A Case Study of the Development of an Agent-based Simulation in the Traffic Signal Control Domain using an MDD Approach

Fernando Santos[1,2], Ingrid Nunes[1,3] ,Ana L.C. Bazzan[1]

[1] Instituto de Informática, UFRGS, Brazil

[2] Depto. de Engenharia de Sofware, UDESC, Brazil

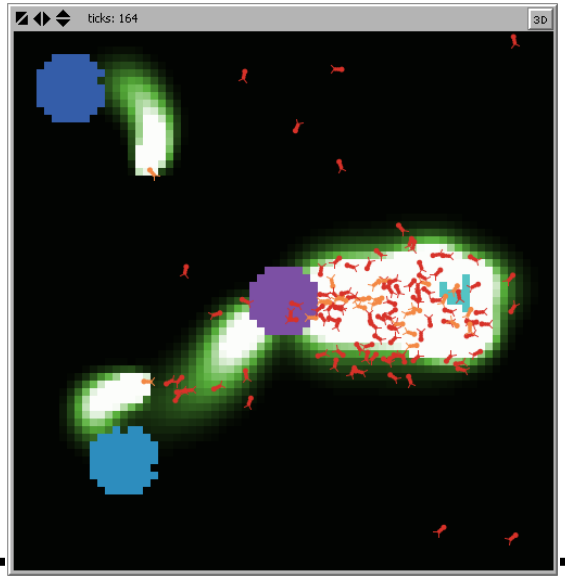
[3] TU Dortmund, Germany

{fsantos, ingridnunes, bazzan}@inf.ufrgs.br

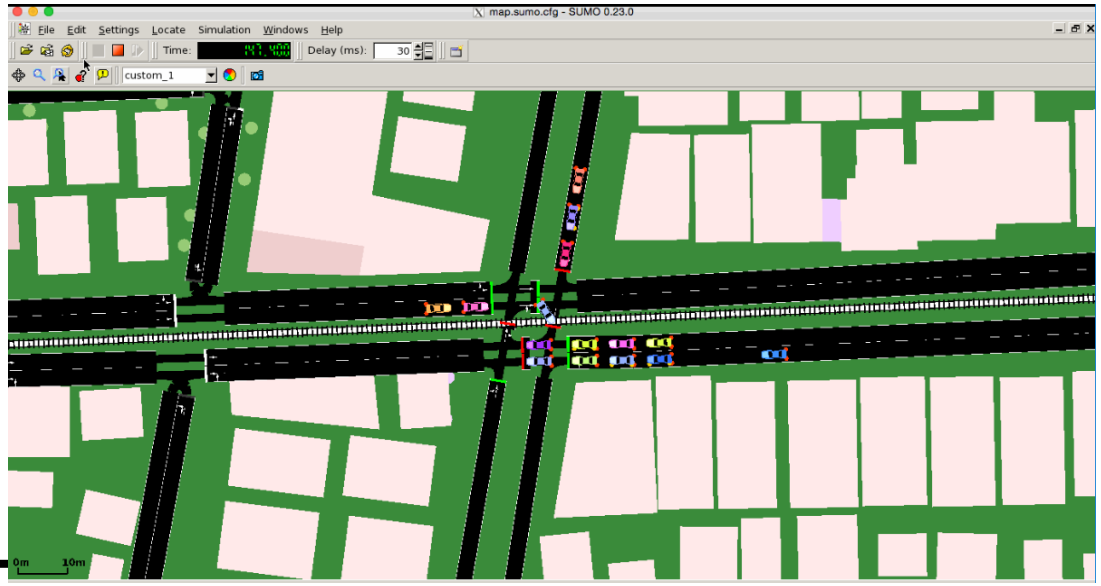
May 8, 2017

ABMS

- Agent Based Modeling and Simulation (ABMS)
  - **Paradigm** that uses **agent-based simulations** to [re]produce, analyze, or predict a phenomenon under study
  - Particularly suitable for **complex systems** and **emergent phenomena**



Ant foraging

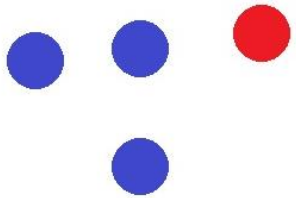


Traffic

Agent-based Simulation Development

- Agent-based Simulation (ABS) Platforms

GAMA PLATFORM



SeSAm

Shell for Simulated Multi-Agent Systems

v1.3 Jan2017

- Demand for technical expertise
- No **building blocks** for recurrent concepts and behaviors

Model-driven Development (MDD)

- Models as *first-class citizens*
- Trades *generality* for *expressiveness*
  - Domain concepts are available for modeling
  - Reduces the abstraction gap and increases productivity
- MDD in ABMS: **Limitations**
  - Limited to particular MDD aspects
    - Metamodels: AMASON, MAIA, metamodel of Ribino *et al*. (2014)
    - Methods for identifying certain domain concepts: easyAMBS, IODA
  - Much is left to be **developed manually**
    - Often, only code skeletons are produced automatically
  - **Lack of evidence of the real benefits** that an MDD approach can promote for developing agent-based simulations.

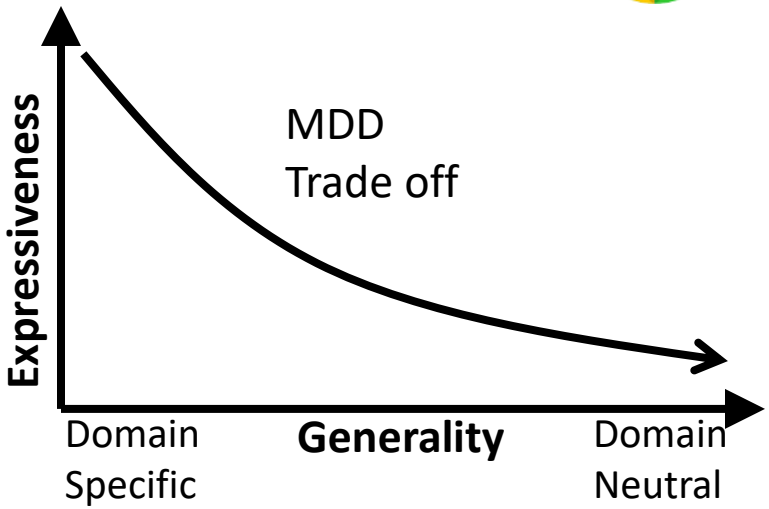
Research Question

*What is the **benefit** an MDD approach can provide for developing agent-based simulations?*

- We explore this question through a case study
  - Provision of an MDD approach for ABMS
  - Empirical assessment of its gains
    - Development effort

MDD for ABMS: preliminaries

- The more specific the application domain, the higher the chance of success
  - J. Hutchinson, M. Rouncefield, and J. Whittle. Model-driven engineering practices in industry. In *International Conference on Software Engineering*, 633-642, 2011.



