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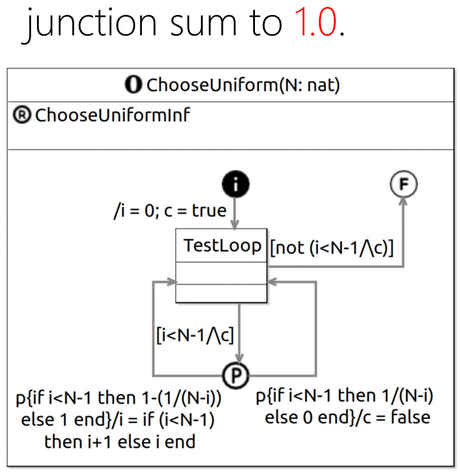
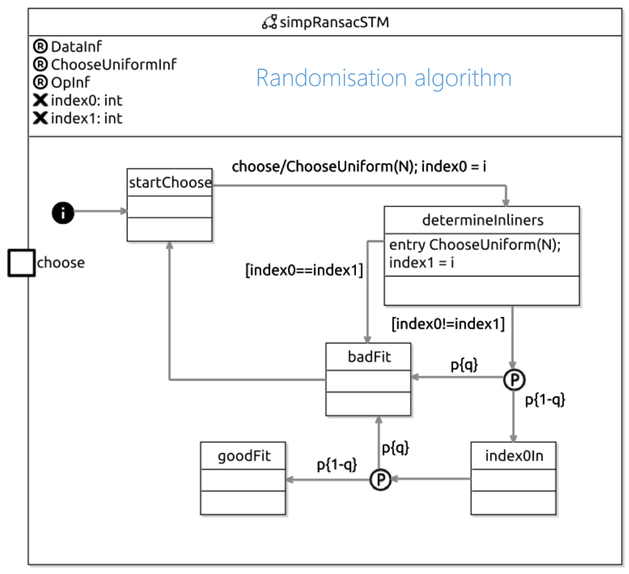
Probabilistic modelling and verification, and Animation in RoboChart

Probabilistic Modelling

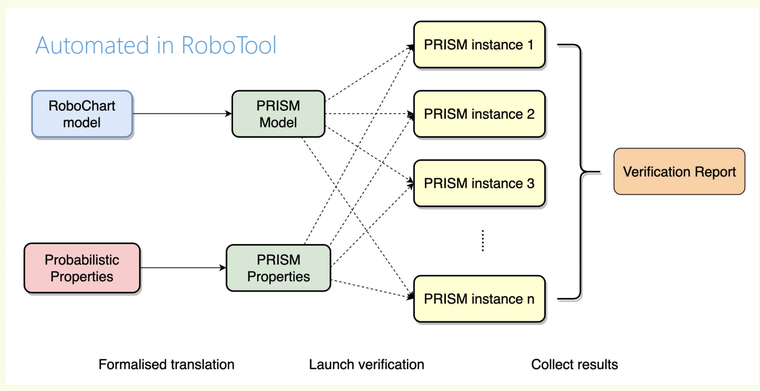
- Probabilistic choice is made at probabilistic junctions.
- Each outgoing transition must have a probability value (inside p{ }) between 0.0 and 1.0.
- Probability values of all outgoing transitions from a probabilistic junction sum to 1.0.





Probabilistic Model Checking

- RoboChart's probabilistic semantics given in MDP and automated generation of semantics for PRISM in RoboTool
- Formalised translation from RoboChart to PRISM
- Run multiple instances of PRISM: one for each property
- Easily extended to other probabilistic model checkers like Storm and MODEST.



Assertion: P_deadlock_free

Assertion	states:	transitions:	result:	checkTime:
P_deadlock_free	3322	3742	true	0.004 seconds

Assertion: P_nr_of_tries

Assertion	states:	transitions:	result:	checkTime:
P_nr_of_tries	3322	3742	1.6998561958204306	0.055 seconds

Assertion: P_nr_of_choices

Assertion	states:	transitions:	result:	checkTime:
P_nr_of_choices	3322	3742	2.6998527952527036	0.092 seconds

Assertion: P_goodfit

Assertion	states:	transitions:	result:	checkTime:
P_goodfit	3322	3742	1.0	0.029 seconds

Probabilistic Property Language

- Based on the PRISM's property language (PCTL*) for DTMC and MDP
- Allow to specify properties using variables, expressions, states, events, functions, operations, etc. from RoboChart models.
- Properties are specified in a particular constant configuration, function definitions, or uncertain environment.

