PRISM

ETAPS Test-of-Time Tool Award 2024

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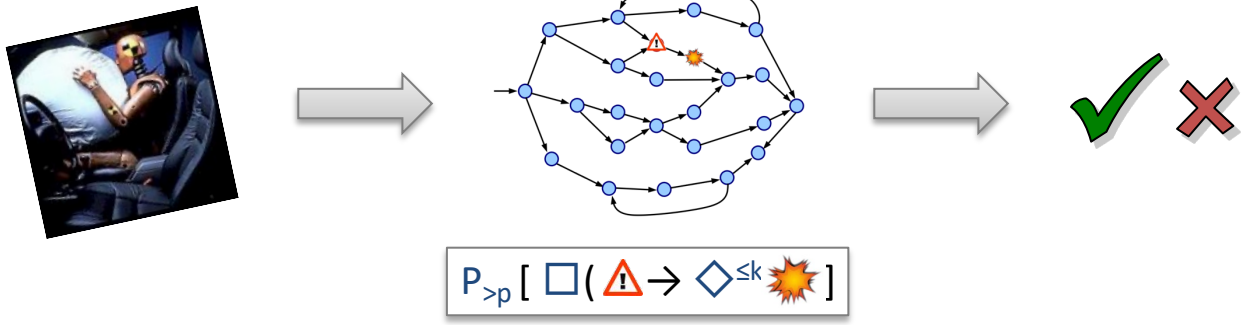
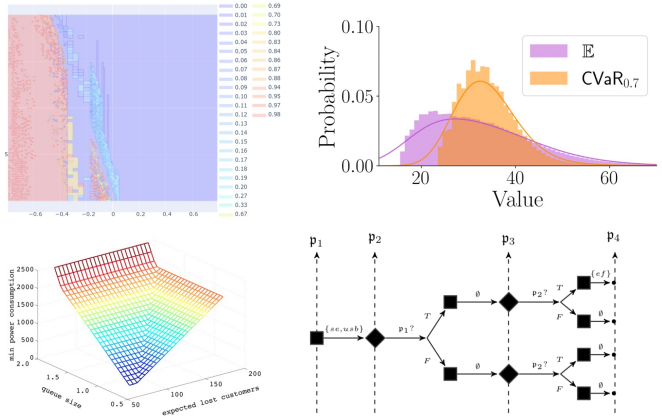
prismmodelchecker.org

What is PRISM?

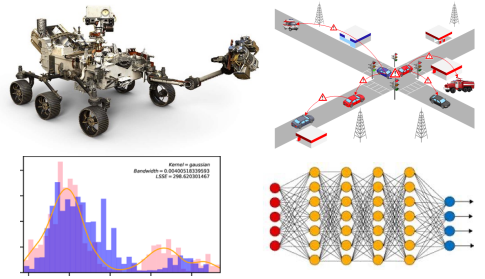
- PRISM: Probabilistic (symbolic) model checker





CTMC, CSG, DTMC, LTS, MDP, POMDP, POPTA, PTA, STPG, SMG, TPTG, IDTMC, IMDP

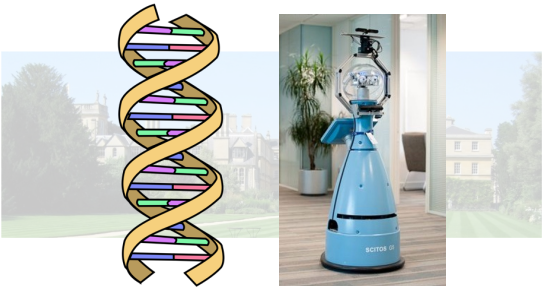
- PRISM today
  - 12 types of probabilistic models, many probabilistic temporal logics
  - uses: logic, automata, Markov models, optimisation, SMT, simulation, game theory, artificial intelligence, learning…
  - >400 case studies across a broad range of application domains