- Selected domain
  - **Agent-based simulations** of Adaptive Traffic Signal Control (ATSC)

Adaptive Traffic Signal Control

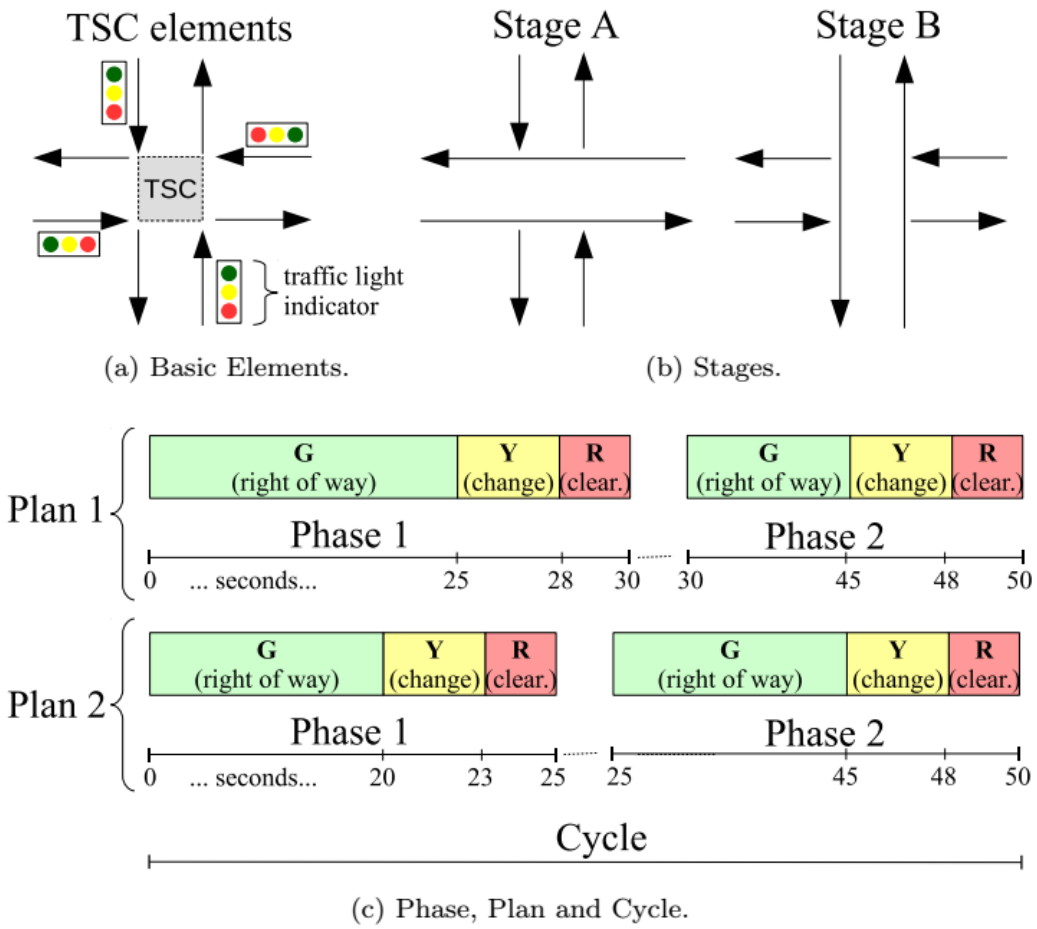
ATSC

- Traffic Signal Control (TSC) agents in charge of managing traffic light indicators so as to:
  - Maximize traffic flow
  - Minimize travel time
  - Other metrics

- Distributed and autonomous agents
- Availability of decision-making techniques

ATSC elementary concepts

- TSC agents
- Incoming/outgoing lanes
- Traffic light indicators
- Stages
- Phases
- Plans
- Cycle



MDD for ABMS: elements

1. Metamodel
   - Domain concepts → meta-entities and their relationship
   - Built through a domain analysis activity

2. Domain-specific language (DSL)
   - Building blocks for recurrent concepts → expressiveness
   - Allow modeling in an expressive way (abstraction gap)

