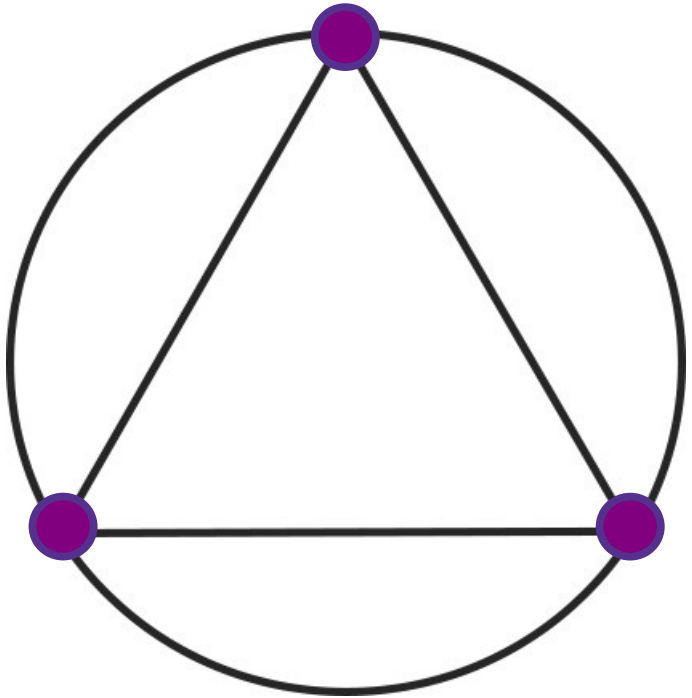
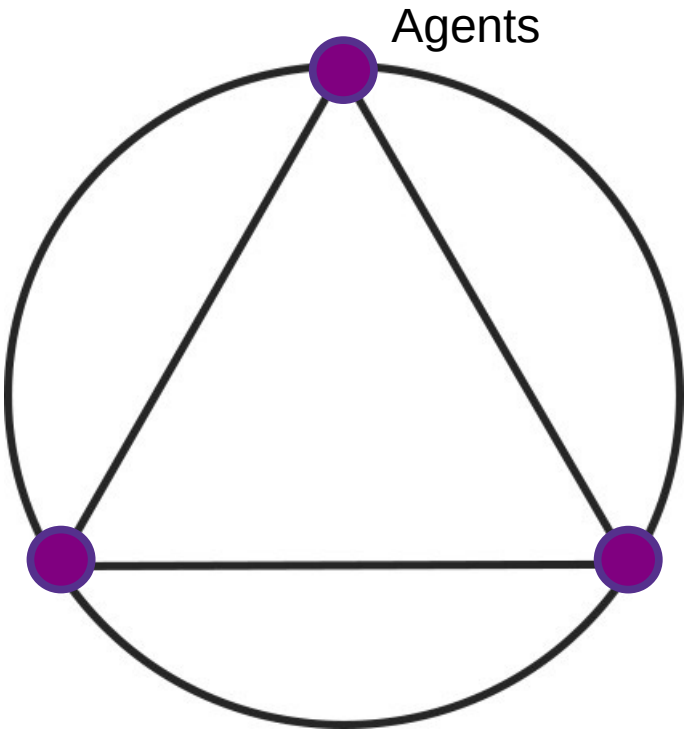
Geometric and Spatial Reasoning in BDI Agents: a Survey

