



Building Multiagent Systems: An Ontology-Driven Approach with SPADE

DSC Europe 2024

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This document
and the accom-
panying material
are available
online



Introduction

Introduction

Assistant Professor at the University of Zagreb **Faculty of Organization and Informatics**, and a member of the Artificial Intelligence Laboratory at UNIZG FOI.

Scientific interests mainly in:

- multiagent systems,
- semantic modelling,
- gamification,
- artificial intelligence,
- computer games.

Introduction

One of the teachers of the following courses in Croatian or English:

- Multiagent Systems,
- Database Theory,
- Declarative Programming,
- Introduction to Artificial Intelligence,
- Introduction to Computer Games,
- Internet Security,
- Computer Game Development Platforms.

Introduction

Engaged in international activities and promoting international relations:

- Erasmus student at [Karl-Franzens University of Graz](#) (AT),
- Erasmus intern at [Jožef Stefan Institute](#) in Ljubljana (SI),
- Erasmus+ intern at [Elettra Sincrotrone](#) in Trieste (IT),
- 3-month research stay at [Universitat Politècnica de València](#) in Valencia (ES),
- ITEC student at [Centre for Development of Advanced Computing](#) in NOIDA (IN),
- 16-month research visit at [Universitat Politècnica de València](#) in Valencia (ES),

Introduction

Publications



Project activity



BSc and MA Mentees



Agents and Multiagent Systems

*'[...] we require systems that can **decide for themselves** what they need to do in order to achieve the objectives that we delegate to them. Such computer systems are known as **agents**. Agents that must operate robustly in rapidly changing, unpredictable, or open environments, where there is a significant possibility that actions can **fail**, are known as **intelligent agents**, or sometimes **autonomous agents**.' [1]*

Agents and Multiagent Systems

What is an Agent?

Agents and Multiagent Systems: What is an Agent?

'An agent is anything that can be viewed as perceiving its environment through sensors and acting upon that environment through actuators.' [2, p. 54]

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Agents and Multiagent Systems: What is an Agent?

'An agent is anything that can be viewed as **perceiving** its environment through sensors and **acting** upon that environment through actuators.' [2, p. 54]

More specifically,

'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 achieve its delegated objectives.' [1]

Agent

Figure 1: Visual definition of an artificial agent, based on [2, p. 55]

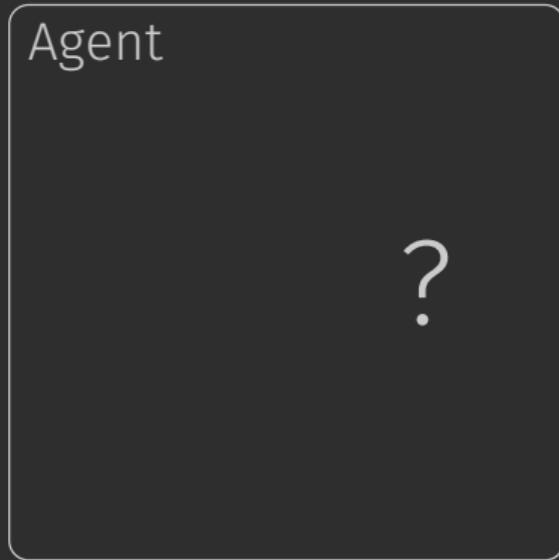


Figure 1: Visual definition of an artificial agent, based on [2, p. 55]

Agents and Multiagent Systems

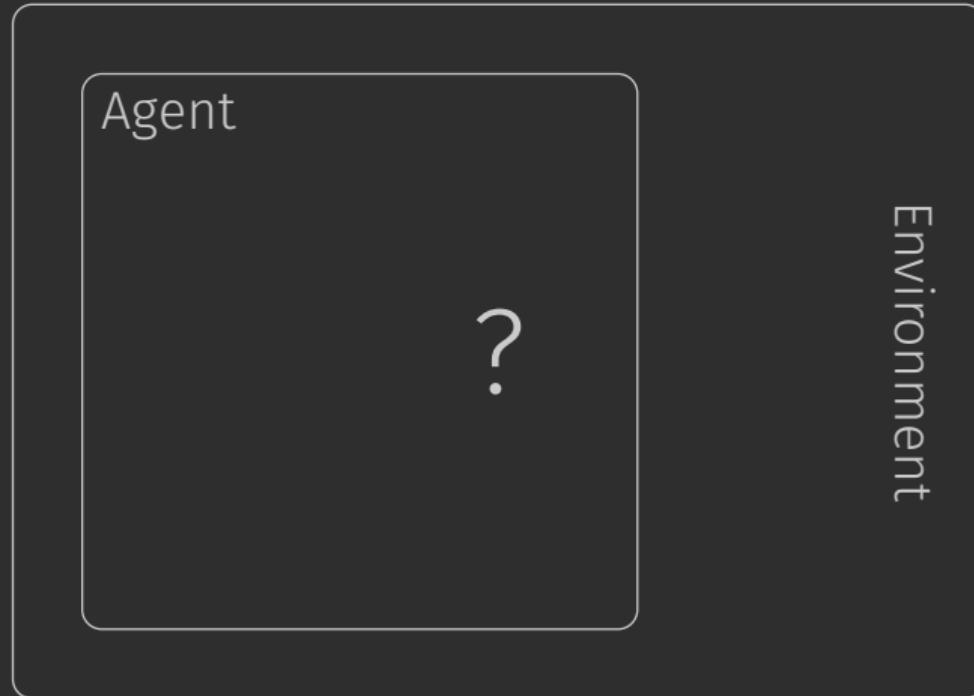


Figure 1: Visual definition of an artificial agent, based on [2, p. 55]

Agents and Multiagent Systems

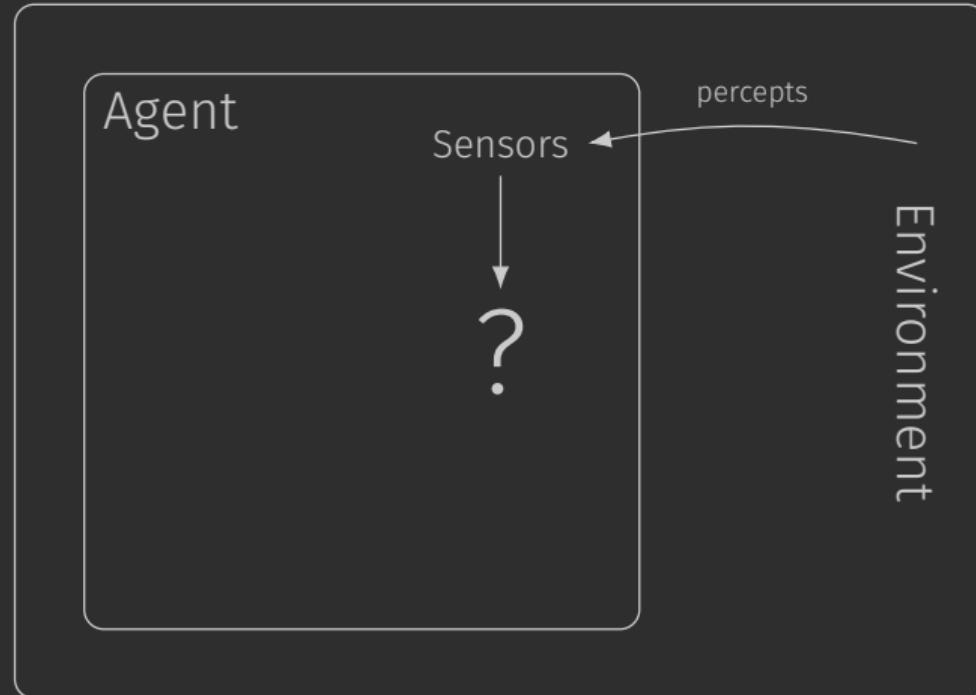


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Agents and Multiagent Systems

