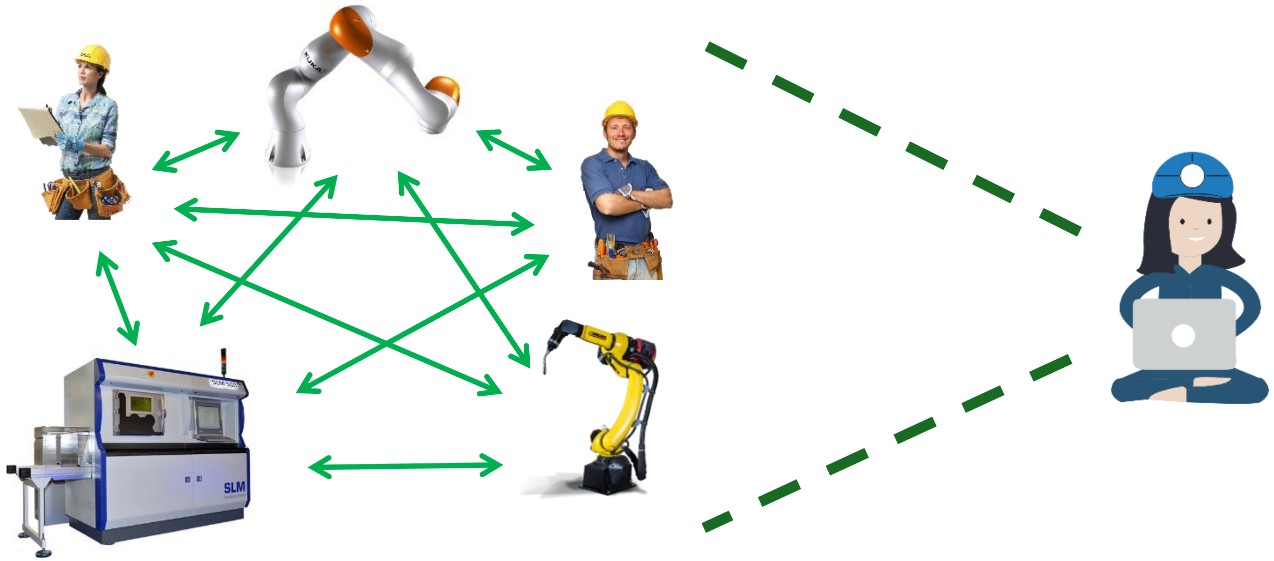
Programming Multi-Agent Systems Using JaCaMo

Flexible Industrial Manufacturing

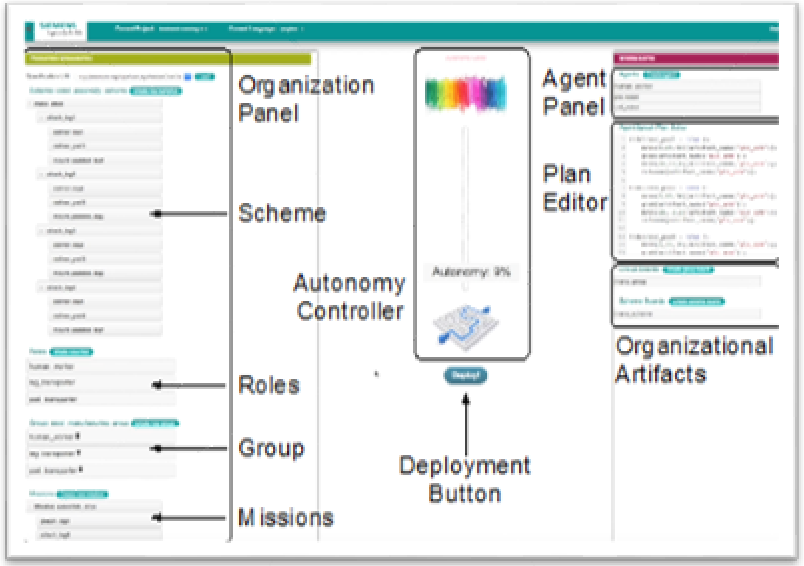
Domain problem (“lot-size-one manufacturing”): **unique** products at **mass production costs**

- customization is **expensive**: production lines are **optimized**, **inflexible**, and have **large lifespans** (> 30yr)
  - ○ we need production lines that can be **repurposed on-the-fly**

SIEMENS



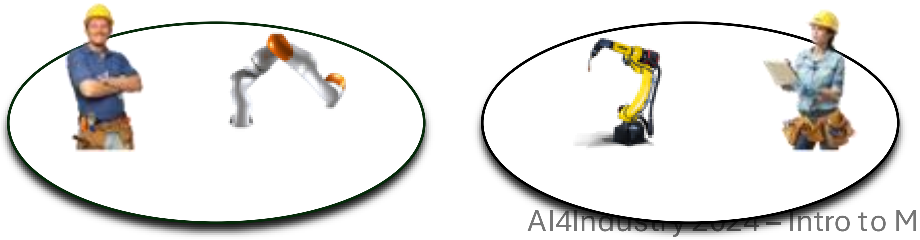
Factory workers and artificial agents working towards shared goals



End-user programming for production engineers

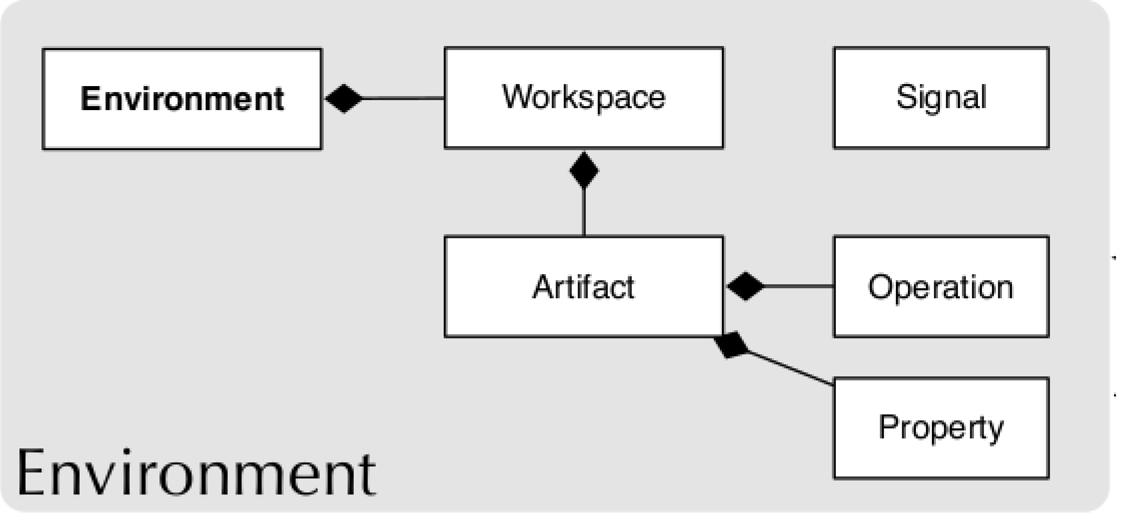
(Ciortea et al., 2018)

