Experience in developing the mCRL2 toolset

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mCRL2, what is it?

- Toolset for verification of software
- Process algebra based
- Explicit state model checking + symbolic transformations
- Support for modal $\mu$-calculus with data + time
mCRL2, overview
Example

Process that merges two streams of natural numbers, producing a locally ascending output sequence

\[ \begin{array}{ccc}
6 & 5 & 3 \\
2 & 5 & 1 \\
\end{array} \rightarrow \quad \text{Merge} \quad s \quad \begin{array}{ccc}
r_1 & & \text{8} \\
r_2 & & 5 \\
& & 1 \\
\end{array} \]
Example: specification

Merge

\[
\text{Merge} = \sum_{m \in \mathbb{N}} (r_1(m) \cdot \text{Merge}_1(m) + r_2(m) \cdot \text{Merge}_2(m))
\]

\[
\text{Merge}_1(n : \mathbb{N}) = \sum_{m \in \mathbb{N}} r_2(m) \cdot \text{Merge}_3(n, m)
\]

\[
\text{Merge}_2(m : \mathbb{N}) = \sum_{n \in \mathbb{N}} r_1(n) \cdot \text{Merge}_3(n, m)
\]

\[
\text{Merge}_3(n, m : \mathbb{N}) = n \leq m \rightarrow s(n) \cdot \text{Merge}_2(m) + m \leq n \rightarrow s(m) \cdot \text{Merge}_1(n)
\]
Example: linear process

\[
\text{Merge}(\sigma, i_1, i_2 : \mathbb{N})
\]
\[
= \sum m : \mathbb{N}. \sigma = 0 \rightarrow r_1(m) \cdot \text{Merge}(2, m, i_2)
+ \sum m : \mathbb{N}. \sigma = 0 \rightarrow r_2(m) \cdot \text{Merge}(1, i_1, m)
+ \sum m : \mathbb{N}. \sigma = 1 \rightarrow r_1(m) \cdot \text{Merge}(3, m, i_2)
+ \sum m : \mathbb{N}. \sigma = 2 \rightarrow r_2(m) \cdot \text{Merge}(3, i_1, m)
+ \sum m : \mathbb{N}. \sigma = 3 \land i_1 \leq i_2 \rightarrow s(i_1) \cdot \text{Merge}(1, i_1, i_2)
+ \sum m : \mathbb{N}. \sigma = 3 \land i_2 \leq i_1 \rightarrow s(i_2) \cdot \text{Merge}(2, i_1, i_2)
\]
Example: property

If the input streams are ascending, then the output stream is ascending.

Modal formula:

\[
(\nu X(j_1, j_2, o: \mathbb{N} := 0, 0, 0). \forall l: \mathbb{N}. \quad ([r_1(l)](l \geq j_1 \Rightarrow X(l, j_2, o)) \land [r_2(l)](l \geq j_2 \Rightarrow X(j_1, l, o)) \land [s(l)](l \geq o \land X(j_1, j_2, l))))
\]
Example: parameterised Boolean equation system

Combining LPS and formula, and applying simplifications, we get

$$\nu X(\sigma, i_1, i_2, j_1, j_2, o: \mathbb{N}) = \forall l: \mathbb{N}$$

$$(\sigma = 0 \Rightarrow l \geq j_1 \Rightarrow X(2, l, i_2, l, j_2, o))$$

$$\wedge (\sigma = 0 \Rightarrow l \geq j_2 \Rightarrow X(1, i_1, l, j_1, l, o))$$

$$\wedge (\sigma = 1 \Rightarrow l \geq j_2 \Rightarrow X(3, i_1, l, j_1, l, o))$$

$$\wedge (\sigma = 2 \Rightarrow l \geq j_1 \Rightarrow X(3, l, i_2, l, j_2, o))$$

$$\wedge ((\sigma = 3 \land i_1 \leq i_2) \Rightarrow (i_1 \geq o \land X(1, i_1, i_2, j_1, j_2, i_1)))$$

$$\wedge ((\sigma = 3 \land i_2 \leq i_1) \Rightarrow (i_2 \geq o \land X(2, i_1, i_2, j_1, j_2, i_2))))$$

Observe that $$i_1 = j_1 \land i_2 = j_2 \land o \leq \min(i_1, i_2)$$ is an invariant, now this can automatically be solved, and the property holds for $$\text{Merge}(0, 0, 0)$$
History of mCRL2

- Based on $\mu$CRL
- Development started in 2004, using code from $\mu$CRL
- 22 developers with commit access
- Currently 240949 Lines of code (obtained using SLOCcount)
Process related issues

1. Rapid turnover of resources
2. Programming not 1st priority

Three kinds of developers:

- Scientific programmers: long period of time (3+ years), dedicated time available
- (Bachelor + Master) students: short period of time (3-6 months), little time for programming
- Other staff: long period of time (3+ years), little time for programming, not 1st priority

Leads to single components that have been modified by 10 people in disjoint time spans
Commits made per developer
Consequences

- Poorly documented code
- Lack of user documentation
- Most code not maintained by original author(s)
- Multiple ad-hoc solution attaining same goal; code duplication
- Little attention for refactoring/restructuring code
Code base related issues

- Adopting an existing code base
  - Fixes major design choices
  - Based on ATerm library (having untyped interfaces)
  - Low level of abstraction
  - Inheriting other people’s choices/bugs
  - Poorly programmed (heavy use of unsafe type casts)
Code base related issues

2 Poor documentation of code
   - Hardly any explicit documentation; choices exists in developer’s minds
   - **Big trouble** when developers leave!

3 Supporting multiple platforms
   - Was problematic with legacy code
Lessons learned

1. Document properly

   - Four kinds of documentation:
     1. User documentation (aimed at tool users)
     2. User documentation (aimed at library users)
     3. Source code documentation (using Doxygen)
     4. Algorithm documentation (detailed algorithm descriptions)

   - Documentation is reviewed by another developer

Results:

   - Decrease learning curve for new developers
   - Decrease source code duplication
Lessons learned

2. Perform systematic tests
   - New components are equipped with unit tests
   - Unit test added for each bug
   - Performance of tools monitored using real-life examples
   - Tests and performance measurements run automatically on a daily basis, with web reports available
   - For performance measurements: historic data, observe trends
Online regression test results
Online performance measurements

Time consumption of lps2lts -rjitty

User + Sys time (sec)
SVN Revision

1394-fin
abp
allow
block
brp
cabp
chatbox
clobber
dining8
domineering
lift3-final
lift3-init
magic_square
othello

4000 4500 5000 5500 6000 6500 7000 7500
Lessons learned

3. Enhance reusability of code
   - Generate code from smaller specifications
   - Use high level of abstraction:
     - Transition legacy code from C to C++
     - Use object oriented techniques
     - Use generic programming techniques (now + future)

4. Use generic, cross-platform libraries (BOOST, wxWidgets)

5. Strictly adhere to C++ standard
Future directions

- Systematically generating code from specifications (started)
  - Allow flexibility in supported input language
  - Avoid tedious handwriting of uniform sections of code
  - Prevent typo’s and copy-paste mistakes

- Perform testing with random inputs

- Increase use of generic programming techniques