OpenModelica - The Common Requirement Modelling Language (CRML) Integration

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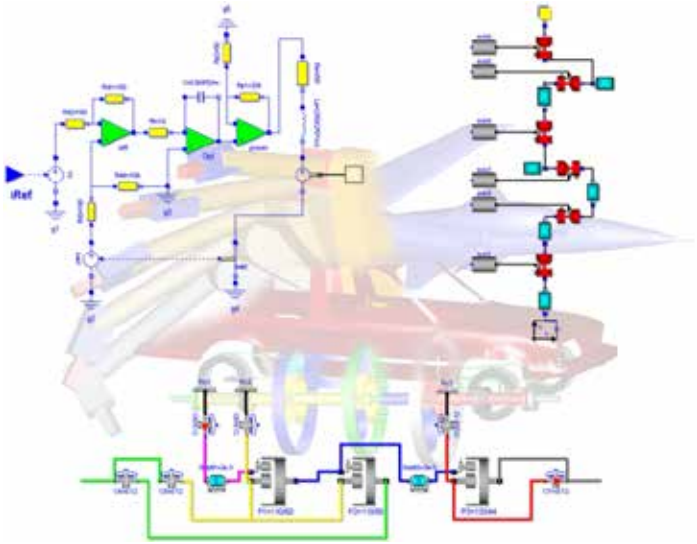
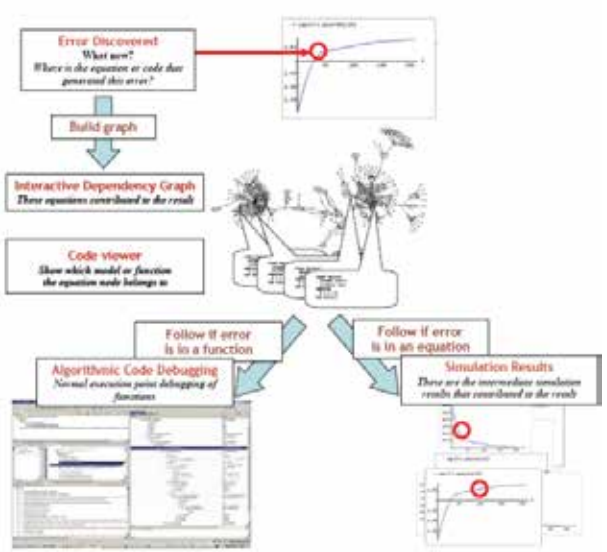
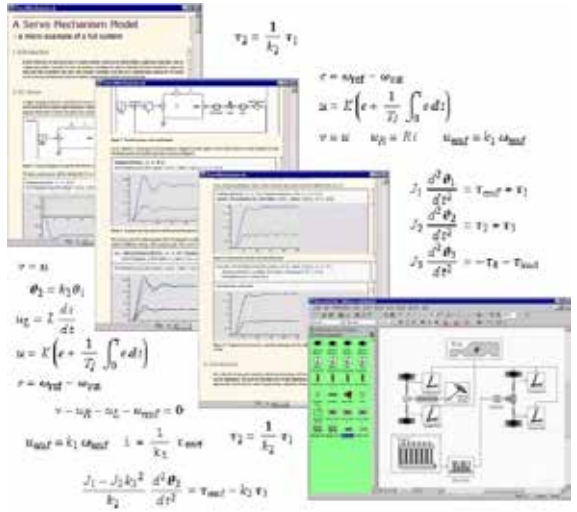
Open Source Modelica Consortium
PELAB, Linköping University
EDF, Électricité de France







Outline

- What is CRML
  - The Common Requirement Modelling Language
- CRML Tooling
  - The CRML Compiler
- CRML Integration
  - OMEdit
  - VSCode
  - Online
- Future work

What is CRML?

- The Common Requirement Modelling Language
  - Language for Verifying Realistic Dynamic Requirements

- Started at EDF around 2006
- Further developed during the ITEA3 EMBrACE project

Ambition: Effective Engineering of Large CPS

Scope: Cyber-Physical Systems (CPS), especially energy systems

Characteristics

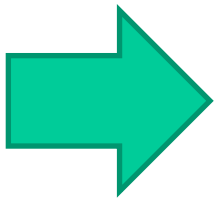
- CPS Projects have often strong **social and environmental impacts**
- They are **long lasting** projects involving numerous stakeholders
- They should obey to **multiple even conflicting requirements**
- **Project performance is a key** as large over costs may be induced quickly due to financial charges (discount rate)

Challenges

- How to focus on conceiving systems more sustainable, trusty and resilient?
- How to solve over-constrained problems? How to coordinate stakeholders efficiently?
- How to specify the right need without going into realization details? How to reconcile innovation with what already exists?
- How to propagate changes in assumptions all over the system design cycle?
- How to evaluate design alternatives efficiently?
- How to perform failure modes, effects, and criticality analysis (FMECA) all along design lifecycle?
- How to justify and document design choices for future generations?

Examples of Challenges - Related to Energy Systems

- Interconnected systems with stringent physical constraints to ensure grid balancing
- Long system lifecycles: new solutions built on existing ones (they are not created from scratch)
- Compliance with strict safety and environmental rules
- Compliance with dependability and availability constraints (to ensure security of energy supply)
- Involvement of multiple stakeholders: clients, regulatory authorities, grid operators, energy providers, insurers, urban and land-use planning, plant operators…, with different and possibly contradictory objectives
- Moving context with increasing uncertainties (due to geopolitical tensions, energy market instabilities, climate change, lack of energy policy coordination between countries, evolution of demand wrt. new usages…)

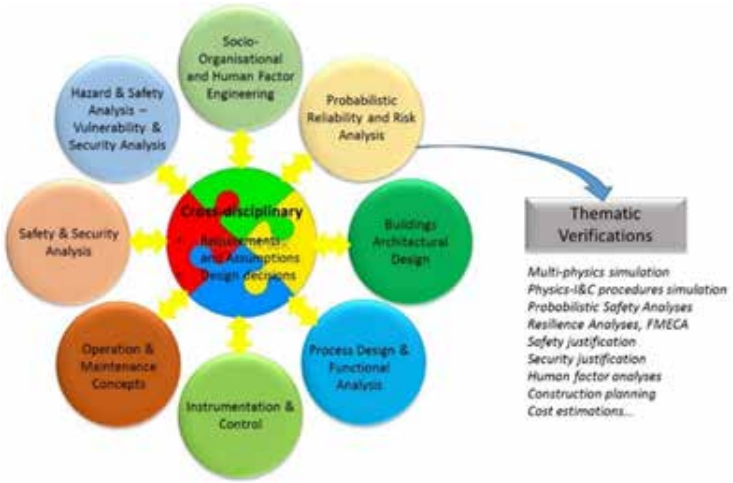


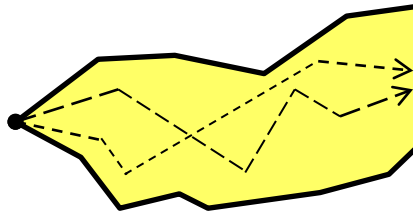
Energy systems are globally over constrained.
New generation of methods & tools are needed to help engineers
find the best compromise for covering multiple "what-if" operational situations (incl. variabilities and hazards)

What Should Be Improved in CPS Engineering?

- **Today**
  - **system evaluation** is performed mostly with **static models** **(or dynamics are considered too late)**
  - most **verifications are performed manually** **(or with domain-specific tools)** and hence not as often as necessary
  - **information is difficult to share** between disciplinary engineering teams

è oversizing, late error detections, and eventually delays and cost overruns





Figures:
T. Nguyen

- There is a **need for more rigorous engineering method** to
  - **Be more effective assessing the impact of each solution** all along the system lifecycle including during preliminary design phases
    à guide and justify design choices also for non-experts
  - **Open the solution space to innovative products or services**
    à specify only “what is needed”

CRML – A Part of the Solution

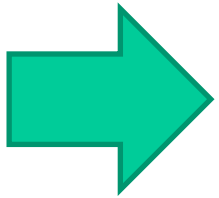
Idea =

Use of **realistic dynamic behavioral models** to better handle multi-physics & systems' interactions **à e.g. Modelica**

Use of **formal dynamic requirement models** to automate verifications and evaluate multiple "what-if" scenarios **à CRML**

Rationale

- Consideration of "System Dynamics" as time may be part of new solutions to cover non-regular situations and hence source of cost reductions
- Formal verifications since for many CPS demonstration that the system operates safely is as important as the design itself