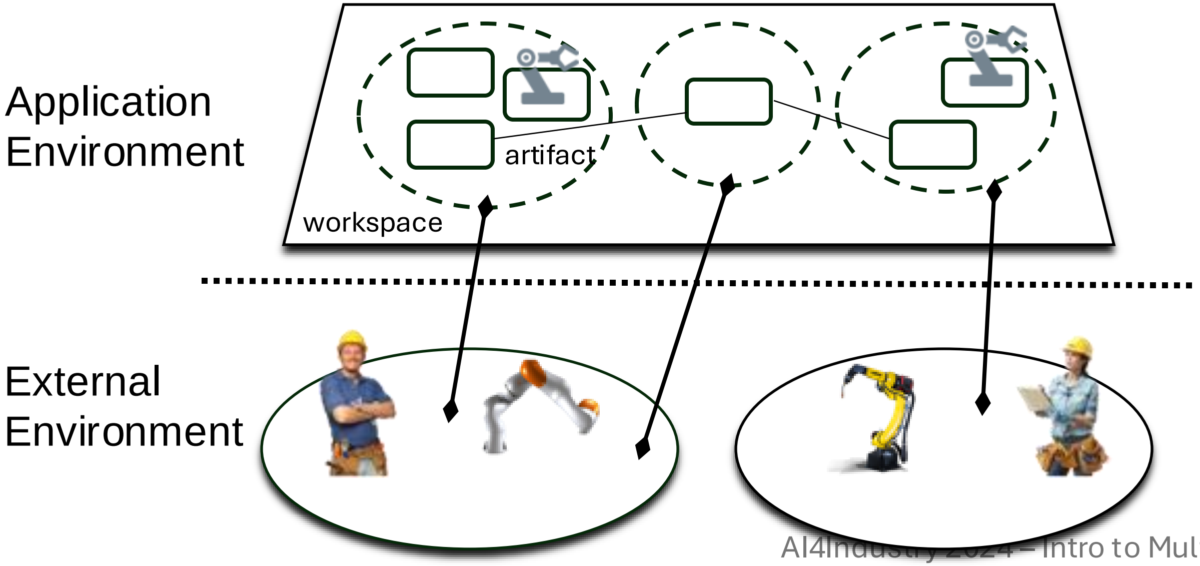
Flexible Industrial Manufacturing



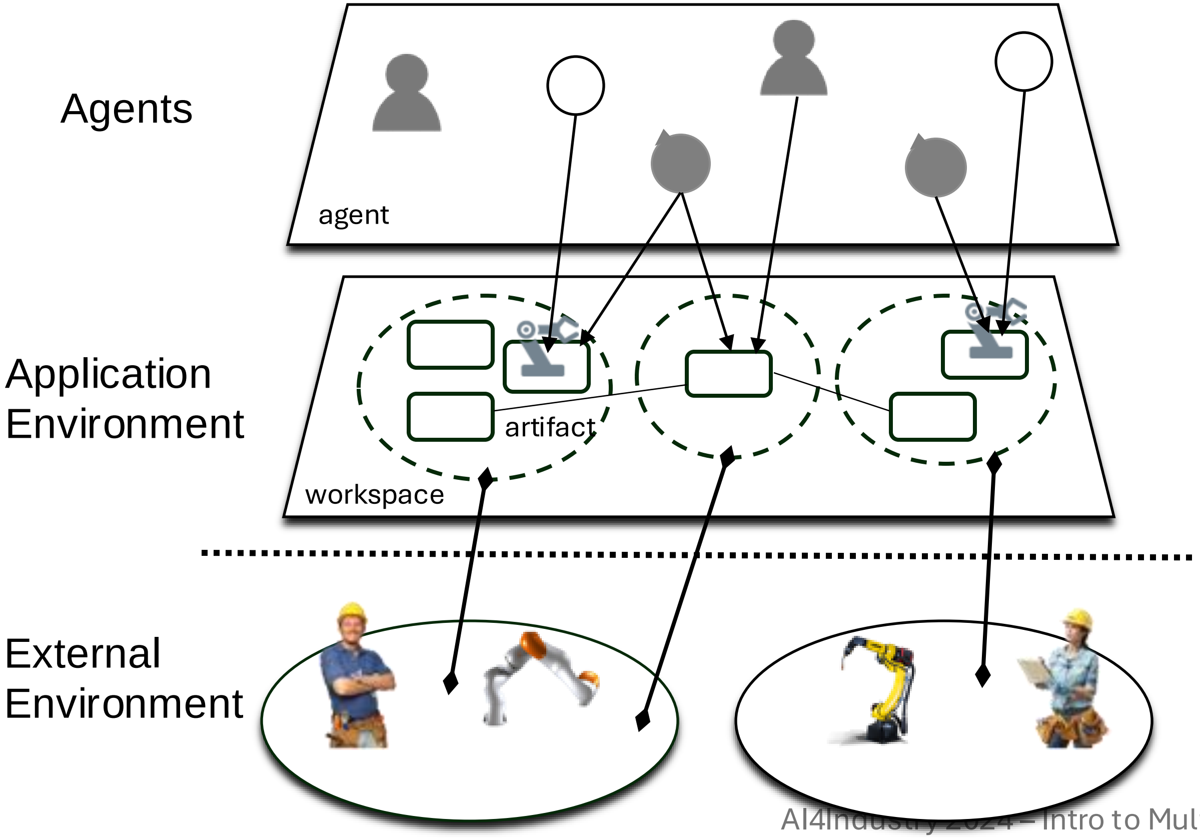
External
Environment

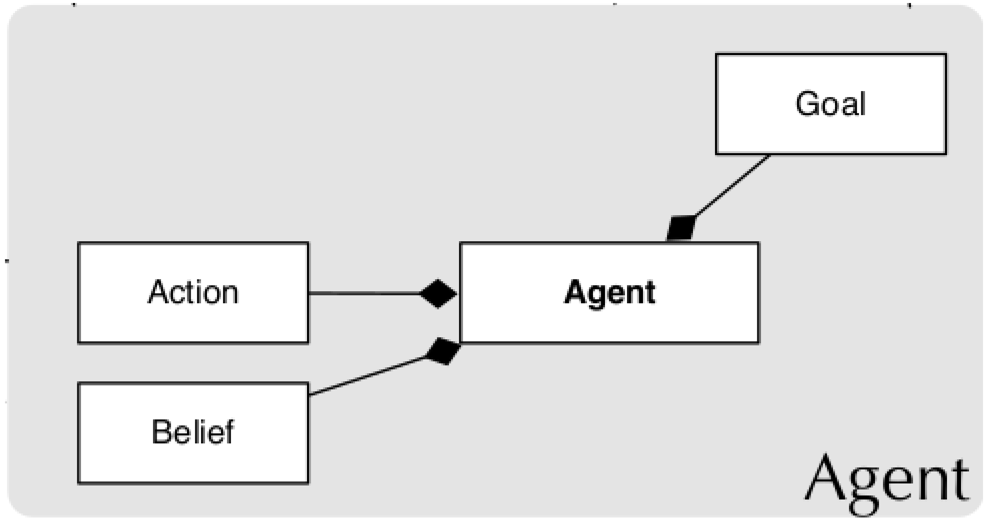
Environment Dimension



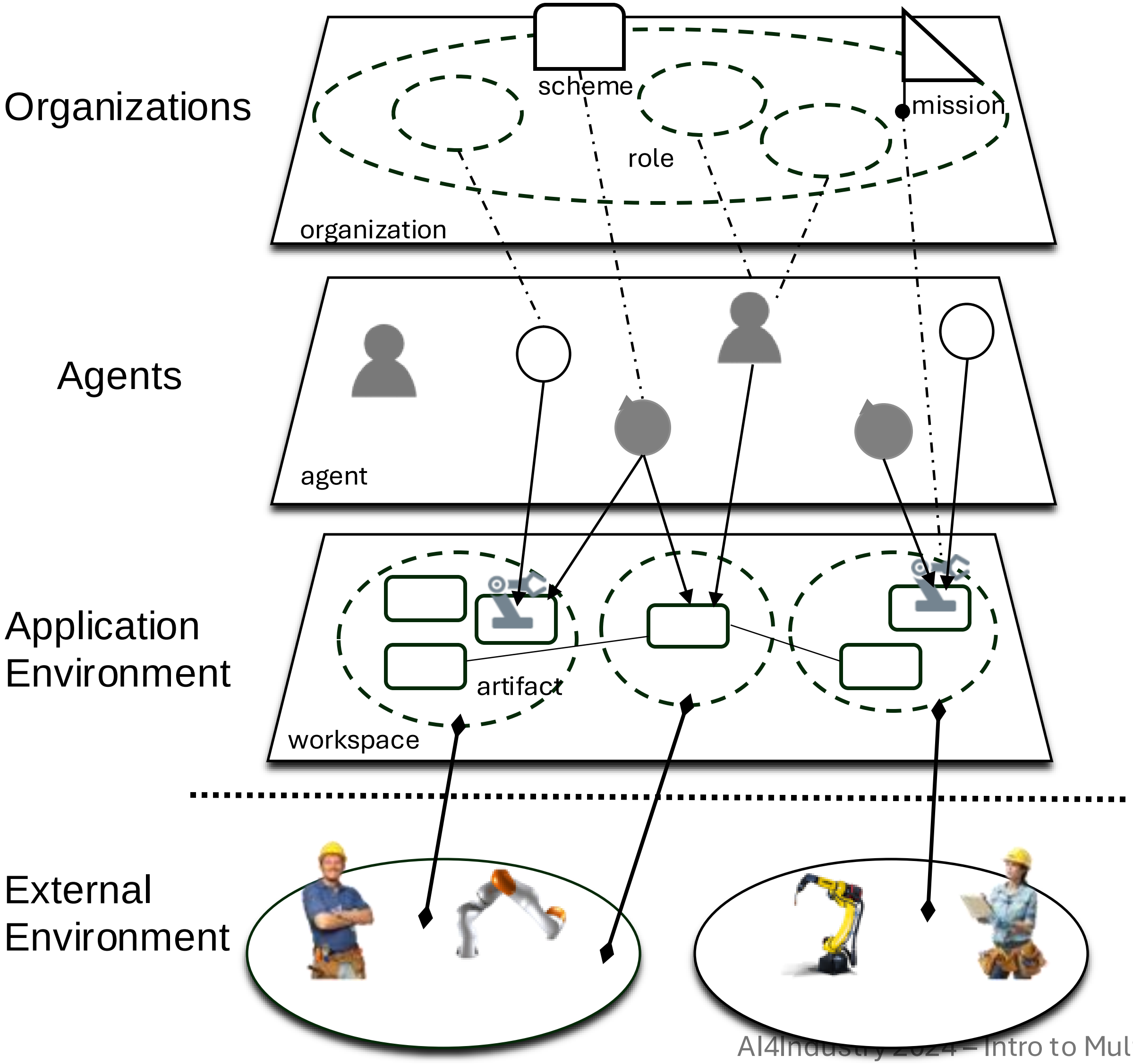


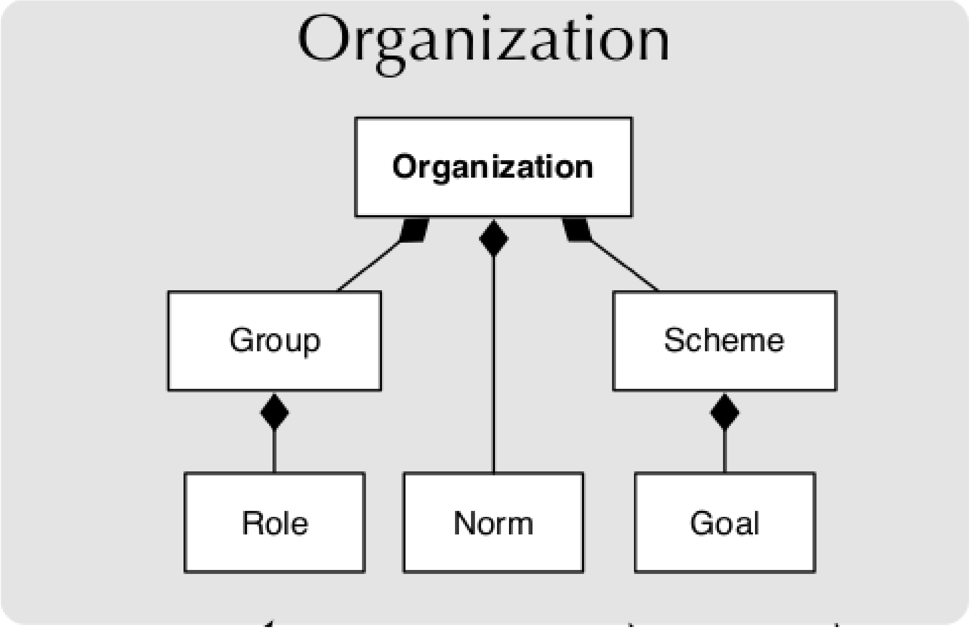
Agent Dimension



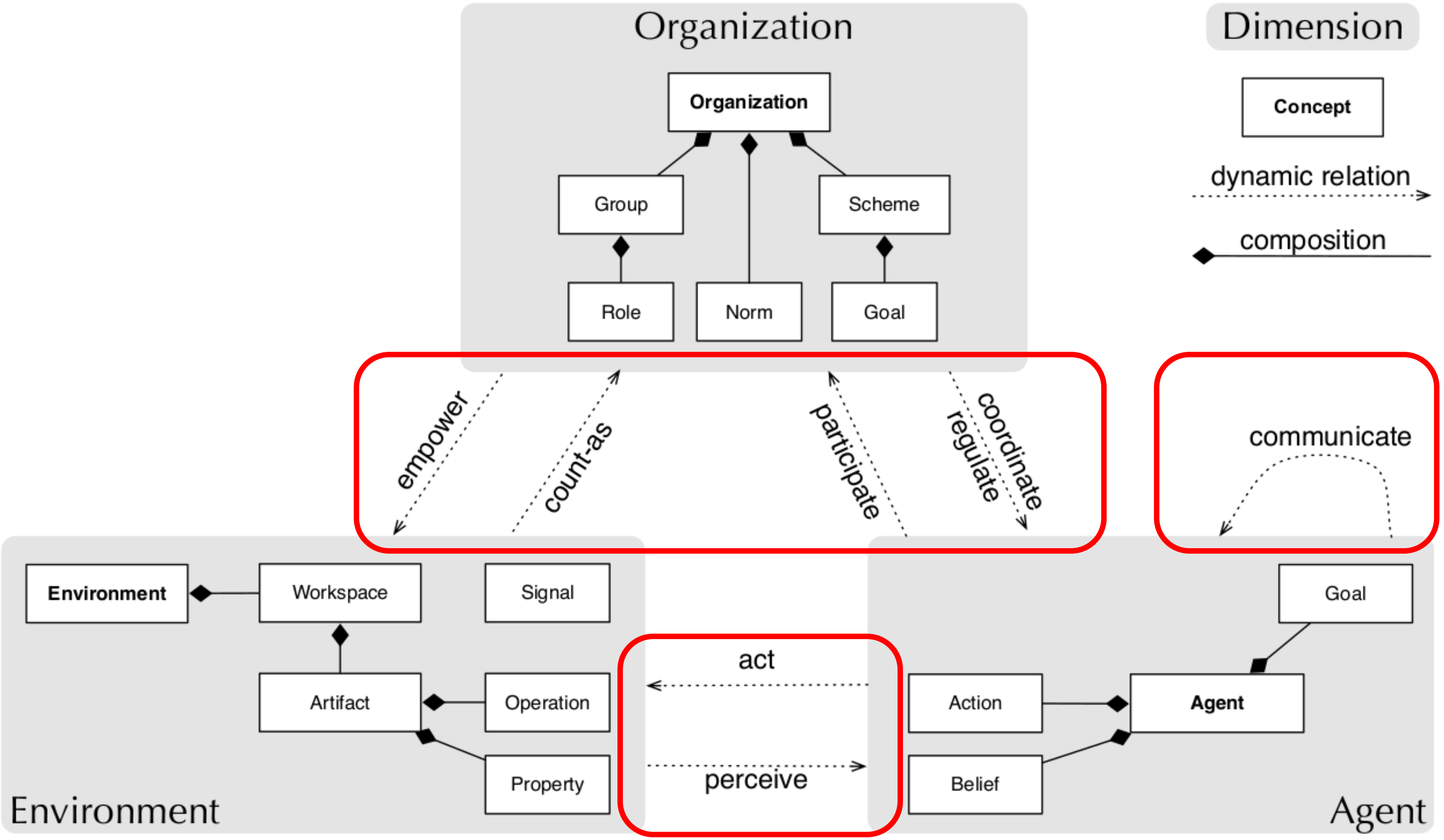


Organization Dimension

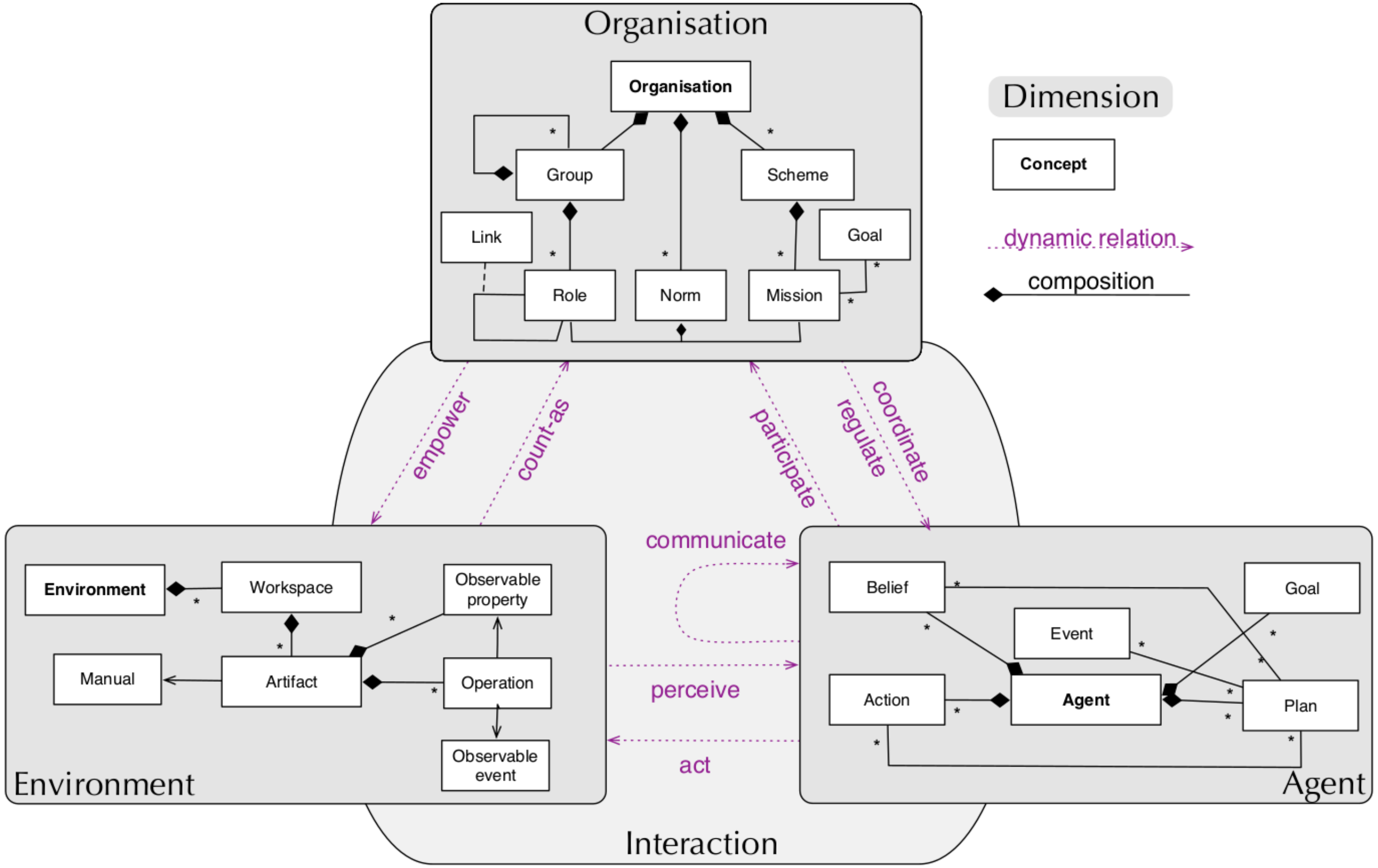




Interaction Dimension



JaCaMo Metamodel – Multi-Agent Concepts



Smart Room Scenario

Develop one room controller agent to manage a “Heating, Ventilating and Air Conditioning” (HVAC) device to reach a desired temperature based on agents’ preferences acting on behalf of users

