Model-based Verification of Safety Contracts

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Agenda

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Introduction (I): Motivation

Safety assessment

- Needed by some systems (e.g. critical systems)
  - Industrial equipment, road vehicles, avionics. . .
  - Requirements specified by industrial standards (IEC-61508, ISO-26262, DO-178C)
- Later verification induces budget overruns
  - Example: Half of the overall costs in avionics software domain

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Introduction (II): Motivation

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Contract-based design

- Popular approach for the design of complex systems
- Safety properties are difficult to guarantee $\rightarrow$ use of contracts

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Contracts

- Commonly used to specify relationships between system components
- Pre- and post-conditions of a system component
- Refinement idea: safety contract
  - Assumptions; Guarantees
  - Aim: to assure a certain level of confidence of a component

Introduction (III)

UML

- Well-known modelling language in the industry
- Vehicle to integrate safety requirements into software lifecycle

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Merging two domains...

- UML: Standard engineering practice
  - UML SM and UML SD: Dynamic part of the system
  - UML Composite diagram: Static one → enriched with safety contracts
  - UML profile (MARTE): Performance system information
  - Representation of safety contracts as OCL constraints

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  - Representation of safety contracts as OCL constraints
- Petri nets: Formal safety analysis
  - Compute probabilities of reaching "safe conditions"

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Previous Concepts (I)

UML and UML profiles

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UML and UML profiles

- Semi-formal modelling language
- Tailored for specific domains by profiling
  - Stereotypes: Concepts in the target domain
  - Tagged values: Stereotype attributes
- Enriches UML semantics, commonly used for NFPs specification

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  - Stereotypes: Concepts in the target domain
  - Tagged values: Stereotype attributes
- Enriches UML semantics, commonly used for NFPs specification
- Profile examples:
  - Modelling and Analysis of RT and Embedded systems (MARTE)
    - Generic Quantitative Analysis Model framework, `gaStep` stereotype (activity durations)
  - Dependability Analysis and Modelling (DAM)
  - Security Analysis and Modelling (SecAM)

Previous Concepts (II)

- UML + MARTE not suitable for performance evaluation or model-checking
- Formal models may help for this goal
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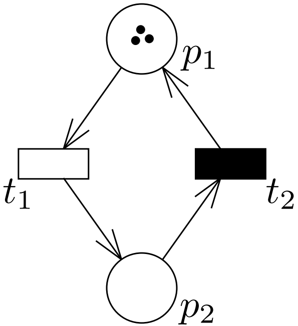

GSPN

- Bipartite graph
- Places (circles, p_X)
- Transitions (bars, t_X)
  - Immediate ($t = 0$)
  - Timed (exponential, deterministic firing distributions)
- Arcs (with directions, and weight)
- Tokens

