Markov Reward Model Checker

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Outline

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Introduction to MRMC

What is MRMC?

- A probabilistic model checker for DTMCs, CTMCs and MRMs
- A command-line tool implemented in C
- The tool is:
  - available for Windows, Mac OS X and Linux
  - distributed under the GPL license

What makes MRMC so special?

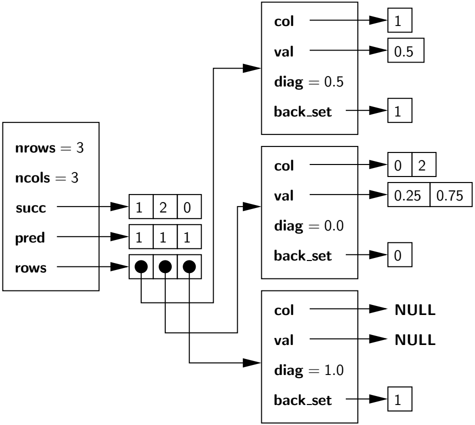
- It is small and fast, perfect as a backend
- It supports:
  - Bisimulation minimization [KKZJ07]
  - Precise on-the-fly steady-state detection [KZ05]
  - Improved model checking for steady-state properties

The hart of MRMC

Sparse matrices

$$\mathbf{P} = \begin{bmatrix} 0.50 & 0.50 & 0.00 \\ 0.25 & 0.00 & 0.75 \\ 0.00 & 0.00 & 1.00 \end{bmatrix}$$

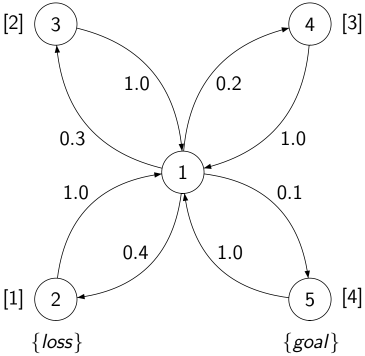
nrows	# rows
succ	# successors
pred	# predecessors
rows	matrix rows
col	non-zero col. indexes
val	non-zero elem. values
diag	a diagonal value
back_set	predecessors



A simple DMRM model

- Consider a dice with only four wedges: 1, 2, 3 and 4
- The outcomes have probabilities 0.4, 0.3, 0.2 and 0.1
- the outcome 4 is the *goal* state
- the outcome 1 is the *loss* state
- $\mathrm{P}_{>0.5}\left(\neg \mathit{loss}\ \mathrm{U}^{[0,199]}_{[5,50]}\ \mathit{goal}\right)$

game.tra	game.lab	game.rew
STATES 5	#DECLARATION	2 1
TRANSITIONS 8	loss goal	3 2
1 2 0.4	#END	4 3
1 3 0.3	2 loss	5 4
1 4 0.2	5 goal	
1 5 0.1		
2 1 1.0		
3 1 1.0		
4 1 1.0		
5 1 1.0		



Verifying $\mathrm{P}_{>0.5}\left(\neg \mathit{loss}\ \mathrm{U}^{[0,199]}_{[5,50]}\ \mathit{goal}\right)$ with MRMC

```
MRMC/bin> mrmc prctl game.tra game.lab game.rewi
...
Logic                   = PRCTL
Loading the 'game.tra' file, please wait.
States=5, Transitions=8
Loading the 'game.lab' file, please wait.
Loading the 'game.rew' file, please wait.
The Occupied Space is 992 Bytes.
Type 'help' to get help.
>>P{>0.5}[ !loss U[0,199][5,50] goal]
$RESULT: ( 0.0647999, 0.0000000, 0.0959998, 0.1199998, 0.1199997 )
$STATE: {  }
The Total Elapsed Model-Checking Time is 45 milli sec(s).
>>
```

Getting MRMC models

PRISM [HKNP06]

- A high-level state-based description language based on the Reactive Modules formalism.
- The underlying models are DTMCs, CTMCs, MDPS and MRMs.
- The tool allows for exporting its models into the MRMC file formats.

PEPA Workbench [TG06]

- An algebraic process-oriented language for modeling concurrent systems.
- The underlying models are CTMCs.
- The tool allows for exporting PEPA models into the MRMC file formats.

MRMC versus PRISM, Ymer, VESTA, ETMCC

Supported platforms

Tool	Linux	Windows	Solaris	Mac OS X
PRISM	✓	✓	✓	✓
MRMC	✓	✓		✓
ETMCC	✓	✓	✓	
VESTA	✓	✓	?	
Ymer	✓			

MRMC versus PRISM, Ymer, VESTA, ETMCC

Models and logics

Tool	**DTMC**	**CTMC**	**MDP**	**DMRM**	**CMRM**	**GSMP**
MRMC	✓	✓		✓	✓	
PRISM	✓	✓	✓	✓	✓	
VESTA	✓	✓				
Ymer		✓				✓
ETMCC		✓				

Only MRMC supports all of PCTL, CSL, PRCTL and CSRL!

