Cosmos: Evolution of a Statistical Model Checking Platform

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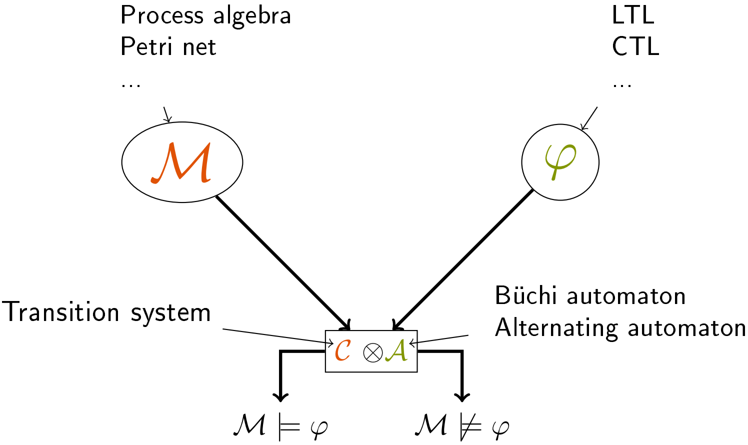
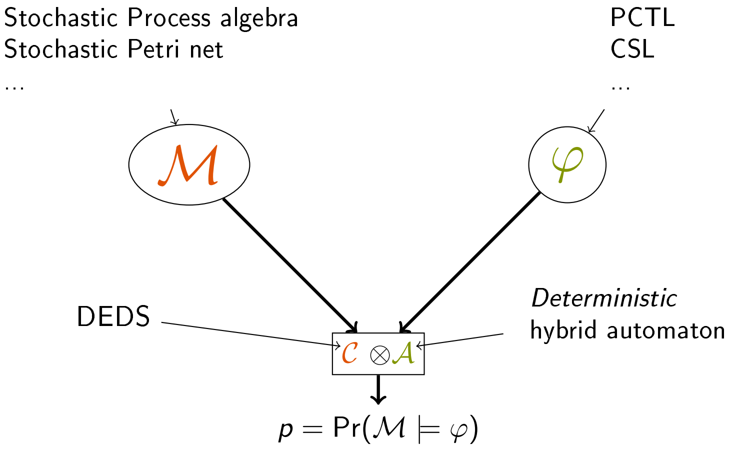
Friday, 12 November, TOSME21

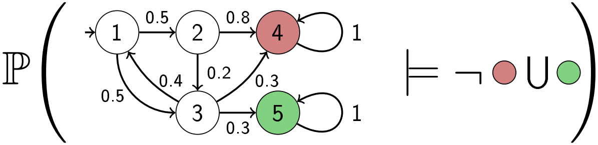
Model Checking



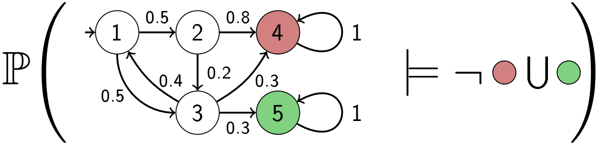
Model Checking for Stochastic Systems



Numerical vs Statistical Approaches



Numerical vs Statistical Approaches



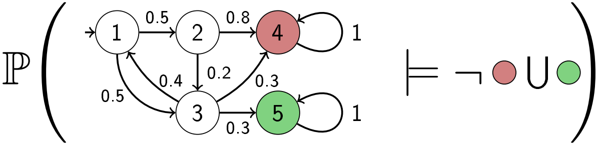
Numerical Model Checking

$$\begin{pmatrix} -1 & 0.5 & 0.5 & 0 & 0 \\ 0 & -1 & 0.2 & 0.8 & 0 \\ 0.4 & 0 & -1 & 0.3 & 0.3 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1 \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{pmatrix} = \begin{pmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 1 \end{pmatrix}$$

$$\Downarrow$$

$$x_1 = 0.2368$$

Numerical vs Statistical Approaches



Statistical Model Checking

$1 \to 2 \to 4$ **x**

$1 \to 3 \to 1 \to 3 \to 5$ ✓

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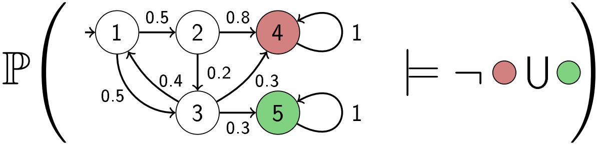
...

$\Downarrow$

$x_1 \in [0.19, 0.26]$

Numerical vs Statistical Approaches



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Numerical vs Statistical Approaches

Numerical approach

- Precise value (but prone to numerical errors)
- Strong probabilistic hypotheses
- Memory space proportional to the size of the stochastic process

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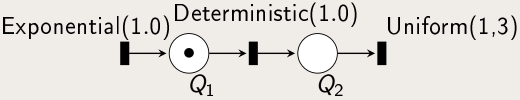
Hybrid approaches

Combine both approaches; usually using stochastic bounds

Generalised Stochastic Petri Net with General Distribution

Example Description (Tandem Queues)



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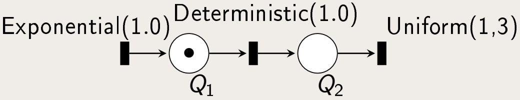

Description

- A Petri net; defines state space, events and transitions.
- After a transition is enabled the time before firing is distributed according to the distribution.
- The next event is the transition with smallest firing time.