3. Transformations & Code Generation
   - Rules for producing code automatically → productivity

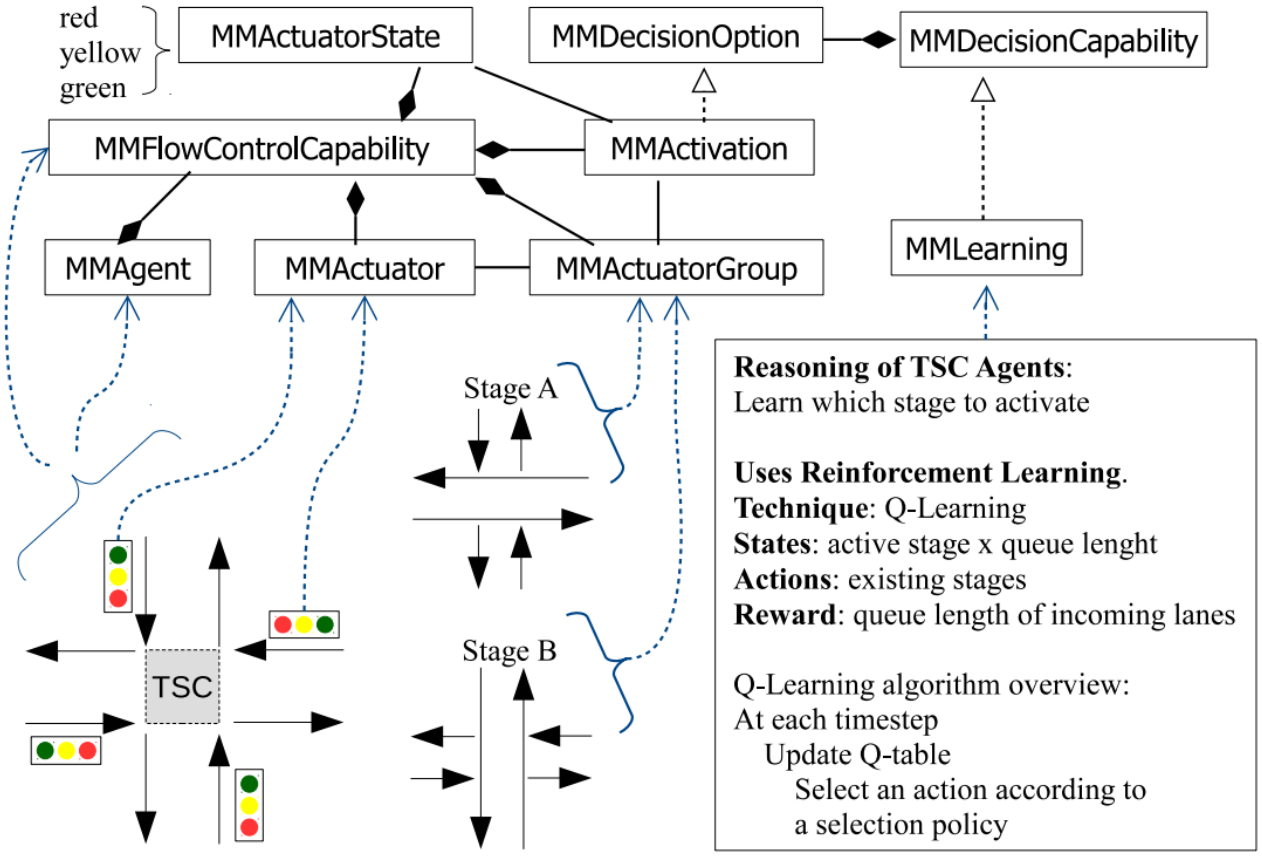
Domain Analysis Method

- Bottom-up, based on existing simulations
  1. Build a preliminary list of agent-related concepts following the steps of existing methodologies for ABMS
  2. Refine the identified concepts using the ODD protocol
     - Adaptation, learning, collectives, …
  3. Find the essence behind each identified concept
     - Recurrent characteristics and behaviors
  4. Build the domain model

Domain Analysis

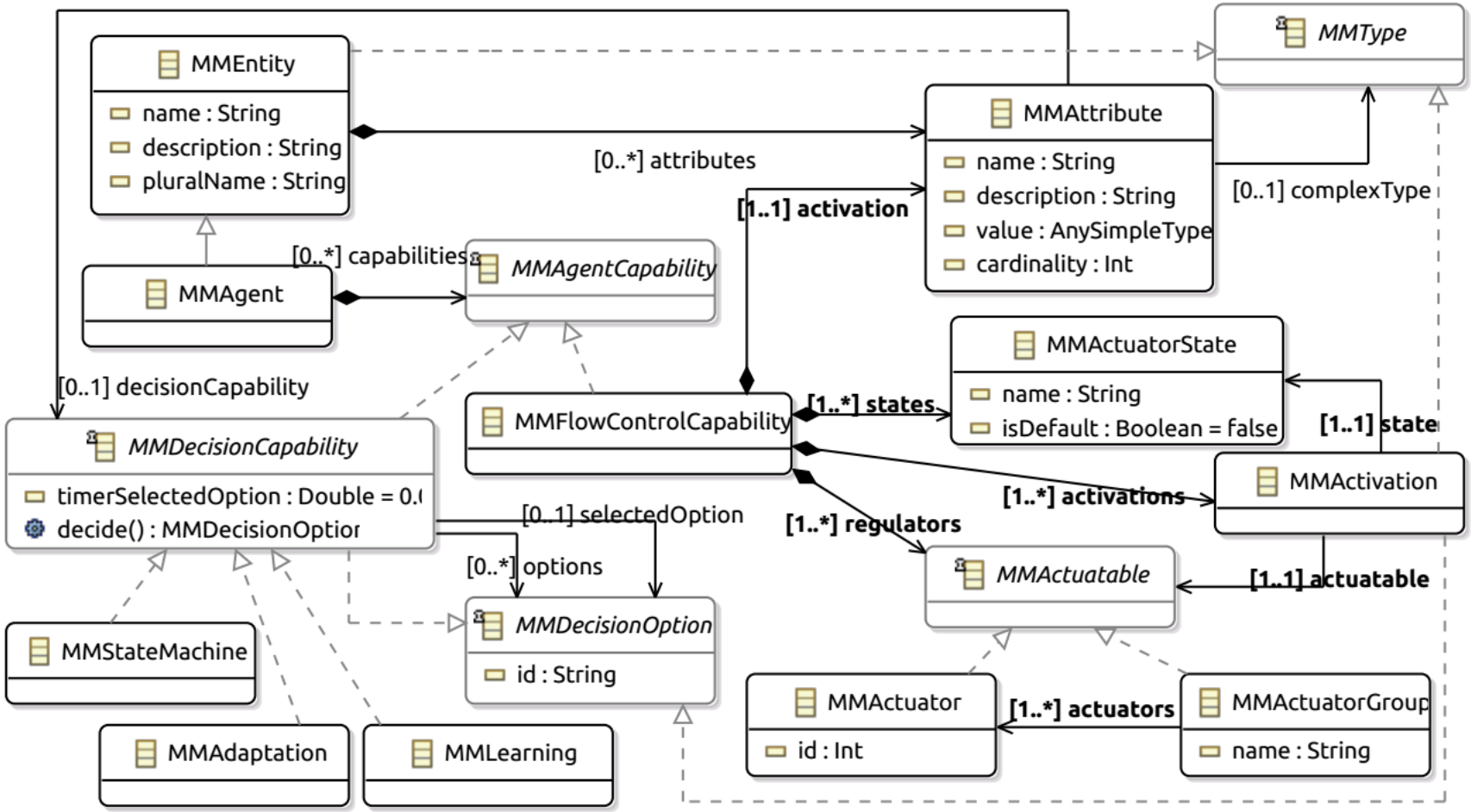
Step 3

- How domain concepts were abstracted:



Metamodel

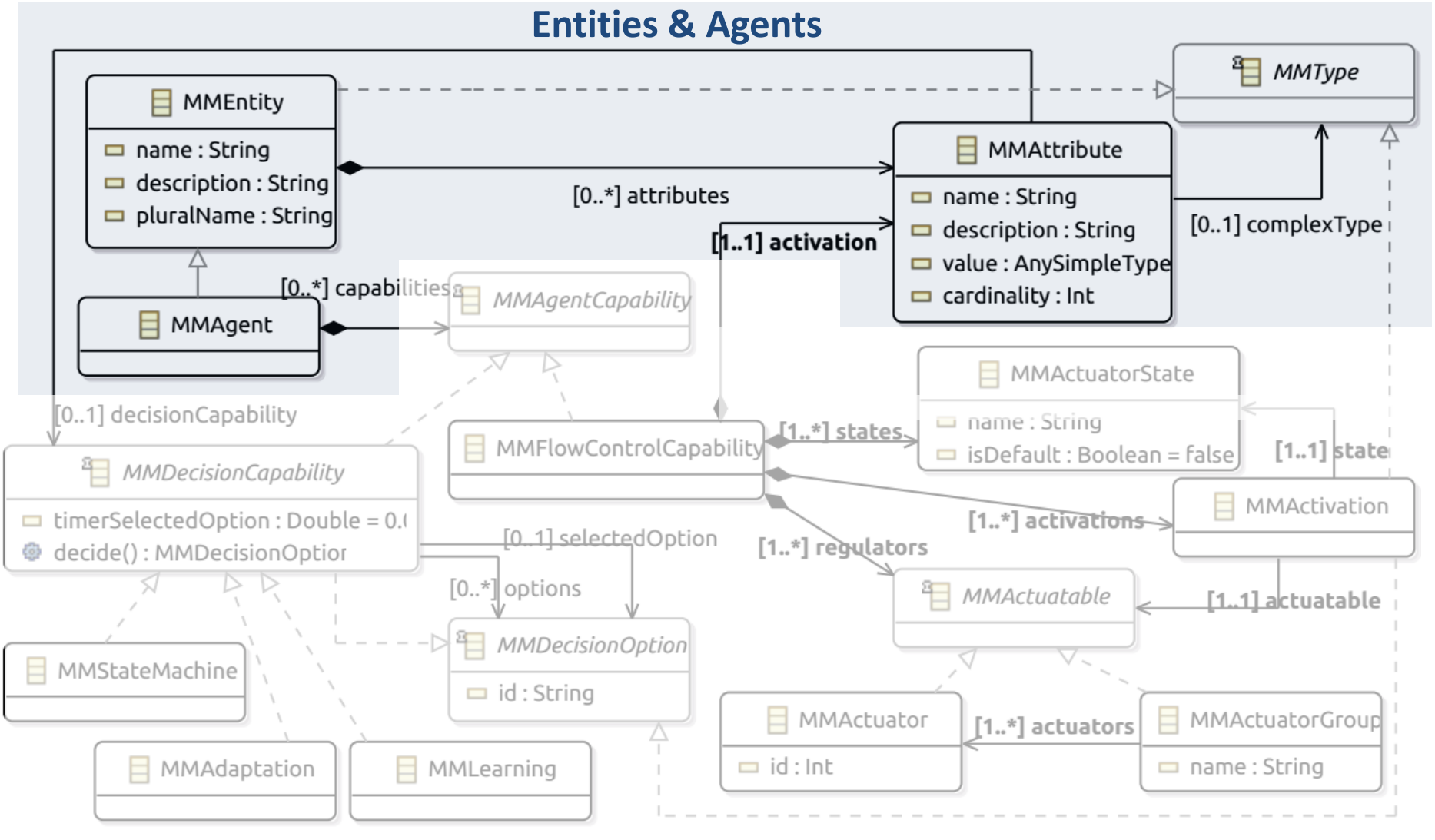
Step 4



- Also, acts as the DSL abstract syntax

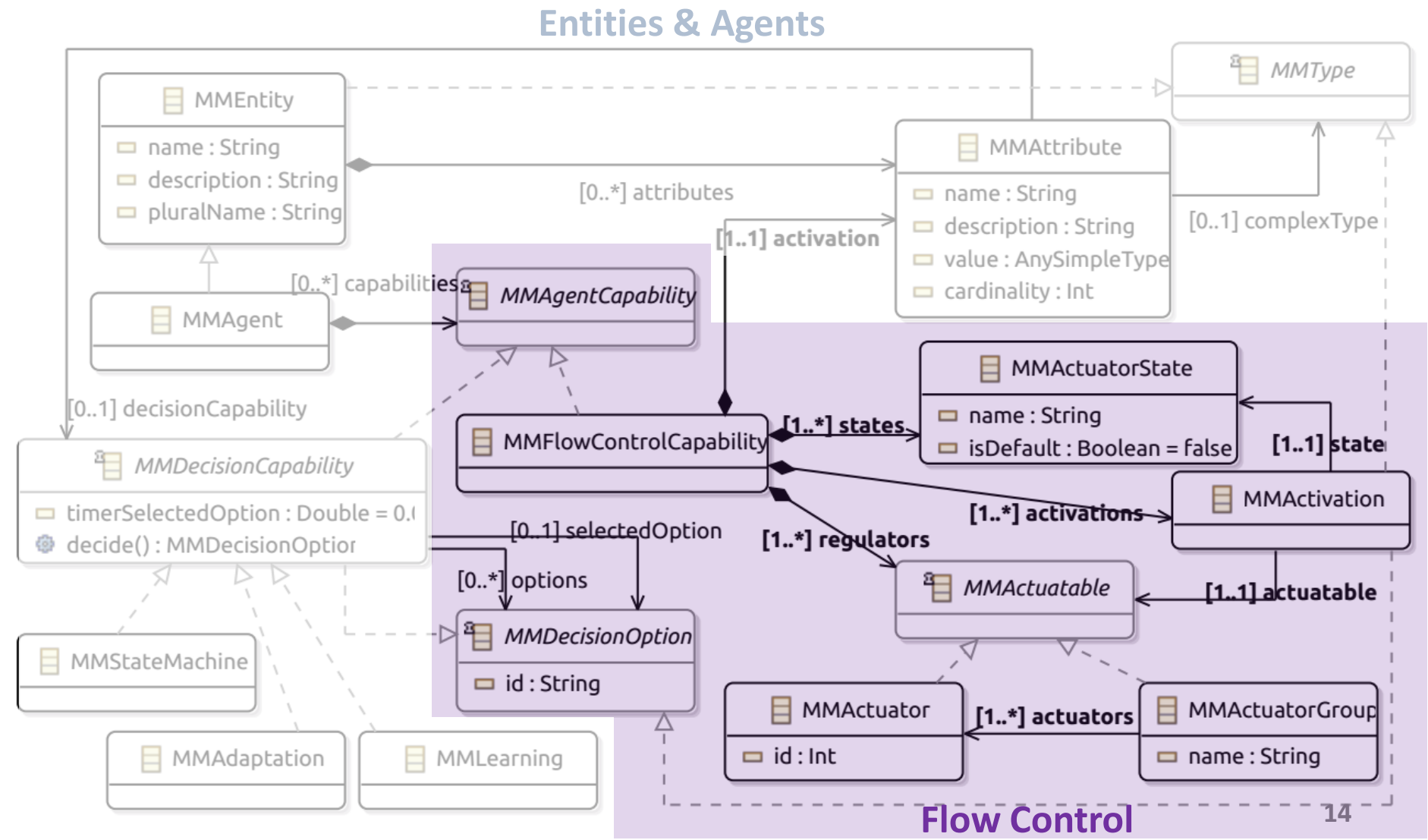
Metamodel

Step 4



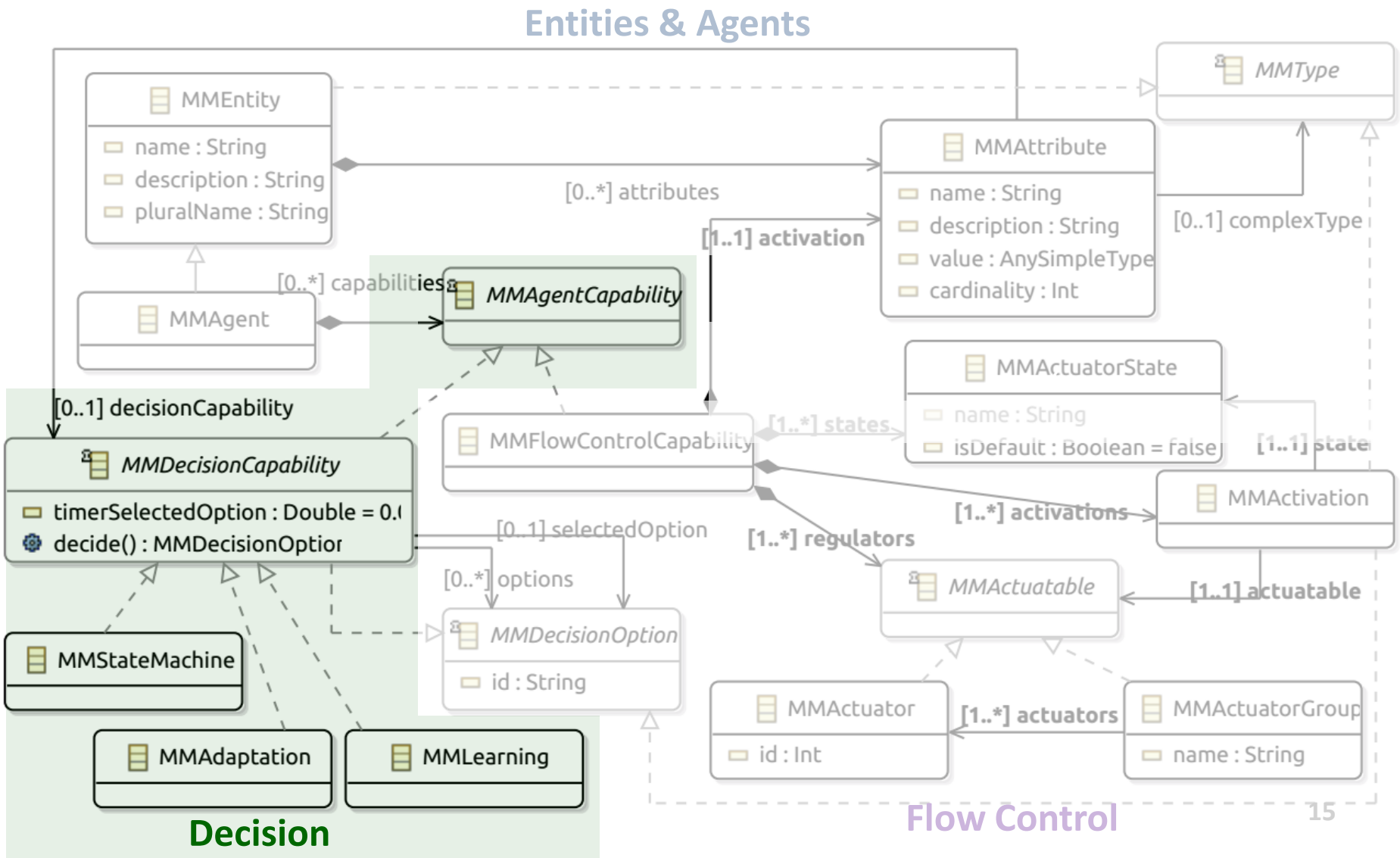
Metamodel

Step 4



Metamodel

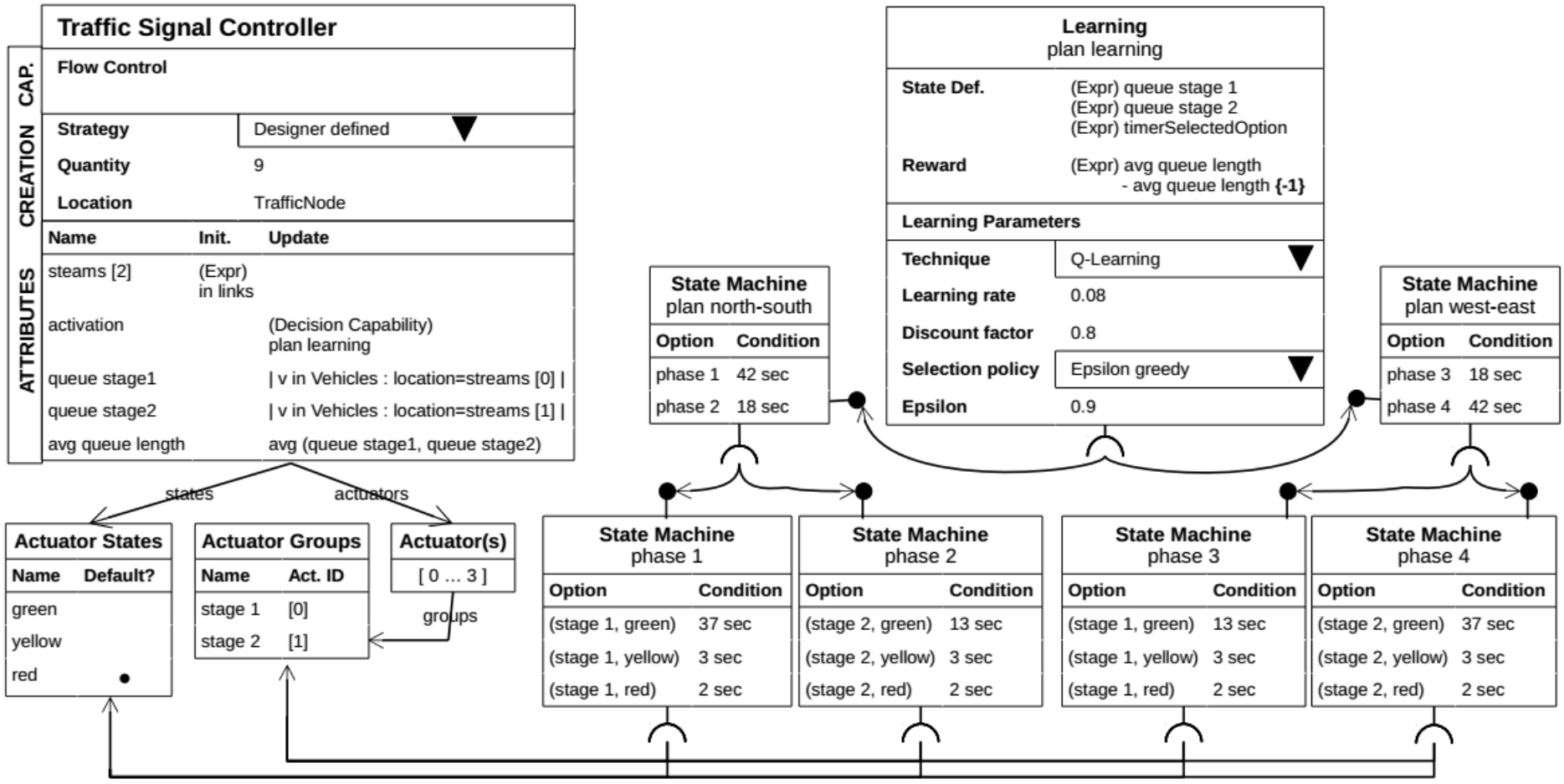
Step 4



DSL4ABMS: Modeling Language

Concrete Syntax

- UML-inspired building blocks for ABMS elements



Model-to-code Transformations

- Production rules to generate NetLogo code. E.g.:

Production Rule	Transformations to NetLogo Code