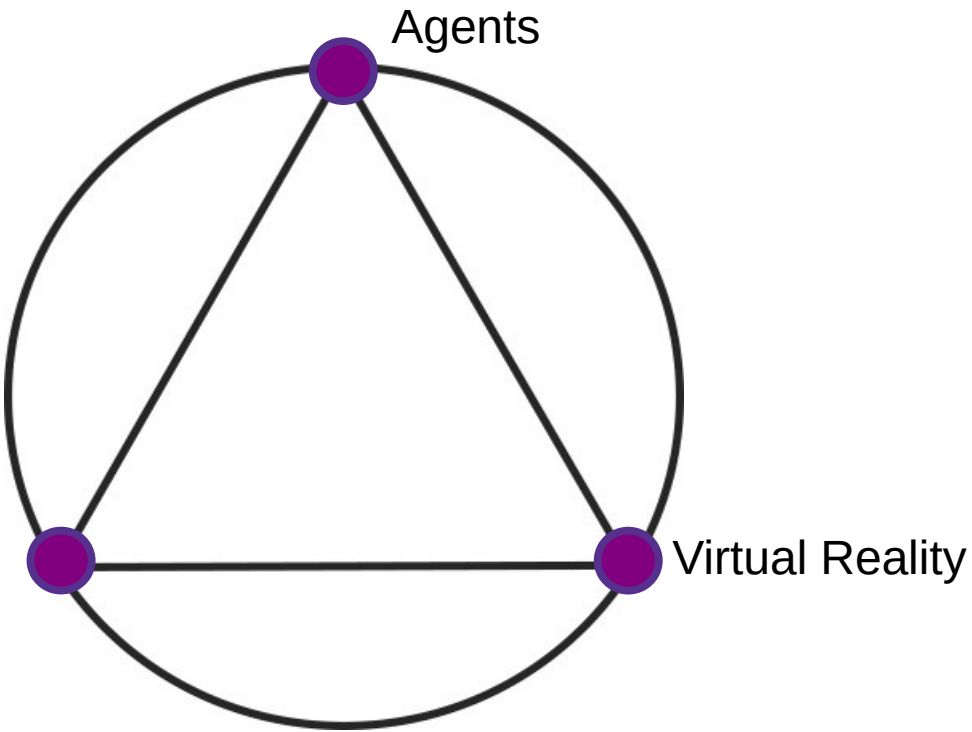
The context



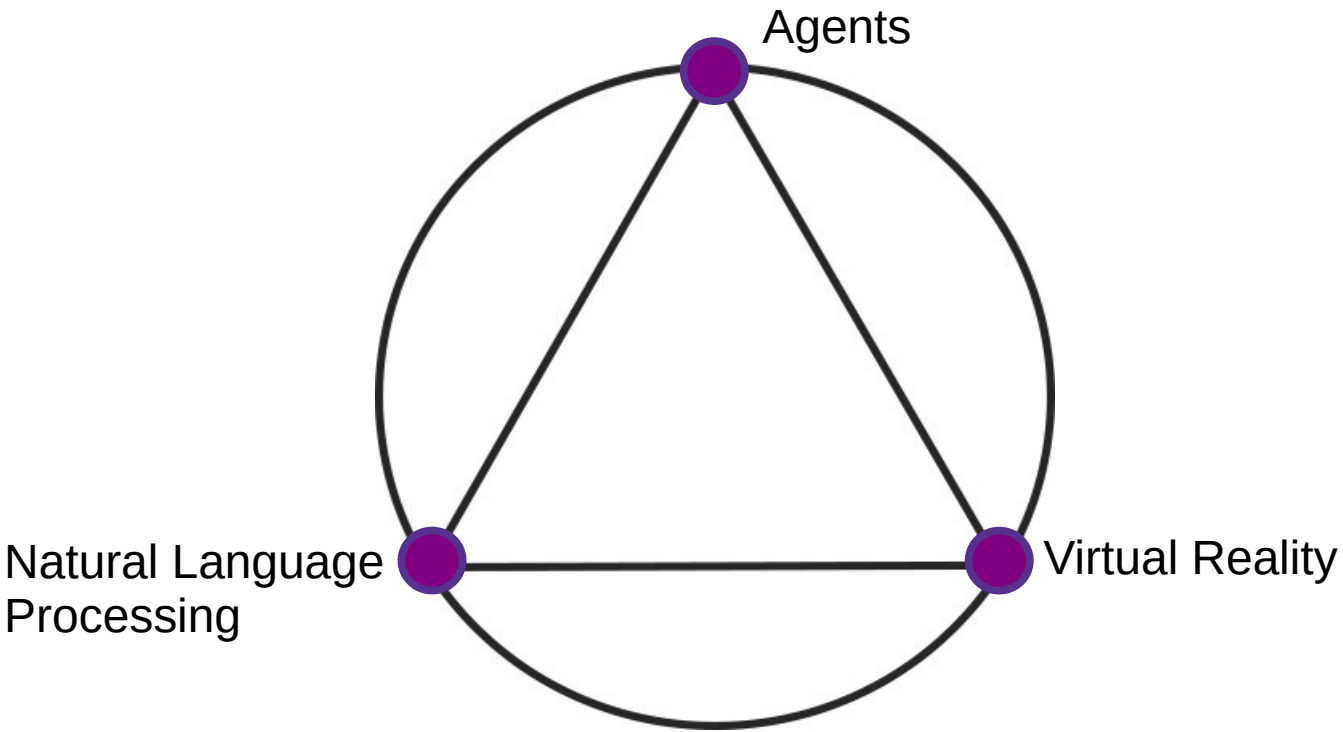
ENGINES

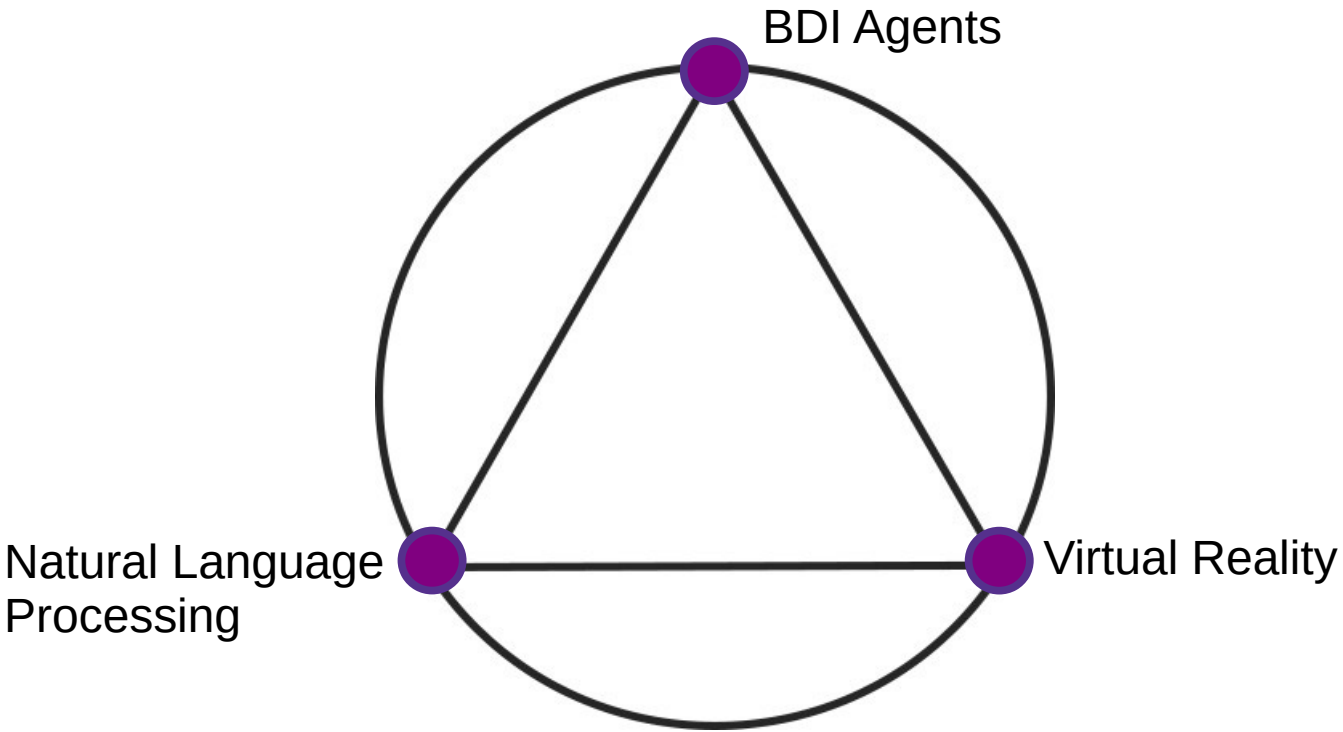


ENGINES

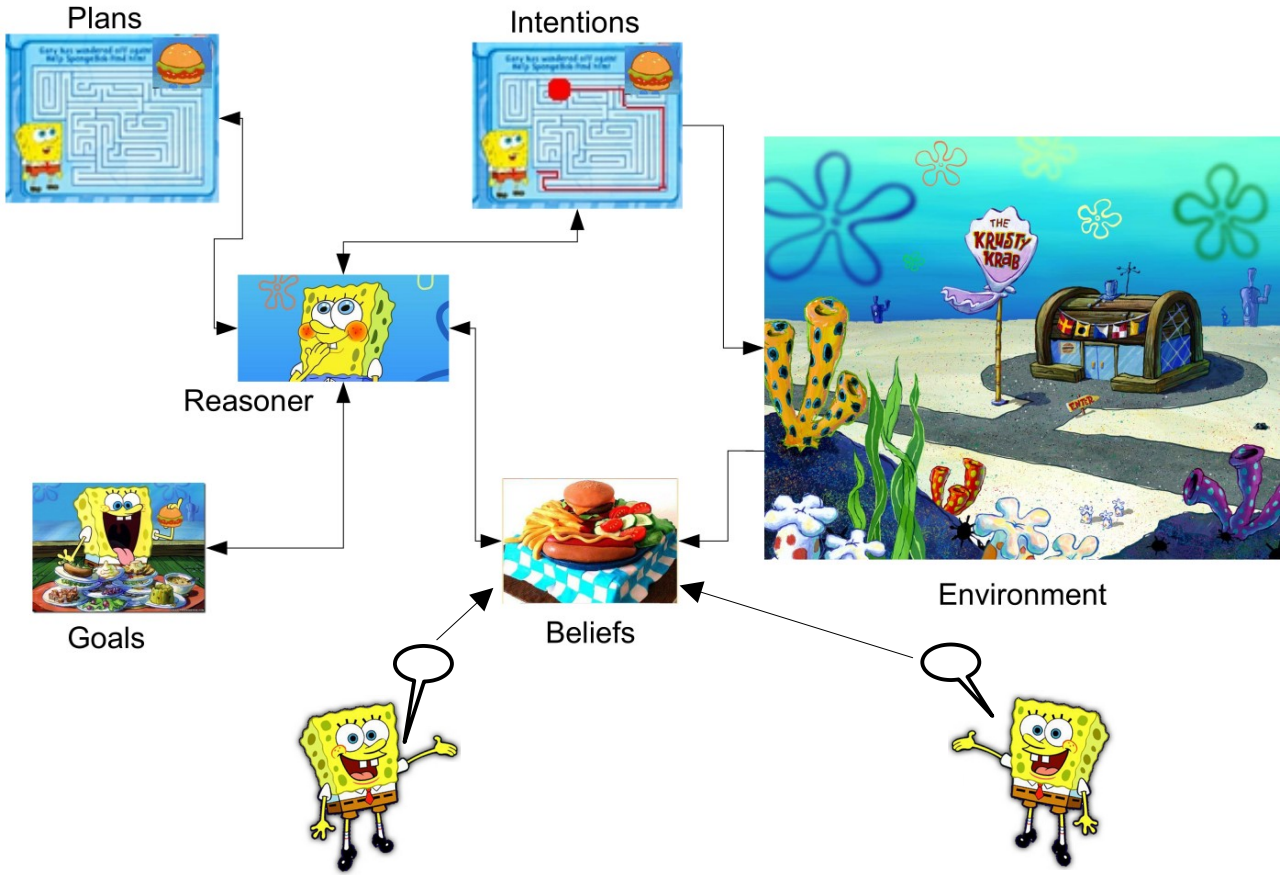


ENGINES


Agents
Natural Language Processing
Virtual Reality


BDI Agents
Natural Language Processing
Virtual Reality

The BDI architecture



VEsNA

VEsNA

Andrea Gatti, Viviana Mascardi:
VEsNA, a Framework for Virtual Environments via Natural Language Agents and Its Application to Factory Automation. Robotics 12(2): 46 (2023)
(revised and extended version of an **AREA 2022** paper)

ENGINES

VEsNA

Open source project available at: https://github.com/driacats/VEsNA

ENGINES

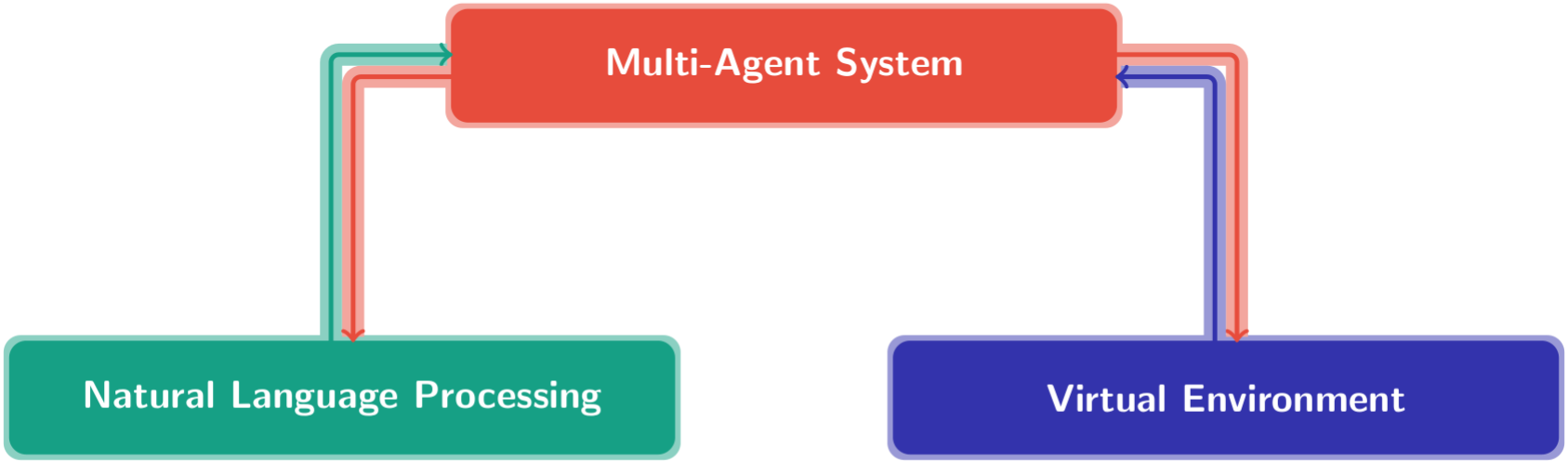
Virtual Environments via Natural language Agents