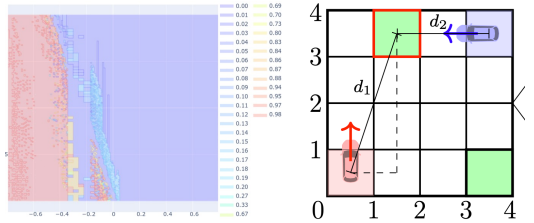


- PRISM development: driven by challenges, applications, users

PRISM: A brief history

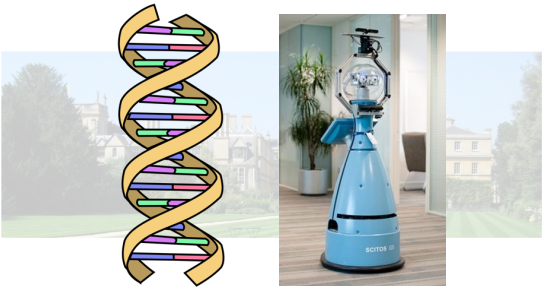
- 1998: tool development begins (Birmingham)
  - symbolic probabilistic model checking
- 2001: first official public release of PRISM
- 2004 & 2006: PRISM 2.0 & 3.0
  - new GUI, logics, cost/reward models, simulator engines
- 2011: PRISM 4.0
  - probabilistic real-time systems, PRISM benchmark suite
  - multi-objective model checking & assume-guarantee
- 2013: first release of PRISM-games
- 2016 & 2020: PRISM-games 2.0 & 3.0
  - multi-objective, concurrent stochastic games, equilibria
- 2020-2024: policy/strategy synthesis, POMDPs, uncertain MDPs, …

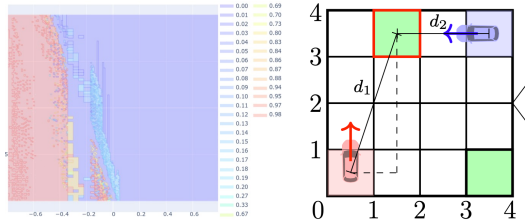




PRISM: A brief history

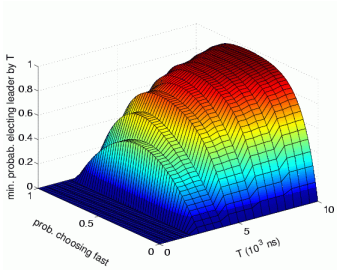
- 1998: tool development begins (Birmingham)
  - symbolic probabilistic model checking [TACAS'00,'02]
- 2001: first official public release of PRISM
- 2004 & 2006: PRISM 2.0 & 3.0 [TACAS'06]
  - new GUI, logics, cost/reward models, simulator engines [TACAS'04]
- 2011: PRISM 4.0
  - probabilistic real-time systems, PRISM benchmark suite
  - multi-objective model checking & assume-guarantee [TACAS'07,'10,'11]
- 2013: first release of PRISM-games [TACAS'12,'13]
- 2016 & 2020: PRISM-games 2.0 & 3.0
  - multi-objective, concurrent stochastic games, equilibria [TACAS'15,'16,'22]
- 2020-2024: policy/strategy synthesis, POMDPs, uncertain MDPs, …



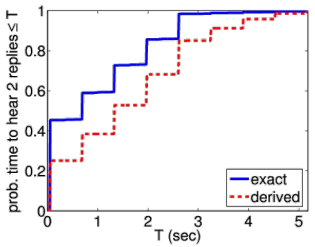


Early applications of PRISM

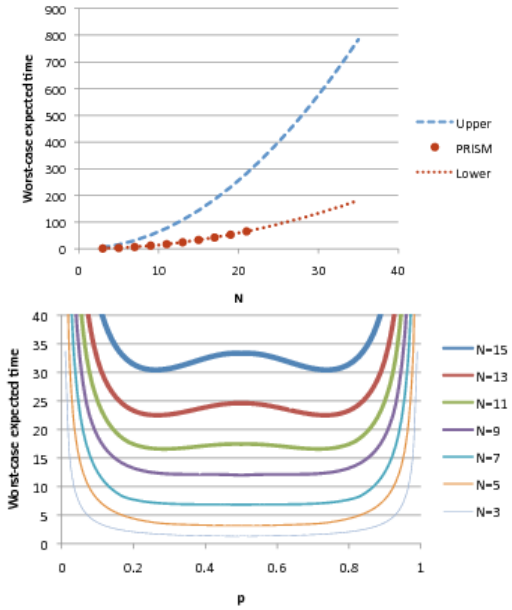
- Randomised distributed algorithms/protocols
  - modelled as MDPs/probabilistic automata
  - key motivating example for probabilistic verification