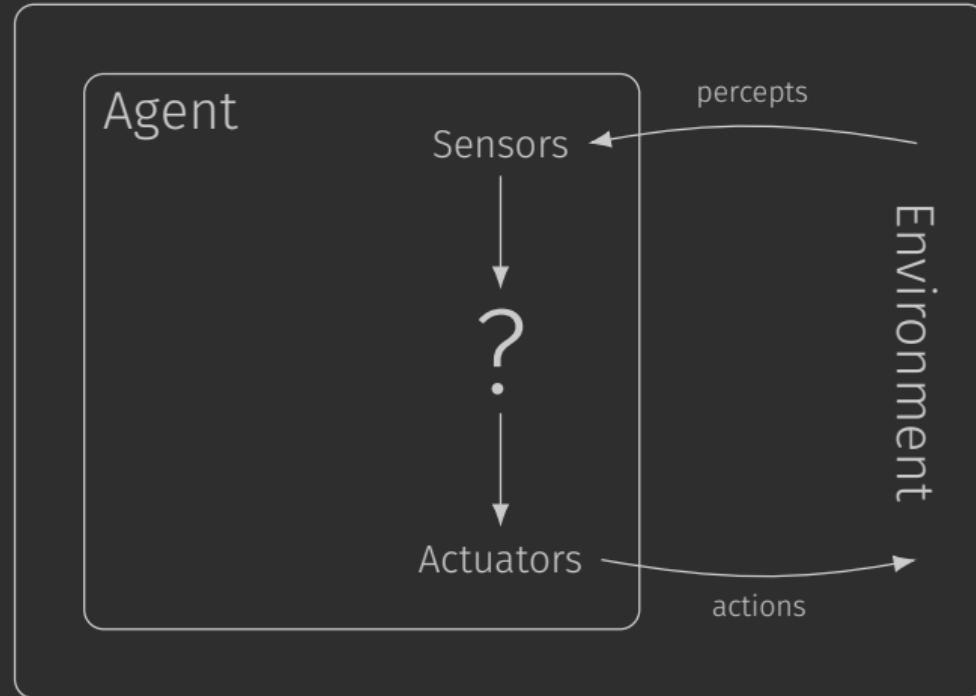


Figure 1: Visual definition of an artificial agent, based on [2, p. 55]

Agents and Multiagent Systems

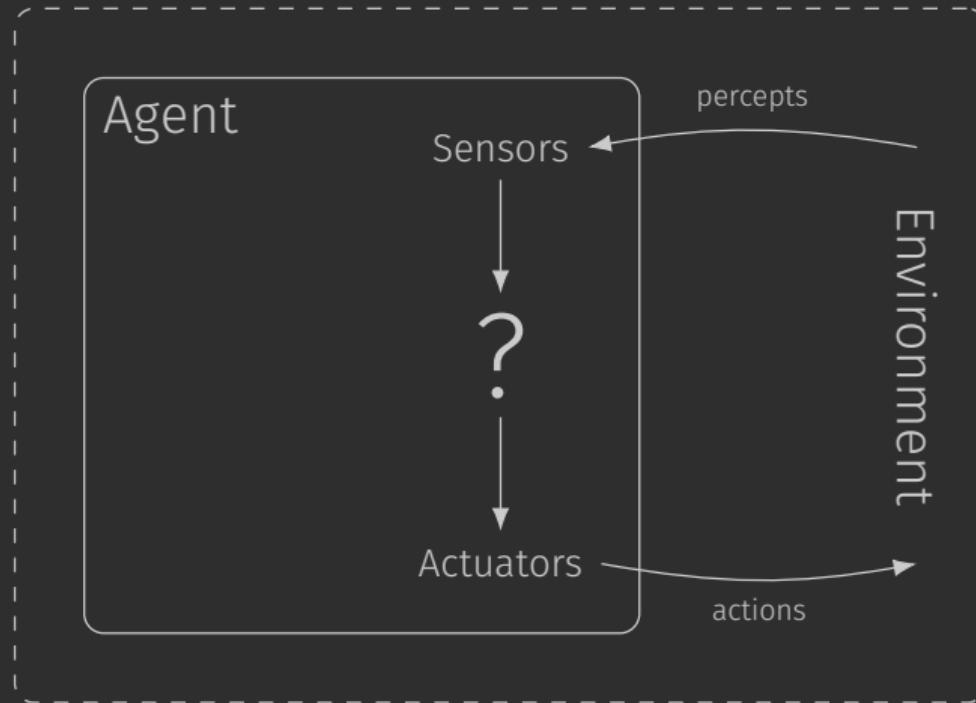


Figure 1: Visual definition of an artificial agent, based on [2, p. 55]

Agents and Multiagent Systems

$\text{Agent} \in \text{Multiagent System}$

Agents and Multiagent Systems: Agent \in Multiagent System

A multiagent system (MAS) is a system wherein ‘[...] an agent must make decisions in environments that contain multiple actors.’ [2]

Agents and Multiagent Systems: Agent \in Multiagent System

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In more detail, a MAS is a system wherein [3]:

- each agent has incomplete information or capabilities for solving the problem and, thus, has a **limited viewpoint**;
- there is no system global **control**;
- data are **decentralized**;
- computation is **asynchronous**.

Agents and Multiagent Systems: Agent \in Multiagent System

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- data are **decentralized**;
- computation is **asynchronous**.

Agents can be cooperative or competitive. Often modelled as organisations.

Agents and Multiagent Systems

Implementing Agents

Agents and Multiagent Systems: Implementing Agents

Smart Python Agent Development Environment (SPADE) is a multiagent systems implementation platform written in Python and based on instant messaging using extensible messaging and presence protocol (XMPP).

Agents and Multiagent Systems: Implementing Agents

SPADE is a multiagent systems implementation platform written in Python and based on instant messaging using XMPP.

To be run and to communicate, a SPADE agent must be connected to an XMPP server using its JID comprising its name and the hostname of the server, e.g.:

alice @ localhost

Agents and Multiagent Systems: Implementing Agents

The XMPP server of choice is Prosody.

- `docker-compose.yml` for running Prosody,
- `prosody.cfg.lua` for configuration that requires no user registration,
- generating or using SSL/TLS certificates.

