Embedded UML Model Execution to Bridge the Gap between Design and Runtime

First International Workshop on Model-Driven Engineering for Design-Runtime Interaction in Complex Systems (MDE@DeRun 2018)
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Overview

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Context

Observations

- Increasing complexity of embedded systems
- Emergence of new needs and applications
- Connection of these systems to networks (IoT)

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Observations

- Increasing complexity of embedded systems
- Emergence of new needs and applications
- Connection of these systems to networks (IoT)

Consequences

- Software programs increasingly difficult to design, maintain, and evolve
- Bugs and design faults increasingly difficult to detect and fix

Problem

Issues in terms of design, implementation, and analysis

More and more difficult to:

- Understand diagnosis results in terms of design concepts
- Give runtime feedbacks on the design model
- Visualize and analyze system execution
- Carry out diagnosis activities and runtime measures analysis

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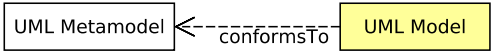
Formulation of the problem

How to link design and runtime concepts?

Classical Approaches and their Issues



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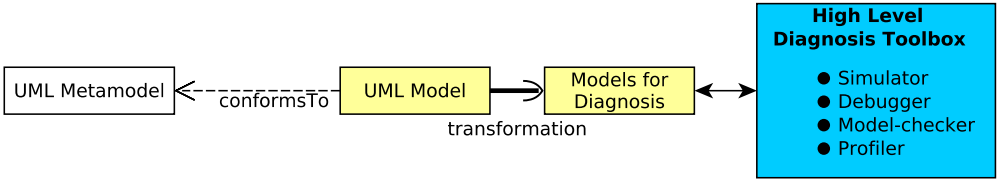

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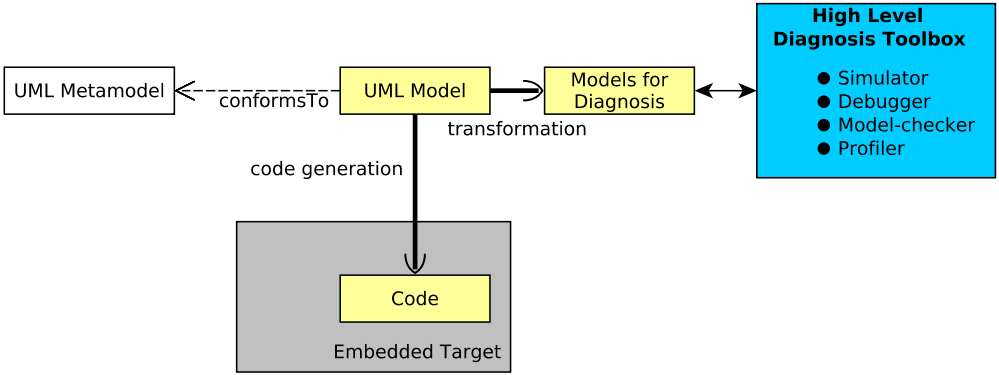

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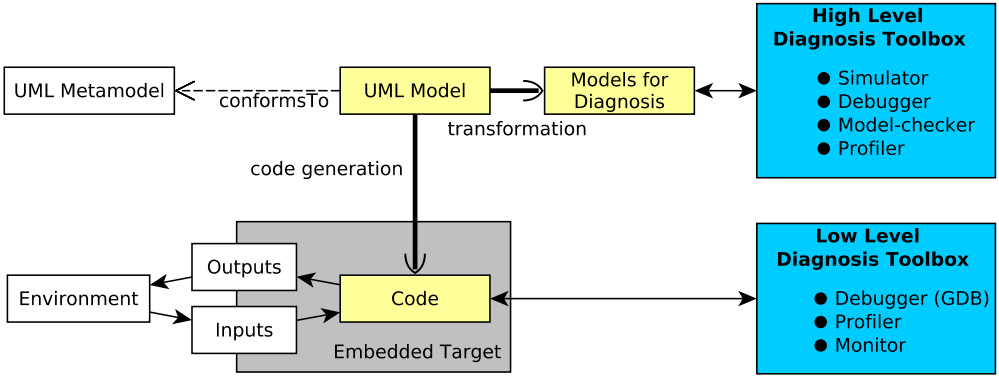