FireWire protocol

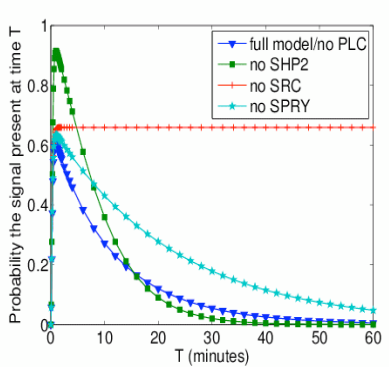


Bluetooth device discovery

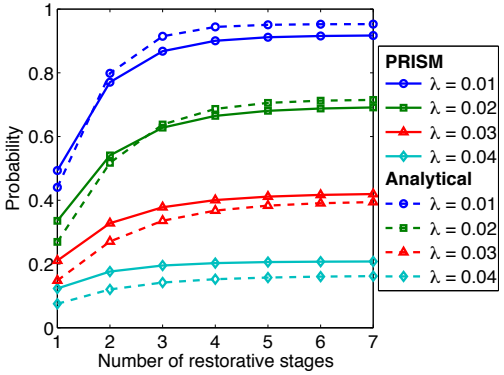


Herman's self-stabilisation

- Performance modelling & biochemical reactions
  - modelled as Markov chains



FGF cell signalling pathway experiments

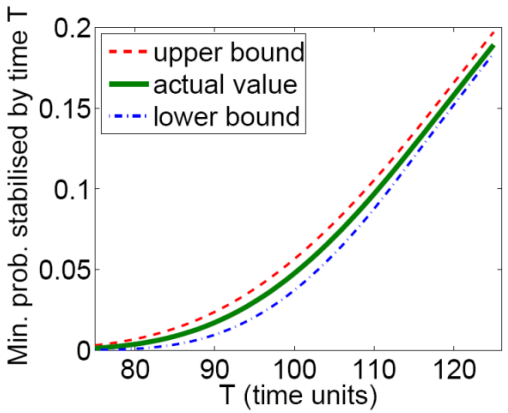


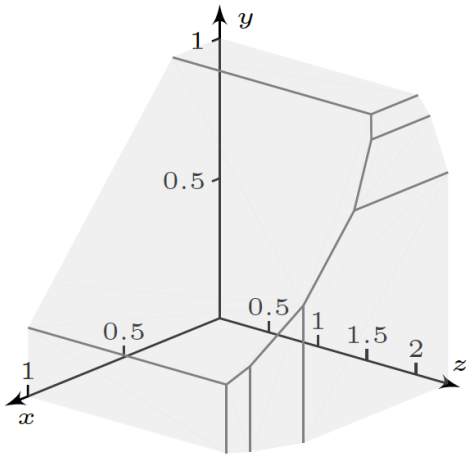
Reliable multiplexing in nanotechnology

Multiple flaws, bugs, anomalies found…

Enabling technologies

- Challenge-driven tool development
  - Symbolic model checking
    - [TACAS'00] [TACAS'02] [STTT'04] [CAV'06] …
  - Real-time probabilistic verification
    - [TCS'02] [FMSD'06] [Info&Comp'07] [FORMATS'09] …
  - Game-based abstraction refinement
    - [QEST'06] [VMCAI'09] [FMSD'10] [QEST'11] …
  - Multi-objective & compositional verification
    - [TACAS'10] [QEST'10] [FASE'11] [Info&Comp'13] …
  - Multi-agent model checking (stochastic games)
    - [TACAS'12] [Inf-&Comp'17] [FMSD'21] [TACAS'22] …