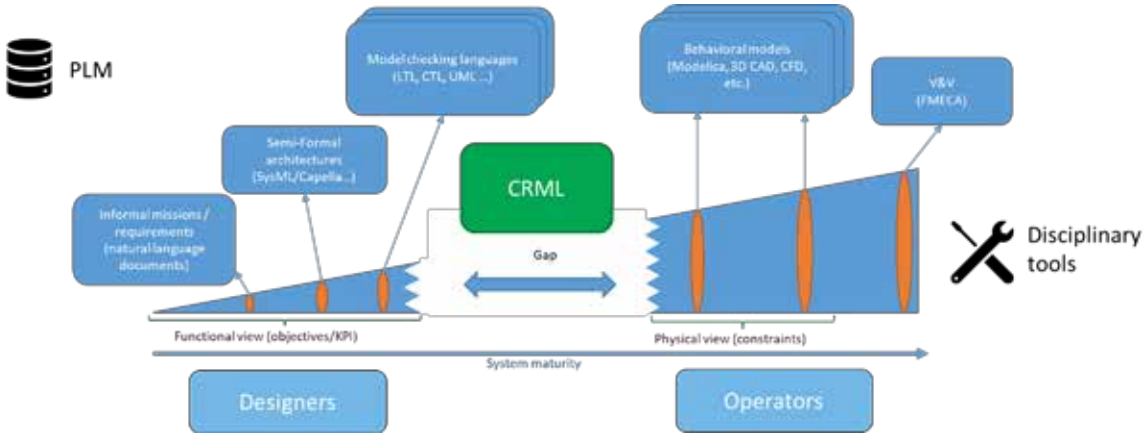


Scope of ITEA EMBrACE Project
"An enabler for making the best decisions at each step of the project cycle"

CRML: A Language for Verifying Realistic Dynamic Requirements

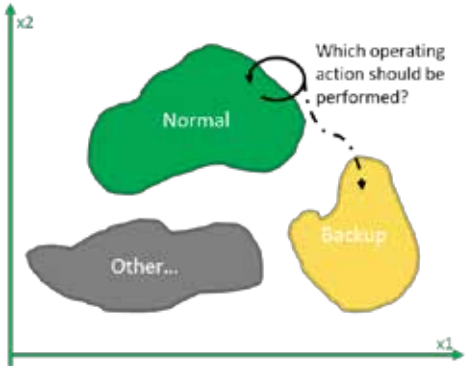
Why a new language?

- Main principles from « System Engineering »
- Tools exists but are incomplete or essentially made for software design
- Native difficulty to address requirements that are « realistic » for systems with strong physical aspects
- In particular to study their dynamical interactions with their environments



CRML positioning vs. State-of-the-Art :
a bridge between the physical & the functional views

A typical realistic dynamical requirement is multiple and stochastic …



1. The system should stay within its normal operating domain.
2. If partial requirement 1 above fails, then the system should go back to its normal operating domain within a given time delay.
3. If partial requirement 2 above fails, or if partial requirement 1 fails with a too high failure rate, then the system should go to a safe backup state within a given time delay.
4. The complete requirement made of the conjunction of partial requirements 1, 2 and 3 should be satisfied with a given probability (e.g., > 99.99%).

… and a typical project quickly sees its complexity increase with the number of requirements/stakeholders and evolution over time

CRML: Not a Whim But a Long-Lasting History

- **EUROSYSLIB project:** start reflections on how to specify systems without describing their detailed behavior è need for a formal specification language
  è investigation of the state-of-the-art.

- **OPENPROD project:** proposition of a link between SysML and Modelica
  è ModelicaML prototype developed by Airbus and tested by EDF.

- **MODRIO project:** proposition by EDF of a new language called FORM-L (Formal Requirement Modelling Language)
  - Specification written by EDF (Thuy Nguyen)
  - Blocks as functions in Modelica
  - Development of two Modelica libraries for the formal capture of requirements: Modelica_Requirement (DLR) and ReqSysPro (EDF).
  - Development of a FORM-L compiler (Inria and Sciworks Technology) on an EDF contract.

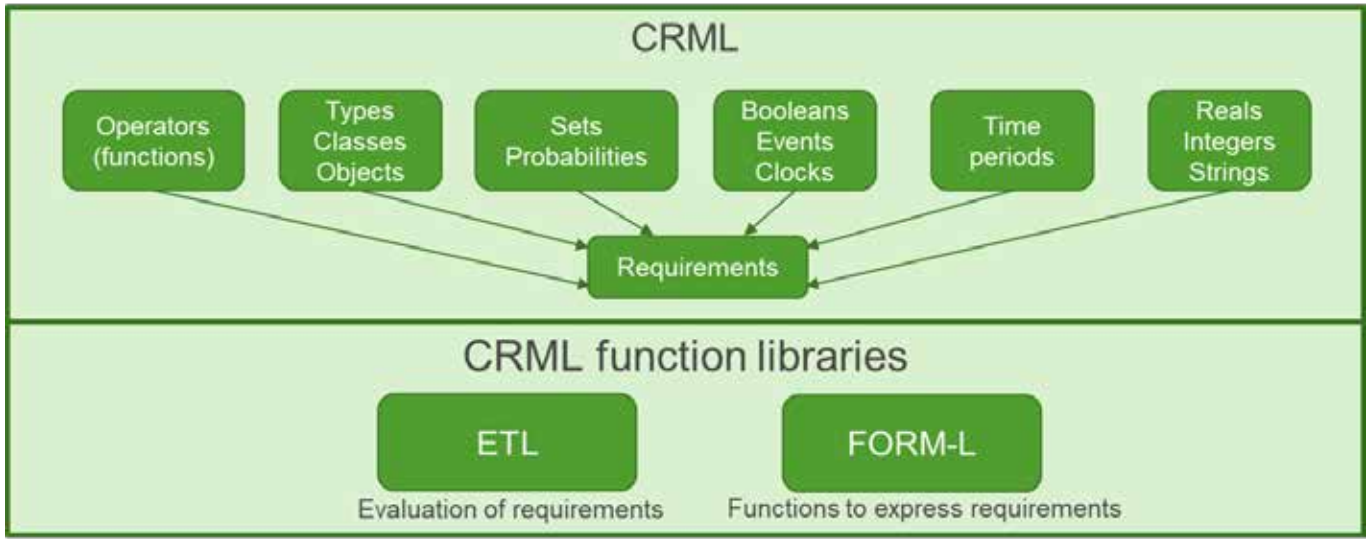
- **EMBRACE project:** proposition of CRML as the formal specification of FORM-L.
  - Specification written by EDF (Daniel Bouskela).
  - CRML compiler developed by University of Linköping.

How To Express a CRML Requirement?

R = [Where or Which] [When] [What] + (optional) [How well]

```
for all' pump 'in' system.pumps 'during' system.inOperation 'check count' (pump.isStarted 'becomes true') '<=' 3;
'during' systemOperatingLife 'check at end' (estimator Probability (noStart at inOperation 'becomes false')) '>' 0.99;
```

- Combination of 4 items
  - Spatial locators
  - Time locators
  - Condition to be checked
  - (optionally) Performance indicator
- Value at instant t is a Boolean4 which can be : `true`, `false`, `undefined` or `undecided`