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Separation of concerns

- Integration and interoperability with the HVAC
  - **environment** modeling
- Strategy to keep the right temperature
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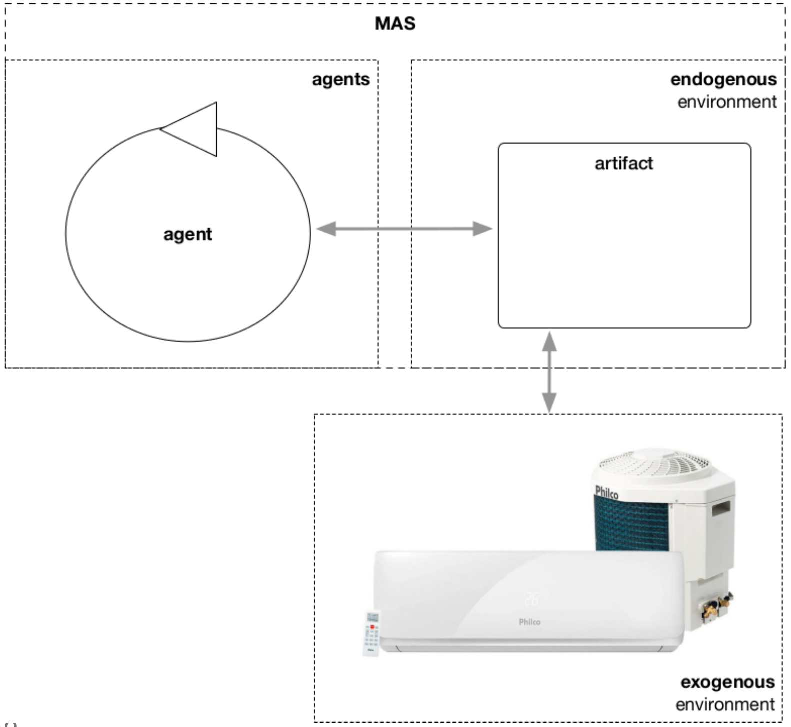
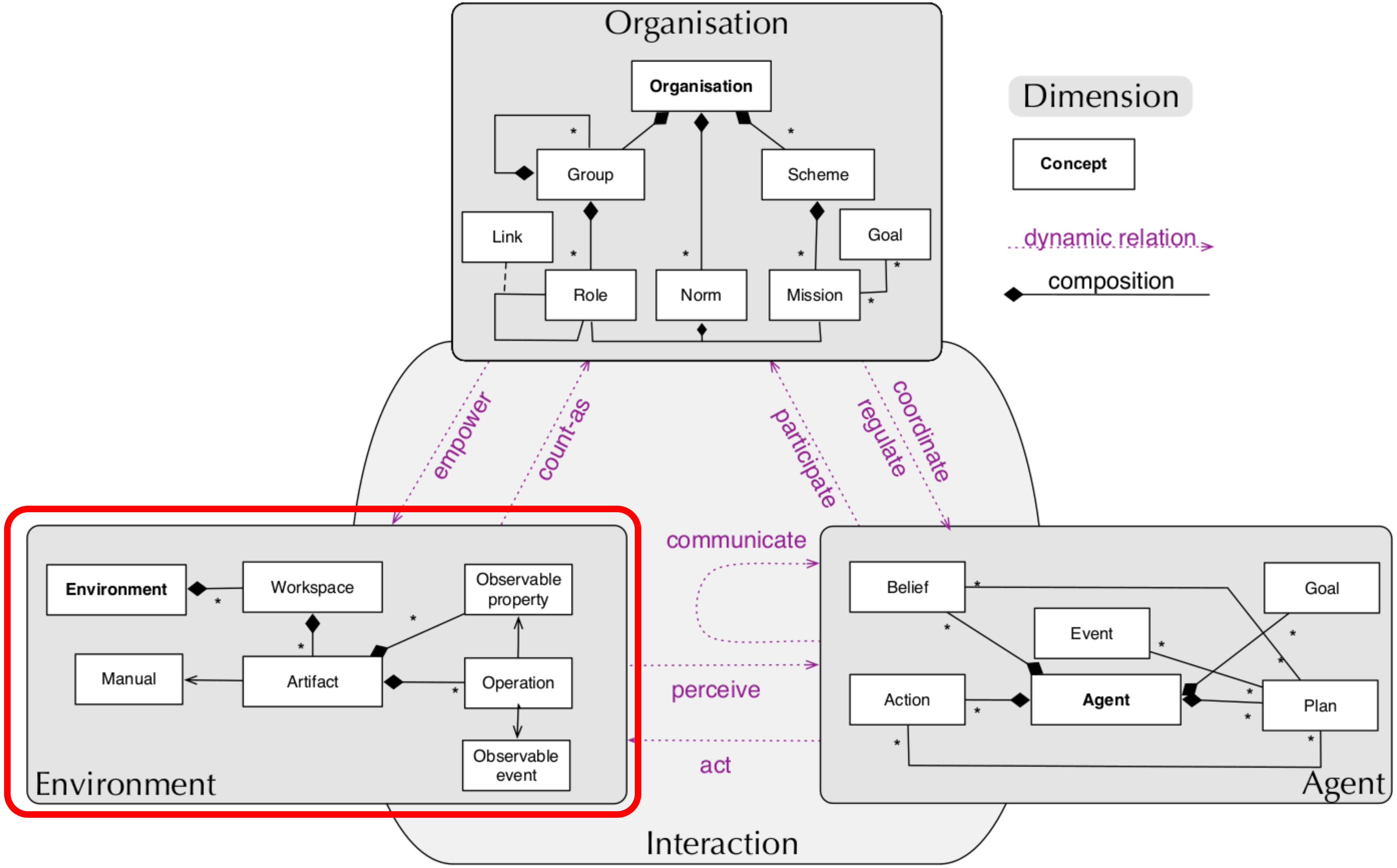


The Environment Dimension

JaCaMo Metamodel – Multi-Agent Concepts



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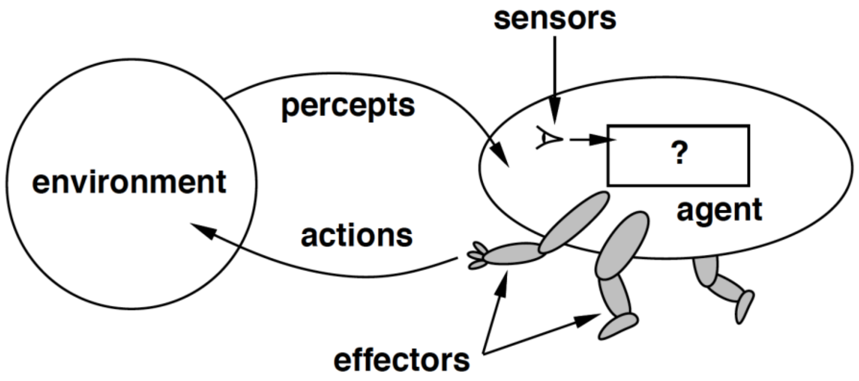

Single-agent system perspective
[Russell & Norvig, 2020]

The **Environment** as the **world external to the system**

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.