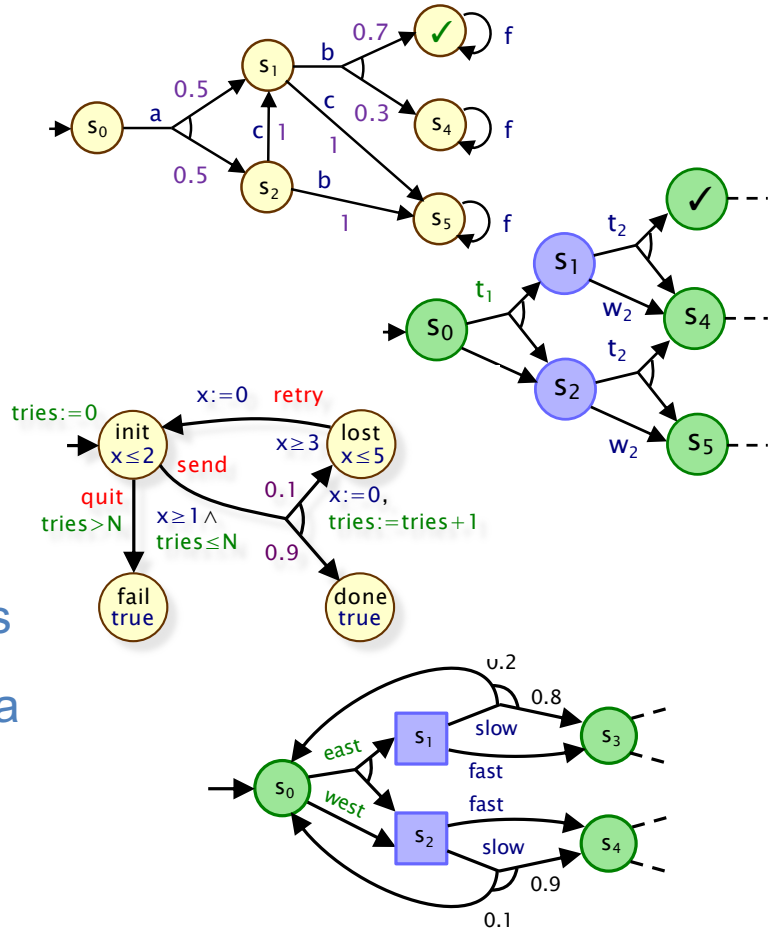




$$\frac{M_1 \models \langle A \rangle_{\geq q} \quad \langle A \rangle_{\geq q}\, M_2\, \langle G \rangle_{\geq p}}{M_1 \,||\, M_2 \models \langle G \rangle_{\geq p}}$$

PRISM models

- Increasing variety (and complexity) of probabilistic models supported
  - discrete-time Markov chains
  - probabilistic automata + concurrency
  - continuous-time Markov chains + exponential delays
  - Markov decision processes (MDPs) + policies / control
  - probabilistic timed automata + real-time clocks
  - partially observable MDPs + observability
  - stochastic multi-player games + multi-agent & strategies
  - concurrent stochastic games + concurrency & equilibria
  - interval Markov chains & MDPs + epistemic uncertainty



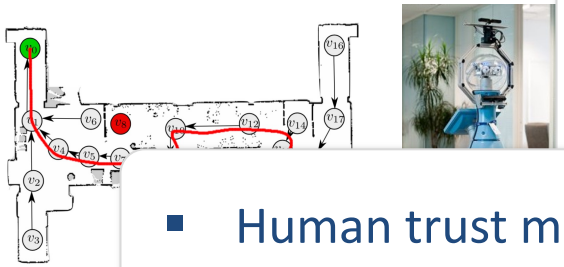
PRISM applications

- Increasing variety (and complexity) of applications tackled

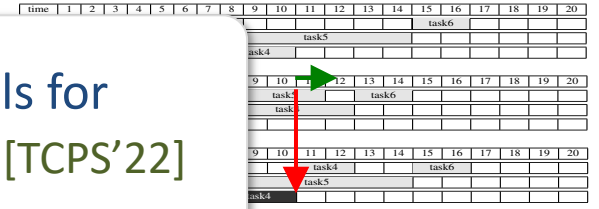
From verification to control problems

- discrete-time Markov chains
- probabilistic automata
- continuous-time Markov chains
- Markov decision processes
- probabilistic timed automata
- partially observable MDPs
- stochastic multi-player games
- concurrent stochastic games
- interval Markov chains & MDPs

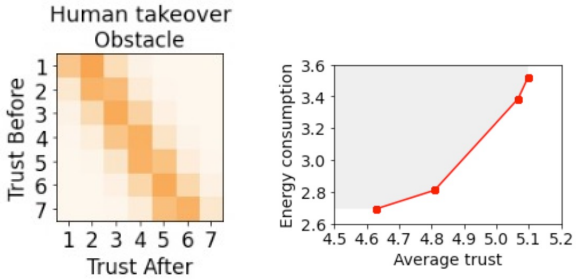
- Long-running autonomous mobile robots [IJRR'19]
  - via multi-objective MDPs



- Real-time task scheduling with faulty processors [FMSD'13]
  - probabilistic timed automata



- Human trust models for automated driving [TCPS'22]
  - via multi-objective POMDPs



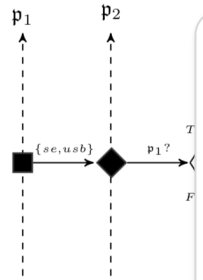
PRISM applications

- Increasing variety (and complexity) of applications tackled

Verification
+ game theory

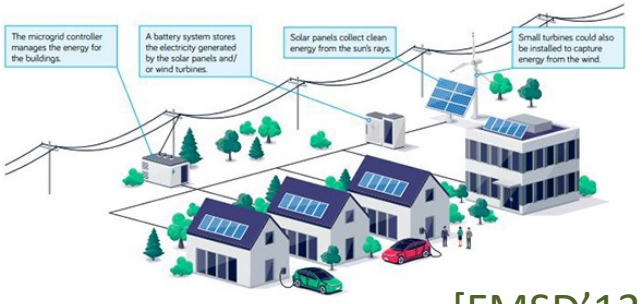
- discrete-time Markov chains
- probabilistic automata
- continuous-time Markov chains
- Markov decision processes
- probabilistic timed automata
- partially observable MDPs
- stochastic multi-player games
- concurrent stochastic games
- interval Markov chains & MDPs