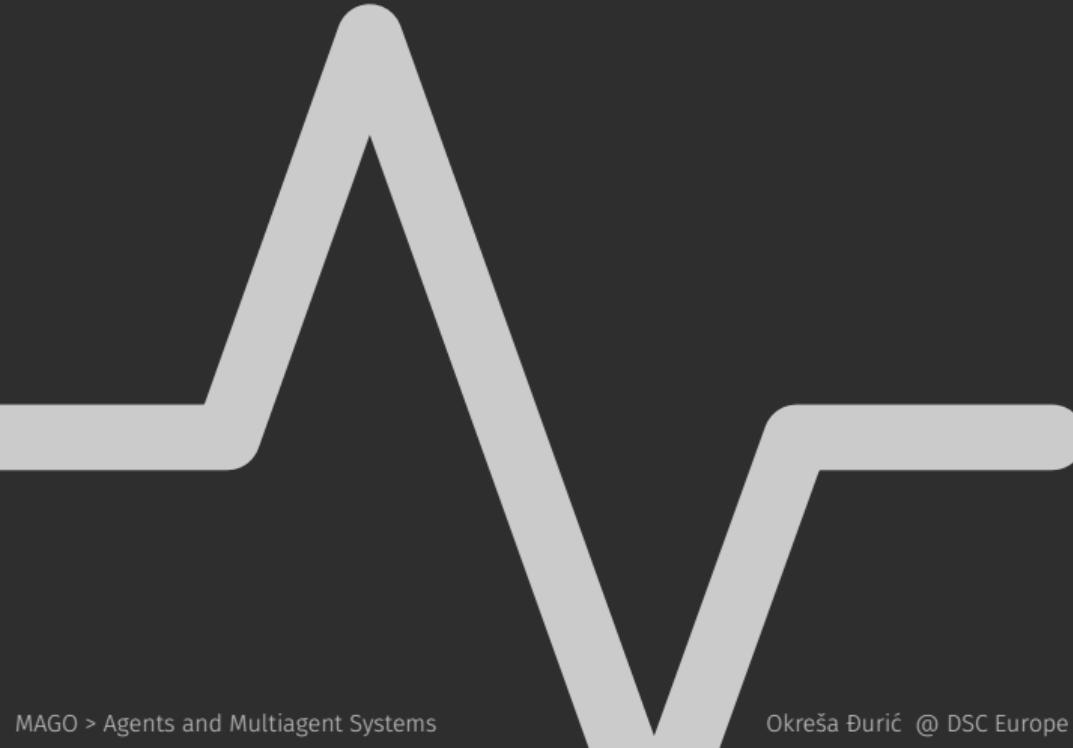
Conda environment with all the required dependencies.



Agents and Multiagent Systems: Implementing Agents

```
1 import spade
2
3
4 class DummyAgent(spade.agent.Agent):
5     async def setup(self):
6         print("Hello, world! I'm agent {}".format(str(self.jid)))
7
8
9     async def main():
10        dummy = DummyAgent("alice@localhost", "password")
11        await dummy.start()
12
13
14 if __name__ == "__main__":
15     spade.run(main())
```

Listing 1: Simple agent



ACTIVITY ➔

agent simple.py

Agents and Multiagent Systems

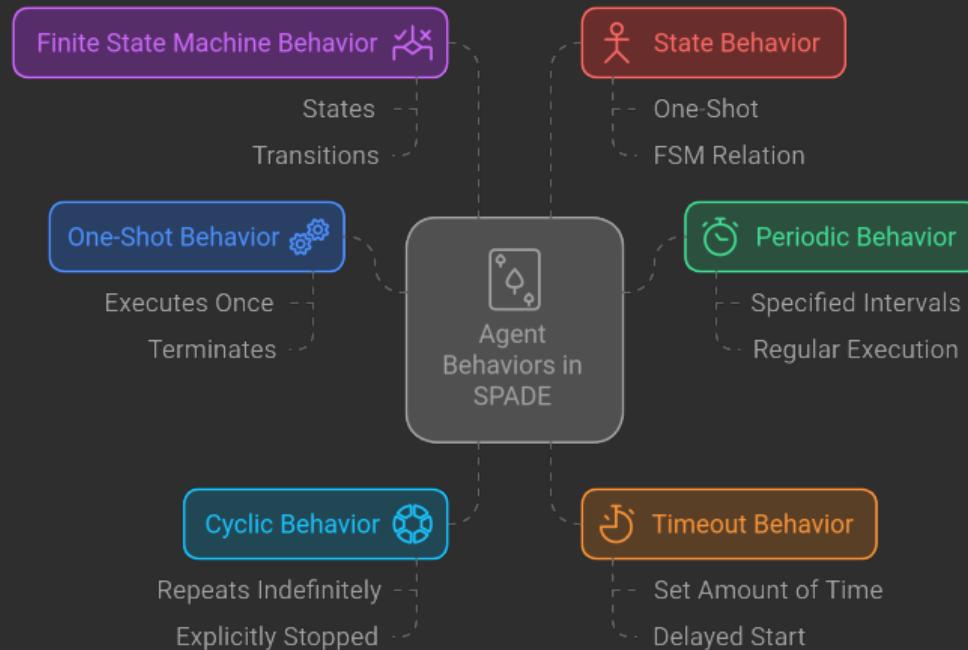


Figure 2: Different types of agent behaviours in SPADE

Agents and Multiagent Systems

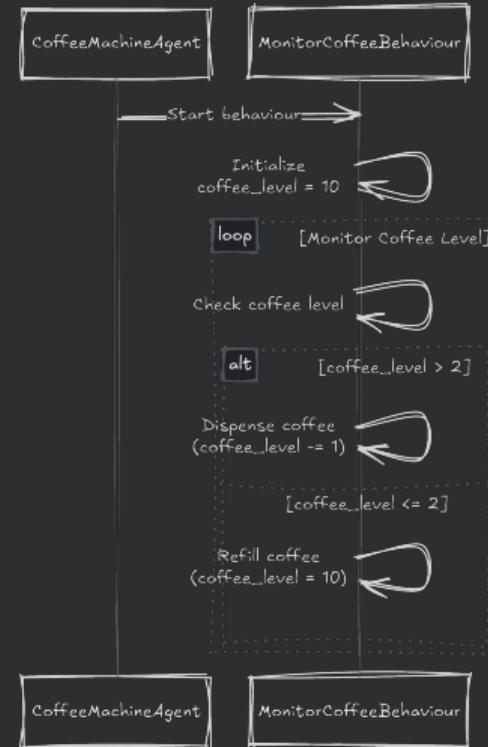
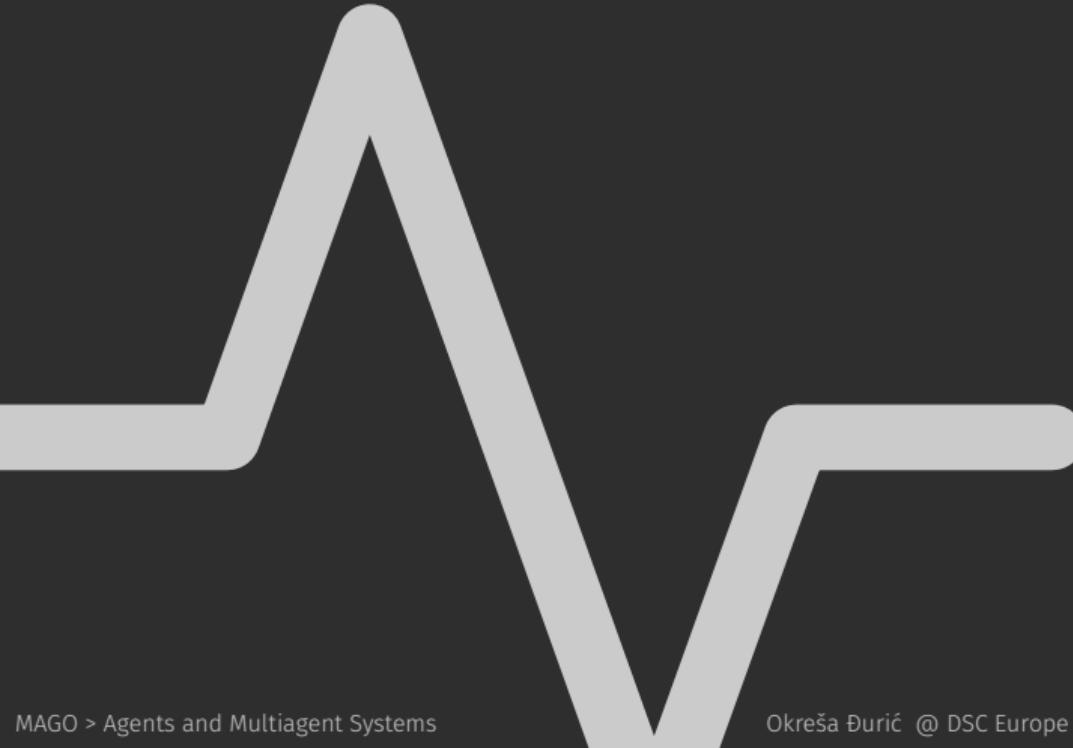


