Software Engineering for Robotics

On the occasion of Jan Peleska's Festschrift

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Testing in RoboStar - a journey

Model-based testing using CSP and CSP-like notations

Early days

- Jan is a pioneer: theory and tool
- Testing for refinement in CSP: inspired on his tests for negative behaviour
- Developers and testers using the same conformance relation
- Data-rich theory: *Circus*
- Inputs and outputs
- Refusal-traces semantics

Testing in RoboStar - a journey

With Jan, and colleagues

- Kripke structures and the UTP
- Finite and complete test suites

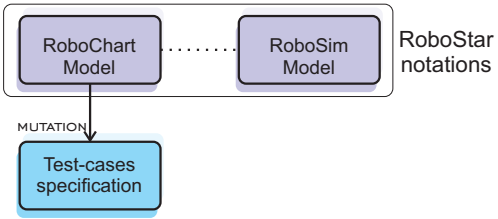
Recently and Now

- Testing theory for *tock*-CSP
- *Using RT-Tester to run simulation and tests*
- RoboStar notations as a front end
- With Alvaro Miyazawa, Uwe Schulze, and Jon Timmis

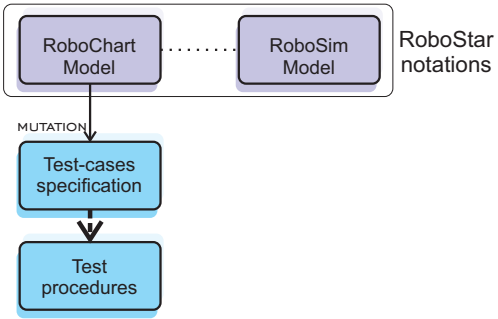
RoboStar and RT-Tester

RoboStar and RT-Tester

RoboStar and RT-Tester



RoboStar and RT-Tester



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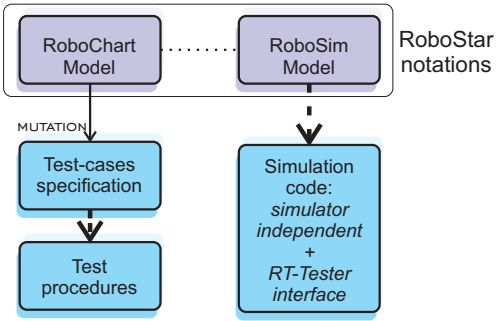

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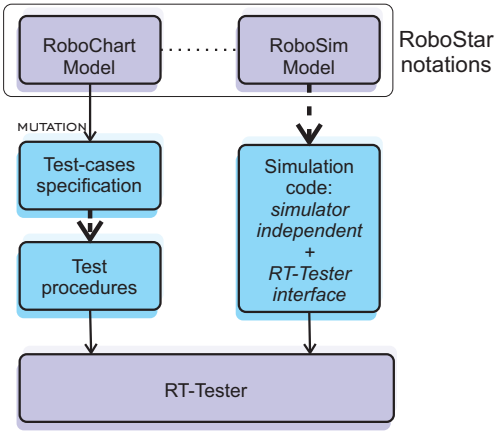

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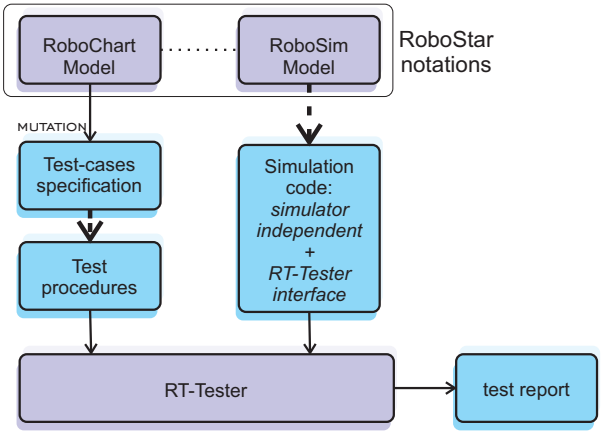