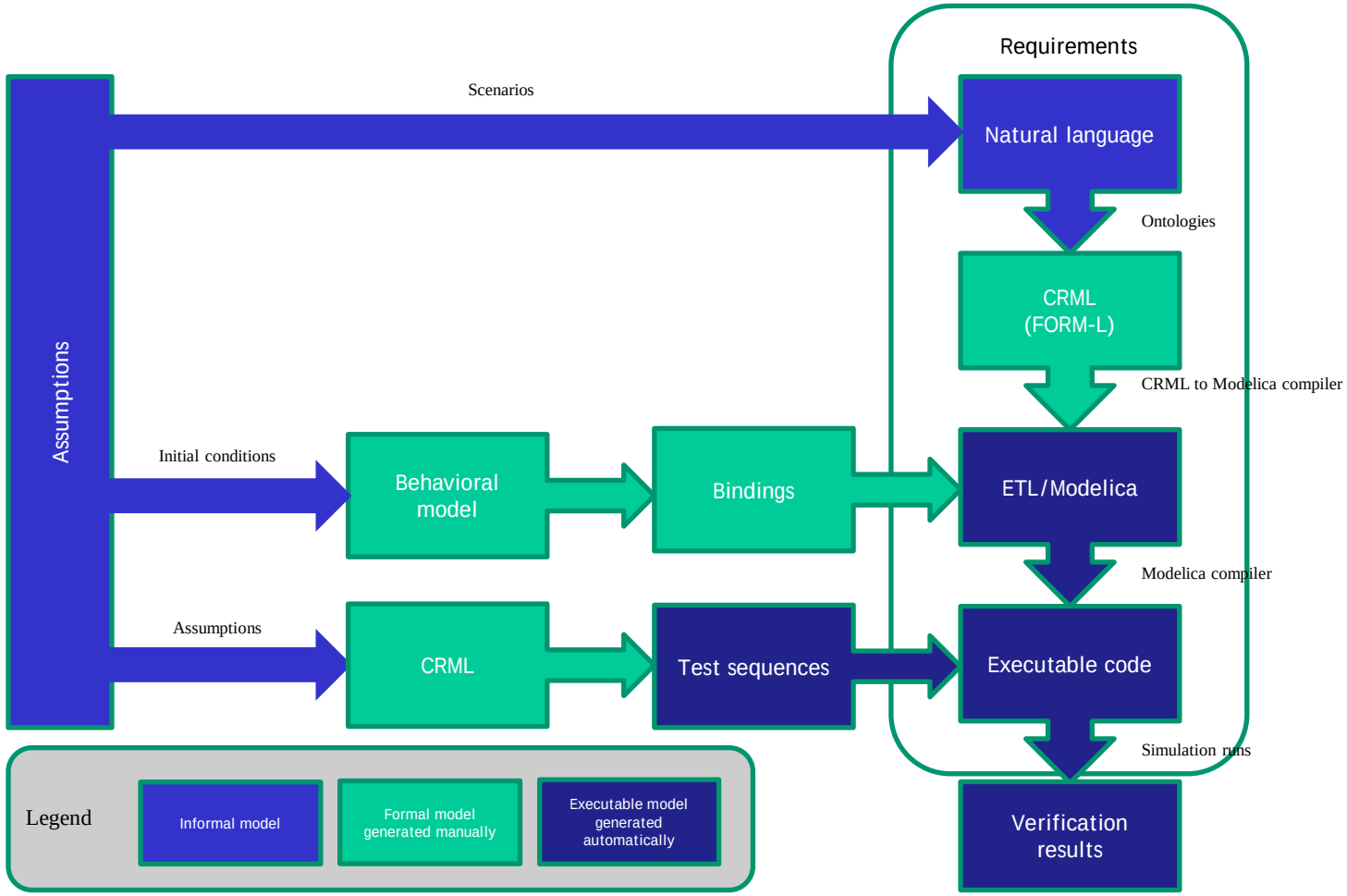


CRML Specification v1.1 (EMBrACE D2.1, Daniel Bouskela)

How to Use CRML for Verifications?

- **Requirement models**
  to capture all constraints on the system and define envelopes of acceptable behaviors
- **Behavioral models**
  to capture the behavior of design solutions

- **Verification models**
  to automate tests by using requirement models as observers to check whether design solutions meet requirements or not.



How To Evaluate a CRML Requirement?

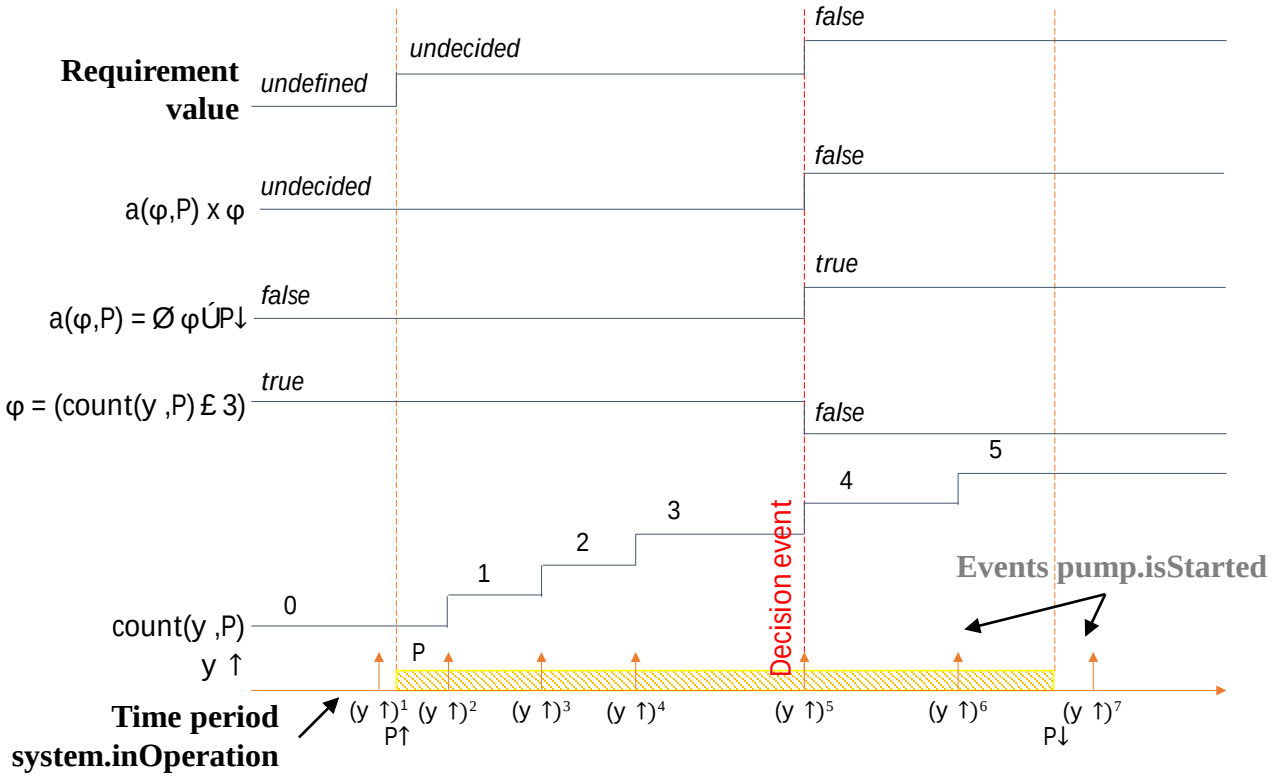
Case 1: Requirement R3 is declared as « violated » as soon as condition φ becomes false

Requirement capture in CRML

```
Class Pump is {
        Boolean isStarted is external};
Class System is {
        Pump{} pumps is external;
        Boolean inOperation is external};
System system;

Requirement R3 is {
  'for all' pump 'in' system.pumps
  'during' system.inOperation
  'check count'(pump.isStarted 'becomes true')
  '<=' 3;
};
```

external keyword is used to retrieve values in solution models
Operators in ‘’ are defined by user to improve readability



Requirement evaluation
via observation of system behavioral dynamics

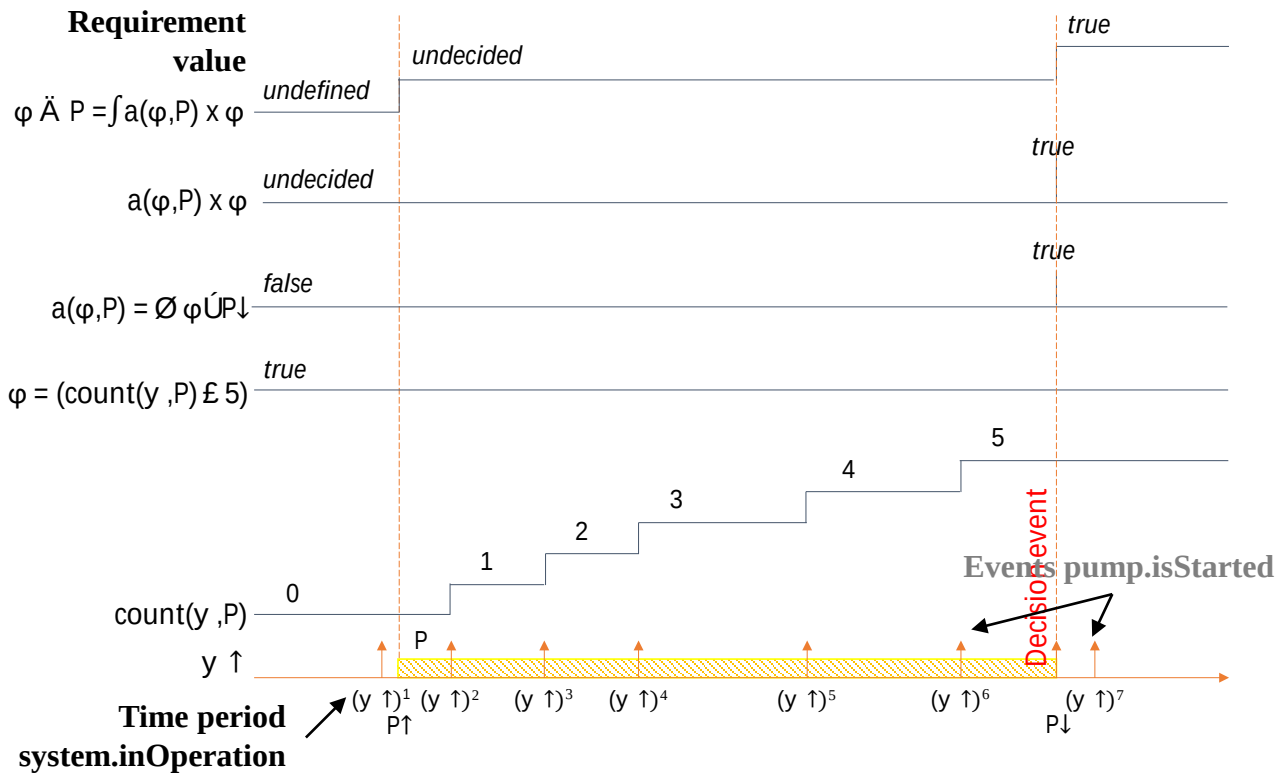
How To Evaluate a CRML Requirement?