Figure 3: Visual representation of a simple coffee machine agent



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agent coffee.py

Agents and Multiagent Systems: Implementing Agents

```
7  class CoffeeMachineAgent(Agent):
8      class MonitorCoffeeBehaviour(CyclicBehaviour):
9          async def dispense_coffee(self):
10              await sleep(1)
11              self.coffee_level -= 1
12
13          async def refill_coffee(self):
14              self.coffee_level = 10
15              print("Coffee refilled to 10 cups.")
16              self.kill()
17
18          async def on_start(self):
19              print("Starting coffee monitoring . . .")
20              self.coffee_level = 10
21
22          async def run(self):
23              print(f"Current coffee level: {self.coffee_level} cups")
24
25          if self.coffee_level <= 2:
26              print("Low coffee level detected! Refilling coffee . . .")
27              await self.refill_coffee()
28          else:
29              print("Sufficient coffee level. Dispensing a cup . . .")
30              await self.dispense_coffee()
```

Listing 2: The coffee machine agent with a single behaviour

Agents and Multiagent Systems

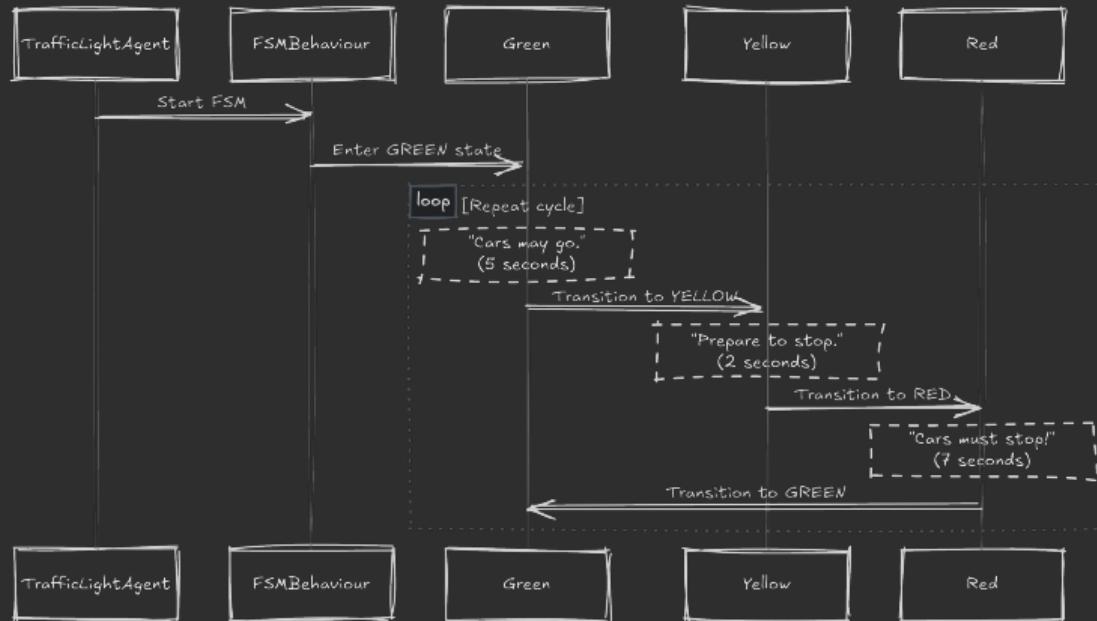
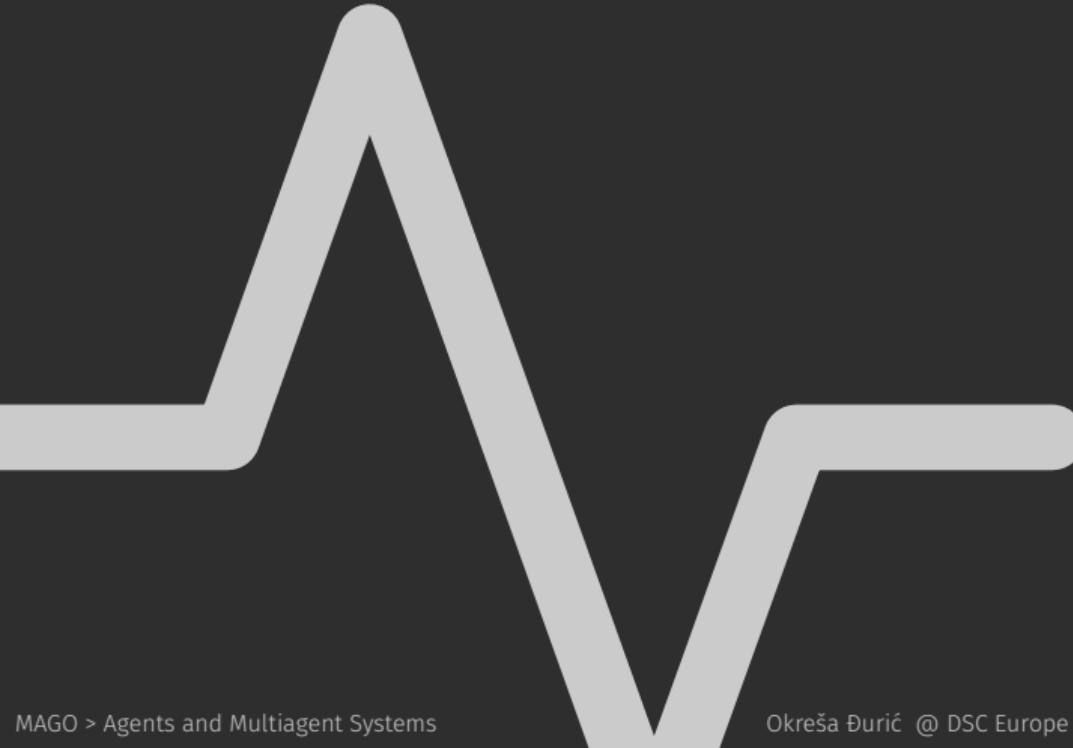


Figure 4: Visual representation of a traffic light agent with a finite state machine behaviour