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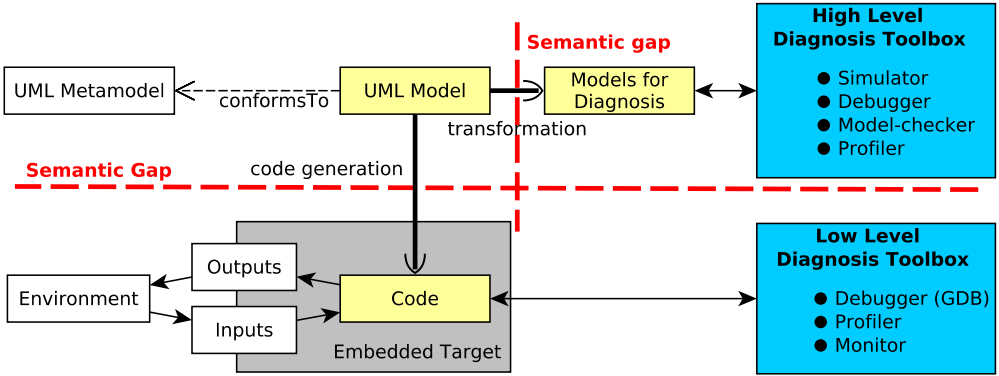

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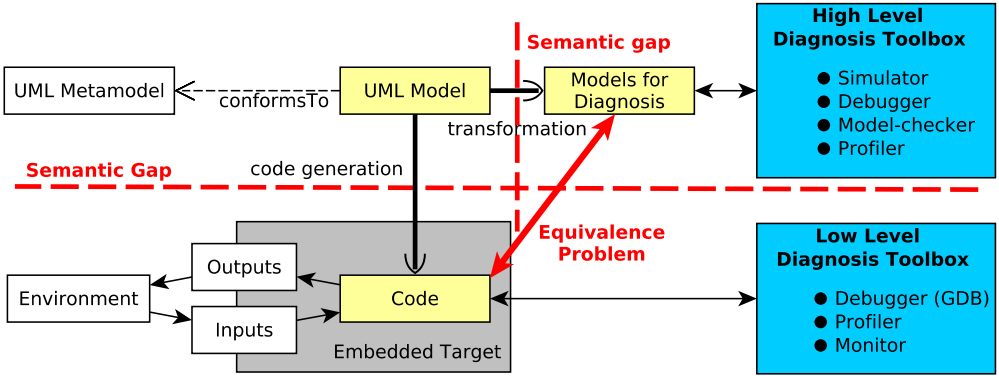

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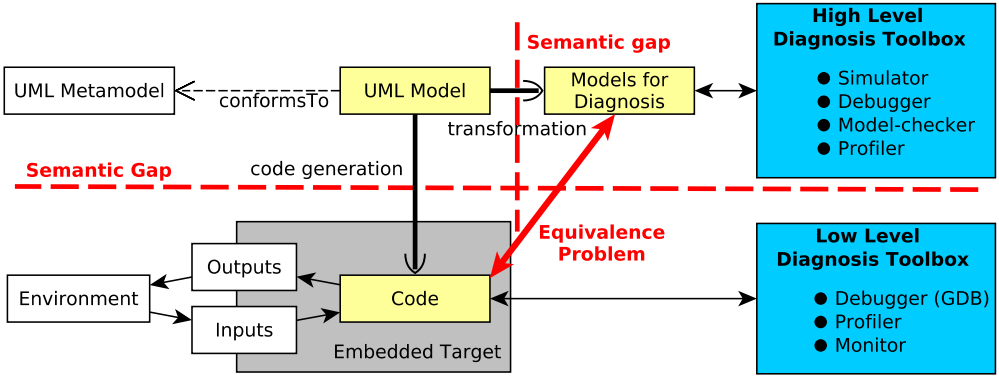
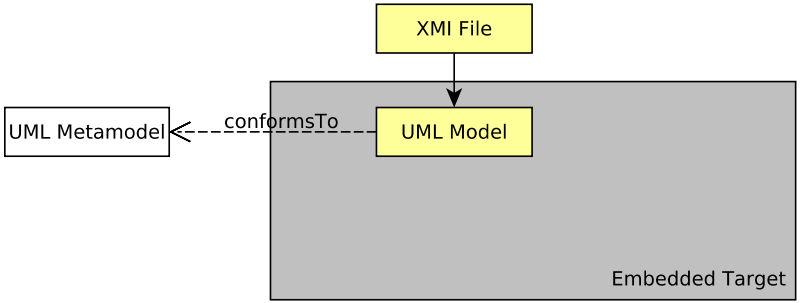