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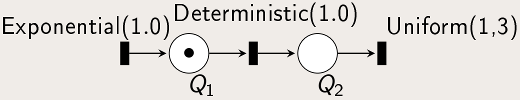

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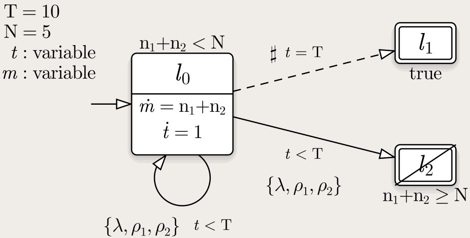
Extensions

- Petri net with inhibitor arcs, marking dependant valuation.
- Coloured Petri net

Specification Language

Linear Hybrid Automaton (LHA)

- An automaton labelled by set of Petri net transitions or #.
- A set of variables with flows.
- Assignment of variable.
- Linear guard and invariant.



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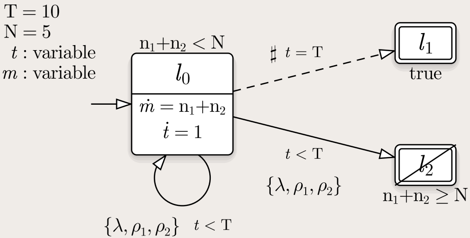

HASL formula

- An LHA
- An expression over variables of the automaton, to compute complex indexes on *accepted* paths.

Cosmos a statistical model checking tool

Development History

- 2009-2012 Joint work LACL and LSV : initial work
  $\Rightarrow$ Hilal Djafri thesis
- 2011-2014 LSV : handling of rare events
  $\Rightarrow$ Benoît Barbot thesis
- 2015-2018 Joint work LACL, LIP6, LSV, IRT SystemX : simulation of hybrid systems for autonomous vehicles
  $\Rightarrow$ Yann Duplouy thesis
- 2015– Joint work LACL, University of Oxford, Verimag : Uniform sampling of timed languages

Cosmos 1/2

Description: a command-line tool

- Input model: a Generalised Stochastic Petri Net with extension
- Input specification: HASL formulas
- Input: Statistical Parameters
- Output: Probabilistic framing of values of HASL formulas

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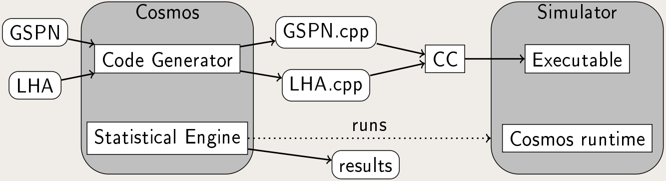
Architecture

- Contains 25 Kloc of C/C++ and OCaml under GPLv2
- Generates code implementing the synchronisation GSPN/LHA
- Distributes simulation



Cosmos 2/2

Features

- Static and Sequential statistical methods: Chernoff-Hoeffding, Chow-Robbins, Gaussian, SPRT
- Several input formats: GrML, Marcie, PNML, Prism
- Several compatible editing tools: Coloane, GreatSPN Editor, Snoopy
- Fast thanks to structural analysis of Petri nets and code generation
- Low memory footprint
- Various possible outputs

Cosmos 2/2

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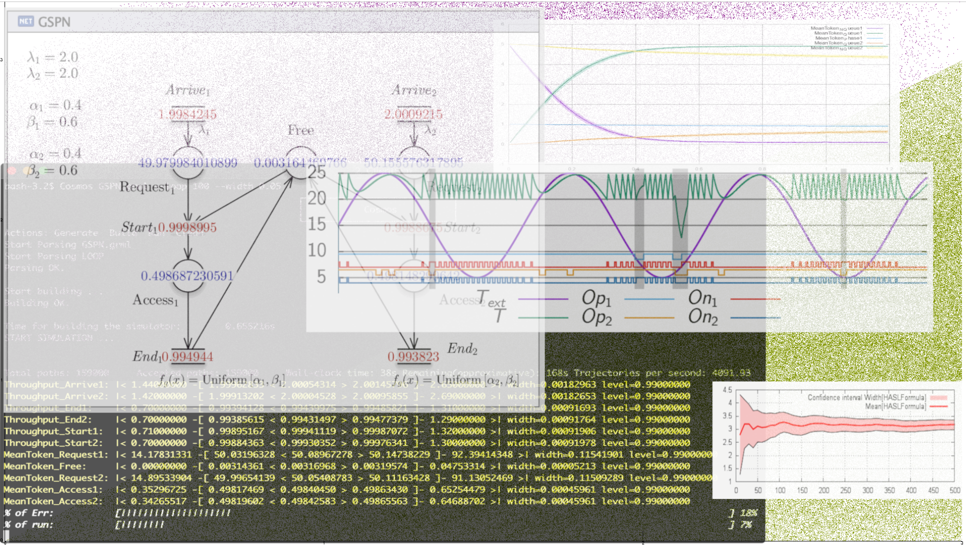
Extensions