MRMC versus PRISM, Ymer, VESTA, ETMCC

The supported operators of PCTL

Tool	$\mathcal{L}_{\bowtie p}[\Phi]$	$\mathcal{P}_{\bowtie p}[\Phi\ \mathcal{U}\ \Psi]$	$\mathcal{P}_{\bowtie p}[\Phi\ \mathcal{U}^{\leq k}\ \Psi]$	$\mathcal{P}_{\bowtie p}[\Phi\ \mathcal{U}^{[k1,k2]}\ \Psi]$
MRMC	✓	✓	✓	✓
PRISM		✓	✓	
VESTA		✓	✓	

MRMC versus PRISM, Ymer, VESTA, ETMCC

The supported operators of CSL

Tool	$\mathcal{S}_{\bowtie p}[\Phi]$	$\mathcal{P}_{\bowtie p}[\Phi\,\mathcal{U}\,\Psi]$	$\mathcal{P}_{\bowtie p}[\Phi\,\mathcal{U}^{\leq t}\,\Psi]$	$\mathcal{P}_{\bowtie p}[\Phi\,\mathcal{U}^{\geq t}\,\Psi]$	$\mathcal{P}_{\bowtie p}[\Phi\,\mathcal{U}^{[t1,t2]}\,\Psi]$	$\mathcal{P}_{\bowtie p}[\mathcal{X}^{\leq t}\,\Psi]$	$\mathcal{P}_{\bowtie p}[\mathcal{X}^{[t1,t2]}\,\Psi]$
MRMC	✓	✓	✓		✓	✓	✓
PRISM	✓	✓	✓	✓	✓		
Ymer			✓		✓	✓	✓
VESTA		✓	✓			✓	
ETMCC	✓	✓	✓				

Implementation metrics

MRMC metrics	**Value**	**Tool**
Lines of code	6738	*Understand C/C++*
Lines of comments	8287	
McCabes cyclomatic complexity	1399	*CCCC*
Development effort estimate	20.31 MM	*SLOCCount*

Test-suite metrics	**Value**	**Tool**
Test coverage	83.46%	*GCov*
Lines of code	1474	*SLOCCount*
Development effort estimate	3.61 MM	

The third-party projects

GreatSPN v2.0

- Department information, Università di Torino, Italy
- Modeling, validation, and performance evaluation of distributed systems
- MRMC as a backend for CSL model checking [CDDS06]

Heuristics-Guided Dependability Analysis

- The chair of Software Engineering, Universität des Konstanz, Germany
- Generating diagnostics information for stochastic models [AL06]
- A prototype tool called DiPro is being linked to MRMC

Reachability analysis in uniform CTMDPs

- Dependable Systems & Software group, Universität des Saarlandes, Germany
- New timed-reachability algorithms for uCTMDPs [BHH$^+$06]
- The tool chain: STATEMATE – extended MRMC

The next release

What to expect from MRMC v1.3?

- Model checking via discrete-event simulation (PCTL, CSL)
- Model checking of uCTMDPs (reachability properties)
- Optimized performance and memory usage
- Improved command-prompt interface:
  - Access to the intermediate model-checking results
  - Context help and run-time settings
  - *Et cetera* ...
- Simplified internal interfaces for the external developers

Conclusions and future work

Conclusions

- MRMC is small and fast
- It is the only tool supporting:
  - PCTL, CSL, PRCTL and CSRL
  - Bisimulation minimization
  - Precise steady-state detection
- It is available for: Windows, Linux and Max OS X
- There are several third-party projects that use MRMC

Future work

- State-space abstractions
- MDPs, CTMCPs, etc.
- Counter examples

Husain Aljazzar and Stefan Leue.
Extended directed search for probabilistic timed reachability.
In *Formal Modeling and Analysis of Timed Systems (FORMATS'06)*, pages 33–51, 2006.

Eckard Bode, Marc Herbstritt, Holger Hermanns, Sven Johr, Thomas Peikenkamp, Reza Pulungan, Ralf Wimmer, and Bernd Becker.
Compositional Performability Evaluation for STATEMATE.
In *QEST '06: Proceedings of the 3rd international conference on the Quantitative Evaluation of Systems*, pages 167–178, Washington, DC, USA, 2006. IEEE Computer Society.

D. Cerotti, D. D'Aprile, S. Donatelli, and J. Sproston.
Verifying stochastic well-formed nets with csl model-checking tools.
In *ACSD '06: Proceedings of the Sixth International Conference on Application of Concurrency to System Design*, pages 143–152, Washington, DC, USA, 2006. IEEE Computer Society.

A. Hinton, M. Kwiatkowska, G. Norman, and D. Parker.
PRISM: A tool for automatic verification of probabilistic systems.
In H. Hermanns and J. Palsberg, editors, *Proc. 12th International Conference on Tools and Algorithms for the Construction and Analysis of Systems (TACAS'06)*, volume 3920 of *LNCS*, pages 441–444. Springer, 2006.

Joost-Pieter Katoen, Tim Kemna, Ivan Zapreev, and David N. Jansen.
Bisimulation Minimisation Mostly Speeds Up Probabilistic Model Checking.
In Orna Grumberg and Michael Huth, editors, *Tools and Algorithms for the Construction and Analysis of Systems, TACAS'07*, volume 4424 of *LNCS*, pages 87–101. Springer, 2007.

J.-P. Katoen and I. S. Zapreev.
Safe On-The-Fly Steady-State Detection for Time-Bounded Reachability.
Technical Report TR-CTIT-05-52, CTIT, University of Twente, 2005.

Mirco Tribastone and Stephen Gilmore.
A New Generation PEPA Workbench.

In *Process Algebra and Stochastically Timed Activities (PASTA'06)*, pages 1820–1845, 2006.