Main cause: Execution and diagnosis formalisms usually differ from the design formalism.

Our Approach



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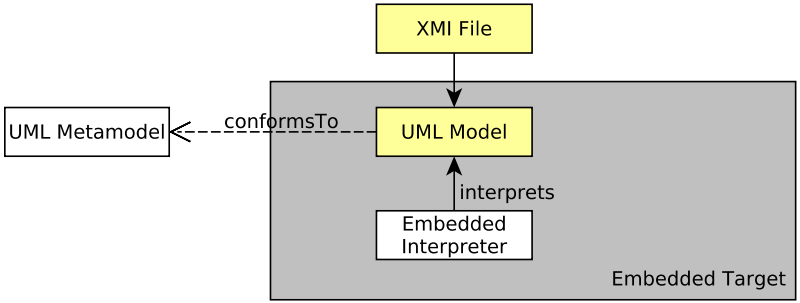

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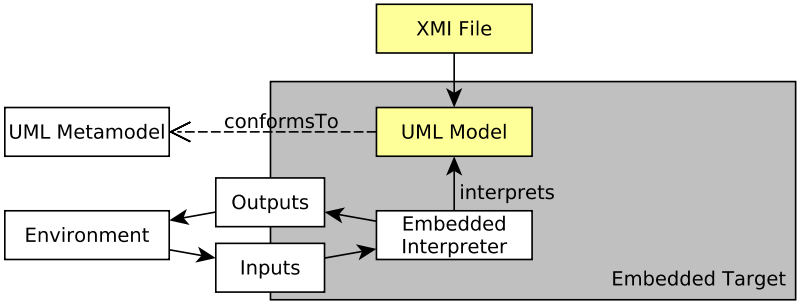

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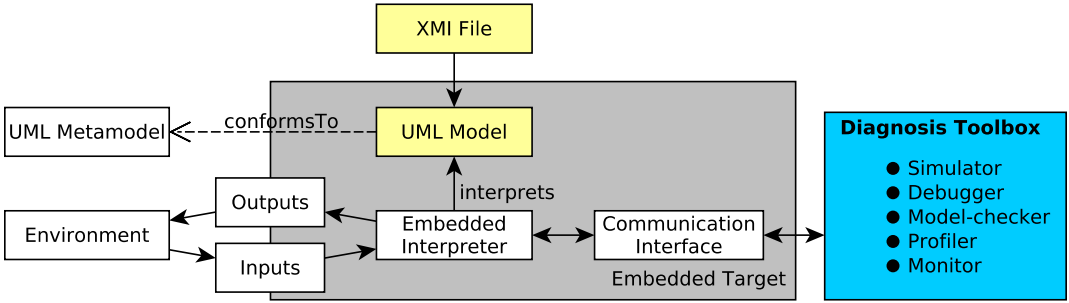
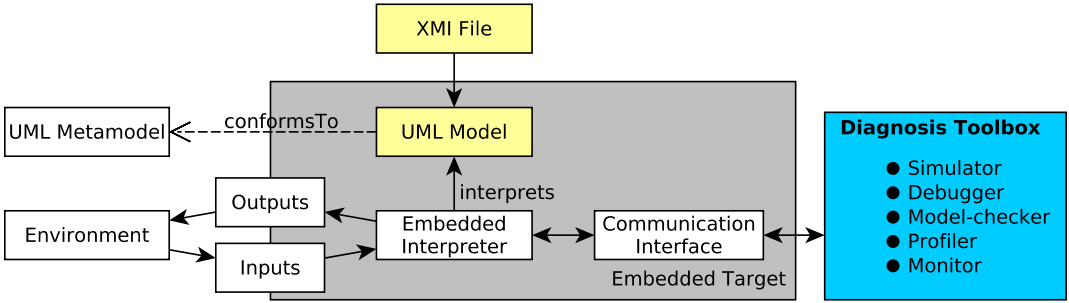