- Computer security attack-defence scenarios
  - stochastic games strategies



[CSF'16]

- Distributed energy protocols
  - flaws fixed via incentives



[FMSD'13]

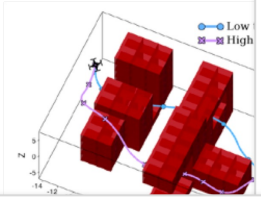
PRISM applications

- Increasing variety (and complexity) of applications tackled

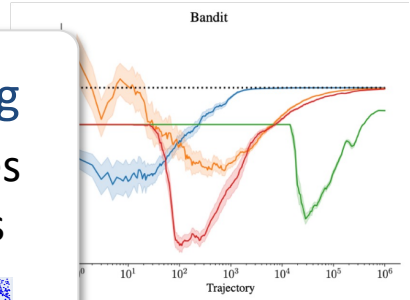
Verification & epistemic uncertainty

- discrete-time Markov chains
- probabilistic automata
- continuous-time Markov chains
- Markov decision processes
- probabilistic timed automata
- partially observable MDPs
- stochastic multi-player games
- concurrent stochastic games
- interval Markov chains & MDPs

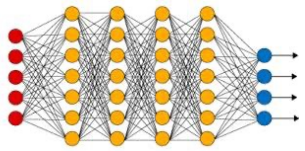
■ Robust AUV control [JAIR'23]
- continuous-space + unknown noise → IMDP

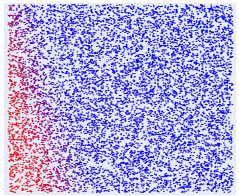


■ Robust anytime learning [NeurIPS'22]
- MDP policies learnt from samples
- IMDPs used for robust guarantees



■ Deep reinforcement learning
- verified probabilistic policies from neural nets, via IMDPs

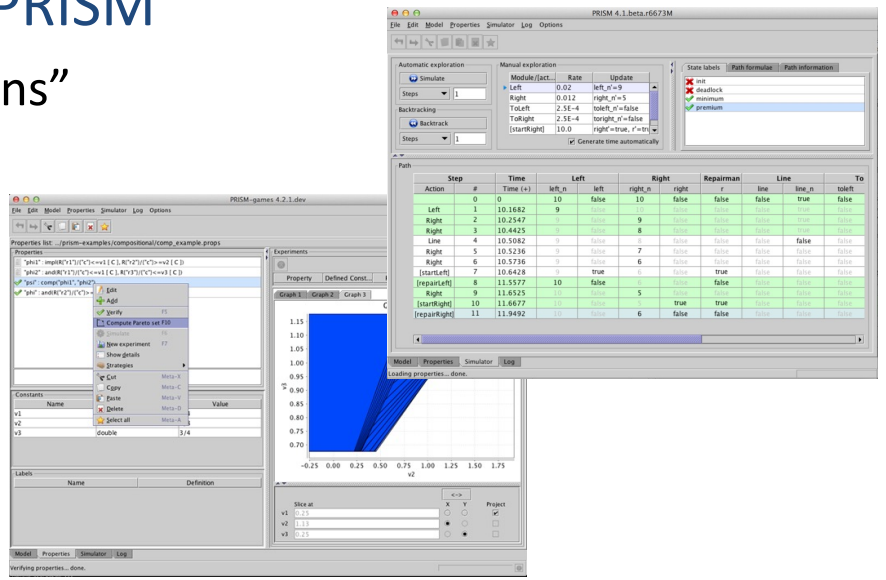




[FORMATS'22]

Who uses PRISM? (and how/why)

- PRISM bibliography[1] lists >850 papers relating to PRISM
  - 375 “case studies”, >100 “extensions”, >250 “connections”
- PRISM applications & users
  - very wide (often non-expert) user base
  - broad applicability of PMC techniques/models
  - easy, self-contained install
  - user interface: model editor, simulator, debugger, graph plotting, …
  - documentation, tutorials, examples
- General aims
  - stable, usable, flexible, coherent framework