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Case Study (I): TCMS

Train Control and Management System

- Complex system distributed along the train
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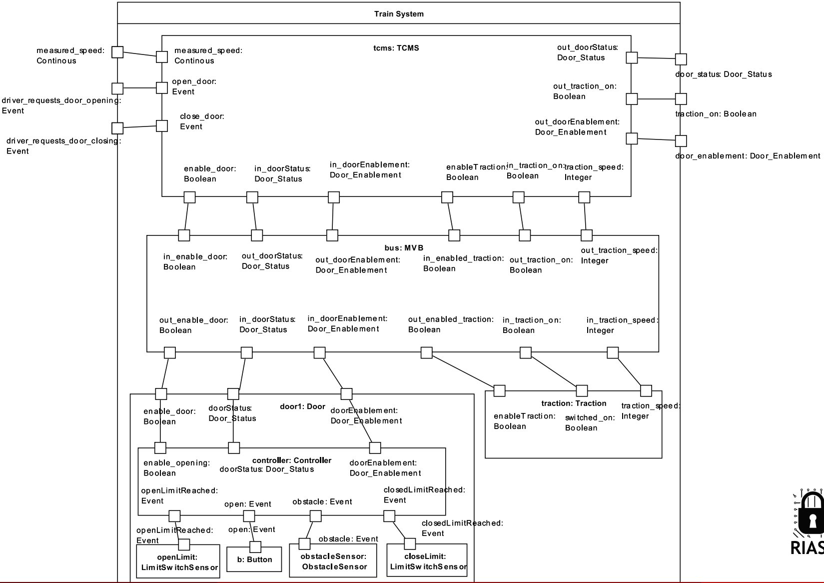
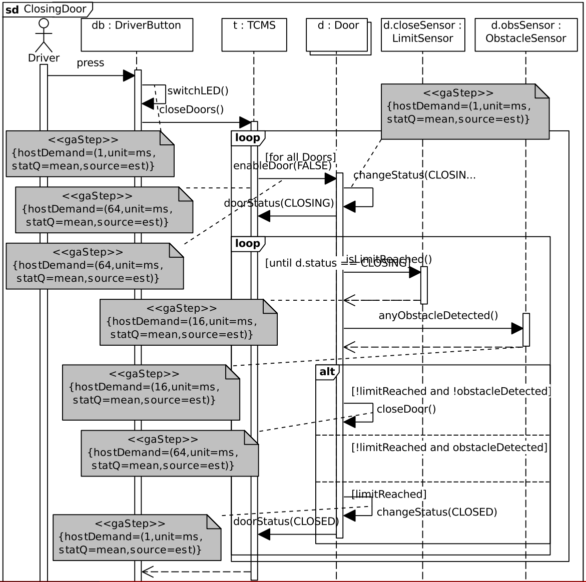
Door control management

- Several actors involved: TCMS, Door, Traction, MVB
  - TCMS: Decides whether enabling or disabling the doors
  - Door: Enabled → opened; disabled → closed
  - Traction: Deals with train movement
  - Multifunction Vehicle Bus: Communicates all components among them

Case Study (II): TCMS UML Composite Diagram



Case Study (III): Door closing UML Sequence Diagram



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- Model is too complex (but also the life. . .)
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  - They interact with the environment
  - Safety critical components are associated to safety contract fragments (SCF)

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  - Safety critical components are associated to safety contract fragments (SCF)

Safety contract fragment $\mathcal{S}_\mathcal{C} = \langle \mathcal{A}, \mathcal{G} \rangle$

- $\mathcal{A}$: Assumptions on the component's environment
- $\mathcal{G}$: What the component guarantees under such an environment
- A component *implements* its contract if it satisfies the guarantees when the environment meets the assumptions

Safety contract transformed to OCL constraints

Agenda

Safety Contract Fragment to OCL (I)

SCF $\mathcal{S}_{\mathcal{C}} = \langle \mathcal{A}, \mathcal{G} \rangle$

- $\mathcal{A} = \mathcal{A}^{+} \bigcup \mathcal{A}^{*}$ (assumptions, input ports)
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OCL

- Express constraints within UML models
- Defined over a context that describes where constraint is acting
- OCL invariant: $\mathcal{R} = \langle \mathcal{X}, \mathcal{V} \rangle$
  - $\mathcal{X}$: Context
  - $\mathcal{V} = \langle ls, rs \rangle$ (joined by a boolean or `implies` operator)

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Given a component $\mathcal{C}$, and $\mathcal{S}_\mathcal{C} = \langle \mathcal{A}, \mathcal{G} \rangle \rightarrow \mathcal{R} = \langle \mathcal{X}, \mathcal{V} \rangle$, where $\mathcal{X} = \mathcal{C}$ and $\mathcal{V} = \langle \mathcal{A}, \mathcal{G} \rangle$

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Safety Contract Fragment to OCL (II): Examples (1)

SR1. *The door opening is not enabled when the traction is on or the train speed is distinct than zero*

- $\mathcal{S}_1 = \langle (traction\ OR\ (tractionSpeed \neq 0)), (NOT\ enableOpening) \rangle$ (TCMS)