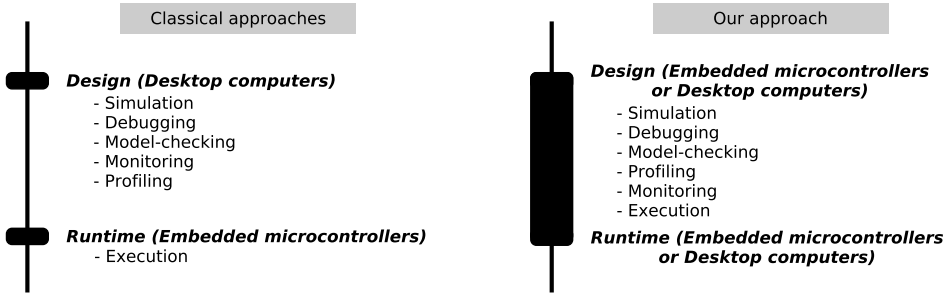
Our Approach



Solution: Execute and analyze the UML design model.

Interactions between *Design* and *Runtime*

- Continuum between *Design* and *Runtime* thanks to the use of:
  - The same model
  - The same execution semantics



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  - The same execution semantics
- Multiple advantages:
  - Easier interactions between *Design* and *Runtime*
  - No semantic gap
  - Direct expression of diagnosis results in terms of UML concepts
    - Simplifying addition of feedback on the model

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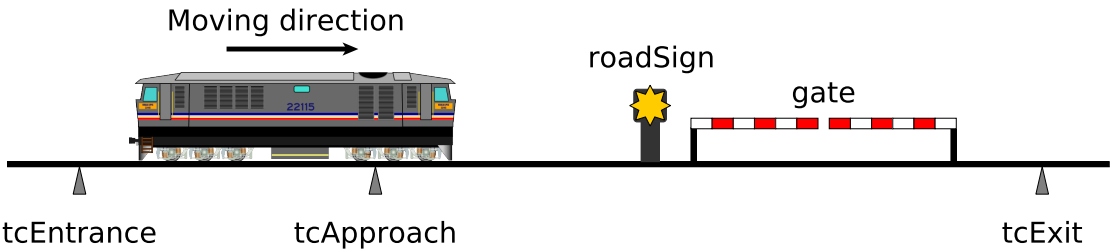
  - Direct expression of diagnosis results in terms of UML concepts
    - Simplifying addition of feedback on the model
- Expected results:
  - Increased development quality
  - Increased productivity
  - Reduced time-to-market