Agent type	For each MMAgent → **`breed`**
RL capability	For each MMReinforcementLearning → • Qlearning init. • Qlearning reward def. • Qlearning update Qtable • Qlearning decision
Qlearning update QTable	executes Qlearning reward def. **`reporter`** to compute reward **`set`** statement for updating the Qtable $Q(s,a) = Q(s,a) + \alpha[r + \gamma \max_{a'} Q(s',a') - Q(s,a)]$

- Specified and implemented using XPand

Evaluation: Questions

- Q1. MDD Effectiveness

  Is our MDD approach able to produce **ready-to-run code** from DSL4ABMS models?

- Q2. MDD Benefits

  Does our MDD approach decrease the **effort** to develop agent-based simulations?

Evaluation: Selected Simulations

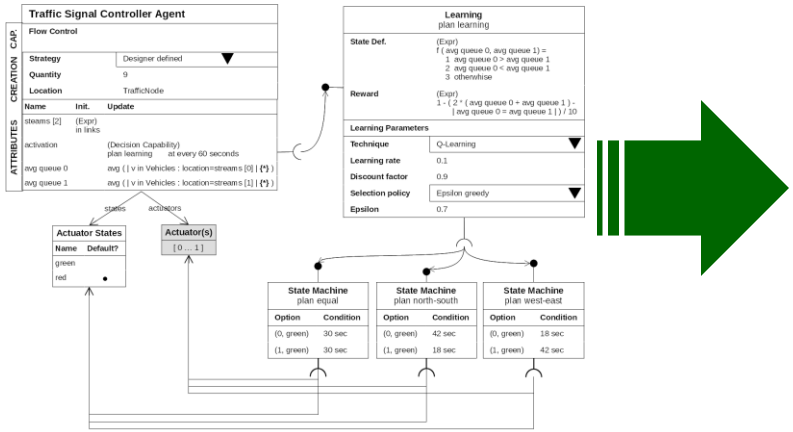
- One simulation was selected for each decision capability

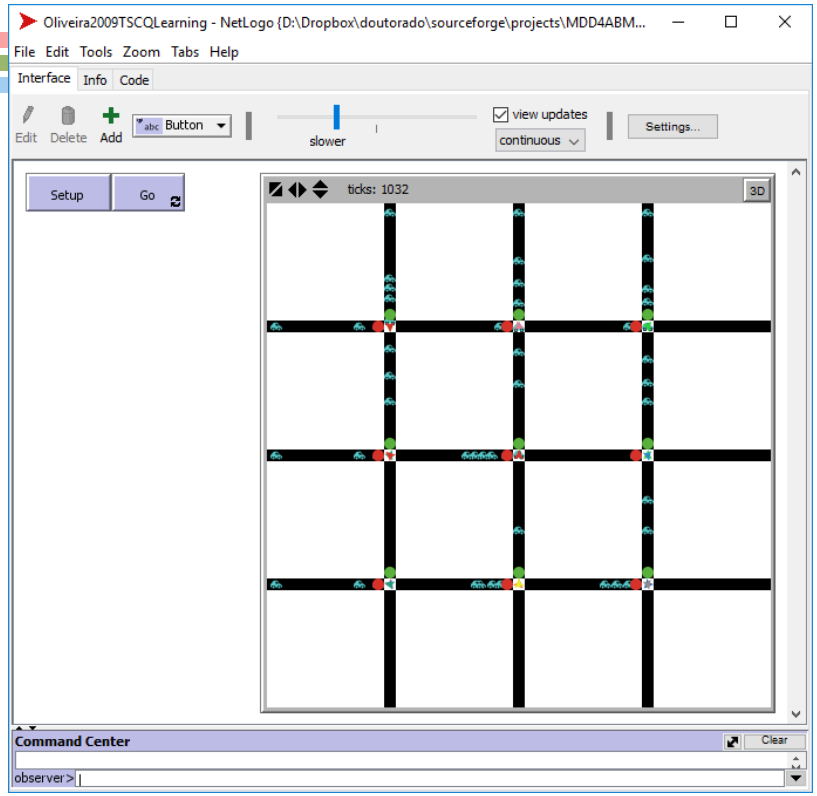
- Fixed plans → State machines
  - U. Wilensky. NetLogo Traffic Grid model. 2003 http://ccl.northwestern.edu/netlogo/models/TrafficGrid.

- Self-organizing Traffic Lights → Adaptation
  - C. Gershenson. Self-organizing traffic lights. Complex Systems. 2005.

- Signal Plan Learning → Reinforcement Learning
  - D. de. Oliveira and A. L. C. Bazzan. Multiagent learning on traffic lights control: effects of using shared information. In Multi-Agent Systems for Traffic and Transportation,. 2009

Q1. Generated Simulations





- TSC-related ready-to-run code was **fully automatically** generated

```
to rl-plan_learning-update-qtable [s a s' r]

    let q_s_a 0
    let q_s'_max_a_value 0
    if table:length s_values_map > 0 and table:has-key? s_values_ma
      set q_s_a table:get s_values_map a
    ]

    if table:length s'_values_map > 0 [
      set q_s'_max_a_value table:get s'_values_map max-action-value
    ]

    let new_q_s_a ( q_s_a + rl_plan_learning_alpha *
            ( r + rl_plan_learning_gamma *
                                q_s'_max_a_value - q_s_a ) )

    table:put s_values_map a new_q_s_a
  ]
end
```

Q2. Development Effort

- **Size metrics**, from cost estimation methods in SE
- **Lines of Code (LoCs)** is a key size measurement
  - Used in methods such as Function Points and COCOMO
  - Can be manually produced (MLoCs) or generated (GLoCs)
- **Atomic Model Element (AMEs)**
  - Used to measure graphical models
  - 1 AME *is a visual element that is equivalent to* 1 LoC
  - Counting rules are detailed in the paper

Q2. Results

Simulation	AMEs	MLoCs	Effort*	GLoCs
Fixed Plan / State Machine				
NetLogo	1	34	**35**	1
Our MDE approach	14	0	**14**	116
Self-organizing Traffic Lights / Adaptation				
NetLogo	1	82	**83**	1
Our MDE approach	15	0	**15**	103
Signal Plan Learning / Reinforcement Learning				
ITSUMO	0	257	**257**	0
Our MDE approach	37	0	**37**	297

60.0%

81.9%

85.6%

*Effort = AMEs + MLoCs

Our MDE approach reduces the effort

Q2. Results

Simulation	AMEs	MLoCs	Effort*	GLoCs
Fixed Plan / State Machine				
NetLogo	1	**34**	35	**1**
Our MDE approach	14	0	14	**116**
Self-organizing Traffic Lights / Adaptation				
NetLogo	1	**82**	83	**1**
Our MDE approach	15	0	15	**103**
Signal Plan Learning / Reinforcement Learning				
ITSUMO	0	**257**	257	**0**
Our MDE approach	37	0	37	**297**

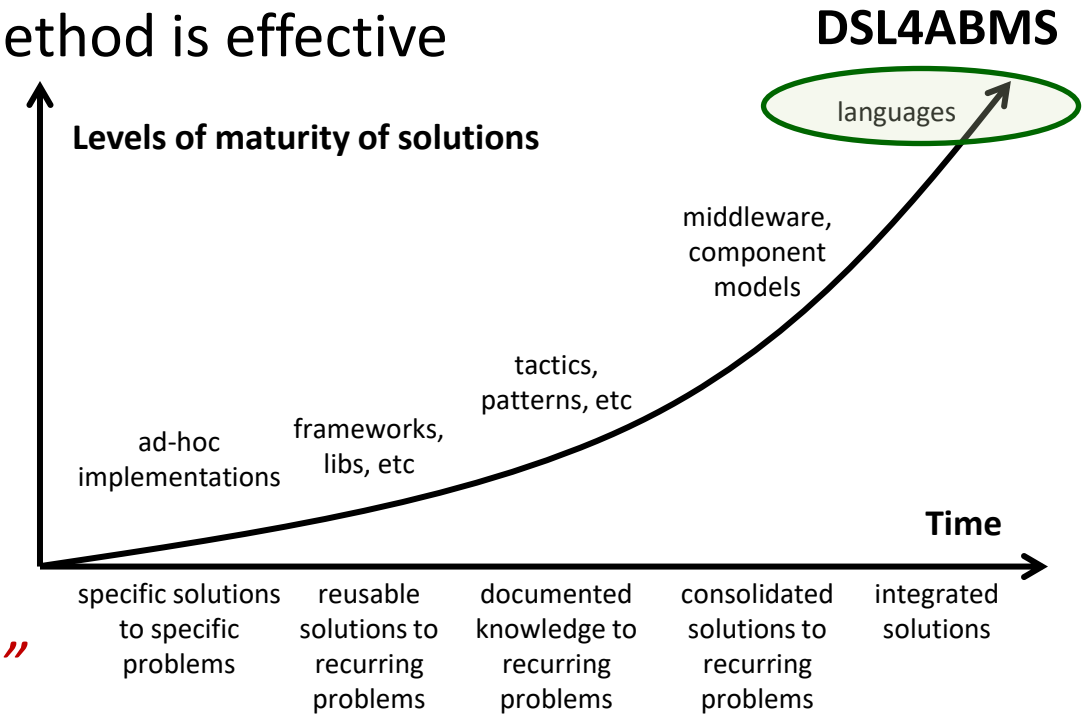
*Effort = AMEs + MLoCs

- Why does our MDD approach produce simulations with more LoCs than NetLogo/ITSUMO?
- It produces code for **reusable** domain-independent abstractions (e.g., state machines)
- But no **human effort** is required to produce it

fsantos@inf.ufrgs.br

Conclusion

- Our MDD approach reduces the effort to develop agent-based simulations in the ATSC domain
- The domain analysis method is effective



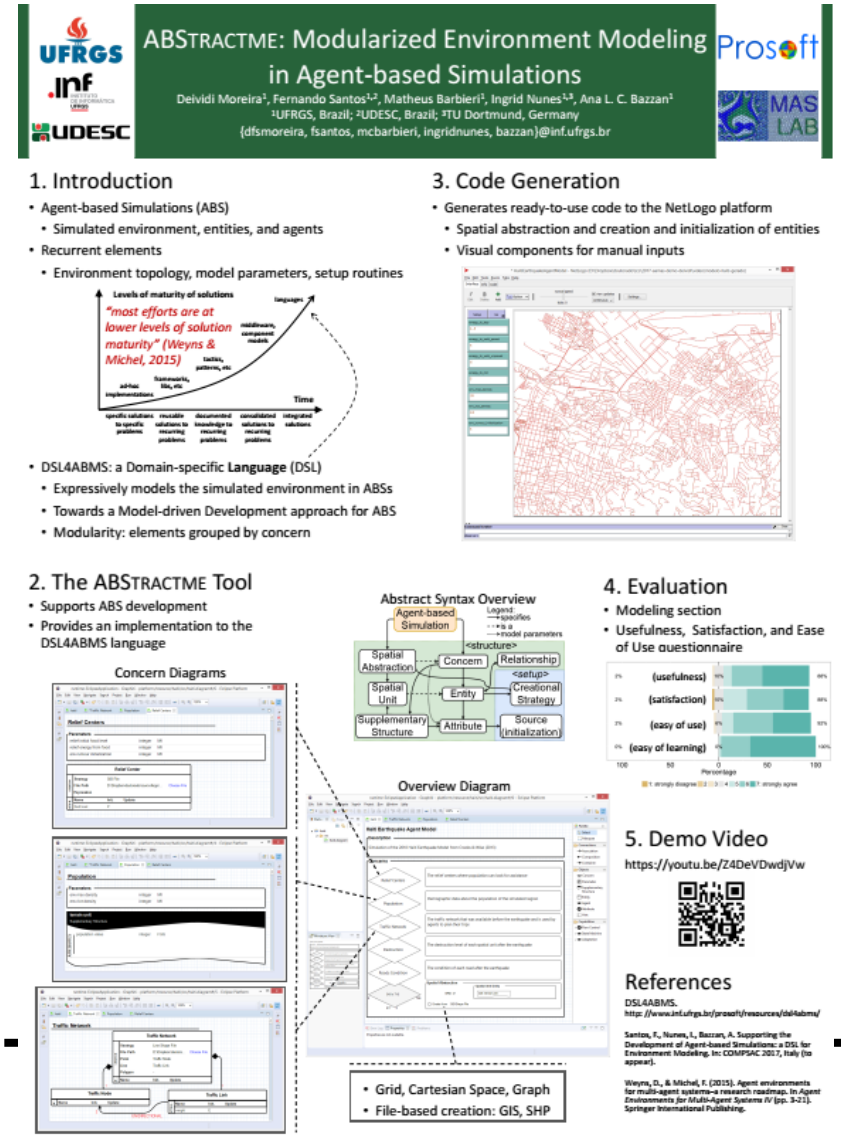
"most efforts are at lower levels of solution maturity"

Weyns, D., & Michel, F. (2015). Agent environments for multi-agent systems–a research roadmap. In *Agent Environments for Multi-Agent Systems IV* (pp. 3-21). LNCS/Springer.

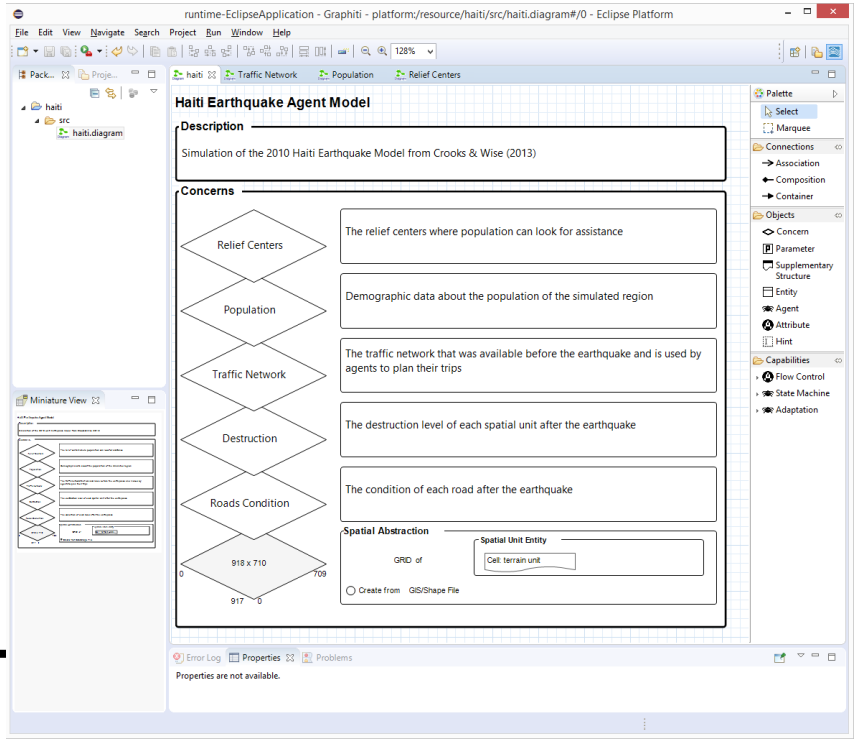
Future Work

- Experiment with humans to evaluate subjective aspects of our MDD approach
  - E.g., usability, comprehensibility
- Incorporate additional simulation concepts
- Long-term goal: to use MDD to ease the development of agent-based simulations

Invitation: Demo Sessions



- Thursday, May 11
  - 10:20h - 11:20h
  - 16:10h - 17:10h



A Case Study of the Development of an Agent-based Simulation in the Traffic Signal Control Domain using an MDD Approach

Fernando Santos[1,2], Ingrid Nunes[1,3] ,Ana L.C. Bazzan[1]

[1] Instituto de Informática, UFRGS, Brazil

[2] Depto. de Engenharia de Sofware, UDESC, Brazil

[3] TU Dortmund, Germany

{fsantos, ingridnunes, bazzan}@inf.ufrgs.br

May 8, 2017