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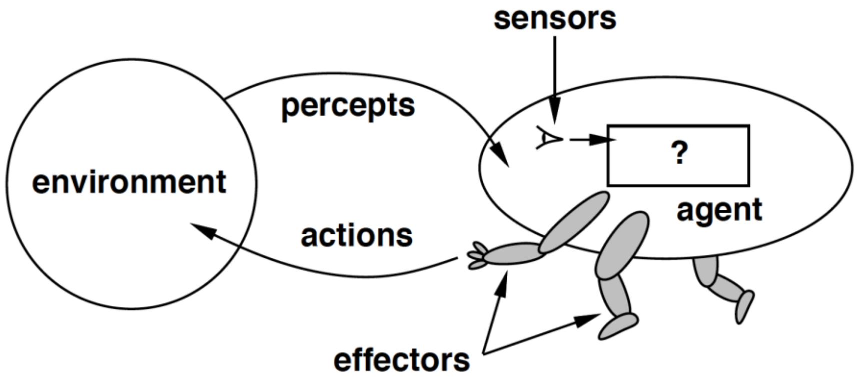

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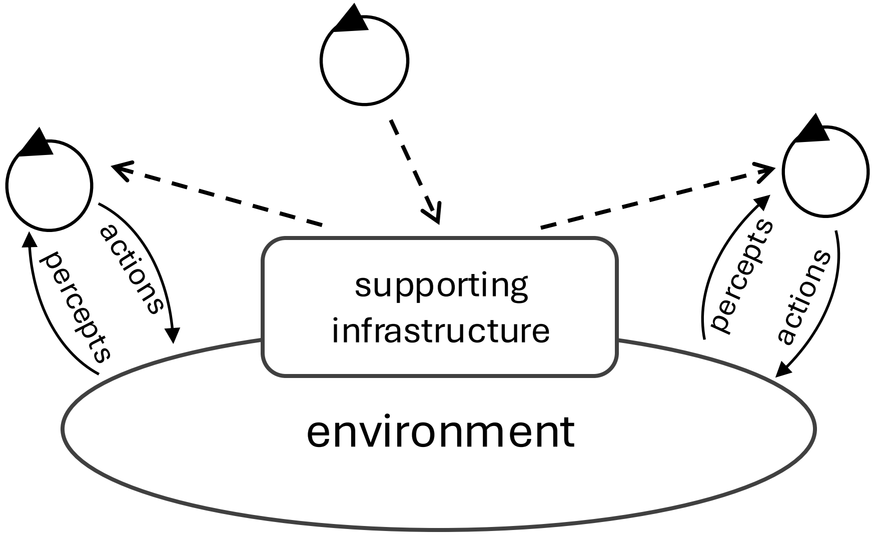

Multi-agent system perspective

The **Environment** as the **world external to the system**

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

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The Environment as a Design Abstraction

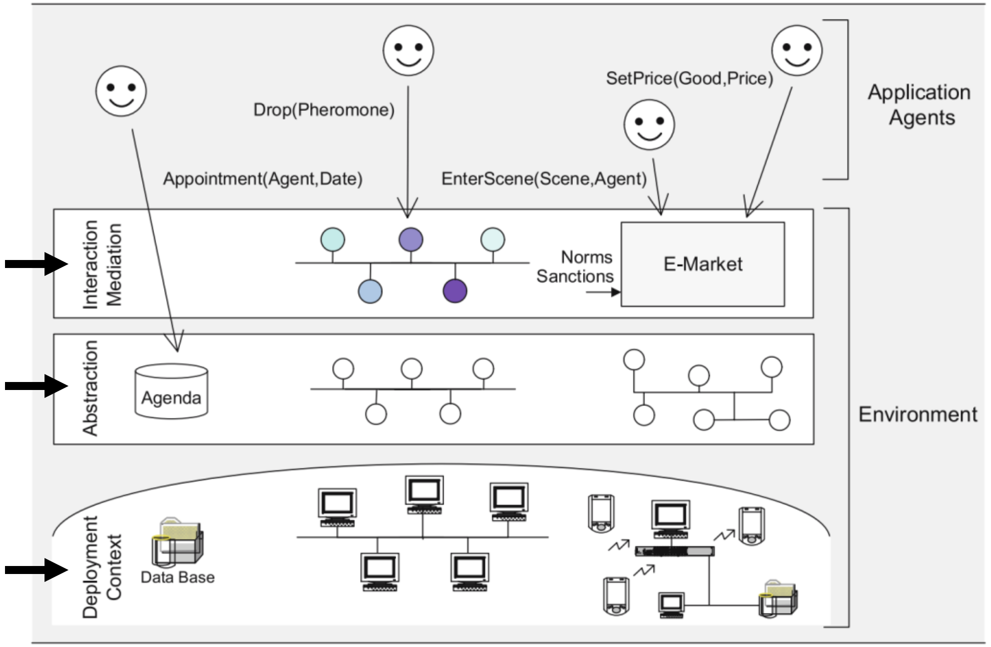
The **environment is a first-class abstraction** that provides the surrounding conditions for agents to exist and that mediates both the interaction among agents and the access to resources [Weyns et al., 2007].

3 levels of support:

Interaction-mediation

Abstraction

Basic



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

Reflection support [Rici et al., 2011]: mechanisms to modify the functional behavior of the environment

- Example: creating and destroying artifacts

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

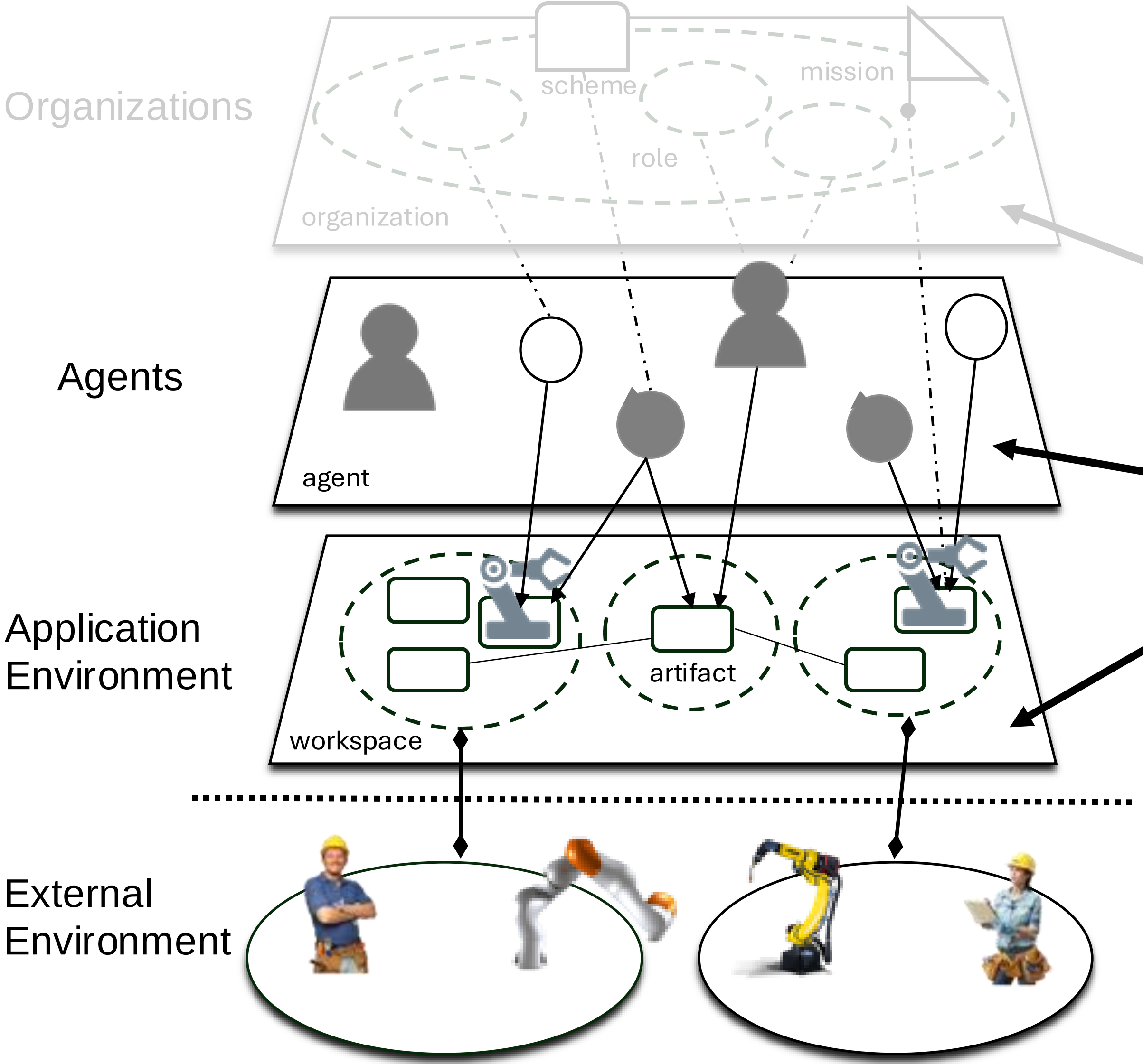
- Example: semantic models, domain-specific abstractions, etc.

Basic interface support: raw access to the deployment context

- Example: Web APIs, device interfaces, etc.

D. Weyns, A. Omicini, and J. Odell. Environment as a first class abstraction in multiagent systems. JAAMAS 14, 5–30, 2007.
A. Ricci, M. Piunti, and M. Viroli. Environment programming in multi-agent systems: an artifact-based perspective. JAAMAS 23, 158–192, 2011.

Flexible Industrial Manufacturing



SIEMENS

collectives of people and artificial agents working towards shared goals

autonomous behavior

non-autonomous behavior

Modularity and **Encapsulation**

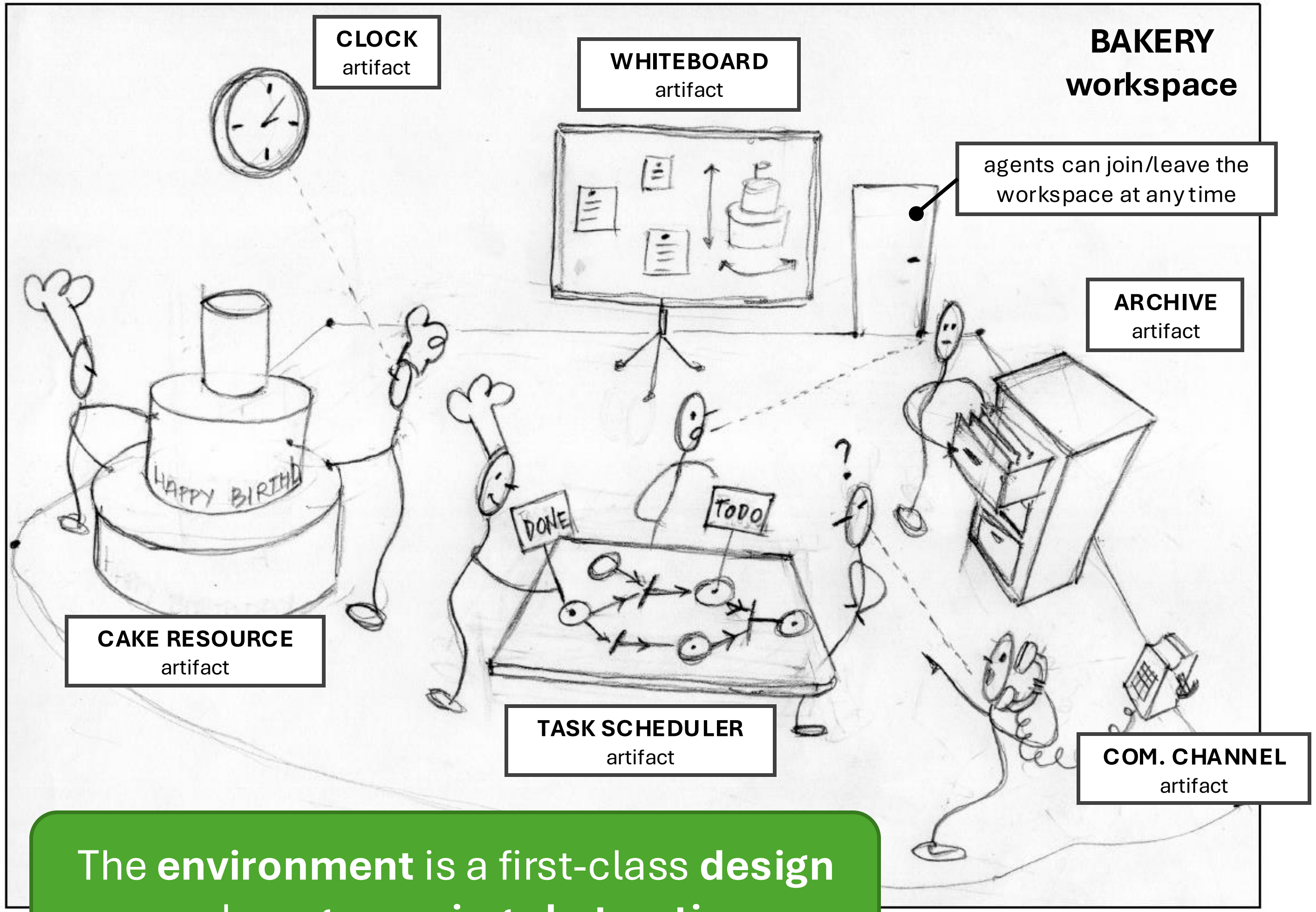
Uniformly **encapsulate** and **modularize** functionalities of the MAS outside of the agents