Multi-Agent System

Natural Language Processing

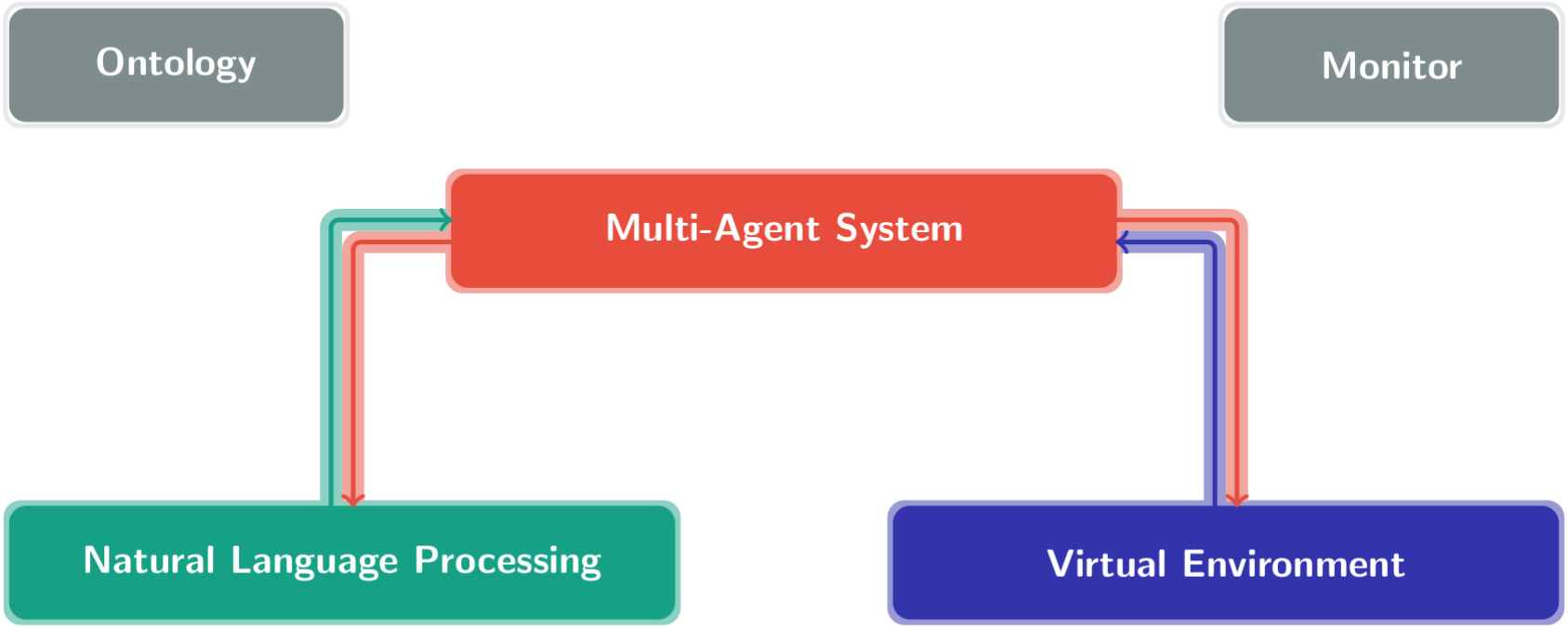
Virtual Environment

Virtual Environments via Natural language Agents



ENGINES

Virtual Environments via Natural language Agents



ENGINES

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