Sommaire

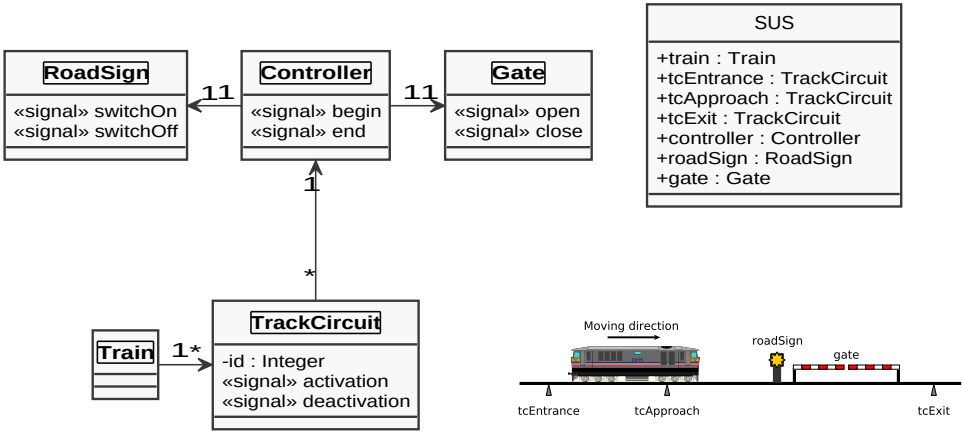
Motivating Example: Level Crossing



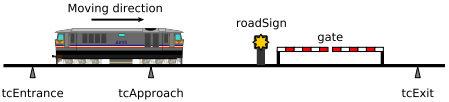
Goal

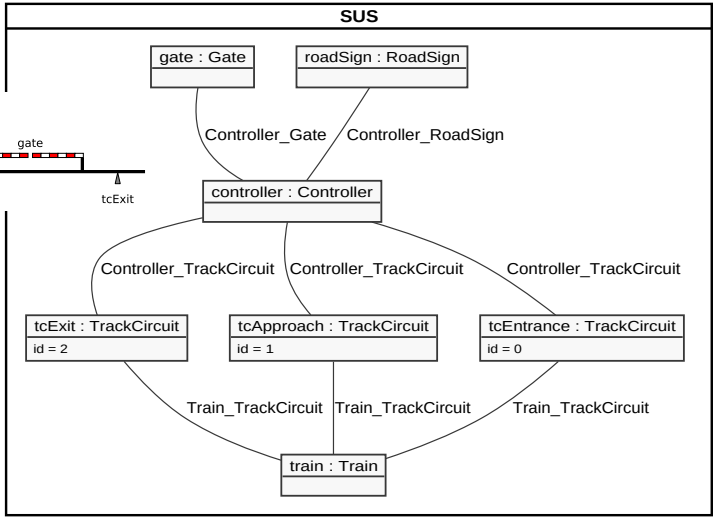
Ensure safety during the passage of the train

Motivating Example: Level Crossing (Class Diagram)

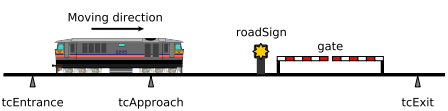


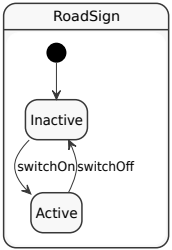
Motivating Example: Level Crossing (Composite Structure Diagram)

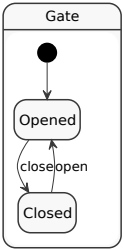


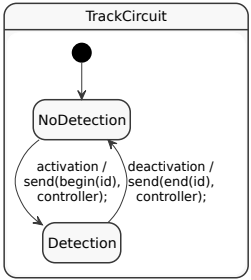


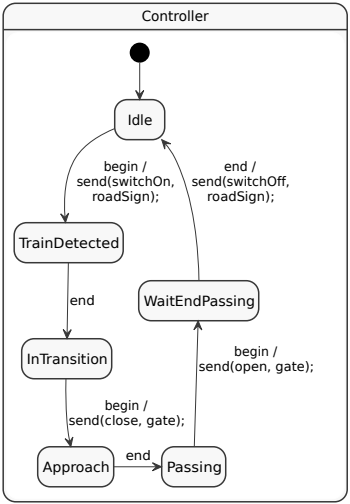
Motivating Example: Level Crossing (State Machines)











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Interactions with Design Tools

Two kinds of interactions

- Online interactions
- Offline interactions

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Three interaction modes

- Simulation (online)
- Execution followed by offline trace analysis
- Debugging (online)

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Communication Protocol

Application layer protocol

Composed of 5 kinds of requests:

- Get configuration
- Set configuration
- Get fireable transitions
- Fire transition
- Reset interpreter

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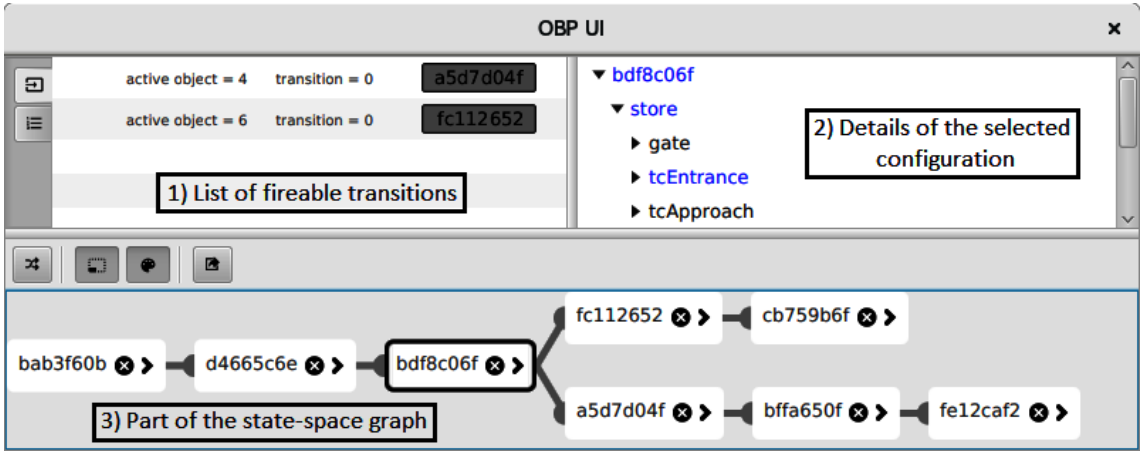
Optimizations

- The *diff mode* enables to exchange only the parts that are different for get and set configuration requests
  - previous configuration + diff(previous, new) = new configuration

Simulation


OBP UI
active object = 4
transition = 0
a5d7d04f
active object = 6
transition = 0
fc112652
1) List of fireable transitions
bdf8c06f
store
gate
tcEntrance
tcApproach
2) Details of the selected configuration
bab3f60b
d4665c6e
bdf8c06f
fc112652
cb759b6f
a5d7d04f
bffa650f
fe12caf2
3) Part of the state-space graph

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Execution

1. Instrumentation of the interpreter code with C macros called when:
   - An active object sends an event
   - A state machine updates its current state
   - An attribute updates its value (optional)
   - No overhead if no trace required

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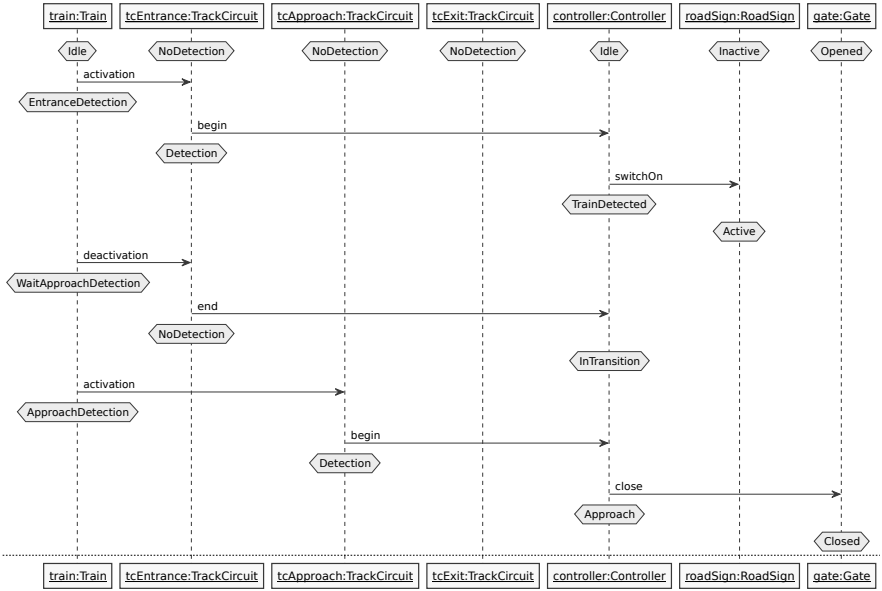
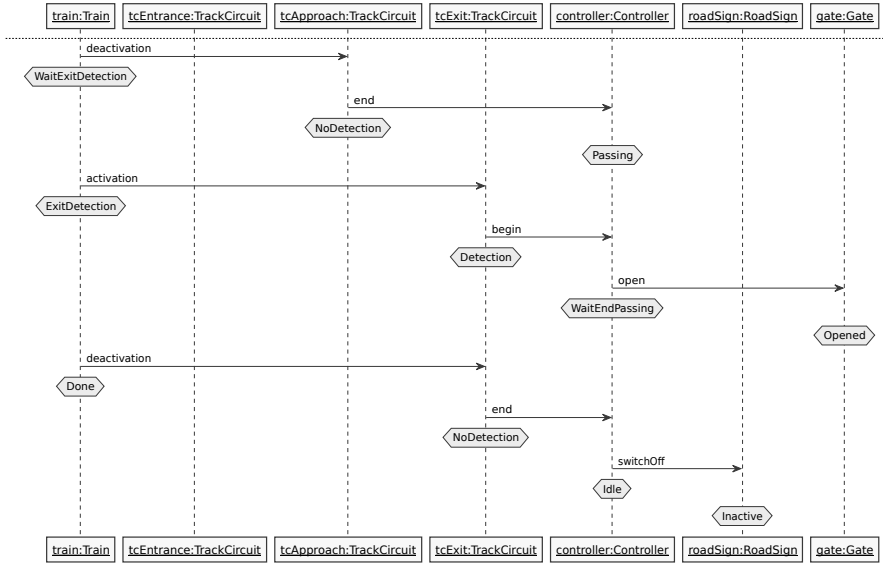
4. Generate a graphical diagram (Message Sequence Chart) of the trace


train:Train
tcEntrance:TrackCircuit
tcApproach:TrackCircuit
tcExit:TrackCircuit
controller:Controller
roadSign:RoadSign
gate:Gate
Idle
NoDetection
NoDetection
NoDetection
Idle
Inactive
Opened
activation
EntranceDetection
begin
Detection
switchOn
TrainDetected
Active
deactivation
WaitApproachDetection
end
NoDetection
InTransition
activation
ApproachDetection
begin
Detection
close
Approach
Closed
train:Train
tcEntrance:TrackCircuit
tcApproach:TrackCircuit
tcExit:TrackCircuit
controller:Controller
roadSign:RoadSign
gate:Gate


train:Train
tcEntrance:TrackCircuit
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tcExit:TrackCircuit
controller:Controller
roadSign:RoadSign
gate:Gate
deactivation
WaitExitDetection
end
NoDetection
Passing
activation
ExitDetection
begin
Detection
open
WaitEndPassing
Opened
deactivation
Done
end
NoDetection
switchOff
Idle
Inactive
train:Train
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Debugging

Debugging loop

Check if there is a command sent by the debugger to process:

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Functionalities

- Optional back-in-time debugging
- Change current state of active objects and inject events into event pools