Software Engineering for Robotics: others are interested

Recently published book

`https://www.springer.com/gp/book/9783030664930`

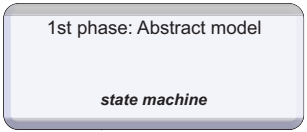
Our distinctive approach

- Complement existing techniques
- Use of domain-specific languages
- Mathematics for validation and verification

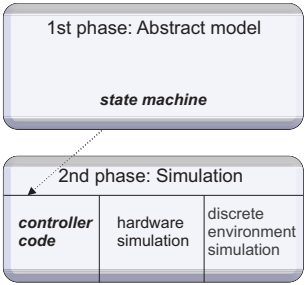
Largest research group in the world in the area

Current approach

Current approach



Current approach



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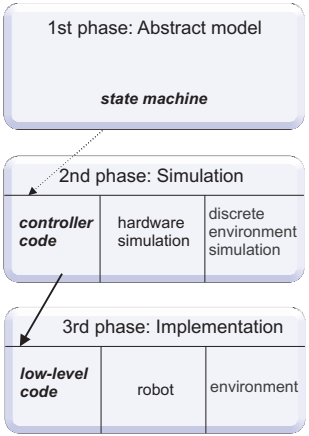

RoboStar vision

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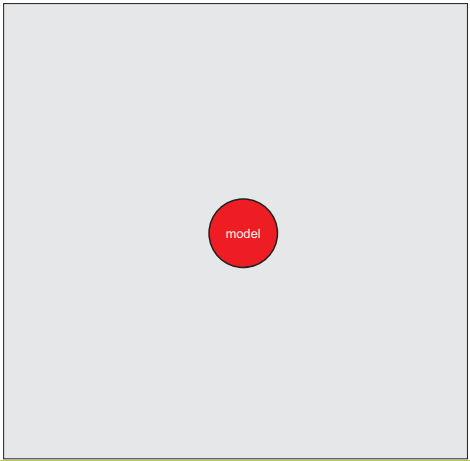

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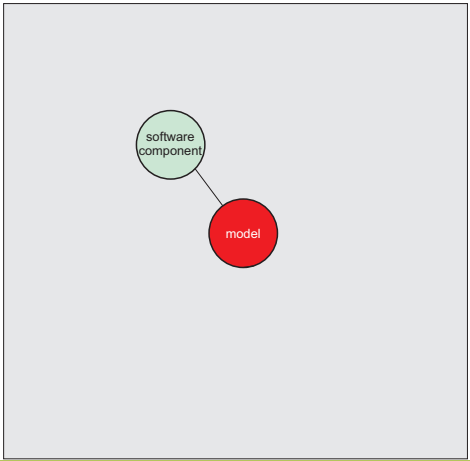

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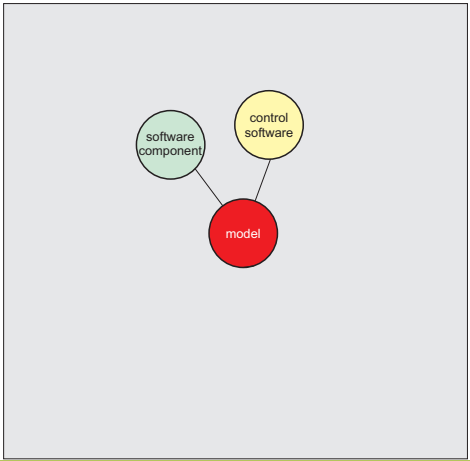

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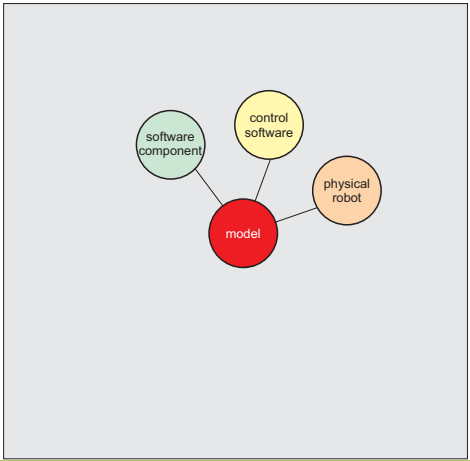

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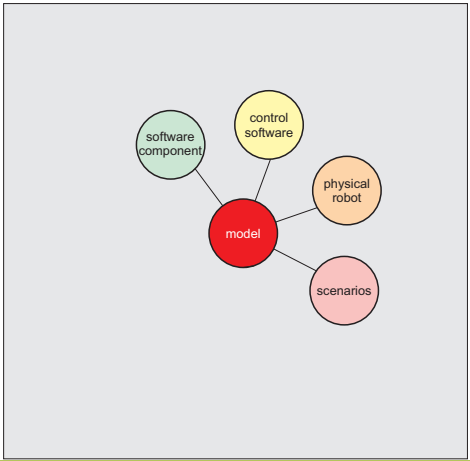

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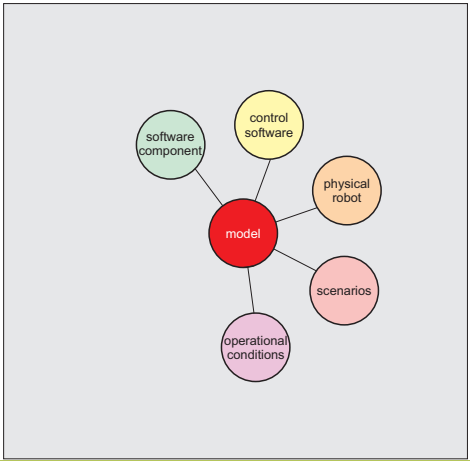

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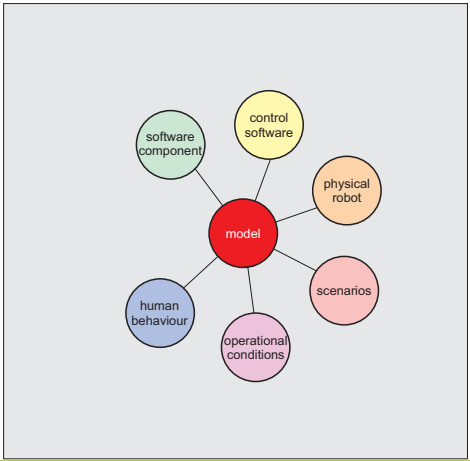

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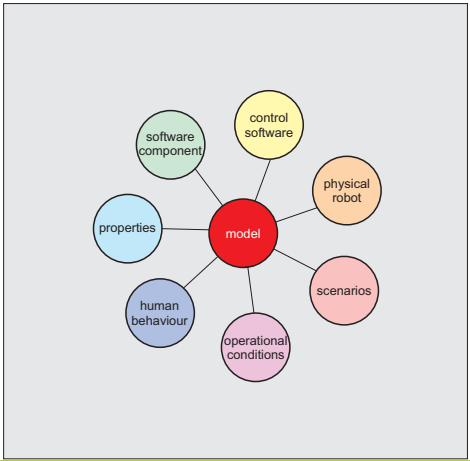

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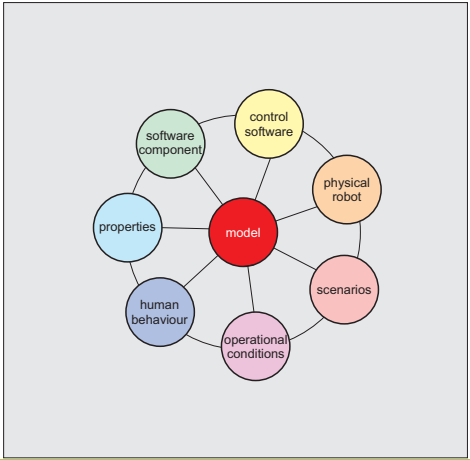

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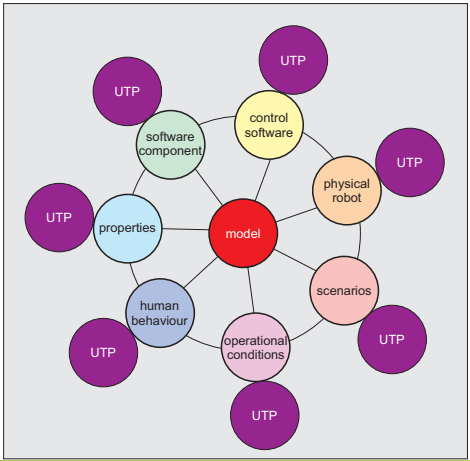

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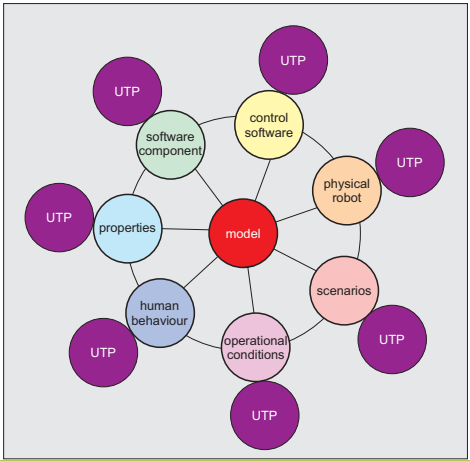
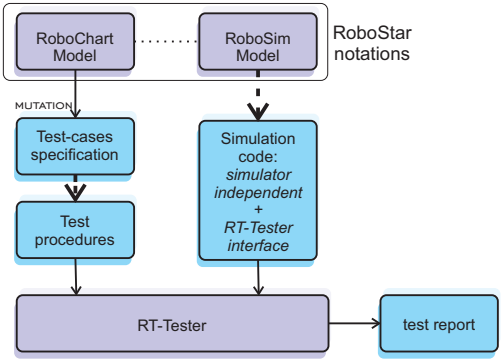


1. Simulation
2. Code
3. Tests
   - simulation
   - deployment
4. Proof
   - model checking
   - theorem proving
5. Evidence of properties

Testing approach

Testing approach



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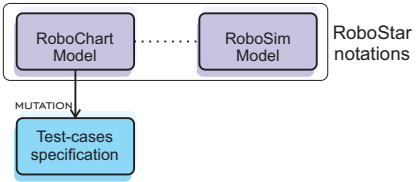

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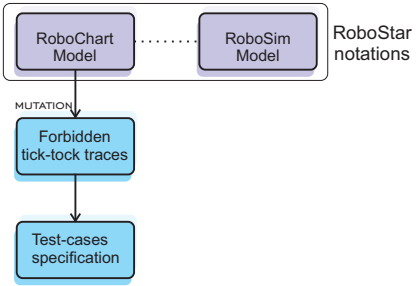

tock-CSP: an overview

Timed process algebra

- Mechanisms modelled by processes that communicate via atomic and instantaneous events
- Special event: *tock*
- Reuse of tools
- Reuse of semantics
- Several challenges
  - Passage of time cannot decide choice
  - Time interrupt is not strict
- FDR support

tock-CSP requirements

- Deadlines: refusal of *tock*
- Termination
- Within each time unit, the standard (untimed) failures semantics of CSP holds.
- Zeno behaviours
- Timewise refinement
- Operators
  - Events are instantaneous: passage of time explicit
  - Maximal progress of internal events
  - Operators as defined in a timed section

✓-tock traces

Example: *RD*

$$takeoff \rightarrow wait\ 1;\ move \rightarrow found \rightarrow land \rightarrow \mathbf{Stop}$$
$$\Box$$
$$turnoff \rightarrow \mathbf{Skip}$$

✓-tock traces

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✓-tock traces - with inputs and outputs

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✓-tock traces - with inputs and outputs

Example: *RD* – Traces

takeoff $\rightarrow$ *wait* 1; *move* $\rightarrow$ *found* $\rightarrow$ *land* $\rightarrow$ **Stop**

$\Box$

turnoff $\rightarrow$ **Skip**

$\langle \Sigma^{\checkmark} \setminus \{takeoff, turnoff\} \rangle$,

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$$\langle takeoff, \Sigma^{\checkmark} \rangle,$$

✓-tock traces - with inputs and outputs

Example: *RD* – Traces

$$(\mathit{takeoff} \rightarrow \mathit{wait}\ 1;\ \mathit{move} \rightarrow \mathit{found} \rightarrow \mathit{land} \rightarrow \mathbf{Stop}) \ \Box\ \mathit{turnoff} \rightarrow \mathbf{Skip}$$

$\langle \mathit{takeoff}, \Sigma^{\checkmark} \rangle, \langle \mathit{takeoff}, \Sigma^{\checkmark}, \mathit{tock} \rangle,$

✓-tock traces - with inputs and outputs

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tock-CSP with inputs and outputs: Main results

Given processes P and Q such that Q is input-enabled, $P \sqsubseteq_{IOTT} Q \Rightarrow Q \text{ tioco } P$.

There are P and Q such that $Q \text{ tioco } P$, but not $P \sqsubseteq_{IOTT} Q$.

Given input-enabled processes P and Q, $P \sqsubseteq_{IOTT} Q \Leftrightarrow Q \text{ tioco } P$.

tock-CSP Testing Theory

Main components

- Verdict events: *inc*, *pass*, *fail*
- SUT is divergence free
- Test execution: SUT behaves like an unknown process *SUT*

$$Execution(SUT, TCS) \mathrel{\widehat=} ((SUT;\ ticktest \to_U \mathbf{Stop}_U) \,[\![\, \Sigma \,]\!]\, TCS) \setminus \Sigma$$

- Fairness condition: all behaviours can be observed
- Verdict

$$SUT\ fails\ TCS \mathrel{\widehat=} \exists\, \rho : TTTrace \bullet \rho \frown \langle evt\ fail, ref\ (\Sigma^{\checkmark}_{tock} \cup V)\rangle \in tt[\![Execution(SUT, TCS)]\!]$$

tock-CSP Testing Theory

Example: *RD*

$$\mathit{takeoff} \rightarrow \mathit{wait}\,1;\ \mathit{move} \rightarrow \mathit{found} \rightarrow \mathit{land} \rightarrow \mathbf{Stop}$$
$$\Box$$
$$\mathit{turnoff} \rightarrow \mathbf{Skip}$$

Forbidden trace: $\langle \mathit{takeoff}, \Sigma^{\checkmark}, \mathit{tock}, \mathit{found} \rangle$

$$\mathit{inc} \rightarrow_U \mathit{takeoff} \rightarrow_U \mathit{inc} \rightarrow_U (\ \mathit{takeoff} \rightarrow \mathbf{Stop}_U \ \Box\ \mathit{move} \rightarrow \mathbf{Stop}_U \ \Box\ \mathit{found} \rightarrow \mathbf{Stop}_U$$
$$\Box$$
$$\mathit{land} \rightarrow \mathbf{Stop}_U \ \Box\ \mathit{turnoff} \rightarrow \mathbf{Stop}_U \ \Box\ \mathit{ticktest} \rightarrow \mathbf{Stop}_U\ )$$
$$\triangle_1\ \mathit{pass} \rightarrow_U \mathit{found} \rightarrow_U \mathit{fail} \rightarrow_U \mathbf{Stop}_U$$

tock-CSP Testing Theory: Main results

Soundness

The test-case specifications formed from forbidden traces that are minimal with respect to a prefixing relation and are output saturated are sound.

Completeness

The test suite containing all test-case specifications formed from forbidden traces that are minimal with respect to a prefixing relation and are output saturated is complete.

Current work: testing with robot in the loop

Hybrid model

- RoboChart + RoboSim p-model: *tock*-CSP + *CyPhyCircus*
- Assumptions:
  1. Forbidden event traces of the software are available.
  2. The software has been verified: at the very least, tests corresponding to the forbidden event traces in a have passed
- Approach: convert the forbidden traces to traces described in terms of inputs of the sensors and outputs of the actuators
- A continuous test contains: trajectories for the inputs and outputs, and verdicts and as function of time.
- For a test drive: project the continuous test over the sample time.

Conclusions

Thanks

- Discrete time in CSP sorted out
- If events are atomic and instantaneous
- Testing theory in place: inputs, outputs, soundness, completeness, ...
- Termination, nondeterminism
- RoboStar notations: practical front-end
- Ongoing: automation