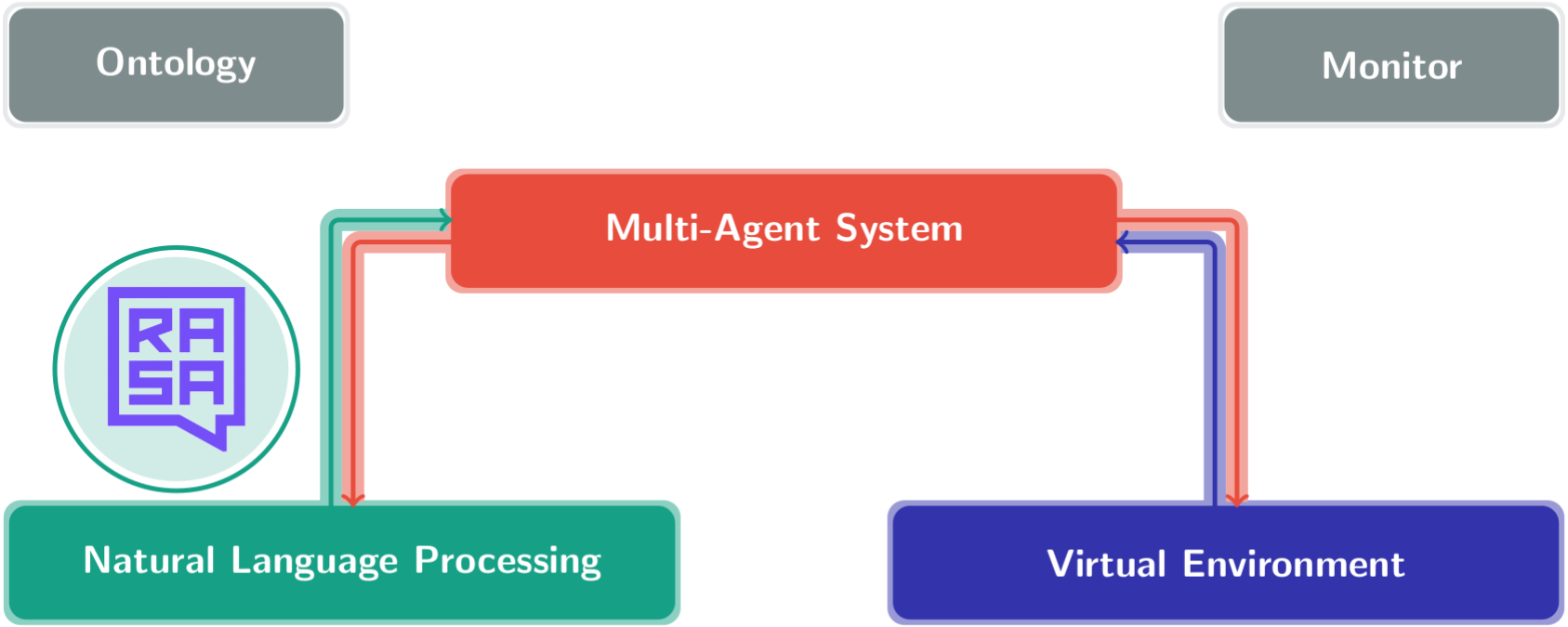
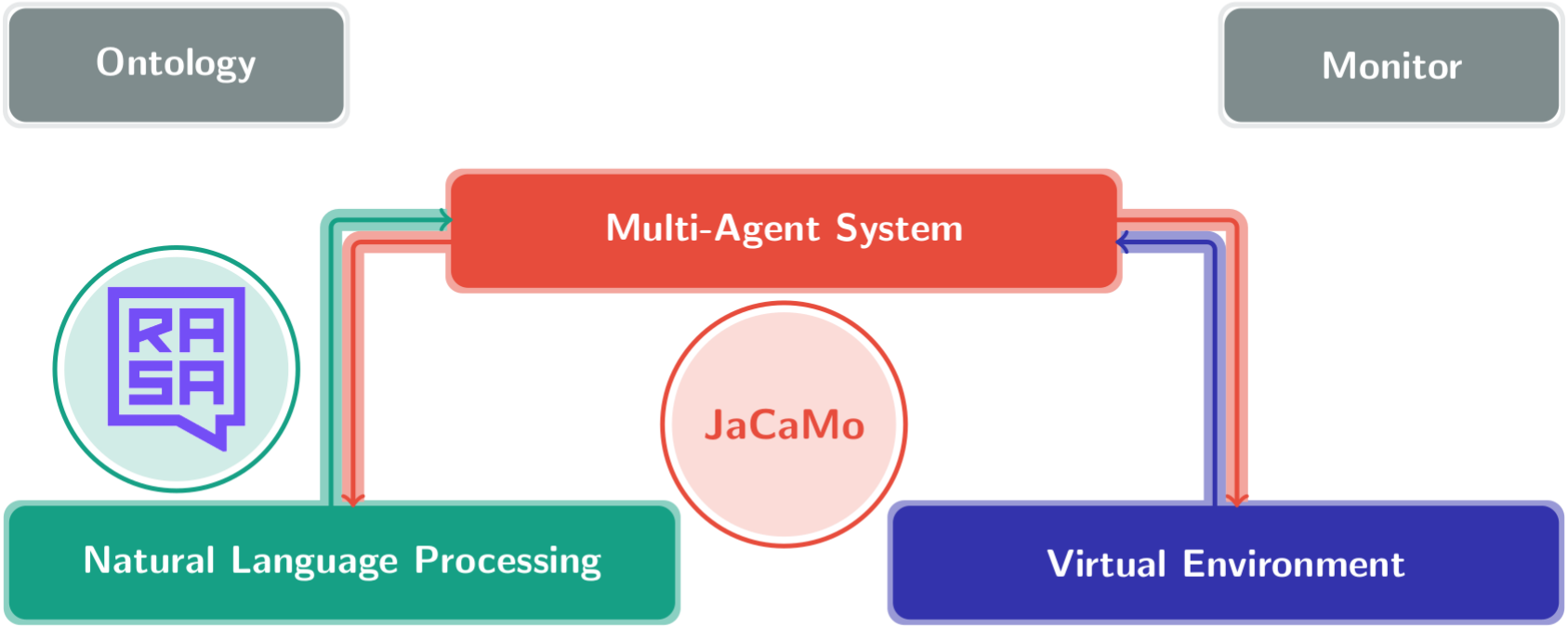
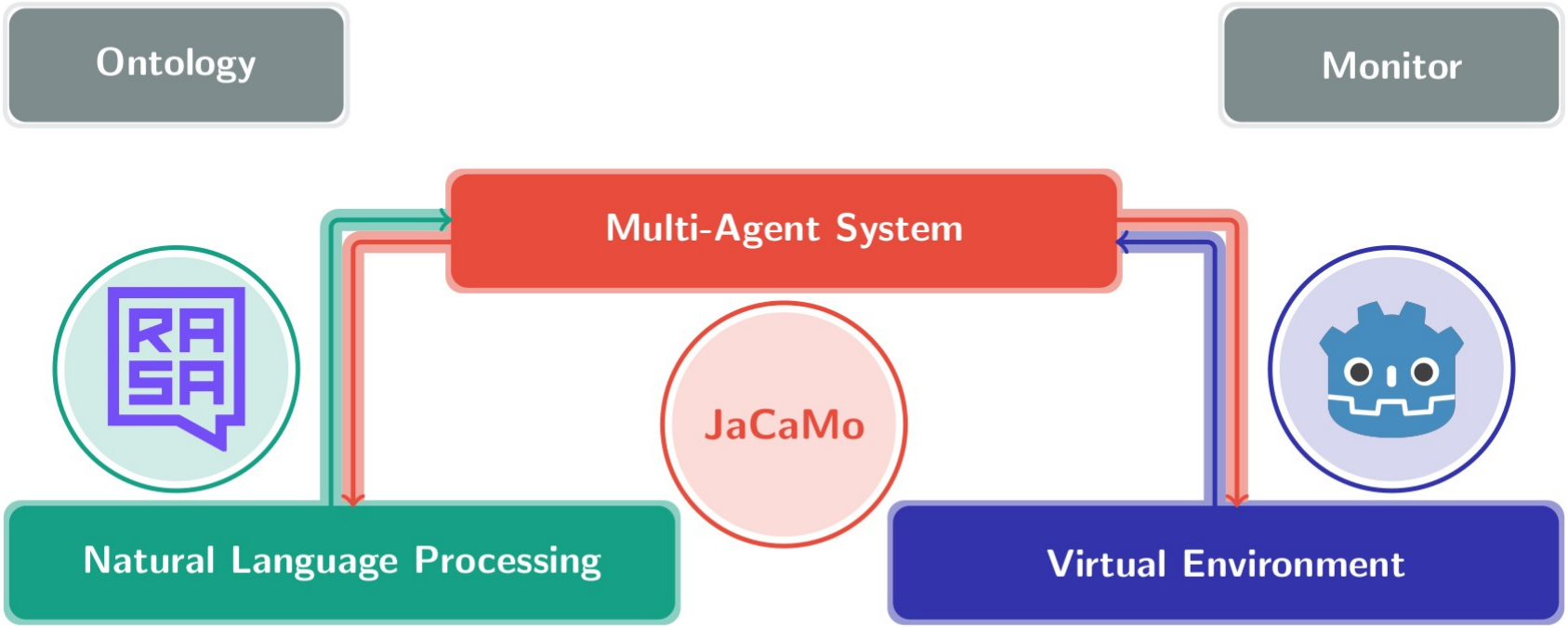


Virtual Environments via Natural language Agents



Virtual Environments via Natural language Agents



On spatial reasoning (this paper)