- PRISM for teaching
  - common basis for the practical component of taught courses on (non-)probabilistic model checking

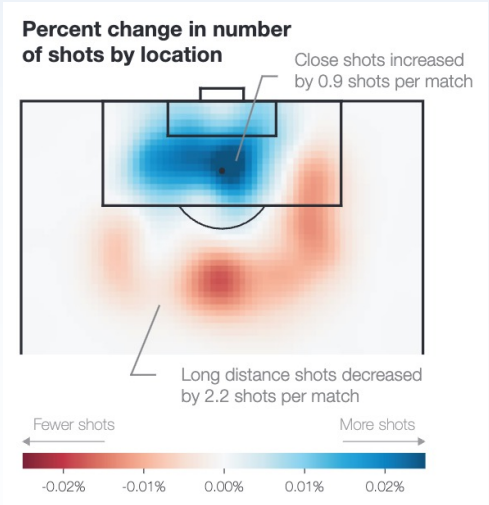
[1] https://prismmodelchecker.org/bib.php

Diverse applications of PRISM

- Cloud computing
  - live migration of VMs
  - plan optimisation for performance guarantees

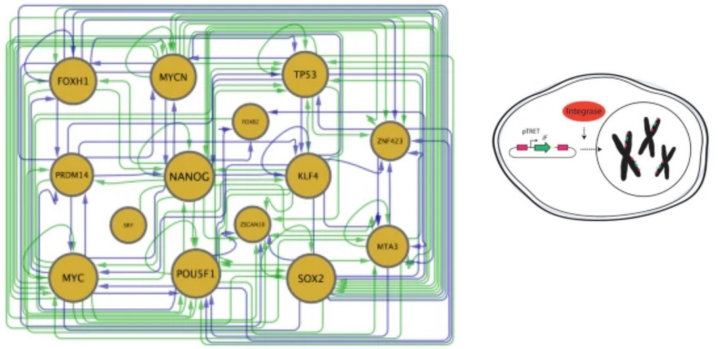
[Kikuchi/Matsumoto (Fujitsu), CLOUD'11] (Best paper)

- Football tactics ⚽
  - team strategies learnt from data
  - tactical efficiency analysed via probabilistic model checking



[Van Roy et al., JAIR'23, MIT-SSAC'24]

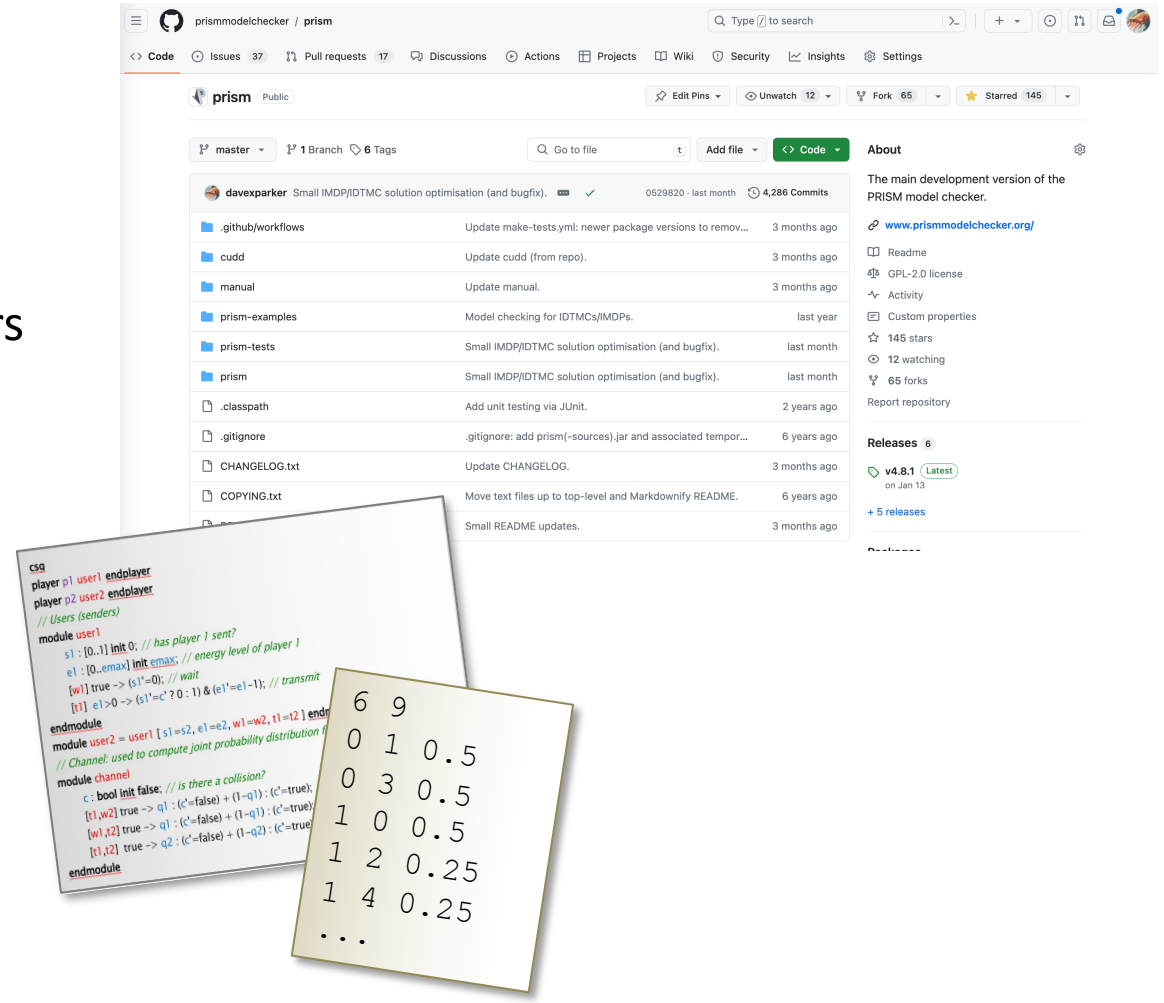
- Human-cell conversion
  - for disease models, gene therapies
  - design tool for optimisation and prediction, based on model checking