⇒ **reusability** of components

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

Andrei Ciortea, Simon Mayer, and Florian Michahelles. Repurposing Manufacturing Lines on the Fly with Multi-Agent Systems for the Web of Things. AAMAS 2018.

The Agents & Artifacts Metamodel



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

Key idea: **separation of concerns**

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

O. Boissier, R. H. Bordini, J.F. Hubner, A. Ricci. *Multi-Agent Oriented Programming: Programming Multi-Agent Systems Using JaCaMo*, The MIT Press, 2020.

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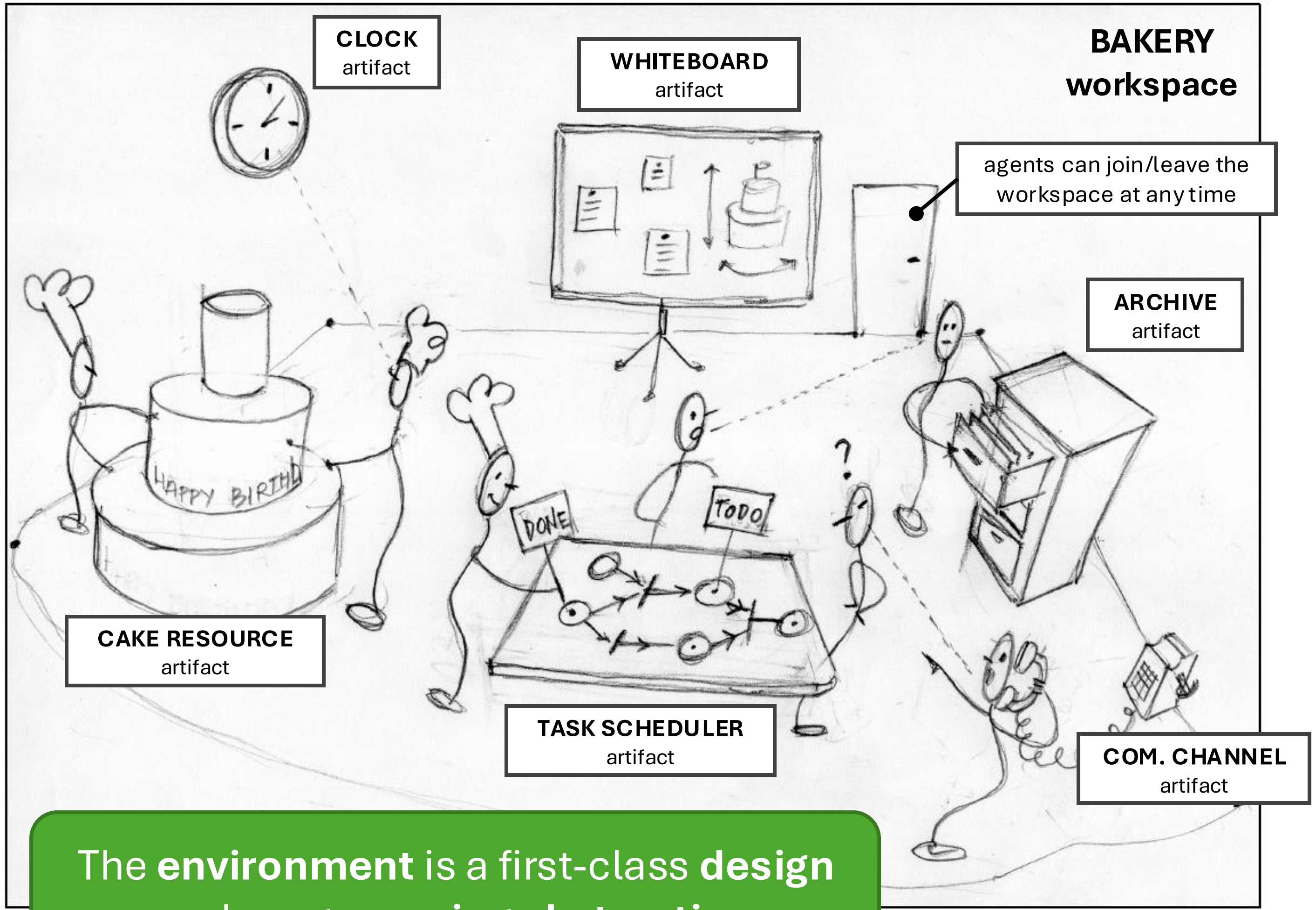

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Programming MAS = Programming **Agents**
+ Programming the **Environment**

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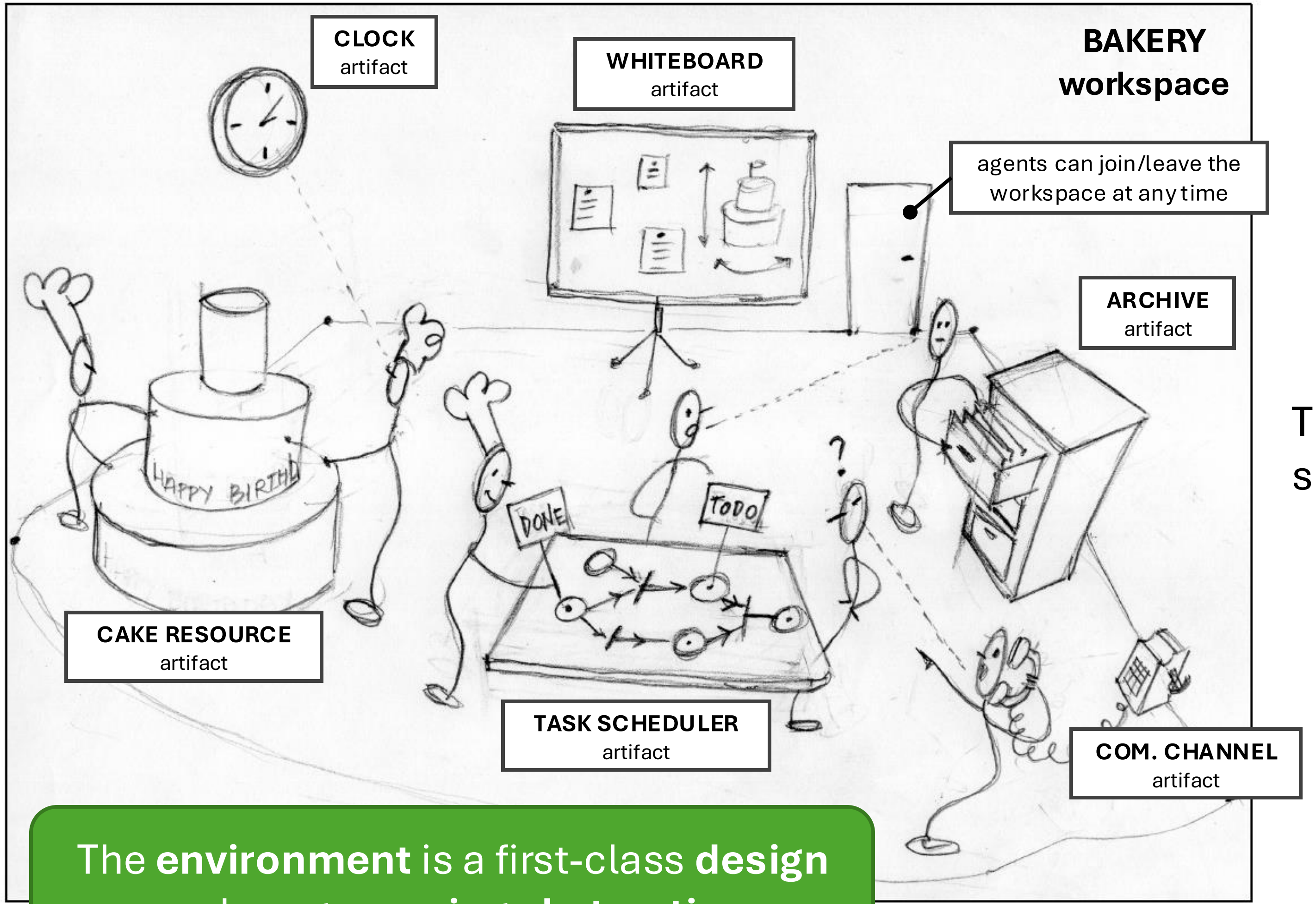

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Programming MAS = Programming **Agents**
+ Programming the **Environment**