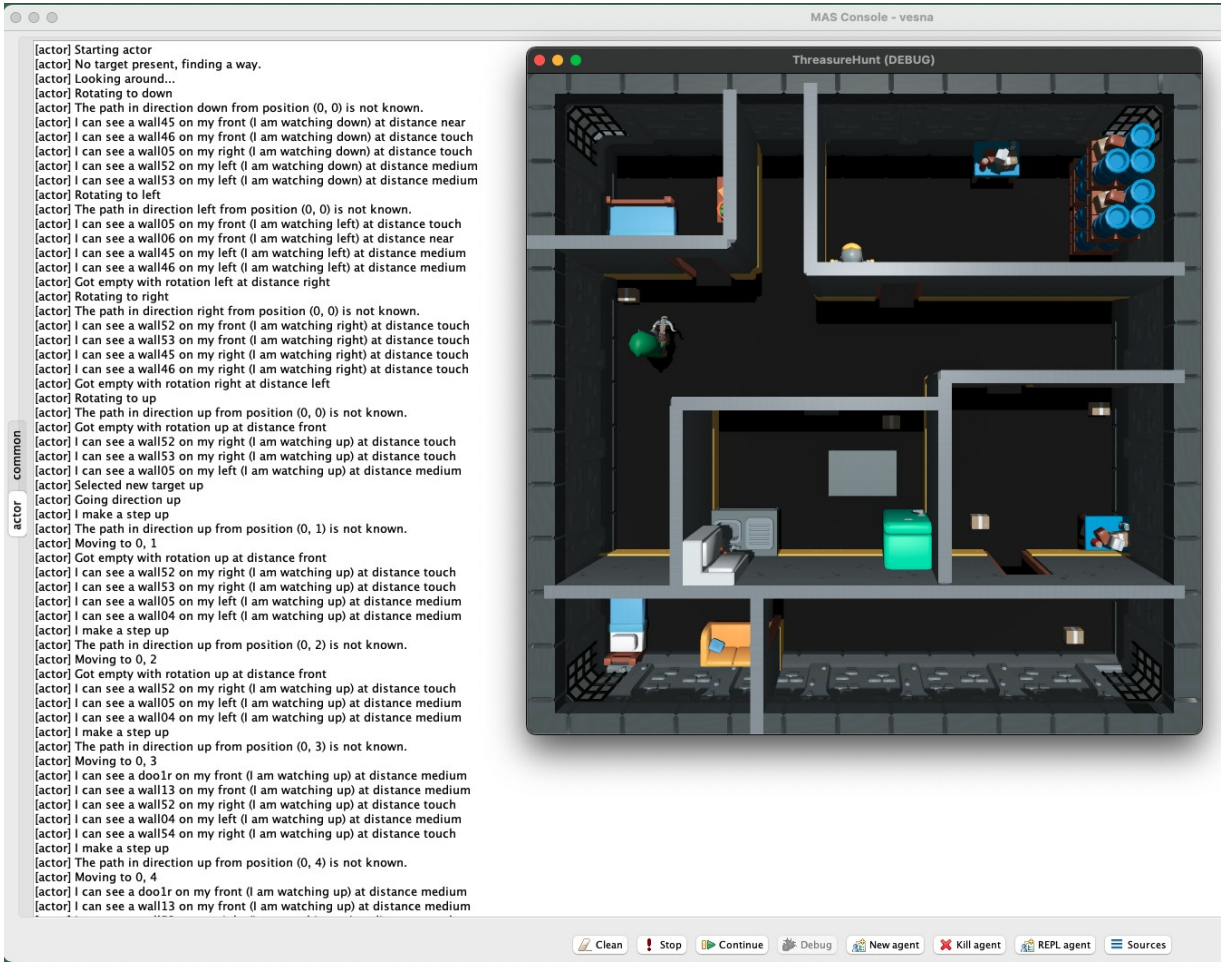
On spatial reasoning (this paper)

Angelo Ferrando, Andrea Gatti, Viviana Mascardi:
Geometric and Spatial Reasoning in BDI Agents: a Survey
CILC 2024

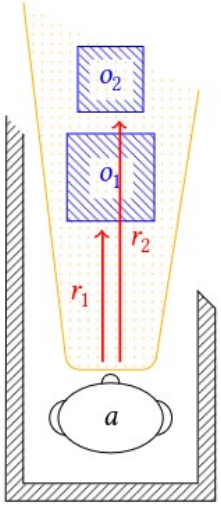
ENGINES

RQ1

How can VEsNA agents perceive the unknown virtual reality they are situated in?


MAS Console - vesna
[actor] Starting actor
[actor] No target present, finding a way.
[actor] Looking around...
[actor] Rotating to down
[actor] The path in direction down from position (0, 0) is not known.
[actor] I can see a wall45 on my front (I am watching down) at distance near
[actor] I can see a wall46 on my front (I am watching down) at distance touch
[actor] I can see a wall05 on my right (I am watching down) at distance touch
[actor] I can see a wall52 on my left (I am watching down) at distance medium
[actor] I can see a wall53 on my left (I am watching down) at distance medium
[actor] Rotating to left
[actor] The path in direction left from position (0, 0) is not known.
[actor] I can see a wall05 on my front (I am watching left) at distance touch
[actor] I can see a wall06 on my front (I am watching left) at distance near
[actor] I can see a wall45 on my left (I am watching left) at distance medium
[actor] I can see a wall46 on my left (I am watching left) at distance medium
[actor] Got empty with rotation left at distance right
[actor] Rotating to right
[actor] The path in direction right from position (0, 0) is not known.
[actor] I can see a wall52 on my front (I am watching right) at distance touch
[actor] I can see a wall53 on my front (I am watching right) at distance touch
[actor] I can see a wall45 on my right (I am watching right) at distance touch
[actor] I can see a wall46 on my right (I am watching right) at distance touch
[actor] Got empty with rotation right at distance left
[actor] Rotating to up
[actor] The path in direction up from position (0, 0) is not known.
[actor] Got empty with rotation up at distance front
[actor] I can see a wall52 on my right (I am watching up) at distance touch
[actor] I can see a wall53 on my right (I am watching up) at distance touch
[actor] I can see a wall05 on my left (I am watching up) at distance medium
[actor] Selected new target up
[actor] Going direction up
[actor] I make a step up
[actor] The path in direction up from position (0, 1) is not known.
[actor] Moving to 0, 1
[actor] Got empty with rotation up at distance front
[actor] I can see a wall52 on my right (I am watching up) at distance touch
[actor] I can see a wall53 on my right (I am watching up) at distance touch
[actor] I can see a wall05 on my left (I am watching up) at distance medium
[actor] I can see a wall04 on my left (I am watching up) at distance medium
[actor] I make a step up
[actor] The path in direction up from position (0, 2) is not known.
[actor] Moving to 0, 2
[actor] Got empty with rotation up at distance front
[actor] I can see a wall52 on my right (I am watching up) at distance touch
[actor] I can see a wall05 on my left (I am watching up) at distance medium
[actor] I can see a wall04 on my left (I am watching up) at distance medium
[actor] I make a step up
[actor] The path in direction up from position (0, 3) is not known.
[actor] Moving to 0, 3
[actor] I can see a doo1r on my front (I am watching up) at distance medium
[actor] I can see a wall13 on my front (I am watching up) at distance medium
[actor] I can see a wall52 on my right (I am watching up) at distance touch
[actor] I can see a wall04 on my left (I am watching up) at distance medium
[actor] I can see a wall54 on my right (I am watching up) at distance touch
[actor] I make a step up
[actor] The path in direction up from position (0, 4) is not known.
[actor] Moving to 0, 4
[actor] I can see a doo1r on my front (I am watching up) at distance medium
[actor] I can see a wall13 on my front (I am watching up) at distance medium
common
actor
ThreasureHunt (DEBUG)
Clean
Stop
Continue
Debug
New agent
Kill agent
REPL agent
Sources

ENGINES



1. `var objects = sight.get_overlapping_bodies()`

2. Does r_1 from a to o_1 intersect other objects? *No*
   Does r_2 from a to o_2 intersect other objects? *Yes, o_1*
   Only o_1 is visible to the agent a , o_2 is occluded, sending:

```
{perception: sight,
 data: {object: o_1, rotation: up, distance: near}}
```

3. The message is received by the environment artifact and a signal is sent to the agent:

```
signal("seen", parseLiteral(obj), parseLiteral(rot), parseLiteral(dist);
```

4. The actor reacts to the signal, knows its actual position and adds a belief:

```
+seen(Object, Rotation, Distance)
    :   position(X, Y)
    <-  +saw(X, Y, Direction, Object, Distance).
```

Assuming the agent in position $(0, 0)$ the new belief is:

```
saw(0, 0, up, o_1, near).
```

ENGINES

RQ2

How can VEsNA agents create and maintain a geometric representation of their environment?