- Handling of Rare Events with importance sampling
- Uniform sampling for timed automata
- Hardware in the loop simulation
- Simulation of hybrid models: Simulink

Cosmos Output



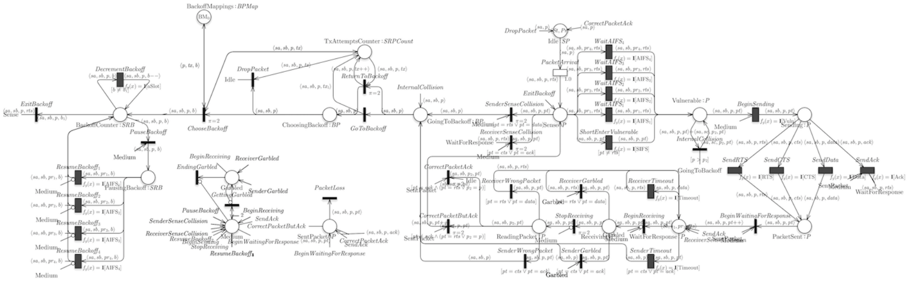
Performance Evaluation of Models

- Waiting Queues [*PT, RareEvents*]
- Databases, Philosophers, Peterson [*Coloured*]
- Flexible Manufacturing Systems [*PT*]
- Molecular Signalling Pathway [*PT, RareEvents*]
- Computation with DNA [*PT*]
- Human Heart and Pacemaker System [*Hybrid model*]
- Autonomous Vehicles [*Hybrid model*]

Modelling of IEEE 802.11 Wireless network

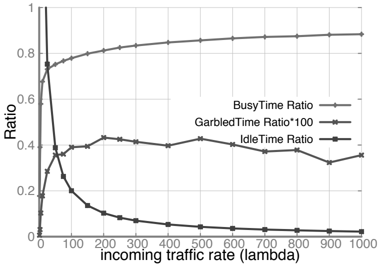
Modelling as a Stochastic Coloured Petri Net [ValueTools19]

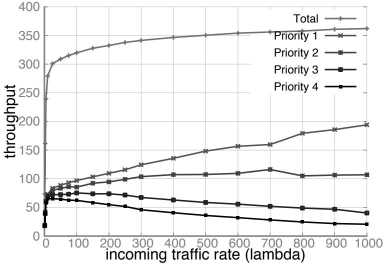
- WiFi with priorities
- Random backoff
- Colored Petri Net
- Large color class



Modelling of IEEE 802.11 Wireless network

Throughput and busytime with increasing loads.





Conclusion

Cosmos

- Fast and lightweight statistical model checker.
- Rich classes of input models.
- Rich specification language.
- Modular and open source.

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cosmos.lacl.fr/publis.html

Cosmos Home Description Installation Tutorial Publications Documentation Extensions PetriNet Editor

Publications on Cosmos

1. B. Barbot, B. Bérard, Y. Duplouy and S. Haddad. Integrating Simulink Models into the Model Checker Cosmos. *In* Proceedings of the 39th International Conference on Applications and Theory of Petri Nets (PETRI NETS'18), pages 363-373, Bratislava, Slovakia, June 2018, LNCS. Springer.
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3. P. Ballarini, H. Djafri, M. Duflot, S. Haddad and N. Pekergin. COSMOS: a Statistical Model Checker for the Hybrid Automata Stochastic Logic. *In* QEST'11, pages 143-144. IEEE Computer Society Press, 2011.
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6. P. Ballarini, B. Barbot, N. Vasselin. Performance modelling of access control mechanisms for local and vehicular wireless networks.. In *Proceedings of the 12th EAI International Conference on Performance Evaluation Methodologies and Tools, VALUETOOLS 2019, pages 111 118. ACM*, 2019.
7. B. Barbot, B. Bérard, Y. Duplouy, and S. Haddad. Statistical model-checking for autonomous vehicle safety validation. In *SIA Simulation Numérique*, 2017.
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12. P. Ballarini and M. Duflot. Applications of an expressive statistical model checking approach to the analysis of genetic circuits. In *Theoretical Computer Science*, Elsevier, DOI, 06/2015.
13. B. Barbot, S. Haddad, M. Heiner and C. Picaronny. A Rare Event Method Applied to Signalling Cascades. International Journal on Advances in Systems and Measurements 8(1-2), 2015.
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17. P. Ballarini, E. Gallet, P. Le Gall, and M. Manceny. Formal analysis of the Wnt/beta-catenin pathway through statistical model checking. *In* proceedings of 6th Int. Symposium On Leveraging Applications of Formal Methods, Verification and Validation (ISOLA), 2014, pag. 193-207.
18. G. Amparore, P. Ballarini, M. Beccuti, S. Donatelli and G. Franceschinis. Expressing and computing passage time measures of gspn models with hasl. *In* proceedings