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agent traffic light.py

Agents and Multiagent Systems

```
11  class TrafficLightFSMBehaviour(FSMBehaviour):
12      async def on_start(self):
13          print(f"Traffic Light FSM starting at
14              → initial state {self.current_state}")
15      async def on_end(self):
16          print(f"Traffic Light FSM finished at
17              → state {self.current_state}")
18          await self.agent.stop()
19
20  class GreenLightState(State):
21      async def run(self):
22          print("Green Light: Cars may go!")
23          await asyncio.sleep(5)
24          self.set_next_state(STATE_YELLOW)
25
26
27  class YellowLightState(State):
28      async def run(self):
29          print("Yellow Light: Prepare to stop!")
30          await asyncio.sleep(2)
31          self.set_next_state(STATE_RED)
```

```
34  class RedLightState(State):
35      async def run(self):
36          print("Red Light: Cars must stop!")
37          await asyncio.sleep(5)
38          self.set_next_state(STATE_GREEN)
39
40
41  class TrafficLightAgent(Agent):
42      async def setup(self):
43          fsm = TrafficLightFSMBehaviour()
44          fsm.add_state(name=STATE_GREEN,
45              → state=GreenLightState(), initial=True)
46          fsm.add_state(name=STATE_YELLOW,
47              → state=YellowLightState())
48          fsm.add_state(name=STATE_RED,
49              → state=RedLightState())
50          fsm.add_transition(source=STATE_GREEN,
51              → dest=STATE_YELLOW)
52          fsm.add_transition(source=STATE_YELLOW,
53              → dest=STATE_RED)
54          fsm.add_transition(source=STATE_RED,
55              → dest=STATE_GREEN)
56          self.add_behaviour(fsm)
```

Listing 3: Agent communication example

Agents and Multiagent Systems

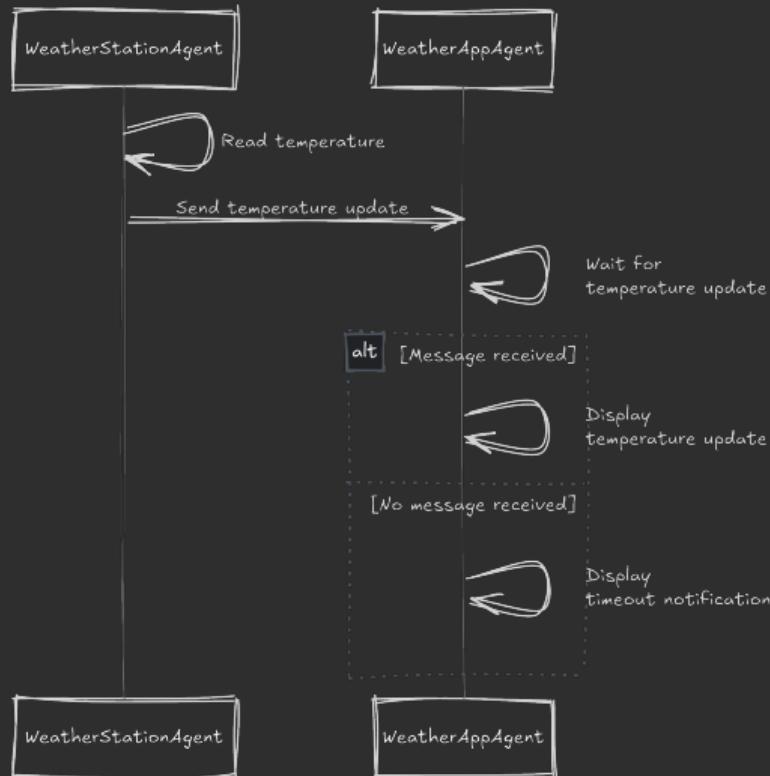
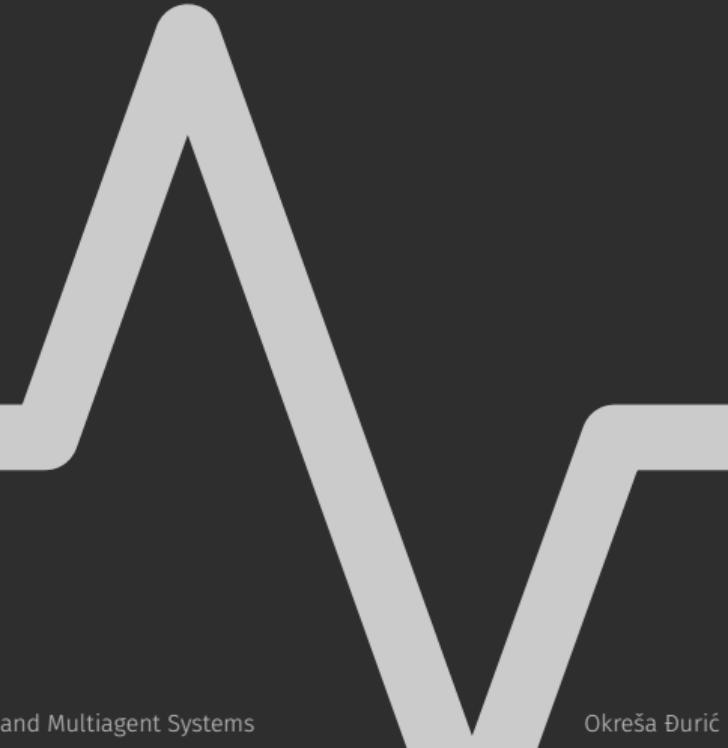


Figure 5: Visual representation of two communicating agents



ACTIVITY ➔

agent weather.py

Agents and Multiagent Systems

```
9  class WeatherStationAgent(Agent):
10     class
11         ↪ SendWeatherUpdateBehaviour(OneShotBehaviour):
12             async def run(self):
13                 temperature = random.uniform(-10, 40)
14                 msg =
15                     ↪ Message(to="weather_app@localhost")
16                     msg.set_metadata("performative",
17                         "inform")
18                     msg.body = f"Current temperature:
19                         {temperature:.1f}°C"
20
21                     await self.send(msg)
22                     print(f"Weather update sent:
23                         {msg.body}")
24
25                     await self.agent.stop()
26
27         async def setup(self):
28             behaviour =
29                 ↪ self.SendWeatherUpdateBehaviour()
30                 self.add_behaviour(behaviour)
31
32         ↪ ReceiveWeatherUpdateBehaviour(OneShotBehaviour):
33             async def run(self):
34                 print("Waiting for weather update...")
35                 msg = await self.receive(timeout=10)
36                 if msg:
37                     print(f"Weather update received:
38                         {msg.body}")
39                 else:
40                     print("No weather update received
41                         after 10 seconds.")
42
43             await self.agent.stop()
44
45             async def setup(self):
46                 behaviour =
47                     ↪ self.ReceiveWeatherUpdateBehaviour()
48                     template = Template()
49                     template.set_metadata("performative",
50                         "inform")
51                     self.add_behaviour(behaviour, template)
```

Listing 4: Agent communication example

Ontologies

‘The word ontology means a particular theory of the nature of being or existence. The ontology determines what kinds of things exist, but does not determine their specific properties and interrelationships.’ [2, p. 290]

An ontology is a vocabulary of a chosen domain.

An ontology is a ‘formal specification of a shared conceptualisation’ [4], [5].

An ontology is a knowledge model.

Ontologies

An ontology is often described as a set of **triples**:

(subject , predicate , object)

where:

- subject and object are usually **concepts**, their individuals, or literals,
- predicate is an object or a data **property**.

An example:

(a dog , can play with , a ball)

Common concepts related to ontologies:

Resource description framework (RDF) is a standard for representing data on the web using triples. It helps link and describe information so computers can understand relationships between different concepts.

Web ontology language (OWL) is a language for creating complex models of knowledge (i.e. ontologies) by defining relationships, classes, and rules. It extends RDF to enable reasoning, such as inferring new facts from given data.