[Jung et al., Nature Communications'21]

Building on PRISM

- Extending PRISM
  - open-source codebase (GPL) GitHub
  - primarily implemented in Java Java
    - (some C code and various native libraries)
  - accessibility for student/external contributors
    - “explicit” engine is an easy entry point
- Connections & tool chains
  - via PRISM modelling language
    - e.g. PEPA, bigraphs, RoboChart, SBML
  - via explicit (textual) model files
  - programmatically via API
    - Java, Python, model generators

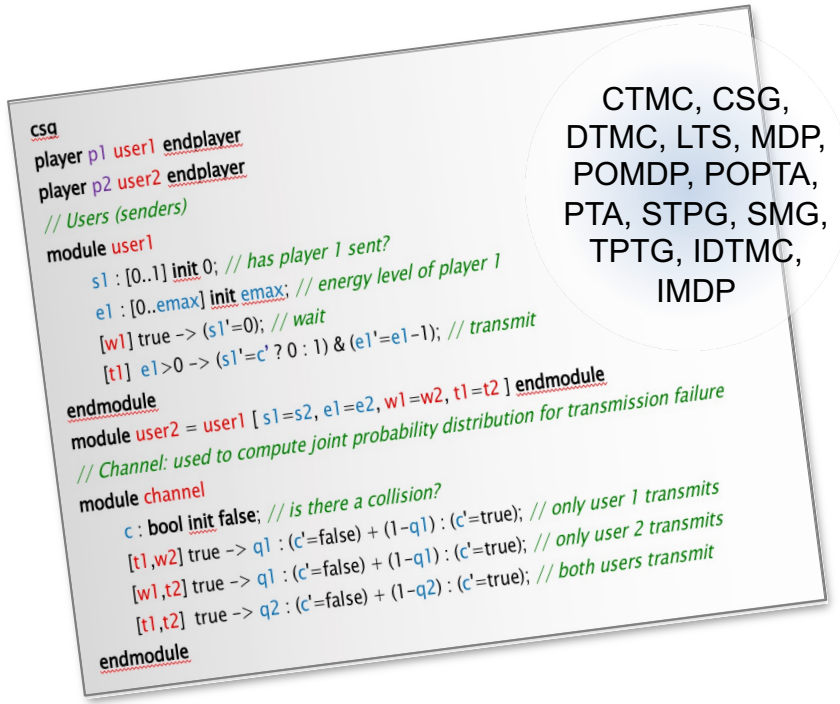


The PRISM language

- PRISM modelling language
  - simple textual language based on guarded commands
  - inspired by: SMV language, Reactive modules
  - de-facto standard for probabilistic verification

- Key ingredients
  - the basics: modules (variables + guarded commands), parallel composition, costs/rewards, parameters (constants)
  - also: clocks, observations, players, epistemic uncertainty, …

- Some design decisions
  - consistent modelling language for many model types
  - (deliberately) simple/low-level, general-purpose language