A constant configuration

```
constants C1:
  ransacMOD::ransacRP::N set to 6,
  and ransacMOD::ransacRP::p set to 1/3
prob property P_deadlock_free:
  not Exists [Finally deadlock]
  with constants C1
```

Simulation with multiple constant configurations

```
constants C1:
  MAX from set {10,000 to 80,000 by step 1000},
  M set to 30, and N set to 30
prob property P_prob_full_coverage_bound:
  Prob>=0.8 of [Finally $visits == M * N]
  using sim with CI at alpha=0.01, n=1000, and pathlen
      =1000000
  with constant C1
```

Quantitative property

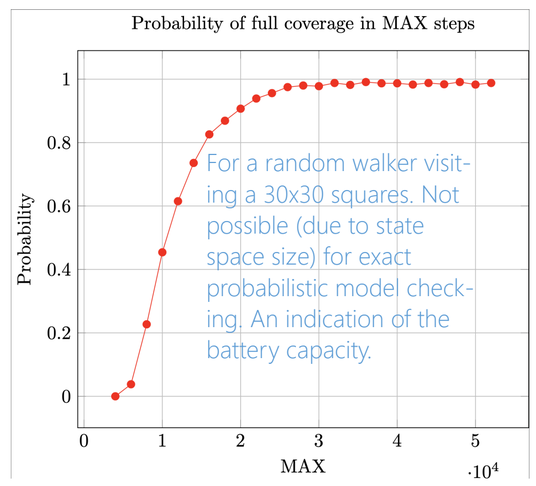
```
prob property P_goodfit:
  Prob=? of [Finally ransacMOD::ransacCTRL::stm_ref0
    is in ransacMOD::ransacCTRL::stm_ref0::goodFit]
```

LTL

```
prob property P_1:
  Forall [Globally (Finally (fd==2) and (Next (fd==0)))]
```

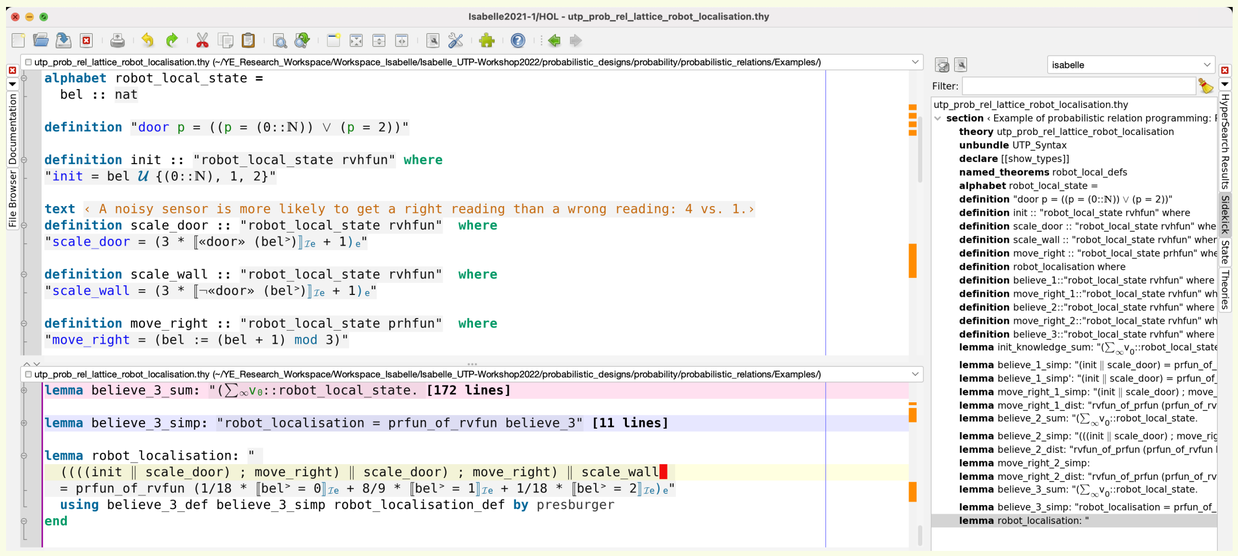
Statistic Model Checking

- Approximate results
- Analyse properties on a large number of (Monte Carlo) simulations
- Able to analyse big models
- Illustrations and debugging problems
- Design space exploration (DSE)
- Generate test cases that satisfy or



Theorem Proving

- Denotational semantics of probabilistic programs in UTP
- Both epistemic and aleatoric uncertainty
- Mechanised in Isabelle/UTP



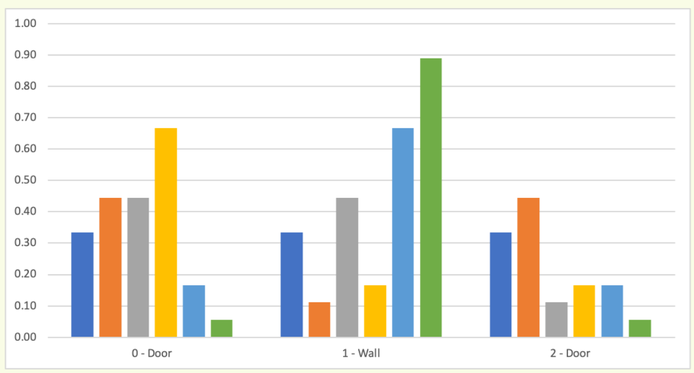
- Able to reason about large models with an infinite state space

For any $N \geq 1$,

$$\left(\textit{true} \vdash \left(\begin{array}{l}(\forall j \bullet j < (N-1) \Rightarrow (prob'\,(\mathbf{v}[j, false/i, c] = 1/N))) \wedge \\ prob'\,(\mathbf{v}[(N-1), true/i, c]) = 1/N\end{array}\right)\right) \sqsubseteq ChooseUniform(N)$$

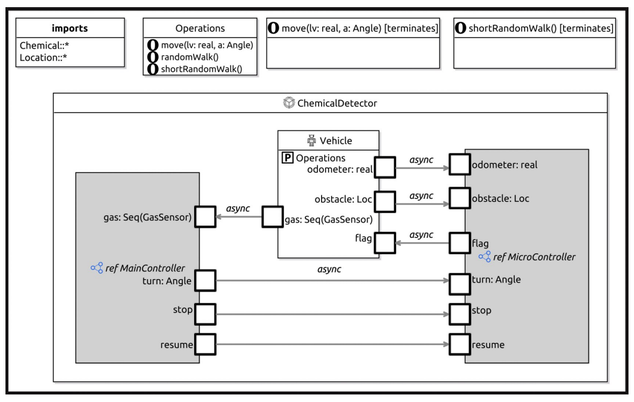
- Bayesian belief model

Localisation: robot's belief in its current position changed after 3 sensor readings and two movements: very likely (nearly 90%) it is in front of wall now.



Formally Verified Animation for RoboChart

- Operational semantics of RoboChart given in interaction trees (mechanised in Isabelle/HOL)
- Generated Haskell code for animation (on terminal now)
- Able to animate a state machine, an operation, a controller, or a whole model



Animation of a chemical detector model in a scenario: detected an intensive gas.

```
Internal Activity...
Events: (1) RandomWalkCall (); (2) Gas (Din, []); (3) Gas (Din, [(0, 0)]); (4) Gas (Din, [(0, 1)]); (5) Gas
 (Din, [(1, 0)]); (6) Gas (Din, [(1, 1)]); (7) Gas (Din, [(0, 0),(0, 0)]); (8) Gas (Din, [(0, 0),(0, 1)]);
(9) Gas (Din, [(0, 0),(1, 0)]); (10) Gas (Din, [(0, 0),(1, 1)]); (11) Gas (Din, [(0, 1),(0, 0)]); (12) Gas
(Din, [(0, 1),(0, 1)]); (13) Gas (Din, [(0, 1),(1, 0)]); (14) Gas (Din, [(0, 1),(1, 1)]); (15) Gas (Din, [(
1, 0),(0, 0)]); (16) Gas (Din, [(1, 0),(0, 1)]); (17) Gas (Din, [(1, 0),(1, 0)]); (18) Gas (Din, [(1, 0),(1
, 1)]); (19) Gas (Din, [(1, 1),(0, 0)]); (20) Gas (Din, [(1, 1),(0, 1)]); (21) Gas (Din, [(1, 1),(1, 0)]);
(22) Gas (Din, [(1, 1),(1, 1)]);
1
[Choose: 1-22]: RandomWalkCall ()
Events: (1) Gas (Din, []); (2) Gas (Din, [(0, 0)]); (3) Gas (Din, [(0, 1)]); (4) Gas (Din, [(1, 0)]); (5) G
as (Din, [(1, 1)]); (6) Gas (Din, [(0, 0),(0, 0)]); (7) Gas (Din, [(0, 0),(0, 1)]); (8) Gas (Din, [(0, 0),(
1, 0)]); (9) Gas (Din, [(0, 0),(1, 1)]); (10) Gas (Din, [(0, 1),(0, 0)]); (11) Gas (Din, [(0, 1),(0, 1)]);
(12) Gas (Din, [(0, 1),(1, 0)]); (13) Gas (Din, [(0, 1),(1, 1)]); (14) Gas (Din, [(1, 0),(0, 0)]); (15) Gas
 (Din, [(1, 0),(0, 1)]); (16) Gas (Din, [(1, 0),(1, 0)]); (17) Gas (Din, [(1, 0),(1, 1)]); (18) Gas (Din, [
(1, 1),(0, 0)]); (19) Gas (Din, [(1, 1),(0, 1)]); (20) Gas (Din, [(1, 1),(1, 0)]); (21) Gas (Din, [(1, 1),(
1, 1)]);
9
[Choose: 1-21]: Gas (Din, [(0, 0),(1, 1)])
Internal Activity...
Events: (1) MoveCall (0,Chemical_Angle_Front);
1
[Choose: 1-1]: MoveCall (0,Chemical_Angle_Front)
Events: (1) Flag Dout;
1
[Choose: 1-1]: Flag Dout
Internal Activity...
Terminated: ()
```

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