Case 2: Requirement R5 is declared as
« undecided » until time period is completed

Requirement capture in CRML

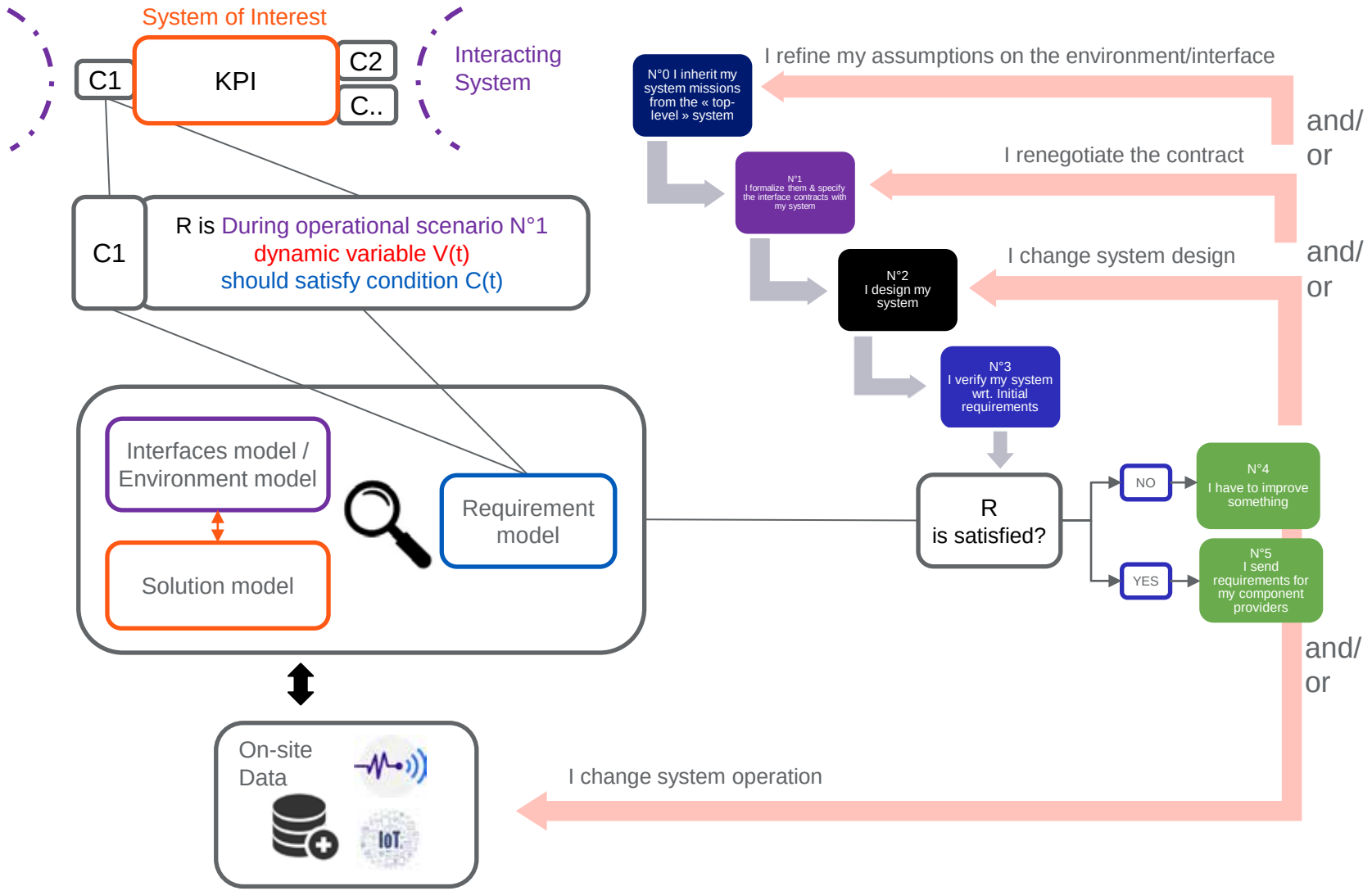
```
Class Pump is {
        Boolean isStarted is external};
Class System is {
        Pump{} pumps is external;
        Boolean inOperation is external};
System system;

Requirement R5 is {
  'for all' pump 'in' system.pumps
  'during' system.inOperation
  'check count'(pump.isStarted 'becomes true')
  '<=' 5;
};
```



Requirement evaluation
via observation of system behavioral dynamics

How to Use CRML As a Decision Tool?