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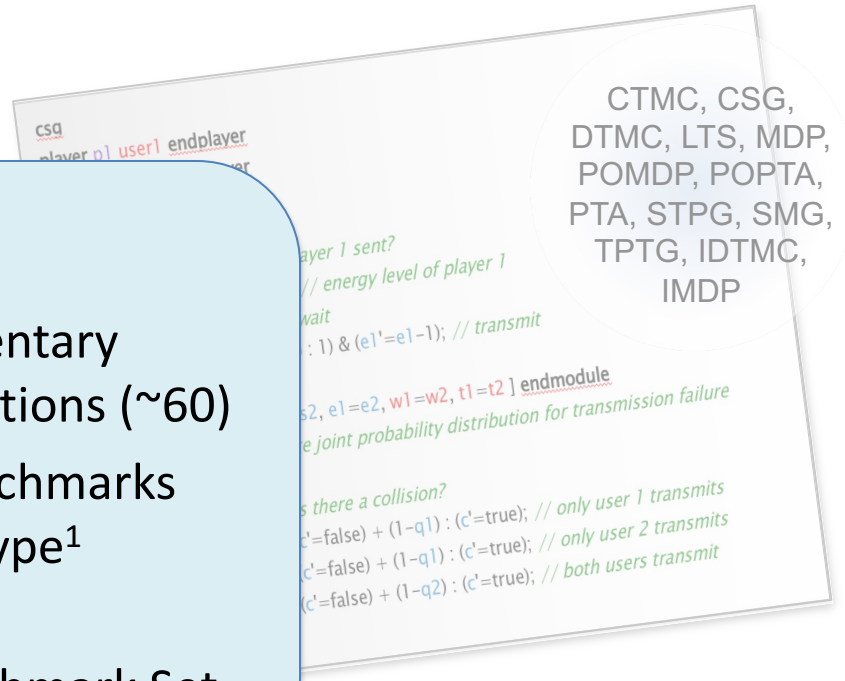
- PRISM models as benchmarks
  - open data: >15 years of supplementary materials pages on PRISM publications (~60)
  - benchmark suite: 36 scalable benchmarks & property queries classified by type[1]

[1] See also: Quantitative Verification Benchmark Set



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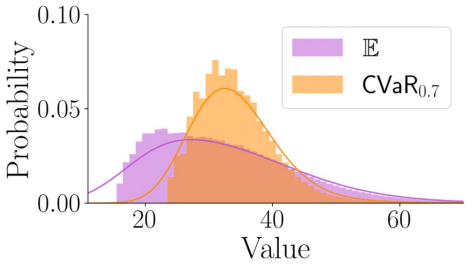
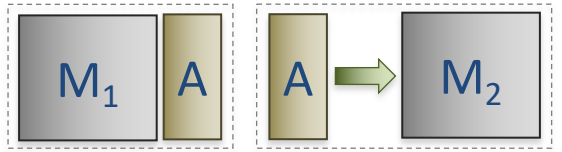
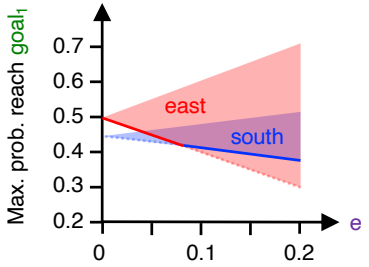
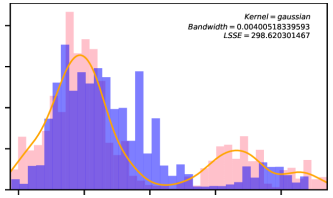
PRISM: Where next?

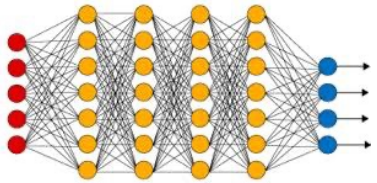
- Coming soon (ish) to PRISM
  - modelling/property language extensions
  - more flexible compositional model specifications
  - improved API access (Java, Python, …)
  - better tool interoperability
- Research advances in model checking functionality
  - epistemic uncertainty (e.g., intervals)
  - learning models/parameters from data,
  - neuro-symbolic models
  - stochastic games & equilibria











Summary

- PRISM (& PRISM-games)
  - approx. 25 years of continuous development
  - challenge-, application- and user-driven tool evolution
  - stable, usable, coherent framework for wide user base
  - many enhancements to come and challenges to tackle

prismmodelchecker.org

PRISM contributors:

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(and many more contributors to underlying theory and techniques)

PRISM supporters: