Trends in Concurrency Theory

The Tester’s Perspective

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New Age Concurrency?

- Several observations lead us to the conviction that “time is right” to invest into changes of paradigm in the field of concurrency and its semantic foundations
  - Multi-core systems – the need for weak memory models
  - E-commerce – new notions of distributed database consistency
  - Cyber-physical systems (CPS) – dynamic re-configuration, adaptive, emergent properties, collaborative, multi formalism development and V&V ...
Three Topics to Address

- **Multi-formalism support** for CPS modelling and verification
- **Dynamicty** – changing CPS configurations
- **Evolving behaviour** of CPS components

All this is presented from the perspective of model-based testing
Multi-formalism support for CPS modelling and verification
Problem Statement

• Different CPS components are developed and verified with \textit{different formalisms}

• This produces \textit{“local” verification results}, presented in different formalisms

• How can we assert the \textit{validity of the required emergent properties} of the CPS?
Two Approaches

• Application of the

  • Theory of (Grothendieck) Institutions

  • Unifying Theory of Programming (UTP)

  to translate

  • theories between different formalisms

  • verification obligations and test cases

  • verification results and test results

between different formalisms
Application scenario

- CPS consists of several components
- Some components are modelled by finite state machines (FSMs)
- Other components are modelled by SysML state machines with Kripke structure semantics
Application scenario – train onboard speed control

- **Onboard main controller**
  - Current speed
  - Current maximum speed

- **PLC brake controller**
  - Automated braking command
    - auto_on, auto_off

- **Train engine driver brake command**
  - man_on, man_off
  - trigger, release

- **Emergency brake**
Application scenario – train onboard speed control

Current speed
Current maximum speed
Emergency brake
- Discrete inputs
- Discrete internal state
- Discrete outputs
- Complete testing strategies available
• Large input domains – speed
• Discrete internal state
• Discrete outputs

Apply input equivalence class testing

Can we also apply a complete strategy?

TTT = Testing Theory Translation using institutions
Verification of emergent properties

- **Application scenario**
  - Onboard controller has been verified and tested using SysML models with Kripke semantics
  - PLC has been verified and tested using FSM models

- **Verification objective.** System satisfies emergent property
  
  **EP.** "As long as the speed is above emergency threshold, the emergency brakes stay active and cannot be manually released"

- **Technical side condition.** EP shall be specified in CSP trace logic
Verification of emergent properties

- Problems to be solved

  - EP can only be specified by referring to properties of both the onboard main controller and the brake controller

  - Properties related to brake controller are specified by FSM I/O sequences $x/y$ – e.g. via intersection with testing automaton

  - Properties related to Onboard speed controller are specified by, e.g. LTL formulas with shared I/O variables as free symbols

  - CSP trace logic formulas are specified over traces of events and refusal sets
Linking Theories by UTP

FSM

α

normalised graphs

traces/maximal refusals

η

reactive processes

θ

Kripke structures

ζ

Galois Connections

Ana Cavalcanti, Wen-ling Huang, Jan Peleska, Jim Woodcock: CSP and Kripke Structures. ICTAC 2015: 505-523
Dynamicity – changing CPS configuration
Problem Statement

- CPS need cooperating components in dynamically changing configurations

- Each component needs to be prepared to
  
  - accept/set up/destroy new communication links from/to other components entering/leaving the configuration
  
  - enter/leave the configuration itself (mobility)
Major Contributions

- **pi-calculus** for dynamic creation of channels

- **Augmented CSP** allowing to simulate Pi-calculus with the means of a “conventional process algebra”

- **Bigraphs** for presenting both topography and communication structure
pi-Calculus and CSP

- Milner’s pi-calculus

\[(\nu x)(\overline{x}\langle z \rangle .0 \mid x(y).\overline{y}\langle x \rangle .x(y).0) \mid z(v).\overline{v}\langle v \rangle .0)\]

allows for **dynamic channel creation** and **communication of channel names**

- Roscoe showed that pi-calculus can be simulated by CSP augmented with **throw operator**

\[P\Theta_AQ\]
pi-Calculus and CSP

- Milner’s pi-calculus allows for dynamic channel creation and communication of channel names.

\[
(\nu x)(\overline{x}(z).0 | x.h_i.y.h_i.x(y).0 | z(v).v.h_v.i.0)
\]

As a consequence, “conventional” model checking (e.g. with FDR) can be used to verify mobile process systems.

- Roscoe showed that pi-calculus can be simulated by CSP augmented with throw operator

\[
P \Theta_A Q
\]

Bigraphs

- Bigraphs allow for representation of
  - process topography
  - communication topology
  - dynamic changes of the former
Bigraphs

**topograph** $G^T: 3 \rightarrow 2$

**regions** …

$s_0$  $s_1$  $s_2$

$v_0$  $v_1$  $v_3$

$r_0$  $r_1$

**monograph** $G^M: \{x_0, x_1\} \rightarrow \{y\}$

**names** …

$x_0$  $x_1$

$v_0$  $v_2$

$v_1$

$v_3$

**bigraph** $G: \langle 3, \{x_0, x_1\} \rangle \rightarrow \langle 2, \{y\} \rangle$

R. Milnor:

*Bigraphs as a Model for Mobile Interaction*

How to Test Dynamic CPS Configurations

- Some things are easier in testing than in general verification

- Only safety properties matter

- Tests terminate after finite amount of time

- Finite variability of HW components implies that only a finite number of configurations can be covered during test execution
How to Test Dynamic CPS Configurations

- Model a **CPS configuration tree**
- Construct **equivalence classes** for configuration changes
- Elaborate **complete testing theory** guaranteeing full fault coverage with finitely many test cases, provided that
  - equivalence classes are adequate
  - CPS components do not have more state equivalence classes than assumed
CPS (or SoS) configuration tree

Pre-post-condition guarding a configuration change

... Further possible configurations reachable from Configuration 1 ...
Evolving behaviour of CPS components
Problem Statement

- CPS components act according to the rely-guarantee paradigm

- The assumptions component C relies on may be violated after some time, due to
  - configuration changes
  - evolving behaviour of other components

- C needs to adapt its behaviour to the new environment conditions
What is to be Solved?

- **Detection.** Component needs to “understand” that its assumptions no longer hold

- **Change of belief.** Component needs to update its assumptions about the environment

- **Adaptation.** Component needs to “optimise” its behaviour w.r.t. the new assumptions
Detection

• For **regular safety properties**, the detection problem is completely solved

• Can be implemented efficiently for **hard real-time** applications

**Recall.** A safety property over atomic propositions $AP$ is regular, if its **bad prefixes** in $(2^{AP})^*$ form a regular language.
Detection

• Therefore, the bad prefix set can be represented by accepting states of an FSM

• **One more problem to solve.** CPS component may not know the trace of system observations from the start, since it may join the configuration at a later state
  
  • Use a **homing algorithm** to determine the FSM state by a sequence of observations

• The detection problem is a **passive testing problem**
Detection – an Example

• Suppose, component C relies on the environment to fulfil safety condition

\[
\Phi \equiv s_0 \land G((s_0 \land X(s_1 \land a)) \lor (s_1 \land X((s_0 \land b) \lor (s_2 \land a))) \lor (s_2 \land X(s_1 \land b)))
\]

with internal state variable \( s_j \) and assumption that a or b must occur in every step

Example trace. \( a.b.a.a.b.a.b.b \ldots \)
Suppose, component C relies on the environment to fulfill safety condition

\[
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\]

with internal state variable \(s_j\) and assumption that \(a\) or \(b\) must occur in every step

**Example trace.** \(a.b.a.a.b.a.b.b\ldots\)
Example (continued). FSM modelling bad prefixes of the safety condition
Example (continued).

Can be generated, for example with \texttt{ltl2ba} from $\neg \Phi$.
Example (continued). Application of the homing algorithm

Initial checking state
Example (continued). Application of the homing algorithm

Observation b
Example (continued). Application of the homing algorithm

Observation $b$ – post-state
Example (continued). Application of the homing algorithm

Observation b.b
Example (continued). Application of the homing algorithm

Observation b.b – post-state
Example (continued). Application of the homing algorithm

Observation b.b.b.b – safety-violation
Change of Belief

- Different options with different complexity

  - **Assumptions are just “true”** – components can adapt to any environment behaviour (examples from control theory)

  - **Expected violations** of assumptions – fault-tolerant adaptation of behaviour under new, pre-defined assumptions

  - **Unexpected violations** of assumptions – new valid assumptions need to be extracted from observations (apply machine learning, construct temporal properties reflecting environment behaviour)
Change of Belief

- Different options with different complexity

- Assumptions are just "true" – components can adapt to any environment behaviour

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Can this be achieved in hard real-time?
Adaptation

• Solved, as far as
  • basic laws of control theory can be applied
  • optimal behaviour can be specified as mathematical boundary value problem or general optimisation problem

• Can be modelled by Hybrid Automata, if discrete changes between different control laws/optimisation methods are required
Adaptation

• Open questions

  • **Q1.** After change of belief system consisting of (temporal) logic formulas: how can we defined the **optimal behaviour** w.r.t. goals and belief system?

  • **Q2.** If such a temporal logic formula for optimal behaviour could be found, could it become possible to **synthesise** the new component behaviour on the fly in hard real-time?
A Tentative Solution for Q1

• Specialised problem statement

  • If, due to changes in the environment behaviour, a CPS component can no longer fulfil its original guarantees, is there a possibility to specify a graceful degradation of behaviour in a well-founded way?

• Suggestion from testing theory

  • Classify component outputs according to criticality

  • Identify outputs of “negligible” criticality

  • Realise behaviour that is equivalent to the original specification, with all outputs of negligible criticality identified
Conclusion

- We discussed 3 topics of new-age concurrency
  - Multi-formalism support for CPS development and verification
  - Modelling and testing of dynamically changing CPS configurations
  - Modelling and testing evolving behaviour of CPS
- We have seen that many “mechanisms” and approaches already exist to tackle these challenges
- Do we need more — a comprehensive new theory & formalism, instead of a “bag of special solutions”? 
Further Reading

• About cyber-physical systems and mobile and channels


• About testing and equivalence classes

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