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- $\mathcal{S}_2 = \langle obstacle, doorStatus = opening \rangle$ (DoorController)

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context DoorController_SR2
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Safety Contract Fragment to OCL (II): Examples (2)

SR3. *The door is closed when the door opening is enabled and the close event is received*

- $\mathcal{S}_3 = \langle (enableOpening\ AND\ close), doorStatus = isClosed \rangle$ (`Door`)

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So, until here we have expressed safety contracts using OCL within UML. Now, **we express these constraints using Petri nets to verify them, check next slide!**

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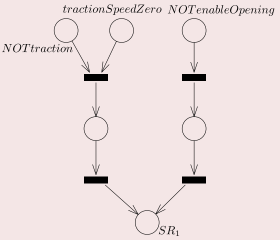
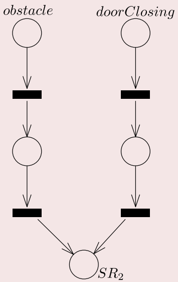
From OCL constraints to Petri nets (I)

- Places representing each condition in the OCL invariant
- $p \Rightarrow q \Leftrightarrow \neg p \vee q$
- Compute the (output) place marking probabilities (by simulating)

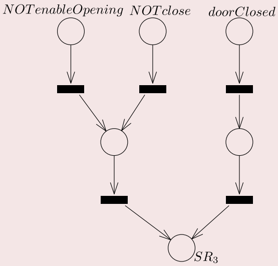
SR1



SR2



SR3



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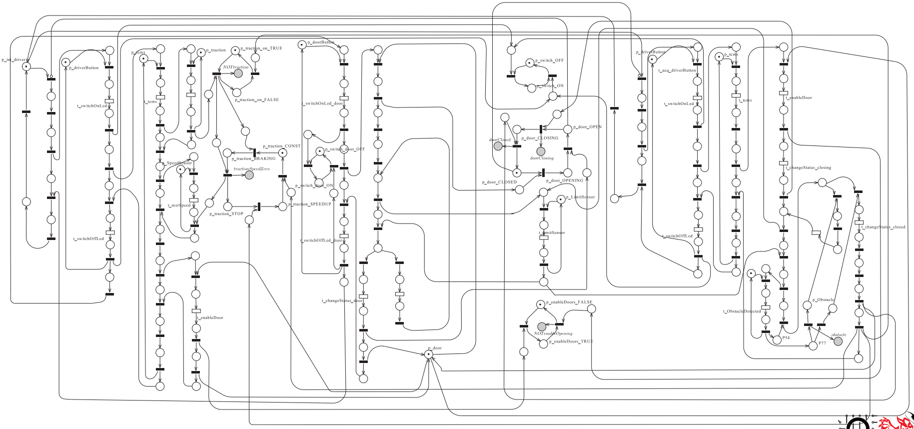
From OCL constraints to Petri nets (II)

Petri net of the door controller



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Related Work (I)

Formal expression of contracts

- Requirements Specification Language, Othello (based on LTL), Modal Transmission Systems
- **Advantage**: expressiveness
- **Disadvantages**:
  - Needed to learn a new formalism each time used
  - Lack of verification (some of them)

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Our proposal

- Enables to analyse also non-functional properties
- Safety contract fragments expressed as OCL
- Could complement OCRA analysis (non-functional properties)
- Strong, weak assumptions: Weak implicitly described with MARTE

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Conclusions and Future Work

- Contract-based design: Good approach for safety-critical systems
- Safety contracts expressed as OCL, and verified into the PN
- All this performed at design phase! → saves budget overruns

Future Work

- Increase complexity of contracts expressed by OCL
  - Event order? Temporal information?
- Safety assessment methodology + a tool to automatise the process

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A last remark

- Final effort must be done in implementation
  - Assure it matches the system model, or otherwise it may lead the system to an unsafe system

- **Acknowledgements**: ARTEMIS JU nSafeCer, n^o 295373

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