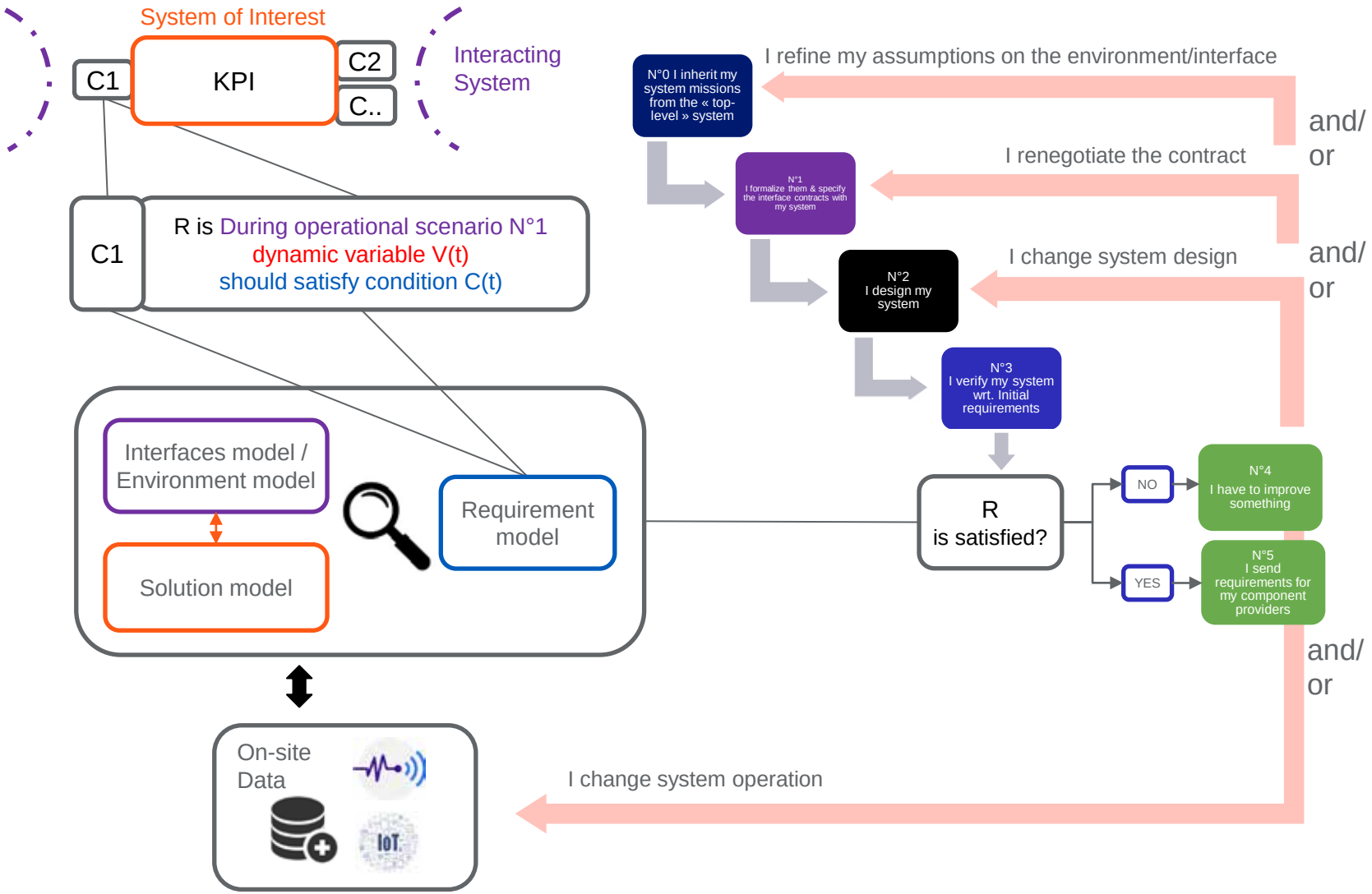
Model to support complexity

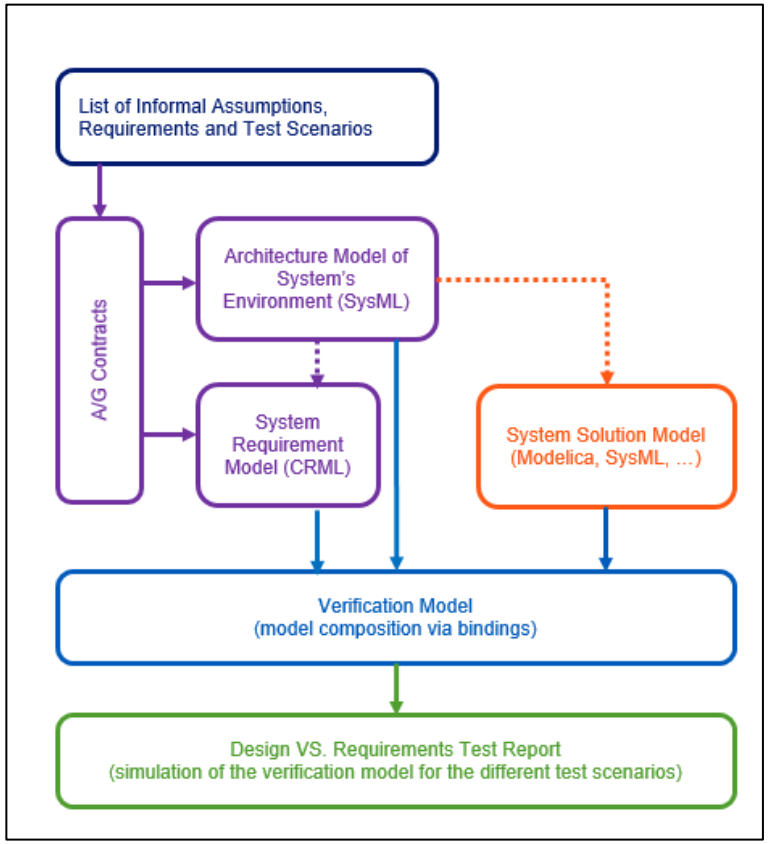
- § Scope of responsibility of stakeholders
- § Multiplicity of constraints and operating scenarios
- § Dynamics of interactions between systems, human and environment

Center development on the requirements

- § Evaluate the impact of each solution on your overall ambition
- § Design only for the « right » need
- § Adapt the studies to « what is just needed »
- § All along the project
- § And according to the data available at instant T

How to Use CRML As a Decision Tool?





Corresponding modelling architecture

CRML Slides, Audrey Jardin – The 15th International Modelica Conference

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  - Online
- Future work

- The CRML compiler
  - https://github.com/lenaRB/crml-compiler/
  - Implemented in Java
  - Translates CRML to Modelica
  - Integrates with Unit testing and Reporting

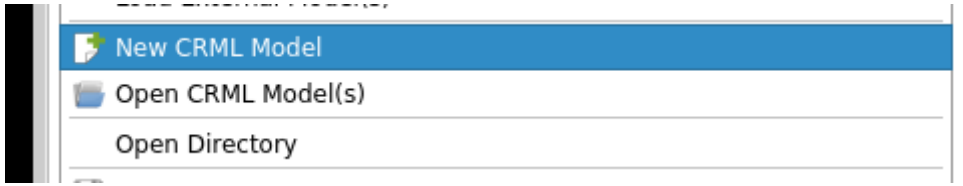
- Ongoing work
  - Support the full CRML specification
  - Integrate with OpenModelica

CRML – OMEdit Integration

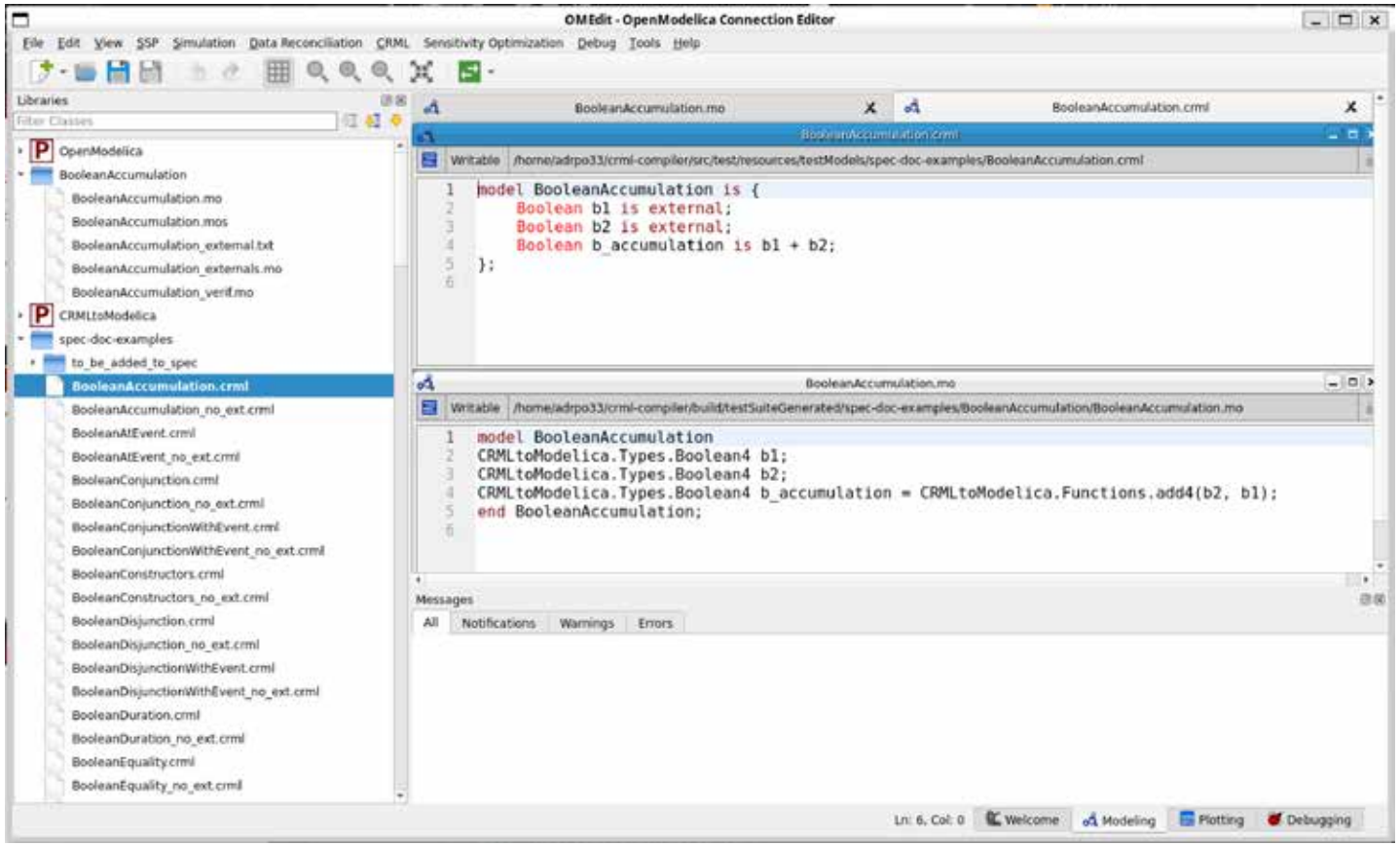
- New CRML menu in OMEdit
  - Generate and load Modelica code (also via the Library/File browser, right click)
  - Call the CRML compiler on the opened CRML file, generate Modelica code, load it into OMEdit, give errors if the code cannot be loaded
- Ongoing
  - dialog for CRML configuration before compilation
  - annotation in the CRML file where one can provide a configuration which will be added as a Modelica annotation in the generated Modelica file

- Run test report
  - Select a directory with CRML files
  - Call the CRML tool to generate the html report
  - Load and display the html report
  - A CRML test will go through these phases
    - Parsing
    - Translation
    - Verification model generation
    - Execution
    - Result Verification

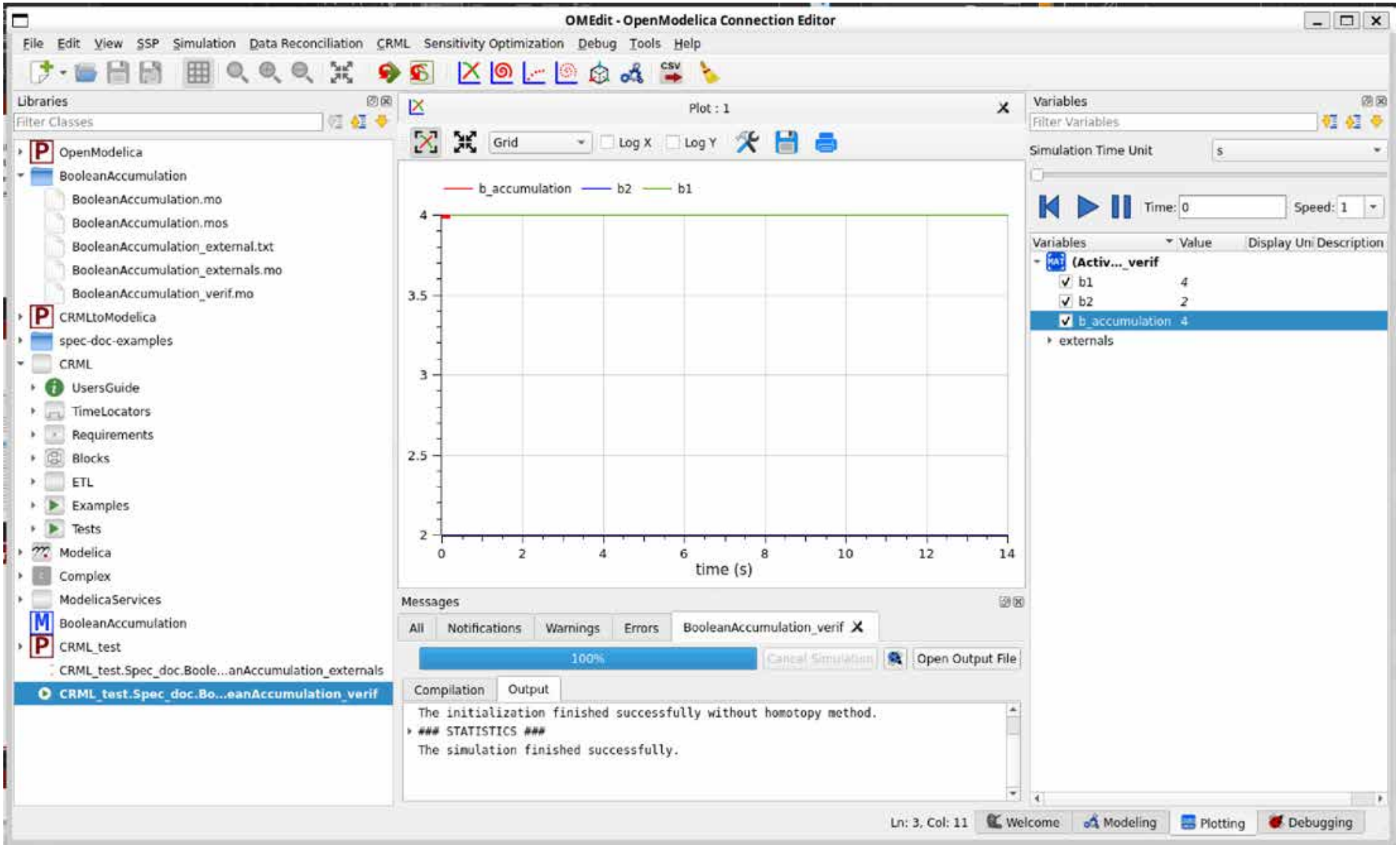
- New / Open CRML models



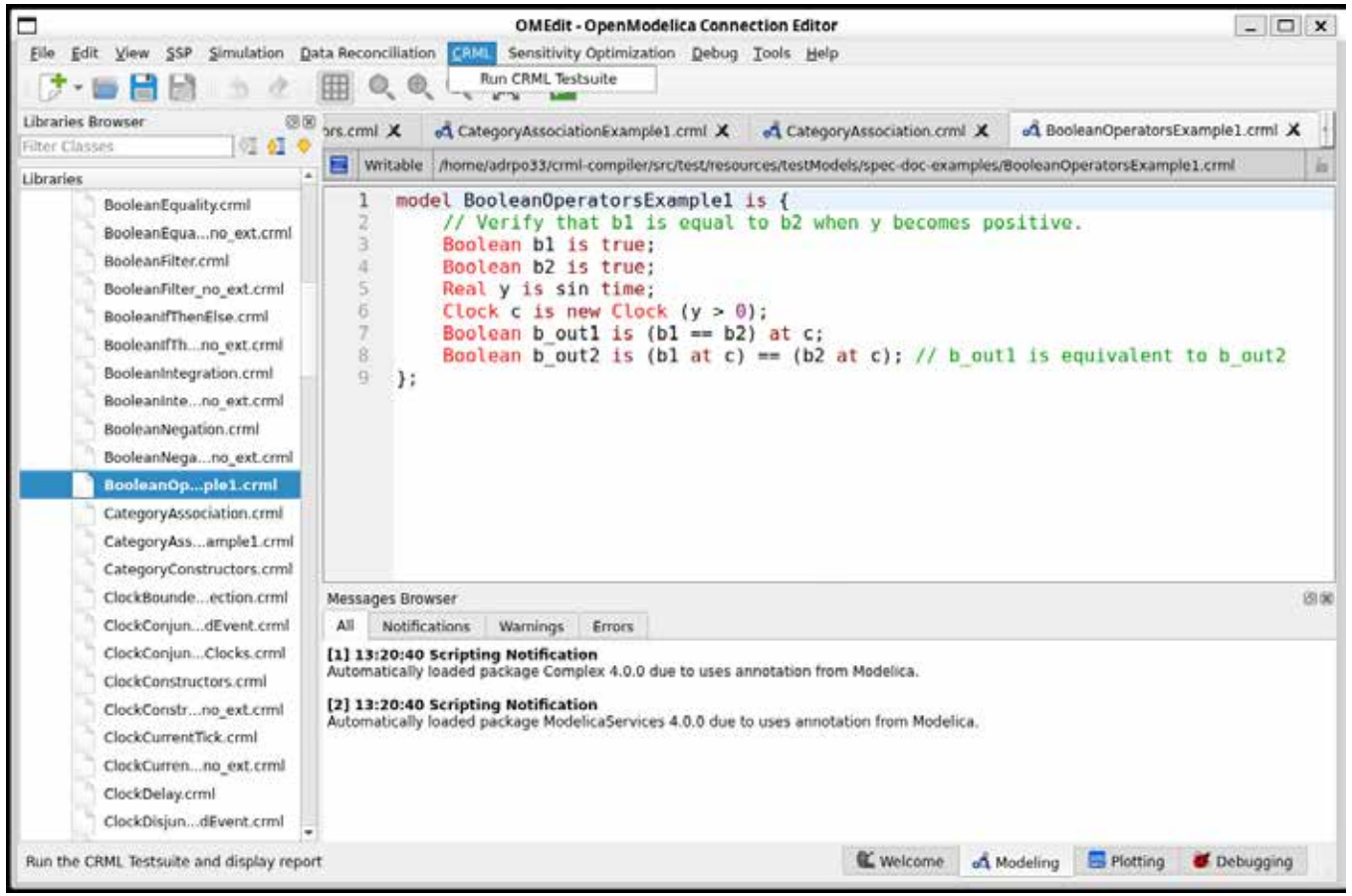
- Load directories containing CRML models
- Syntax Highlighting