Ontologies

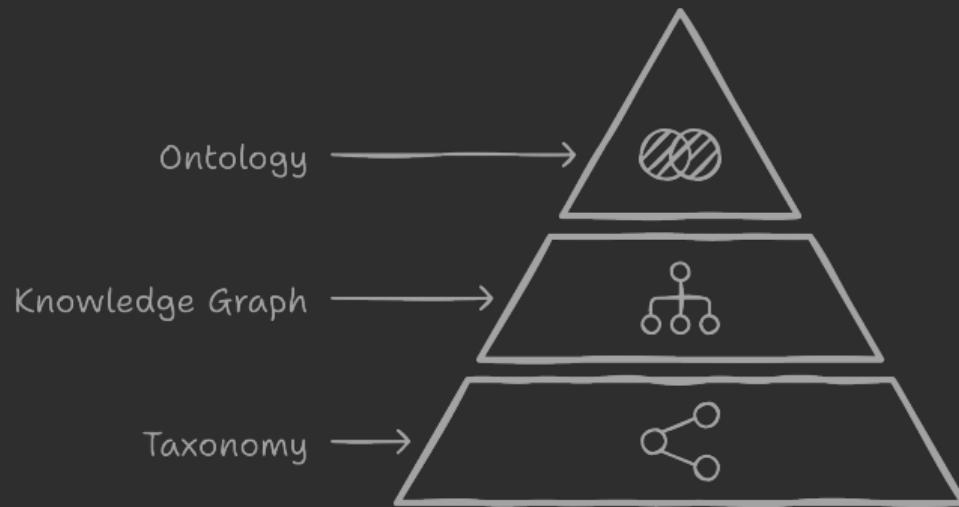


Figure 6: Hierarchical visualisation of information structures taxonomy, knowledge graph, and ontology

Ontologies

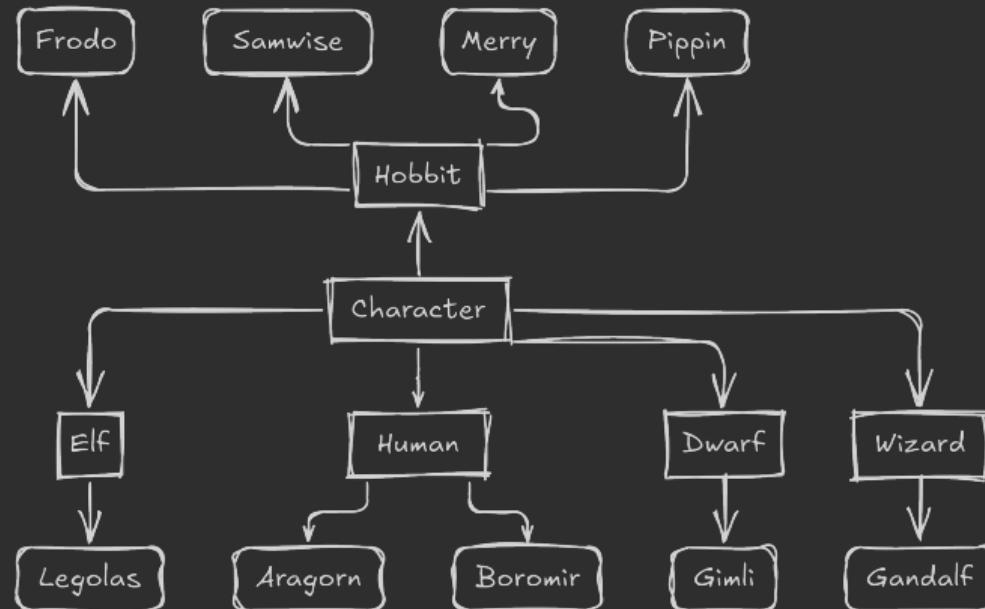


Figure 7: Taxonomy of the selected concepts of the Lord of the Rings novel by J. R. R. Tolkien [6]

Ontologies

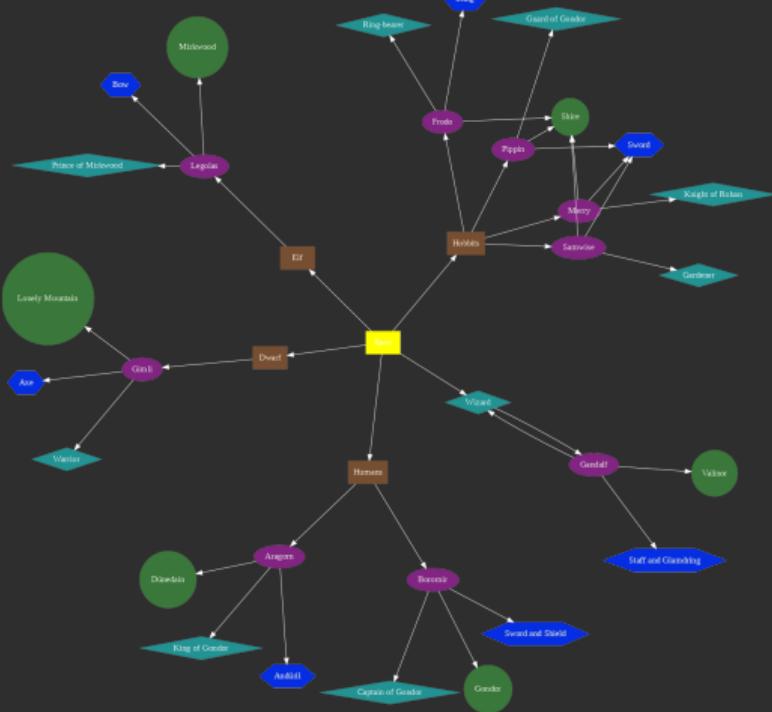


Figure 8: Knowledge graph of the selected concepts of the Lord of the Rings novel by J. R. R. Tolkien

Ontologies

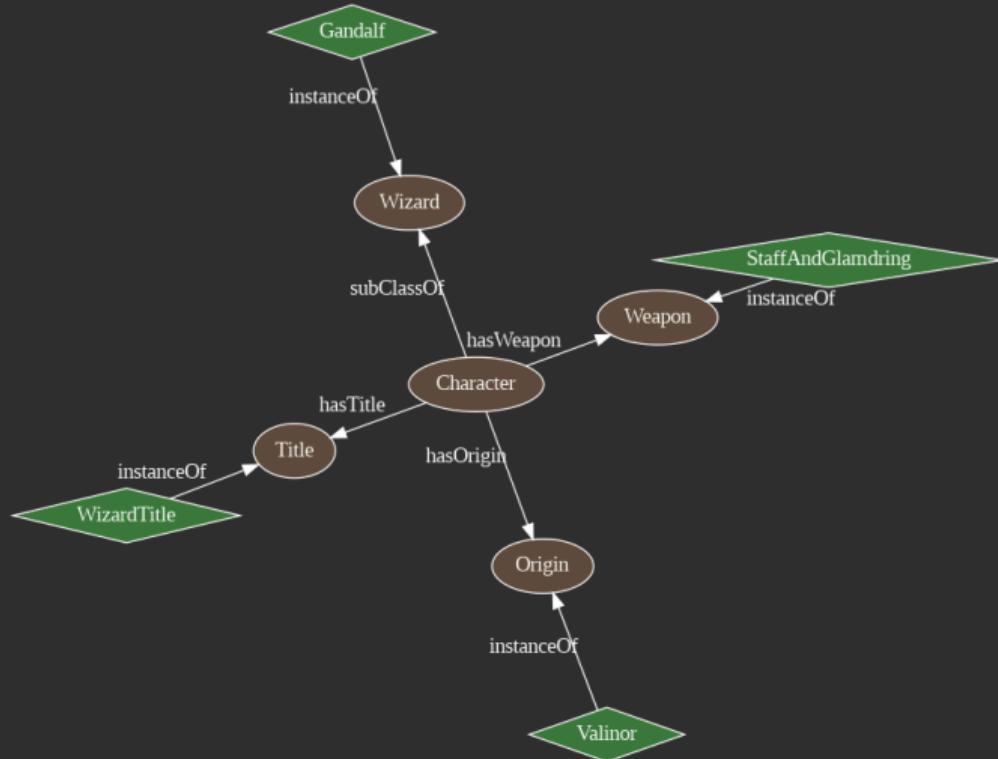


Figure 9: Ontology visualisation of the selected concepts of the Lord of the Rings novel by J. R. R. Tolkien

An ontology is more than a visual representation of related concepts.

Ontologies

```
7 # Ontology
8 <http://example.org/lotr> a
9   → owl:Ontology .
10
11 # Classes
12 :Character a owl:Class .
13 :Wizard a owl:Class ;
14   rdfs:subClassOf :Character .
15
16 :Title a owl:Class .
17 :Weapon a owl:Class .
18 :Origin a owl:Class .
19
20 # Object Properties
21 :hasTitle a owl:ObjectProperty
22   → ;
23     rdfs:domain :Character ;
24     rdfs:range :Title .
25
26 :hasWeapon a
27   → owl:ObjectProperty ;
28     rdfs:domain :Character ;
29     rdfs:range :Weapon .
30
31 :hasOrigin a
32   → owl:ObjectProperty ;
33     rdfs:domain :Character ;
34     rdfs:range :Origin .
35
36 # Individuals
37 :Gandalf a :Wizard ;
38   :hasTitle :WizardTitle ;
39   :hasWeapon
40   → :StaffAndGlamdring ;
41   :hasOrigin :Valinor .
42
43 :WizardTitle a :Title ;
44   rdfs:label "Wizard" .
45
46 :StaffAndGlamdring a :Weapon ;
47   rdfs:label "Staff and
48   → Glamdring" .
49
50 :Valinor a :Origin ;
51   rdfs:label "Valinor" .
```

Listing 5: Ontology serialisation using Turtle syntax

Ontologies

```
33 # Individuals
34 :Gandalf a :Wizard ;
35   :hasTitle :WizardTitle ;
36   :hasWeapon :StaffAndGlamdring ;
37   :hasOrigin :Valinor .
38
39 :WizardTitle a :Title ;
40   rdfs:label "Wizard" .
41
42 :StaffAndGlamdring a :Weapon ;
43   rdfs:label "Staff and Glamdring" .
44
45 :Valinor a :Origin ;
46   rdfs:label "Valinor" .
```

```
1 individual(gandalf).
2 type(gandalf, wizard).
3
4 individual(wizard_title).
5 type(wizard_title, title).
6 label(wizard_title, "Wizard").
7
8 individual(staff_and_glamdring).
9 type(staff_and_glamdring, weapon).
10 label(staff_and_glamdring, "Staff and Glamdring").
11
12 individual(valinor).
13 type(valinor, origin).
14 label(valinor, "Valinor").
15
16 has_title(gandalf, wizard_title).
17 has_weapon(gandalf, staff_and_glamdring).
18 has_origin(gandalf, valinor).
```

Listing 6: Ontology individual serialisation using Turtle syntax vs. ontology individual as Prolog expressions

Ontologies

An ontology is a **shared** vocabulary of a chosen domain.

8 <<http://example.org/lotr>> a owl:Ontology .

Ontologies



Figure 10: Concepts of the MAGO-Ag ontology

RecipeWorld example

RecipeWorld [7] is an agent-based model comprising three distinct foundational elements: recipes, orders, and agents. In general, agents within recipeWorld can be considered as **service providers** and **service consumers**.

Order agents need services as detailed in their recipes, while **factory** agents provide a subset of all the services available in the system.

The original framework's goal is to simulate 'the emergence of networks out of a decentralized autonomous interaction.' [7]



ACTIVITY ↗

Protégé



ACTIVITY ↗

Finalised recipeWorld

MAGO

The result of a cooperation between:

- University of Zagreb Faculty of Organization and Informatics (**UNIZG FOI**) and
- Universitat Politècnica de València (**UPV**), Valencian Research Institute for Artificial Intelligence (**VRAIN**).

The European Union and the Croatian Science Foundation fund this cooperation.

Developing a MAGO

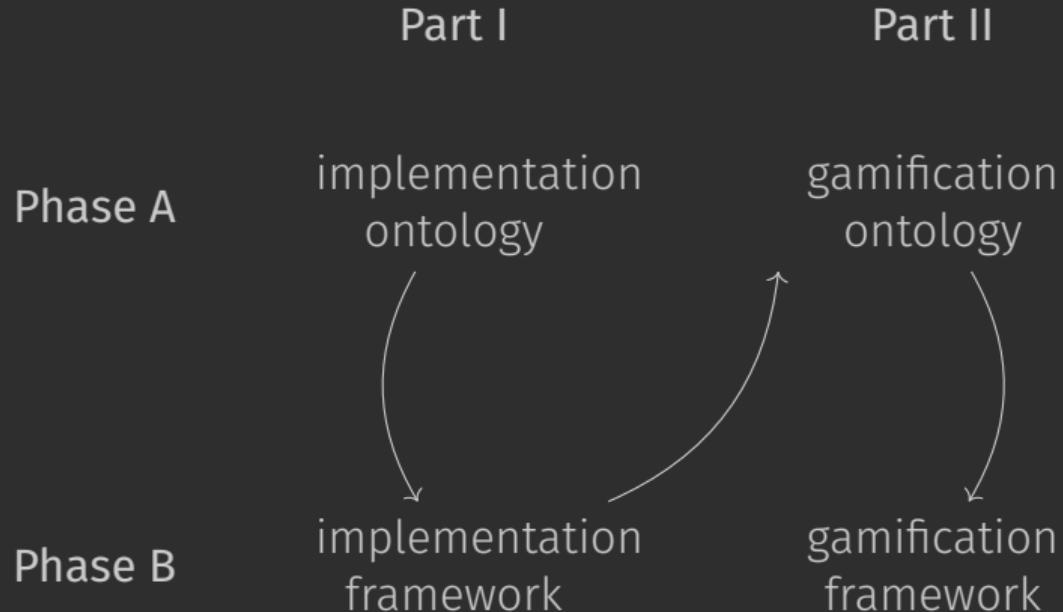


Figure 11: The flow between the parts and the phases of this research

MAGO

MAGO-Ag Ontology

- An ontology comprising concepts applicable to **implementing MASs as intelligent virtual environments (IVEs)**.
- The **main goal** of the ontology is to enable the modelling of a multiagent system in terms of implementation possibilities.
- The ontology contains a selection of modified and enriched concepts of the MAMbO5 ontology, a result of earlier cooperation [8].
 - e.g. Agent, Behaviour, Action, Process, Objective, Artefact