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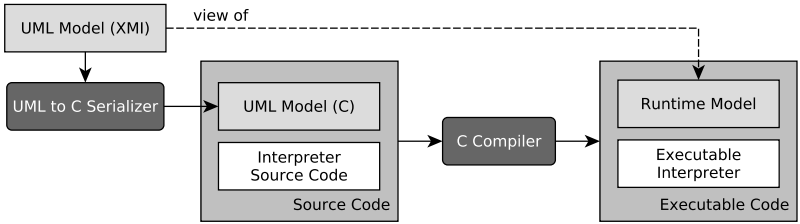
Limitations

- Cannot debug opaque behaviors and opaque expressions implemented as C functions
- No support for adding/removing breakpoints yet

Sommaire

Loading UML Models



- Serialization of the UML model
  - Generate only *data* and not functions (*program*) from both structural (e.g., classes), and behavioral (e.g., state machines) parts of the model
    - Except for opaque expressions and opaque behaviors, for each of which a function is generated

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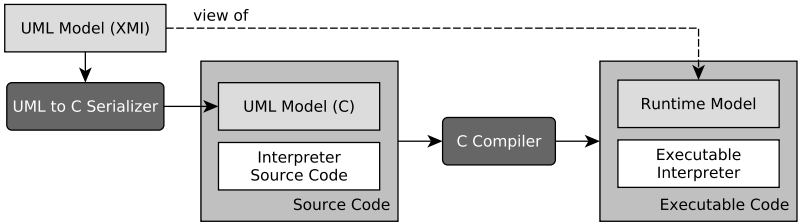

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  - Generate only *data* and not functions (*program*) from both structural (e.g., classes), and behavioral (e.g., state machines) parts of the model
    - Except for opaque expressions and opaque behaviors, for each of which a function is generated
- Compilation of the model (*data*) and of the interpreter (*program*) into executable code
  - Can be seen as compile-time model loading

Interpretation of UML models

Operational semantics (subset of UML)

- A unique implementation of the semantics in the interpreter
- Aiming at compatibility with:
  - Precise Semantics for UML Composite Structures (PSCS)
  - Precise Semantics for UML State Machines (PSSM)

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Targets

- Desktop computers (e.g., PC with a Linux operating system + TCP)
- Embedded microcontrollers on bare-metal (e.g., stm32f4 discovery + RS232)

Sommaire

Conclusion

Our contribution

- Uses the same operational semantics implementation for all activities
- Facilitates interactions between design and runtime concepts
- Expresses diagnosis results in terms of design concepts

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Perspectives

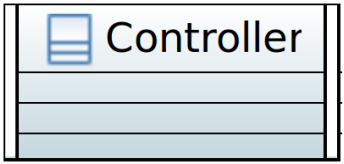
- Support for adding/removing breakpoints
- Support a larger subset of UML
- Integration with UML modelers (e.g., Papyrus)
- Evaluation of the interpreter overhead

Thank you for your attention

Appendix: Loading UML Models

Deployment process

- Design of the level crossing model in Eclipse UML (graphically with Papyrus or textually with tUML)




```
1 class |Controller| behavesAs SM {
2   stateMachine SM {}
3 }
```

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```
<packagedElement xmi:type="uml:Class"
  xmi:id="_hcP2cJFrEeeKv5ZjdgN-yQ"name="Controller"
  classifierBehavior="_hcXyQJFrEeeKv5ZjdgN-yQ" isActive="true">
  <ownedBehavior xmi:type="uml:StateMachine"
    xmi:id="_hcXyQJFrEeeKv5ZjdgN-yQ" name="SM">
  </ownedBehavior>
</packagedElement>
```

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- Serialization into C language as struct initializers

```
1 UML_Class class__Controller = {
2   .c_kind = C_UML_Class,
3   .visibility = UML_PUBLIC,
4   .name = "Controller",
5   .classifierBehavior = (UML_Behavior*)&stateMachine__Controller,
6   .isActive = 1
7 };
```

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- Design of the level crossing model in Eclipse UML (graphically with Papyrus or textually with tUML)
- Serialization into C language as struct initializers
- Model linked at build time with the interpreter