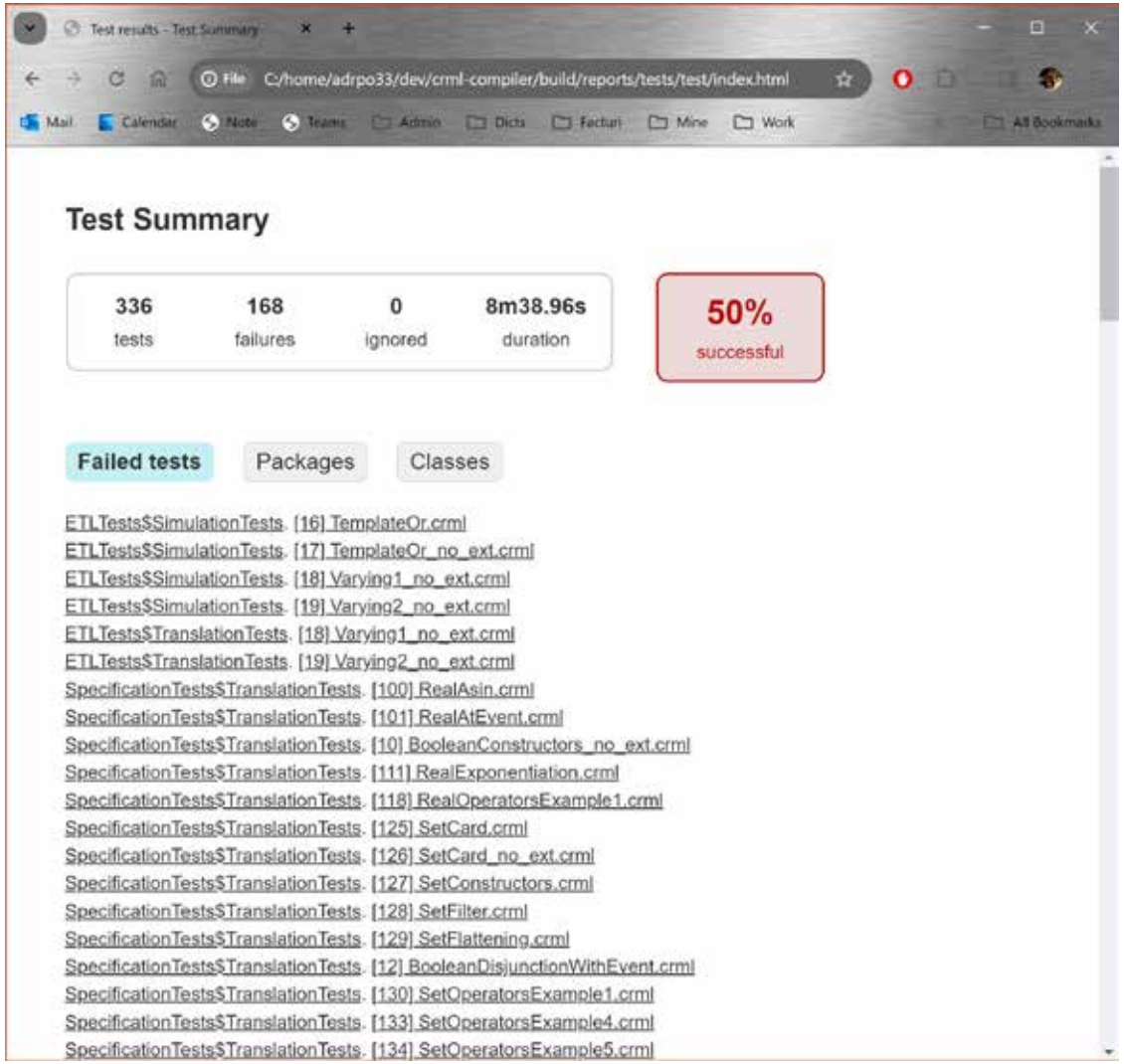


Generate and Simulate Modelica code

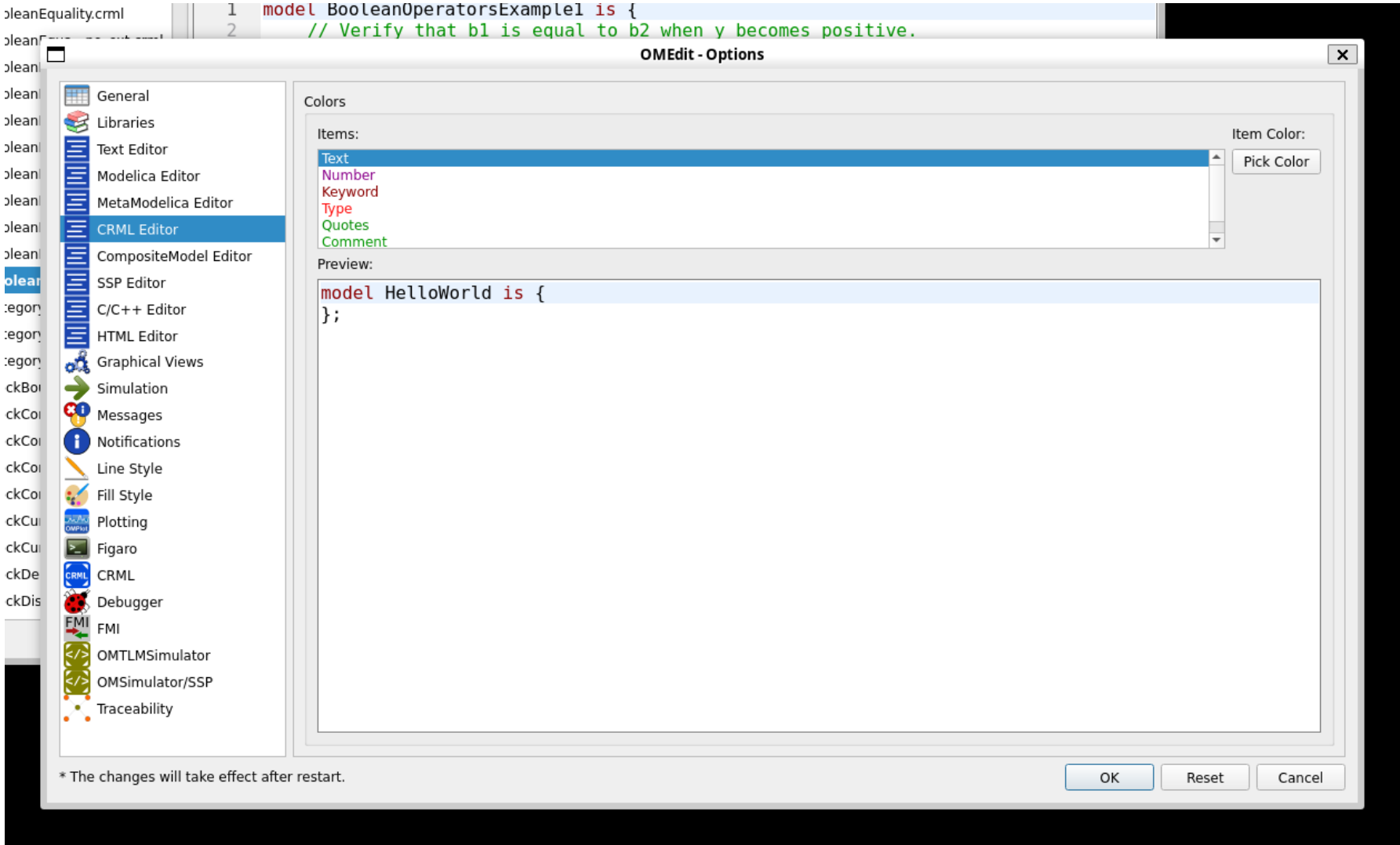


§ Run CRML Testsuite



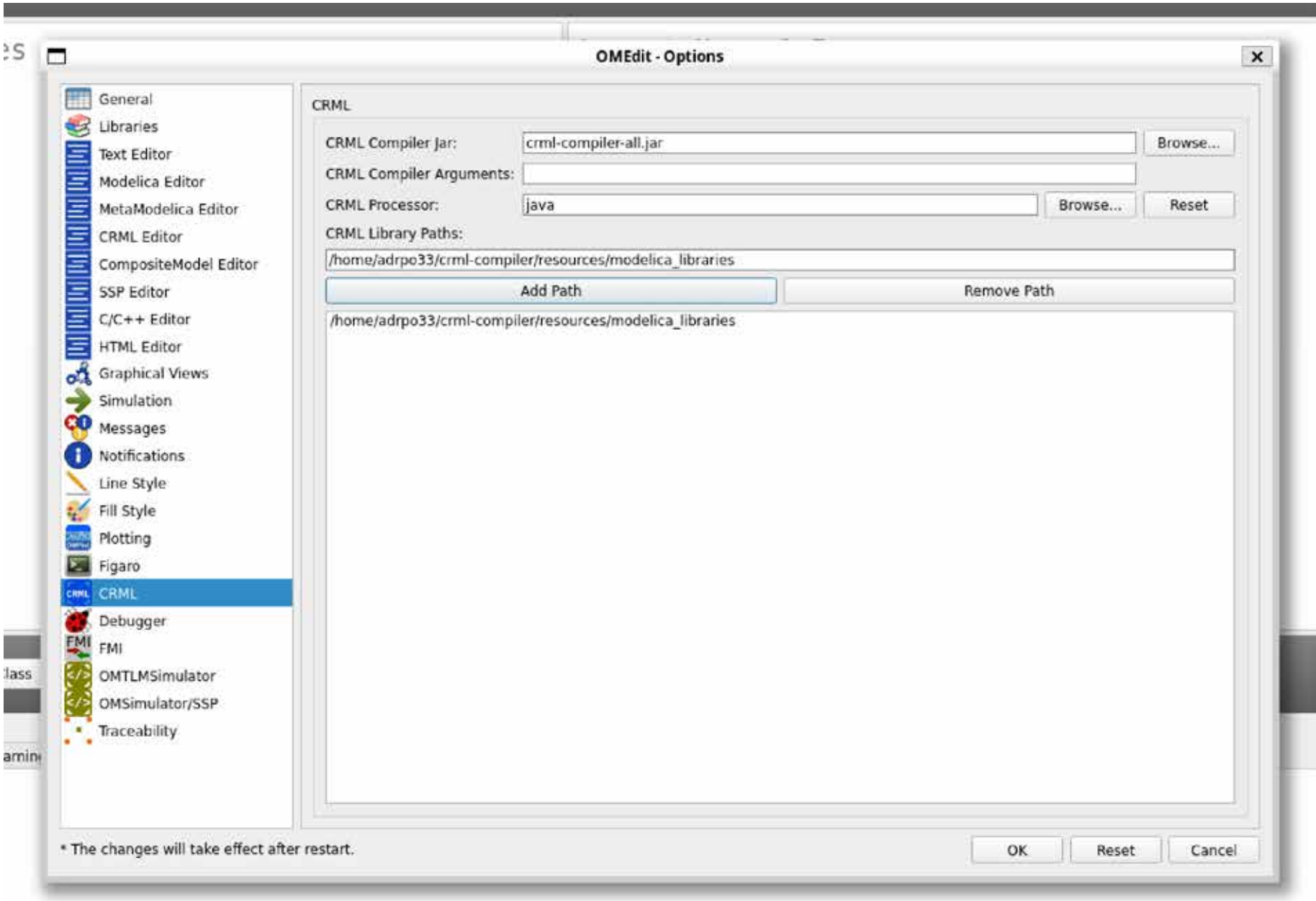


§ Editor Settings



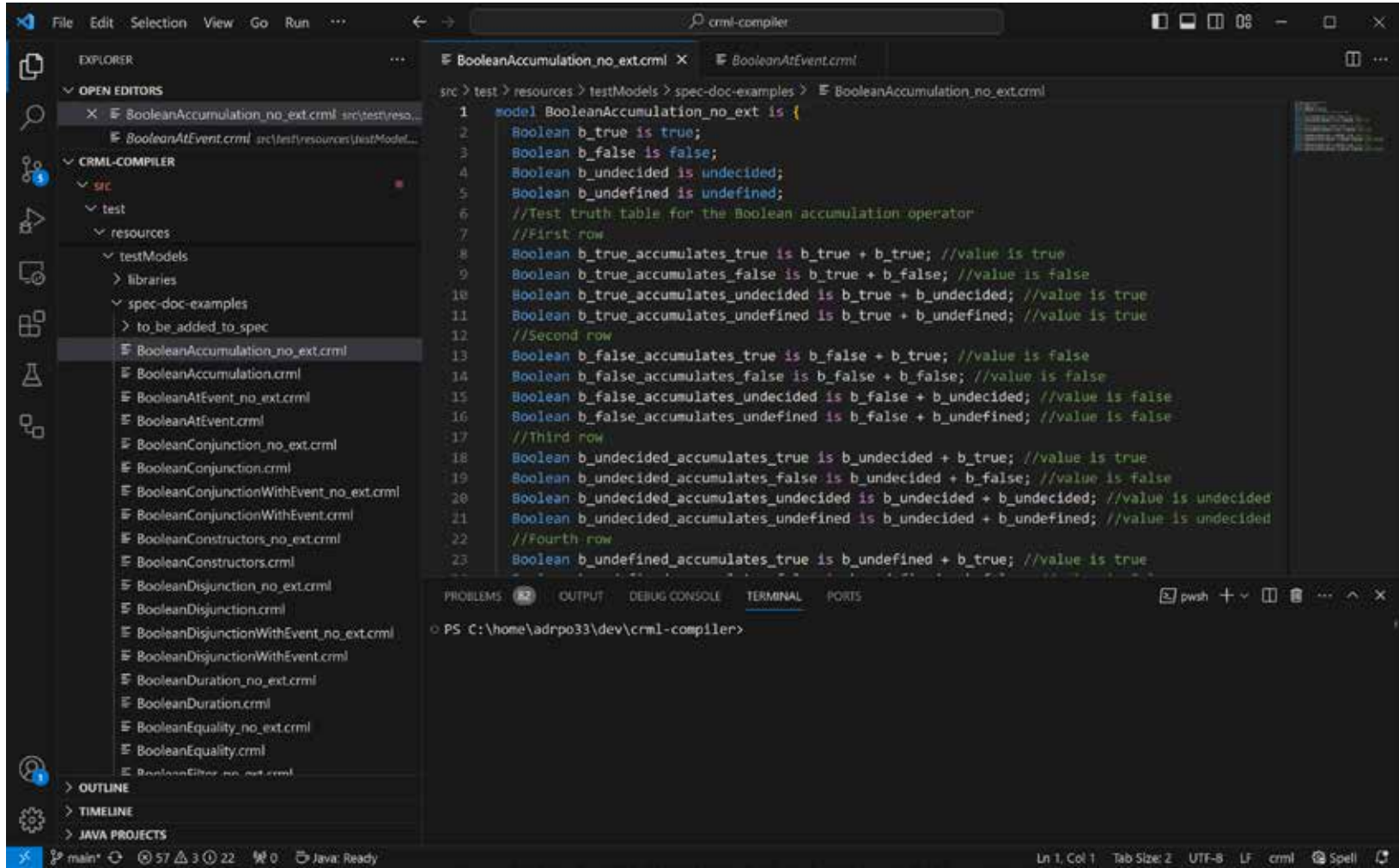
CRML – OMEdit Integration

§ Tool Settings

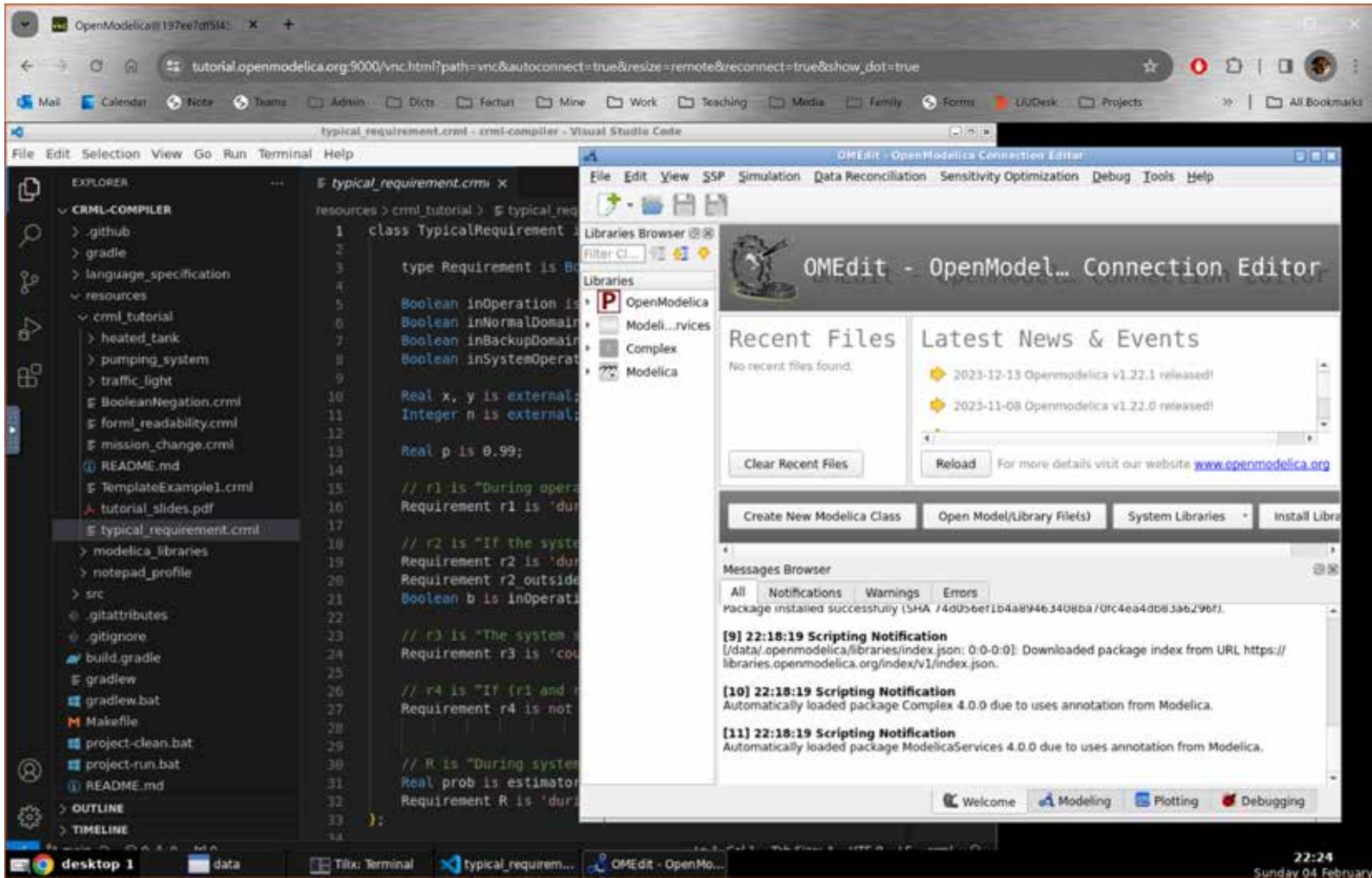


CRML – VSCode integration

- Basic VSCode extension
  - https://github.com/lenaRB/crml-vscode
  - syntax highlighting



- CRML and OpenModelica tutorial available online
  - https://tutorial.opennmodelica.org/
  - No install needed



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Future Work

- Near Future
  - Release the OMEdit integration as part of OpenModelica (v1.23.0)
  - Get more feedback from EDF on the prototype via evaluation on industrial use-cases
- Future
  - How to group together several requirements into a project
  - How to handle debugging (CRML <- Modelica <- C code)
  - Evaluate traceability from CRML to simulation results
  - Integration with dashboards to aggregate requirement information

Thank You!
Questions?

The CRML Project
https://crml-standard.org/

The OpenModelica Project
https://www.OpenModelica.org