Analysis of system behaviour using the mCRL2 toolset

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Analysis techniques

Development of *distributed systems* is inherently complex:

- Needed: assessment and improvement of quality
- Means: analysis techniques

Analysis techniques used in distributed system development:

- Structure: what *things* are in the system?
- Behaviour: what *happens* in the system?

The two techniques complement each other because they focus on *different aspects* of the system.

Analysis of system behaviour

What is analysis of system behaviour about?

- Modelling: create an *abstract* model of the *behaviour* of the system
  - *gain insight* in the behaviour
  - *reduce complexity* to allow for validation and verification
- Validation: are we building the right product?
  - *test requirements* on the model for a number of paths and configurations
- Verification: are we building the product right?
  - *verify requirements* on the model for all possible paths and configurations

mCRL2 toolset

For analysing the behaviour of distributed systems in *industry*, tool support is essential.

The mCRL2 toolset:

- *Supports* many aspects of analysis of system behaviour (modelling, validation, verification)
- Can be *used* to:
  - *detect errors* in the design or implementation of software
  - *prevent errors* already in the design of software

Goals of the mCRL2 toolset:

- Generic basis for the analysis of system behaviour
- Research and development of verification techniques
- Industrial application of verification techniques

mCRL2 toolset: overview

Overview of the mCRL2 toolset:

- 20 years of history:
  - Late 1980s: Common Representation Language (CRL)
  - From 1990: μCRL
  - During 1990s: μCRL toolset
  - From 2004: mCRL2 and mCRL2 toolset
- Collection of tools
- External languages and tools are supported:
  μCRL, CADP, χ, PNML, TorX, LySa, SystemC, LTSmin
- Multi-platform: Windows, Mac and UNIX variants
- Free software licence: Boost licence
- Release policy: fixed release cycle (January and July)

mCRL2 toolset: modelling

Ingredients for modelling:

- *Actions* (push_button, place_order, call_f)
- *Non-deterministic choice*
  (*either* push_button *or* place_order)
- *Sequence* (*first* push_button, *then* place_order)
- *Processes* (Client, WebShop)
- *Parallelism* (Client *in parallel with* WebShop)
- *Synchronous communication*
  (push_button *communicates with* place_order)
- *Data types*
  (push_button(on), Client(1), call_f$(\{x|prime(x)\})$)

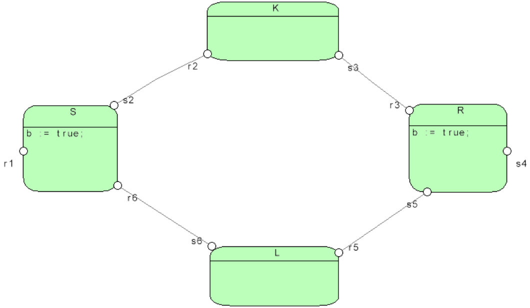
mCRL2 toolset: modelling (2)

The toolset supports two kinds of modelling:

- *Textual*:

$$\textbf{init} \quad \nabla_{\{\mathsf{r1,s4,c2,c3,c5,c6,i}\}}(\Gamma_{\{\mathsf{r2|s2\rightarrow c2,r3|s3\rightarrow c3,r5|s5\rightarrow c5,r6|s6\rightarrow c6}\}}(\mathsf{S}(\mathit{true}) \parallel \mathsf{K} \parallel \mathsf{L} \parallel \mathsf{R}(\mathit{true})));$$

- *Graphical*:



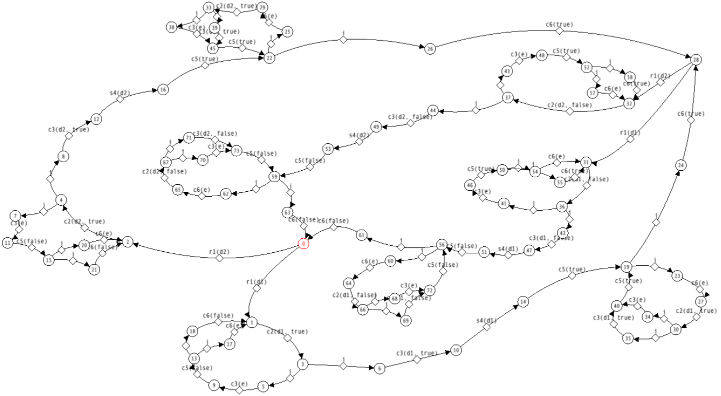
mCRL2 toolset: validation

Validation of models supported by the toolset:

- Manual or semi-automated simulation
- Automated testing using the TorX test tool
- Different types of visualisation

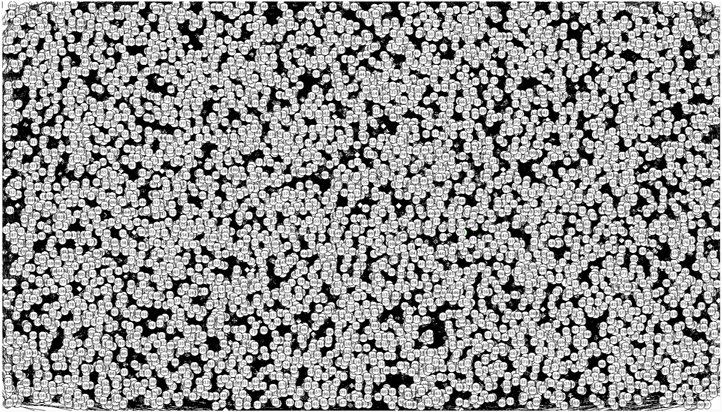
mCRL2 toolset: visualisation

Visualisation as a directed graph using *automatic positioning*:



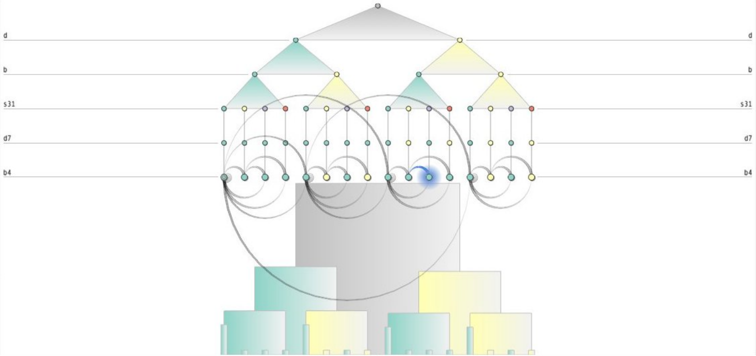
mCRL2 toolset: visualisation

Visualisation as a directed graph is limited to *small models*:



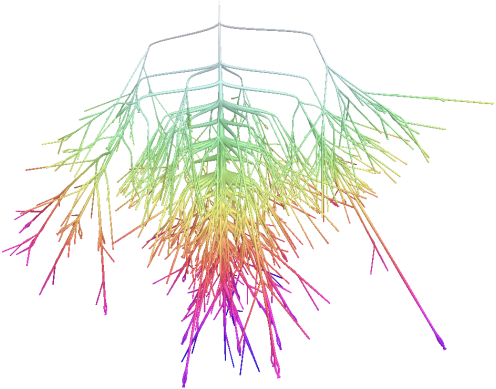
mCRL2 toolset: visualisation

Visualisation as a graph of clusters of states:



mCRL2 toolset: visualisation

Visualisation as a 3D tree of clusters of states:

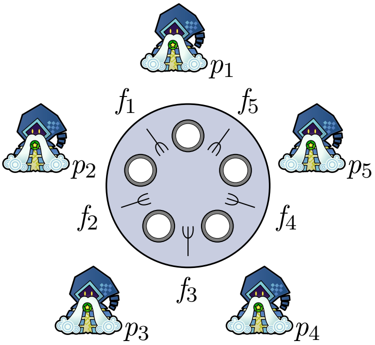


mCRL2 toolset: verification

Toolset support for automated verification
of requirements on the complete model:

- Occurrences of *deadlocks*
- Occurrences of specific *actions*
- *Equivalence* of models
- *Formula checking*:
  - express requirements as *temporal logic formulas*
  - check these formulas on the model

Example: dining philosophers



Abstractly represents various concurrency issues such as *deadlock* and *starvation*.

Example: dining philosophers

Modelling the behaviour of the philosophers:

$$\begin{aligned}
&\textbf{proc}\ \ \mathsf{Phil}(p : \mathit{PhilId}) = \\
&\qquad (\mathsf{get}(p, \mathit{lf}(p)) \cdot \mathsf{get}(p, \mathit{rf}(p)) + \mathsf{get}(p, \mathit{rf}(p)) \cdot \mathsf{get}(p, \mathit{lf}(p))) \\
&\qquad \cdot\, \mathsf{eat}(p) \\
&\qquad \cdot\, (\mathsf{put}(p, \mathit{lf}(p)) \cdot \mathsf{put}(p, \mathit{rf}(p)) + \mathsf{put}(p, \mathit{rf}(p)) \cdot \mathsf{put}(p, \mathit{lf}(p))) \\
&\qquad \cdot\, \mathsf{Phil}(p);
\end{aligned}$$

Modelling the behaviour of the forks:

$$\begin{aligned}
&\textbf{proc}\ \ \mathsf{Fork}(f : \mathit{ForkId}) = \\
&\qquad \textstyle\sum_{p:Phil} \mathsf{up}(p, f) \cdot \mathsf{down}(p, f) \cdot \mathsf{Fork}(f);
\end{aligned}$$

Example: dining philosophers

Modelling the behaviour of the system as a whole:

$$
\begin{array}{l}
\textbf{init} \quad \nabla(\{\mathsf{lock}, \mathsf{free}, \mathsf{eat}\}, \\
\quad \Gamma(\{\mathsf{get}|\mathsf{up} \to \mathsf{lock}, \mathsf{put}|\mathsf{down} \to \mathsf{free}\}, \\
\quad\quad \mathsf{Phil}(p_1) \parallel \mathsf{Phil}(p_2) \parallel \mathsf{Phil}(p_3) \parallel \mathsf{Phil}(p_4) \parallel \mathsf{Phil}(p_5) \parallel \\
\quad\quad \mathsf{Fork}(f_1) \parallel \mathsf{Fork}(f_2) \parallel \mathsf{Fork}(f_3))) \parallel \mathsf{Fork}(f_4) \parallel \mathsf{Fork}(f_5) \\
\quad\quad) \\
\quad);
\end{array}
$$

Example: dining philosophers

Analysis with the mCRL2 toolset:

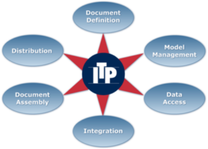
- Verification reveals traces to deadlock states:

$\mathsf{lock}(p_1, f_5)$	$\mathsf{lock}(p_5, f_5)$
$\mathsf{lock}(p_5, f_4)$	$\mathsf{lock}(p_4, f_4)$
$\mathsf{lock}(p_4, f_3)$	$\mathsf{lock}(p_3, f_3)$
$\mathsf{lock}(p_3, f_2)$	$\mathsf{lock}(p_2, f_2)$
$\mathsf{lock}(p_2, f_1)$	$\mathsf{lock}(p_1, f_1)$

- Traces can be validated by means of simulation

Industrial case studies

Selection of industrial case studies performed using the μCRL and mCRL2 toolsets:



Thank you for your attention

More information can be found on `mcrl2.org`.