OpenModelica - The Common Requirement Modelling Language (CRML) Integration

Adrian Pop, Lena Buffoni, Audrey Jardin

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Open Source Modelica Consortium
PELAB, Linköping University
EDF, Électricité de France
What is CRML
  - The Common Requirement Modelling Language

CRML Tooling
  - The CRML Compiler

CRML Integration
  - OMEEdit
  - 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

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
  - Guide and justify design choices also for non-experts
- Open the solution space to innovative products or services
  - Specify only “what is needed”

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Figures: T. Nguyen
CRML - A Part of the Solution

Idea =
Use of realistic dynamic behavioral models to better handle multi-physics & systems’ interactions \( \ddagger \) e.g. Modelica

Use of formal dynamic requirement models to automate verifications and evaluate multiple “what-if” scenarios \( \ddagger \) 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

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 positioning vs. State-of-the-Art:
A bridge between the physical & the functional views
**EUROSYSLIB project:** start reflections on how to specify systems without describing their detailed behavior → need for a formal specification language → investigation of the state-of-the-art.

**OPENPROD project:** proposition of a link between SysML and Modelica → 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?

Combination of 4 items
- Spatial locators
- Time locators
- Condition to be checked
- (optionally) Performance indicator

Value at instant $t$ is a Boolean which can be:
- true, false, undefined
- or undecided

$$R = [\text{Where or Which}] \ [\text{When}] \ [\text{What}] + (\text{optional}) \ [\text{How well}]$$

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;
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.
Case 1: Requirement R3 is declared as « violated » as soon as condition $\varphi$ becomes false

Requirement capture in CRML

```java
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

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

CRML Slides, Audrey Jardin – The 15th International Modelica Conference
How to Use CRML As a Decision Tool?

1. I inherit my system missions from the « top-level » system.
2. I formalize them & specify the interface contracts with my system.
3. I design my system.
4. I verify my system wrt. Initial requirements.
5. I have to improve something.

R is During operational scenario $N^1$ dynamic variable $V(t)$ should satisfy condition $C(t)$?

- System of Interest
- Interacting System
- KPI
- C1
- C2
- C
- C1

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 $T$

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How to Use CRML As a Decision Tool?

1. I inherit my system missions from the "top-level" system.
2. I formalize them & specify the interface contracts with my system.
3. I design my system.
4. I verify my system wrt. initial requirements.
5. I have to improve something.

- N°1: I inherit my system missions from the "top-level" system.
- N°2: I design my system.
- N°3: I verify my system wrt. initial requirements.
- N°4: I have to improve something.
- N°5: I send requirements for my component providers.

R is During operational scenario N°1 dynamic variable V(t) should satisfy condition C(t). If not:

- N°1: I refine my assumptions on the environment/interface.
- N°2: I change system design.
- N°3: I renegotiate the contract.
- N°4: I have to improve something.
- N°5: I change system operation.

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Future work
The CRML compiler

- [https://github.com/lenaRB/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
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
β New / Open CRML models

β Load directories containing CRML models

β Syntax Highlighting
Run CRML Testsuite

Test Summary

<table>
<thead>
<tr>
<th>Total</th>
<th>Failed</th>
<th>Ignored</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>336</td>
<td>168</td>
<td>0</td>
<td>8m 38.96s</td>
</tr>
</tbody>
</table>

50% successful
Editor Settings

```plaintext
model BooleanOperatorsExample is {
  // Verify that b1 is equal to b2 when y becomes positive.
}
```
Tool Settings

CRML - OMEdit Integration

- CRML Compiler Jar: crml-compiler-all.jar
- CRML Compiler Arguments: 
- CRML Processor: java
- CRML Library Paths:
  - /home/adpo33/crml-compiler/resources/modelica_libraries
  - /home/adpo33/crml-compiler/resources/modelica_libraries

* The changes will take effect after restart.
Basic VSCode extension

https://github.com/lenaRB/crml-vscode

Syntax highlighting
CRML and OpenModelica tutorial available online
https://tutorial.openmodelica.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