MAGO-Ag Ontology

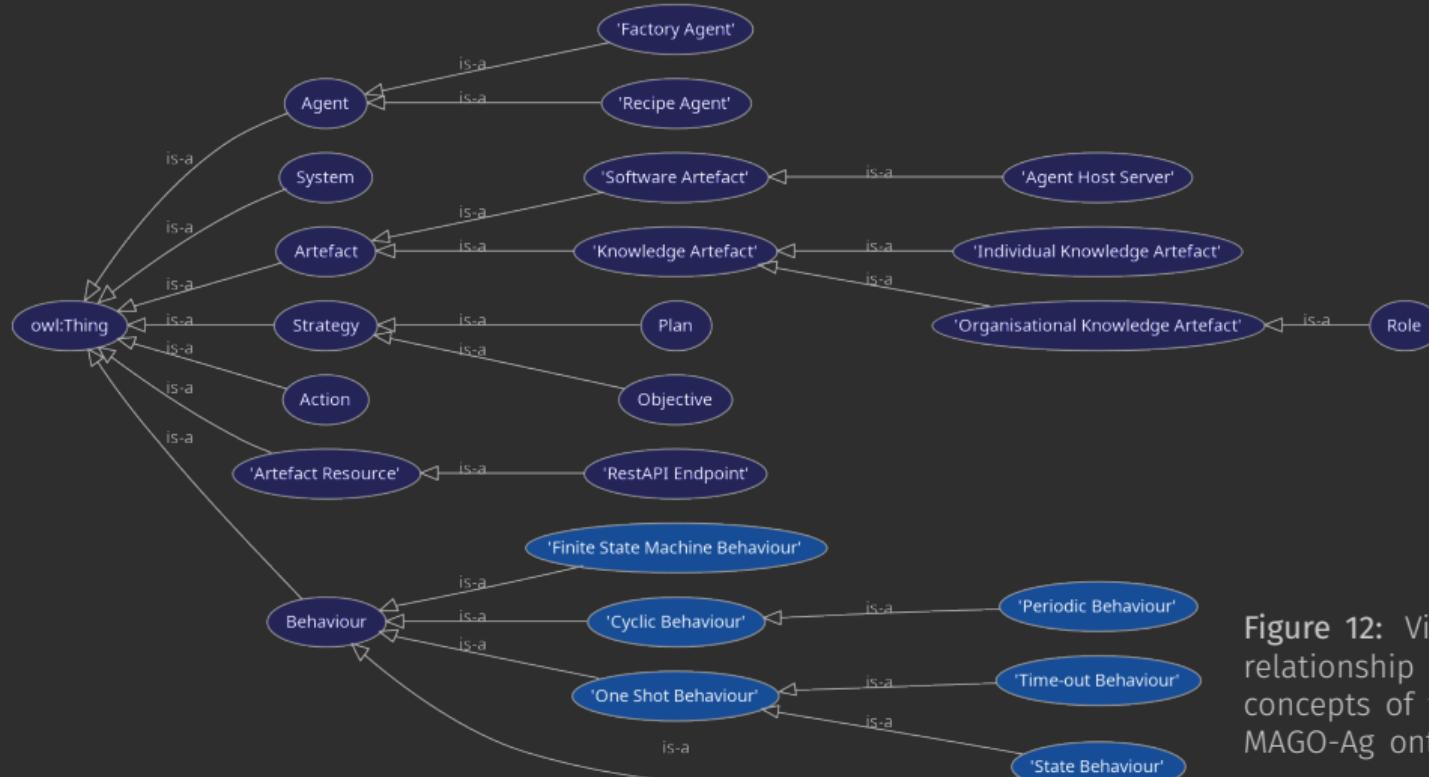


Figure 12: Visual relationship of the concepts of the MAGO-Ag ontology

MAGO

MAGO-Ag Framework

- The **main objective** of the MAGO-Ag framework is to translate a MAS modelled using the MAGO-Ag ontology into an **implementation template** for a MAS comprising SPADE agents.

MAGO-Ag Framework

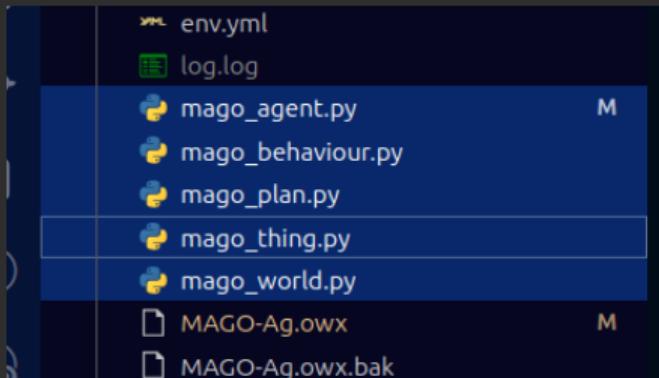


Figure 13: Essential files of the translation process



ACTIVITY

MAGO-Ag framework

MAGO-Ag Framework

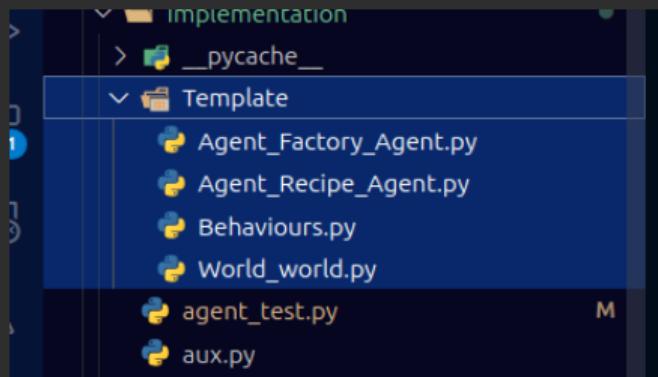


Figure 14: Generated template files for the modelled system

MAGO-Ag Framework

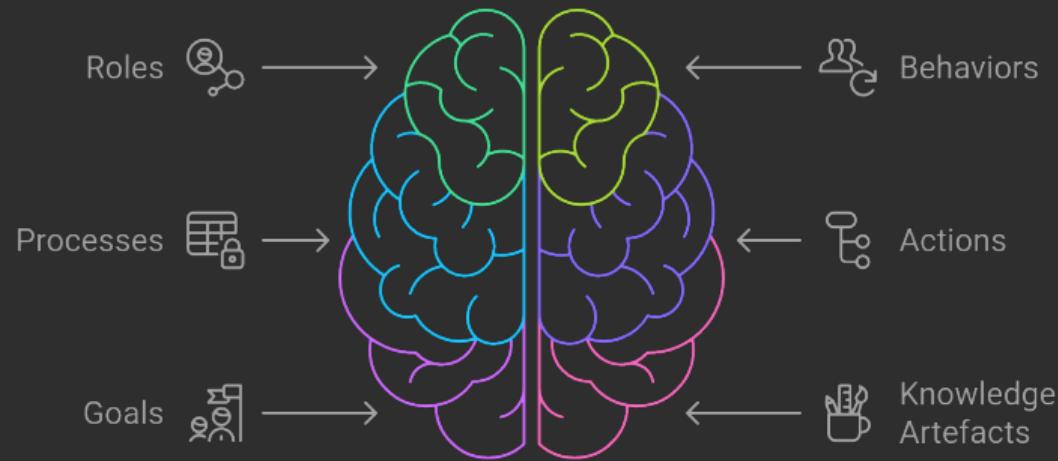


Figure 15: Pieces of knowledge available to agents after template generation

Conclusion

Conclusion

In its presented state, the framework is a **work-in-progress** package.

Further improvements are seen in:

- rendering strategy-related concepts using languages that allow for reasoning;
- implementing the framework as a distributed system that would focus on deploying agent implementation templates over several workspaces;
- use the MAGO-Ag ontology to facilitate sending agent information and whole agents;
- further testing the framework using different scenarios;
- adapting the implementation templates to different agent development frameworks;
- using the MAGO-Ag ontology in combination with a language model.

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