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**

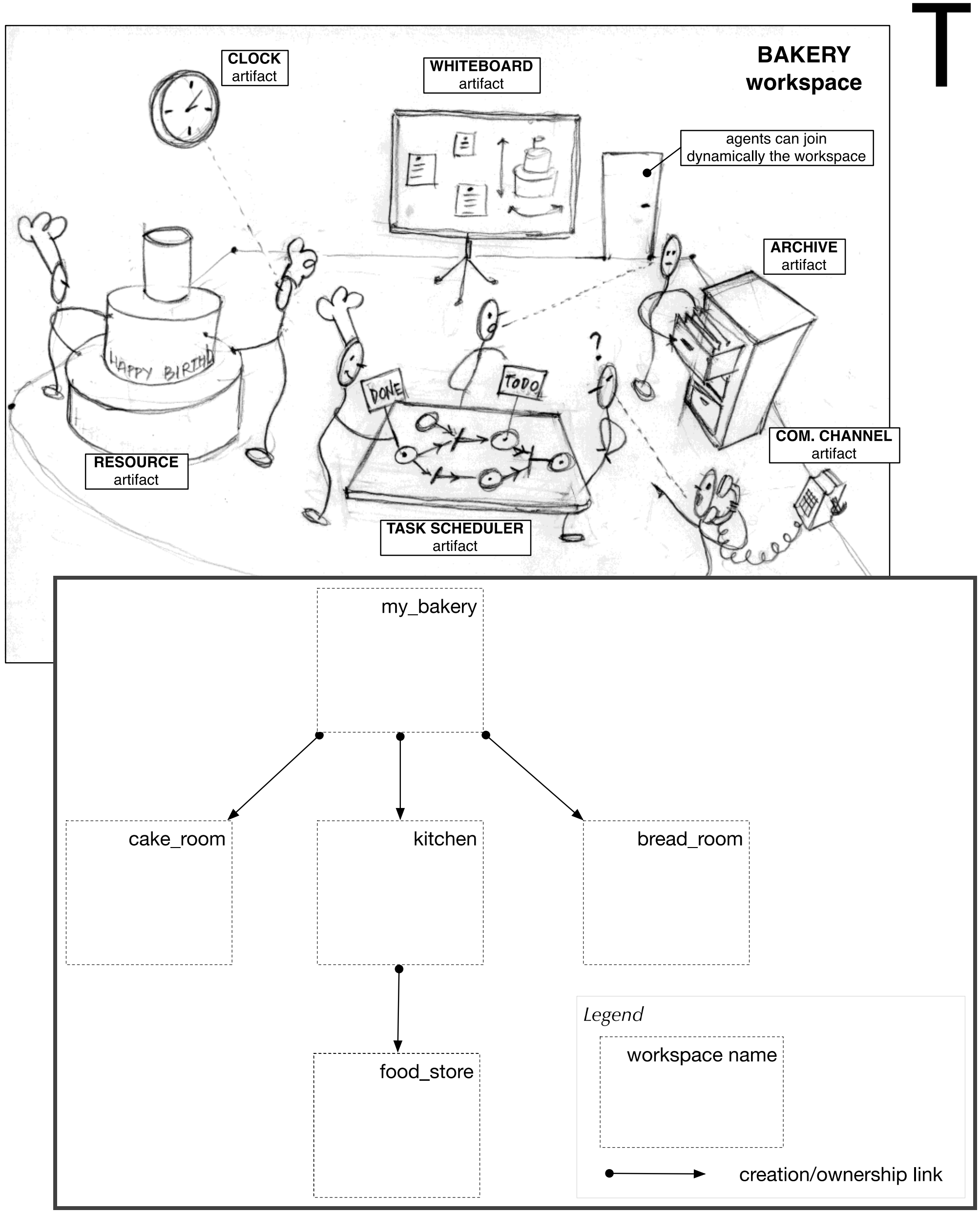
– agents **construct**, **share**, and **use** artifacts to support their working activities

⇒ artifacts are **mediating tools** for goal-directed agents

⇒ agents can **modify** the **functional behavior** of the environment to meet their needs

O. Boissier, R. H. Bordini, J.F. Hubner, A. Ricci. *Multi-Agent Oriented Programming: Programming Multi-Agent Systems Using JaCaMo*, The MIT Press, 2020.

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**

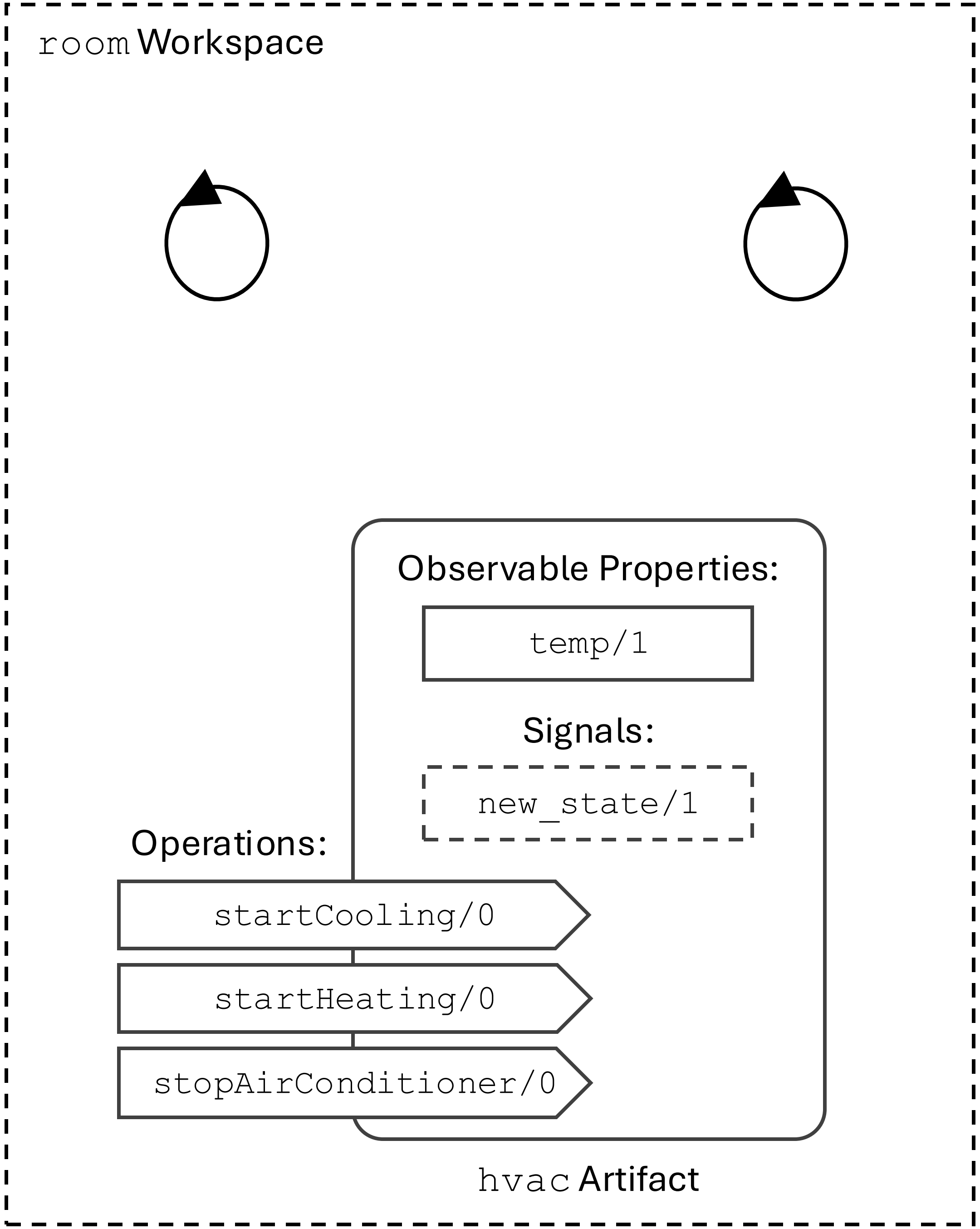
⇒ separation of concerns between the **agent's mind** and the **agent's body**

⇒ allows **heterogeneous agents** (implementing different architectures) to *join* and *work in* the same environment

Workspaces can be distributed over a network

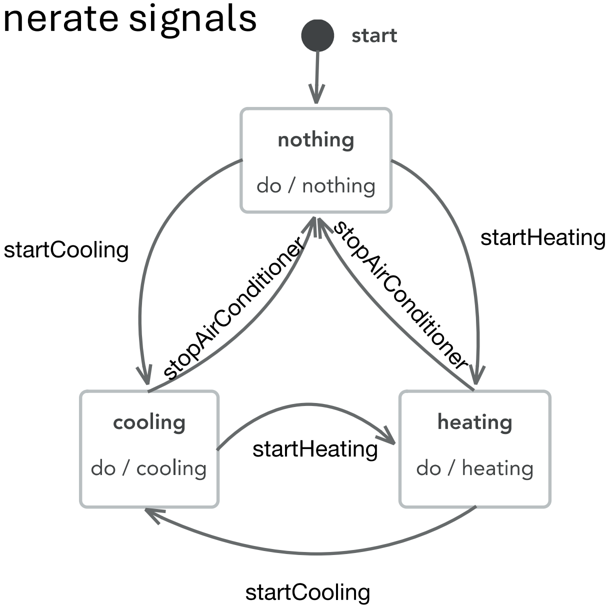
Alessandro Ricci, *Levels of Abstraction in Designing and Programming Systems of Cognitive Agents*, HyperAgents 2019: http://www2019.hyperagents.org/