Review query

("geometry" OR "geometric modeling" OR "geometric modelling") AND "BDI"

ENGINES

Review query

("geometry" OR "geometric modeling" OR "geometric modelling") AND "BDI"

Inclusion: 2005-2024; 20 results under review, only two used the acronym BDI as Belief-Desire-Intention (but I discovered Boron–Diindomethene, Beck Depression Inventory and Blood Damage Index), and they were not relevant for answering Q2.

ENGINES

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ENGINES

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("geometry" OR "geometric modeling" OR "geometric modelling") AND "Belief Desire Intention"

ENGINES

Review query

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("geometry" OR "geometric modeling" OR "geometric modelling") AND "Belief Desire Intention"

Inclusion: 2005-2024; some results related with the BDI architecture as we intend it, but still none provided us with useful hints on how to model the geometric features of a 3D environment in a generic BDI framework.

ENGINES

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("geometry" OR "geometric modeling" OR "geometric modelling") AND "prolog"

ENGINES

Review query

("geometry" OR "geometric modeling" OR "geometric modelling") AND "BDI"

Inclusion: 2005-2024; 20 results under review, only two used the acronym BDI as Belief-Desire-Intention (but I discovered Boron–Diindomethene, Beck Depression Inventory and Blood Damage Index), and they were not relevant for answering Q2.

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Inclusion: 2005-2024; some results related with the BDI architecture as we intend it, but still none provided us with useful hints on how to model the geometric features of a 3D environment in a generic BDI framework.

("geometry" OR "geometric modeling" OR "geometric modelling") AND "prolog"

[21] V. Marinkovic, Prolog in automated reasoning in geometry, in: Prolog: The Next 50 Years, volume 13900 of Lecture Notes in Computer Science, Springer, 2023, pp. 334–345.

ENGINES

Review query

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[21] V. Marinkovic, Prolog in automated reasoning in geometry, in: Prolog: The Next 50 Years, volume 13900 of Lecture Notes in Computer Science, Springer, 2023, pp. 334–345.

RQ3

How can VEsNA agents reason about spatial relations?

SLR Criteria

"spatial reasoning" AND "BDI"
"spatial reasoning" AND "Beliefs Desires Intentions"
"spatial reasoning" AND "prolog"
"spatial reasoning" AND "logic programming"

Inclusion: last 20 years; for each query above, we analysed the first 10 results.

We excluded books, technical reports, PhD theses, master theses (apart the one returned by multiple queries and hence included because of its relevance).

ENGINES

Ref.	Year	Model. lang.	Impl. lang.	Other lang.
[27]	2008	None	Unclear	NetLogo+BDI+FIPA-ACL
[28]	2010	LP	AgentSpeak	Jadex, JTS Topol., PostGIS
[29, 30, 31]	2011-2015	CLP	CLP(QS) (SWI-Prolog)	C++, REDUCE
[32]	2011	Modal Logic	Prolog-like	NetLogo+BDI
[33]	2012	ASP	GQR	Perl, C++, Gringo
[34, 35]	2015-2017	ASPMT	ASPMT(QS)	None
[36]	2015	LP	Unclear	Unclear
[37]	2016	CLP	CLP(QS) (SWI-Prolog)	FreeCAD CGCS
[38, 39, 40]	2016-2018	LP	Prolog-like	NetLogo+BDI
[41]	2017	LP	Prolog	None
[42]	2017	LP	SWI-Prolog	C++
[43]	2018	ASP	Clingo 5.2.0	None
[44]	2018	LP	LogC-QSD (SWI-Prolog)	None
[45]	2018	LP	Prolog	None
[46]	2021	LP	SWI-Prolog	Arcmap
[47]	2021	GeoJSON	GeoJSON + 2P-Kt Prolog	Tile38, Lattuce
[48]	2023	LP, CLP	SWI-Prolog	OpenCV, Tesseract OCR

Table 1
High level formalism for modelling spatial concepts (**Model. lang.**), language for implementing spatial concepts (**Impl. lang.**), other languages and frameworks used for the implementation (**Other lang.**).

Ref.	T.	Calculus	Agnt	Case study	A.
[27]	No	None	BDI	Forest fire scenario	No
[28]	No	RCC	BDI	Autonomous, collision-free motion in dynamic environments in a logistic domain	No
[29], [30], [31]	No	2D point-based spatial calculi	No	Geometric reasoning from Computer-Aided Architecture Design	No
[32]	Yes	Behind, FrontOf, RightOf, LeftOf, On	BDI	Simple example from traffic domain	No
[33]	Yes	QCN	No	Temporal reasoning formalisms, the Interval Algebra and RCC	No
[34], [35]	Yes	Non-monotonic spatial reasoning	No	Ramification problem; geometric reasoning; frame problem; abductive reasoning	[49]
[36]	Yes	QTC, QMPC, RCC	BDI	Fleet of taxi scenario	No
[37]	No	RCC	No	Circle contact; spiral chain; lamp layout	No
[38], [39], [40]	Yes	RCC	BDI	Simple example with agents using electric cars navigating to public charging point	[50]
[41]	No	RCC	No	Simple examples with manually encoded data representing geographical data	No
[42]	No	None	Robot swarm	Simulated & implemented experiments with multi-robot swarms	No
[43]	Yes	TC-6 and TC-10	No	Fleet of taxi, T-Drive dataset	[51]
[44]	No	QSD, QSD-Jux, PLCA	No	Spatial tests on the LogC-QSD-Dataset	No
[45]	No	RCC	No	Layout of Multimedia documents	No
[46]	No	Entity- and Relation-Based Programming	No	Analysis of accidents in Berlin	[52]
[47]	No	Nearby, within, intersect	No	None	No
[48]	No	None	No	Maths puzzles assigned to children of 4th and 5th grade of primary school	[53]

Table 2

Support to temporal relations (**T.**), principal calculus used for spatial reasoning (**Calculus**), integration of the spatial reasoning capabilities into intelligent agents or robots (**Agnt.**), **Case study**, availability of the implemented reasoner/framework to the research community (**A.**).

ENGINES

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[37]	No	RCC	No	Circle contact; spiral chain; lamp layout	No
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NetLogo

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[37]	No	RCC	No	Circle contact; spiral chain; lamp layout	No
[38], [39], [40]	Yes	RCC	BDI	Simple example with agents using electric cars navigating to public charging point	[50]
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[36]	Yes	QTC, QMPC, RCC	BDI	Ad hoc interpreter	No
[37]	No	RCC	No	Circle contact; spiral chain; lamp layout	No
[38], [39], [40]	Yes	RCC	BDI	Simple example with agents using electric cars navigating to public charging point	[50]
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[44]	No	QSD, QSD-Jux, PLCA	No	Spatial tests on the LogC-QSD-Dataset	No
[45]	No	RCC	No	Layout of Multimedia documents	No
[46]	No	Entity- and Relation-Based Programming	No	Analysis of accidents in Berlin	[52]
[47]	No	Nearby, within, intersect	No	None	No
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NetLogo

Table 2

Support to temporal relations (**T.**), principal calculus used for spatial reasoning (**Calculus**), integration of the spatial reasoning capabilities into intelligent agents or robots (**Agnt.**), **Case study**, availability of the implemented reasoner/framework to the research community (**A.**).

ENGINES

Ref.	T.	Calculus	Agnt	Case study	A.
[27]	No	None	BDI	Forest fire scenario	No
[28]	No	QSC	BDI	Autonomous, collision-free motion in dynamic environments in a logistic domain	No
[29], [30], [31]	No	2D point-based spatial calculi	No	Geometric reasoning from Computer Aided Architecture Design	No
[32]	Yes	Density, Proximity, RightOf, LeftOf, On	BDI	Simple example from traffic domain	No
[33]	Yes	QCN	No	Temporal reasoning formalisms, the Interval Algebra and RCC	No
[34], [35]	Yes	Non-monotonic spatial reasoning	No	Ramification problem; geometric reasoning; frame problem; abductive reasoning	[49]
[36]	Yes	QTC, QMPC, RCC	BDI	Fleet of taxi scenario	No
[37]	No	RCC	No	Circle contact; spiral chain; lamp layout	No
[38], [39], [40]	Yes	RCC	BDI	Simple example with agents using electric cars navigating to public charging point	[50]
[41]	No	RCC	No	Simple examples with manually encoded data representing geographical data	No
[42]	No	None	Robot swarm	Simulated & implemented experiments with multi-robot swarms	No
[43]	Yes	TC-6 and TC-10	No	Fleet of taxi, T-Drive dataset	[51]
[44]	No	QSD, QSD-Jux, PLCA	No	Spatial tests on the LogC-QSD-Dataset	No
[45]	No	RCC	No	Layout of Multimedia documents	No
[46]	No	Entity- and Relation-Based Programming	No	Analysis of accidents in Berlin	[52]
[47]	No	Nearby, within, intersect	No	None	No
[48]	No	None	No	Maths puzzles assigned to children of 4th and 5th grade of primary school	[53]

[28] M. Schuele, P. Karaenke, Qualitative spatial reasoning with topological information in BDI agents, in: Proceedings of the 2nd Workshop on Artificial Intelligence and Logistics (AILog), Lisbon, Portugal, 2010, pp. 7–12

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[28]	No	RCC	BDI	Autonomous, collision-free motion in dynamic environments in a logistic domain	No
[29], [30], [31]	No	2D point-based spatial calculi	No	Geometric reasoning from Computer-Aided Architecture Design	No
[32]	Yes	Behind, FrontOf, RightOf, LeftOf, On	BDI	Simple example from traffic domain	No
[33]	Yes	QCN	No	Temporal reasoning formalisms, the Interval Algebra and RCC	No
[34], [35]	Yes	Non-monotonic spatial reasoning	No	Ramification problem; geometric reasoning; frame problem; abductive reasoning	[49]
[36]	Yes	QTC, QMPC, RCC	BDI	Fleet of taxi scenario	No
[37]	No	RCC	No	Circle contact; spiral chain; lamp layout	No
[38], [39], [40]	Yes	RCC	BDI	Simple example with agents using electric cars navigating to public charging point	[50]
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[44]	No	QSD, QSD-Jux, PLCA	No	Spatial tests on the LogC-QSD-Dataset	No
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[46]	No	Entity- and Relation-Based Programming	No	Analysis of accidents in Berlin	[52]
[47]	No	Nearby, within, intersect	No	None	No
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Region Connection Calculus

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[28]	No	RCC	BDI	Autonomous, collision-free motion in dynamic environments in a logistic domain	No
[29], [30], [31]	No	2D point-based spatial calculi	No	Geometric reasoning from Computer-Aided Architecture Design	No
[32]	Yes	Behind, FrontOf, RightOf, LeftOf, On	BDI	Simple example from traffic domain	No
[33]	Yes	QCN	No	Temporal reasoning formalisms, the Interval Algebra and RCC	No
[34], [35]	Yes	Non-monotonic spatial reasoning	No	Ramification problem; geometric reasoning; frame problem; abductive reasoning	[49]
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[44]	No	QSD, QSD-Jux, PLCA	No	Spatial tests on the LogC-QSD-Dataset	No
[45]	No	RCC	No	Layout of Multimedia documents	No
[46]	No	Entity- and Relation-Based Programming	No	Analysis of accidents in Berlin	[52]
[47]	No	Nearby, within, intersect	No	None	No
[48]	No	None	No	Maths puzzles assigned to children of 4th and 5th grade of primary school	[53]

Jadex

Table 2

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Ref.	T.	Calculus	Agnt	Case study	A.
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[44]	No	QSD, QSD-Jux, PLCA	No	Spatial tests on the LogC-QSD-Dataset	No
[45]	No	RCC	No	Layout of Multimedia documents	No
[46]	No	Entity- and Relation-Based Programming	No	Analysis of accidents in Berlin	[52]
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Conclusions

Results so far

Preliminary results

Results so far

Preliminary results

Few papers associated with code

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Results so far

Preliminary results

Few papers associated with code

BDI notion used often as a (vague, catchy) conceptual framework, with limited connection with the original BDI architecture by Rao and Georgeff, ICMAS 1995

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Directions to explore

SLAM: Simultaneous localization and mapping is the computational problem of constructing or updating a map of an unknown environment while simultaneously keeping track of an agent's location within it

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Semantic mapping: A semantic map, in the robotic context, is a models that includes information about spatial elements (rooms, objects, etc.) augmented with the semantics – namely, what are the object for, what can be done with them and what cannot be done, which are the states they can be, etc. – required for an efficient robot operation

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Acknowledgements

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Thank you for your attention!

Any questions?