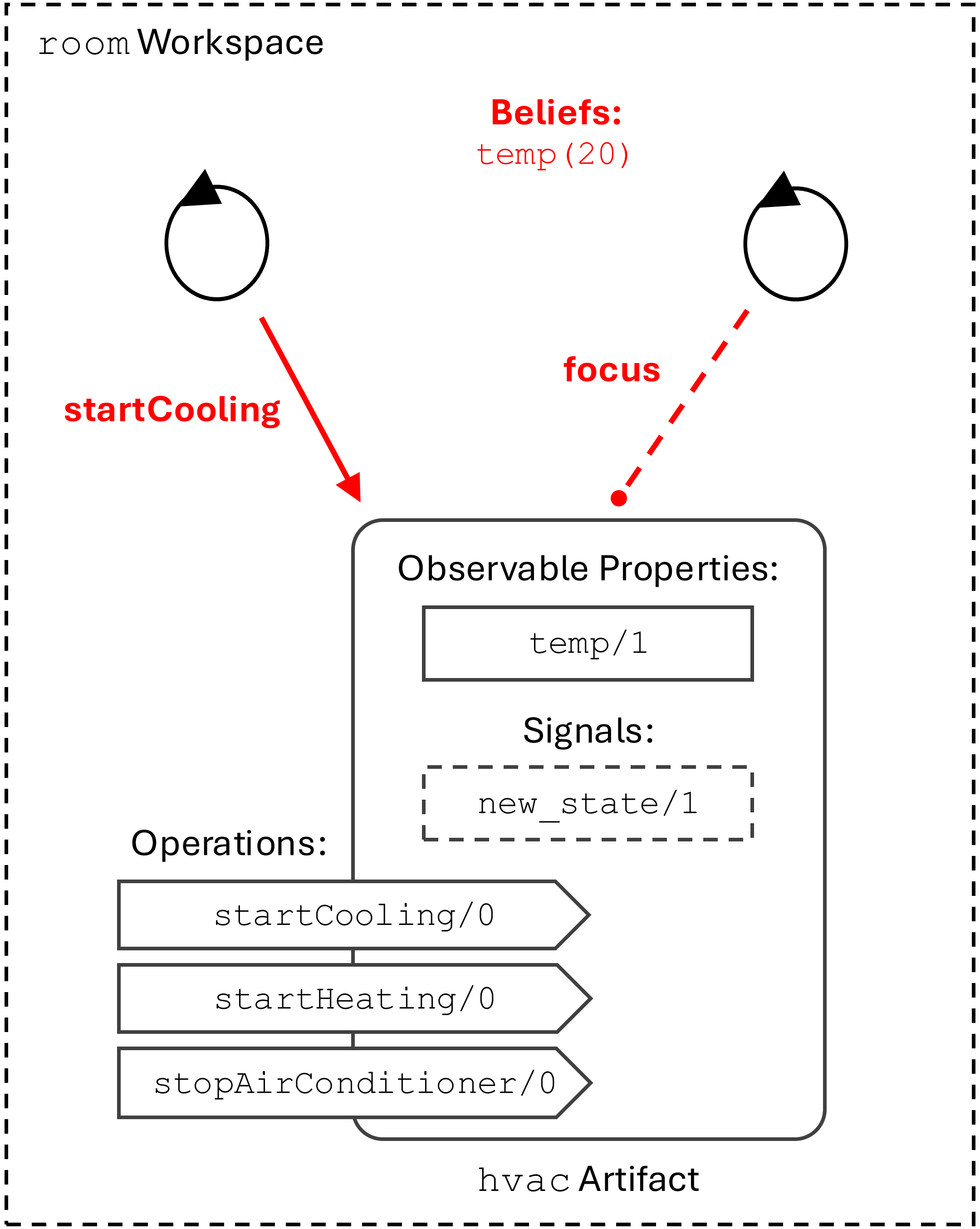
The Artifact Abstraction



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





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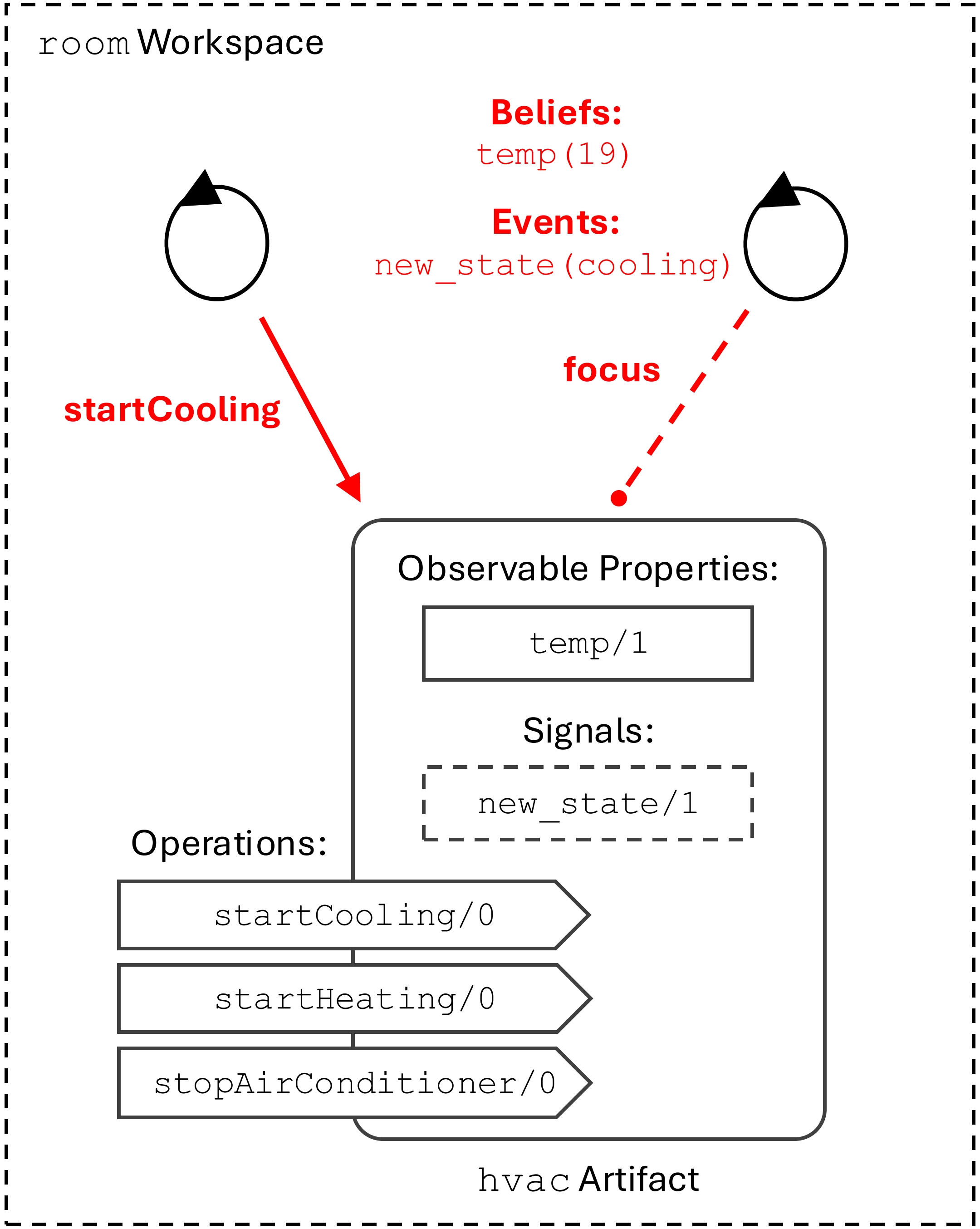
Agents can **focus** on artifacts to **perceive** observable properties and signals



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

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

The Artifact Abstraction

Artifacts as computational objects

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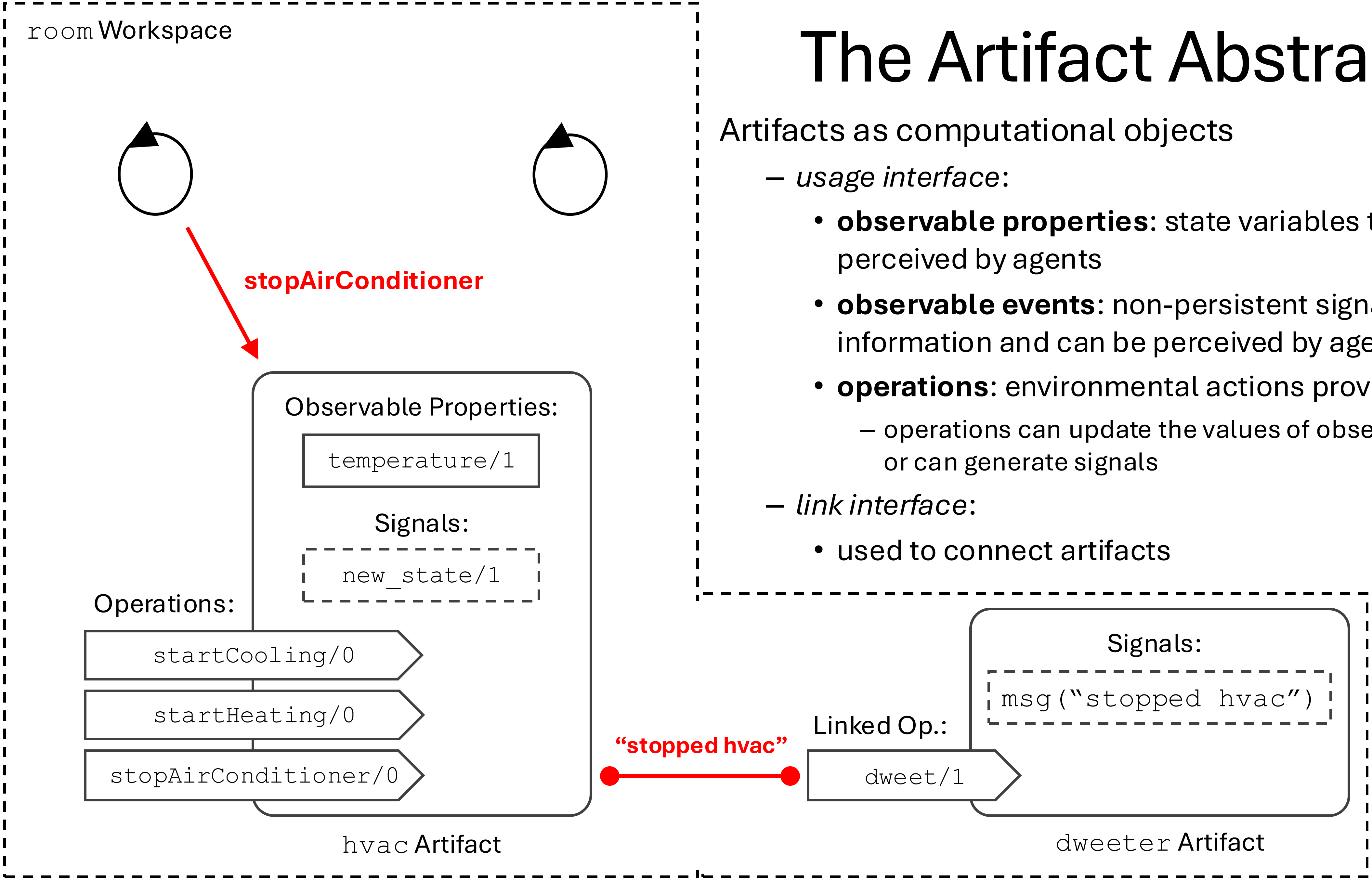
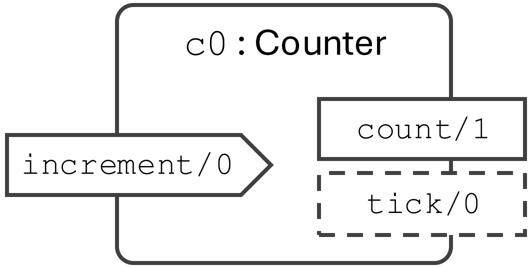
- *link interface*:
  - used to connect artifacts



A Basic Taxonomy of Artifacts

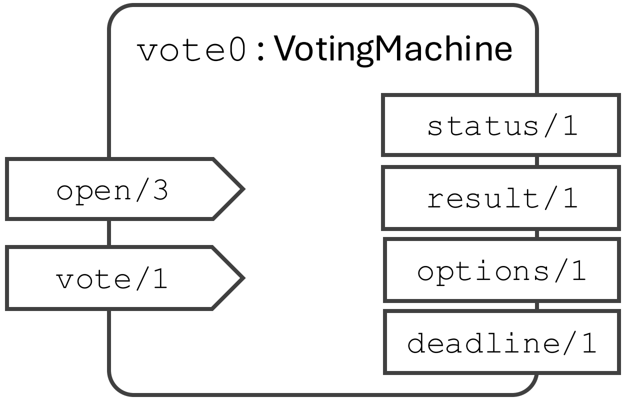


Resource Artifacts

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

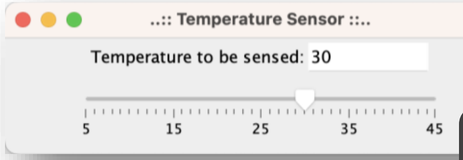
Coordination Artifacts

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

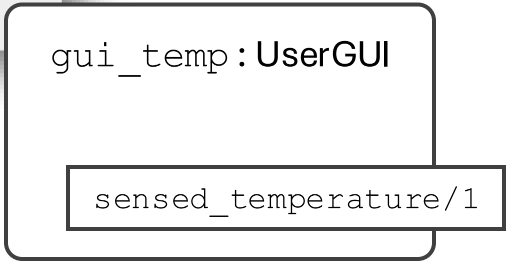


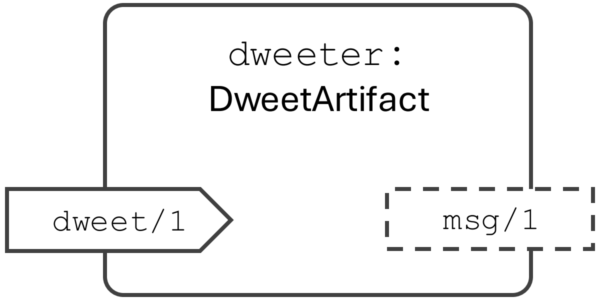
Boundary Artifacts

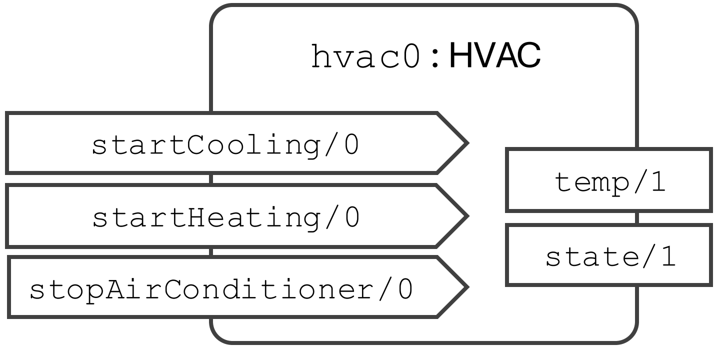
- artifacts that allow agents to interact with human users and, more generally, any actor or system that is external with respect to the MAS


..:: Temperature Sensor ::..

Temperature to be sensed: 30

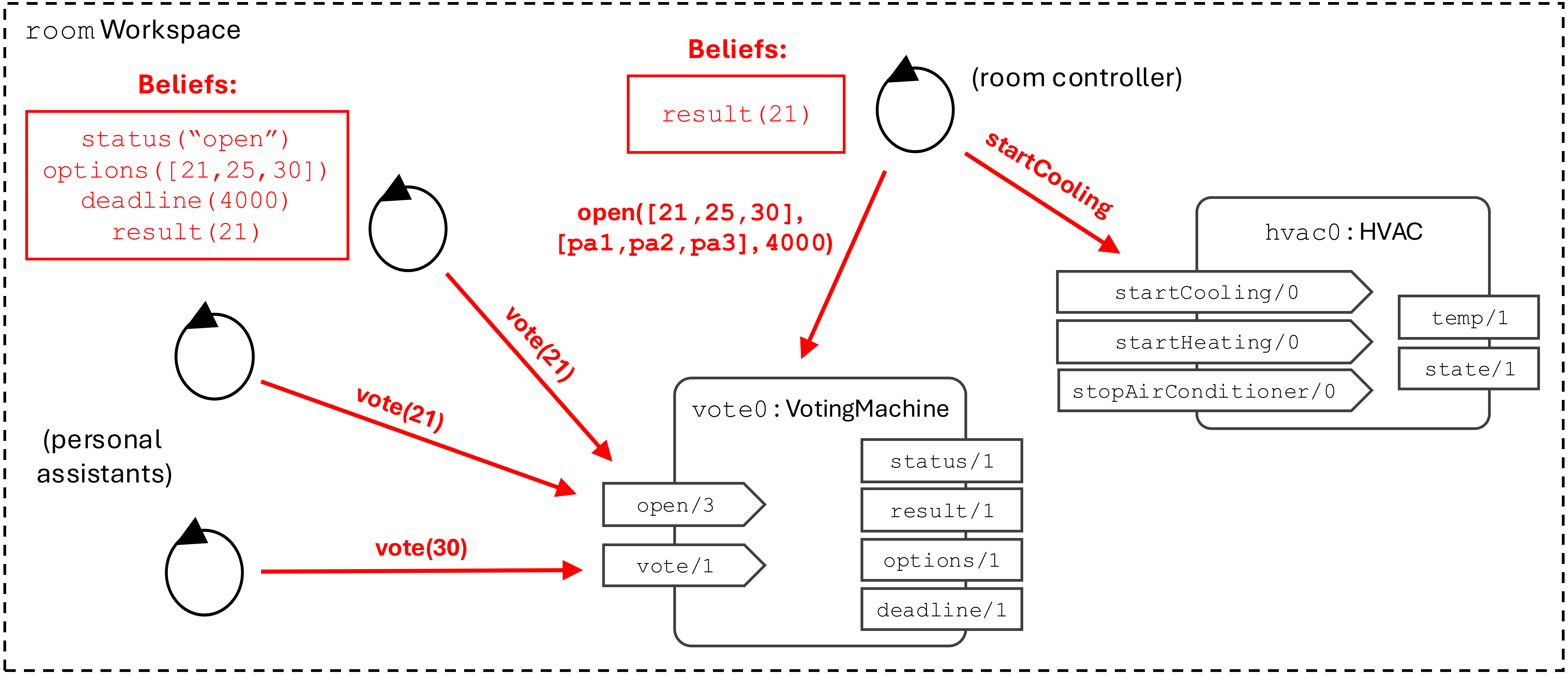






O. Boissier, R. H. Bordini, J.F. Hubner, A. Ricci. *Multi-Agent Oriented Programming: Programming Multi-Agent Systems Using JaCaMo*, The MIT Press, 2020.

Smart Room Scenario Revisited: Voting Machines



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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

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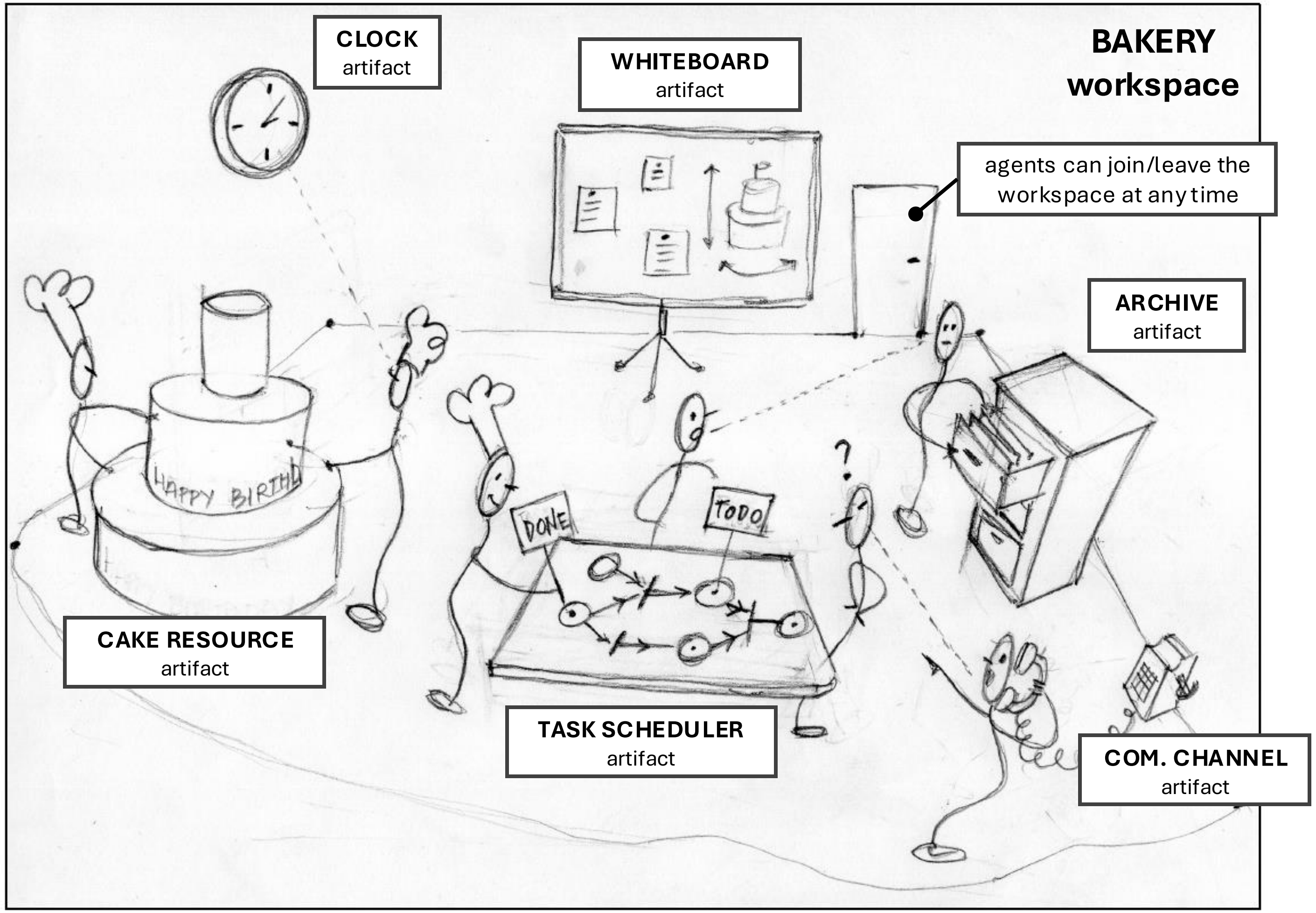
The Agents & Artifacts Metamodel



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

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

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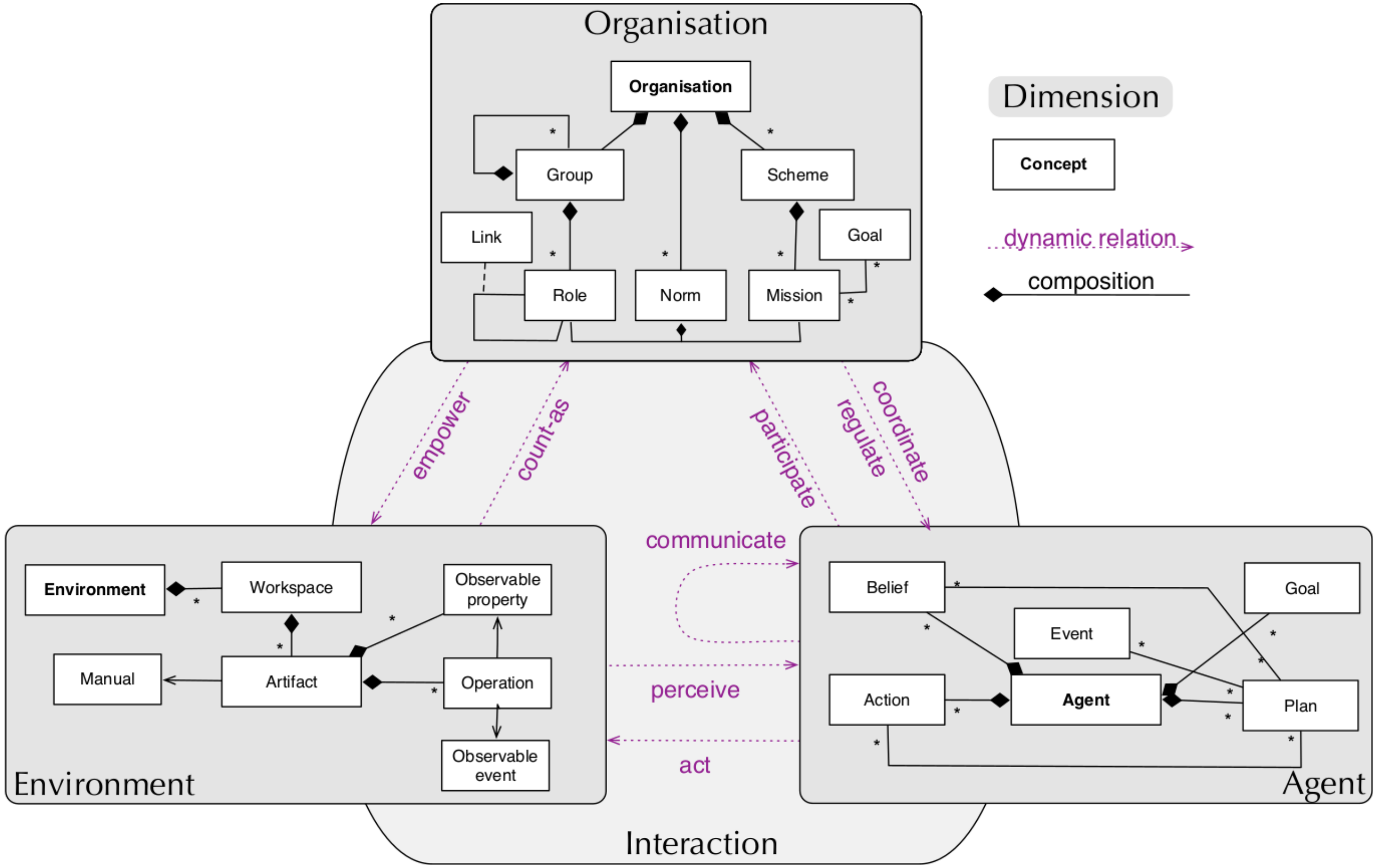
JaCaMo Metamodel – Multi-Agent Concepts



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