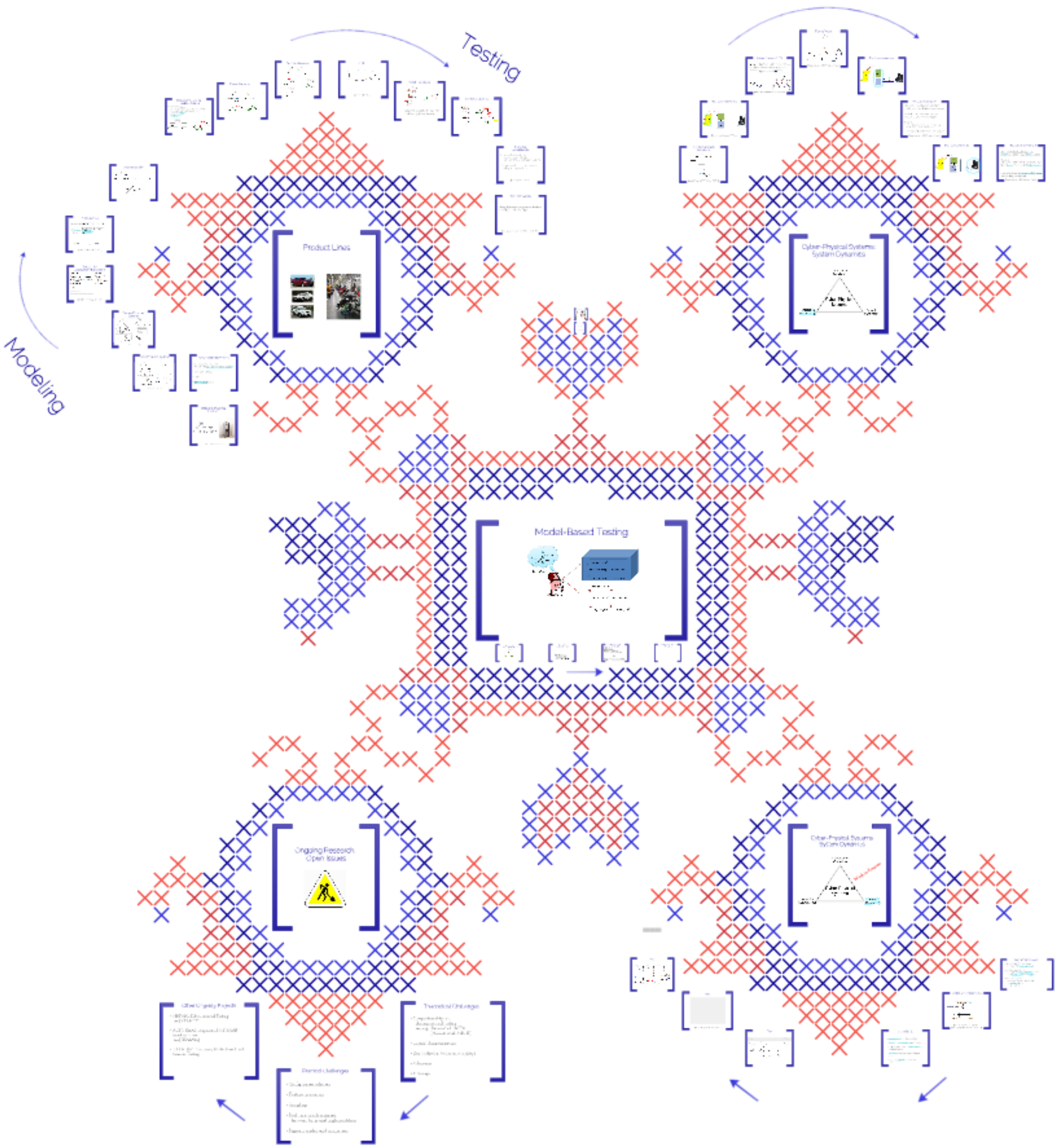


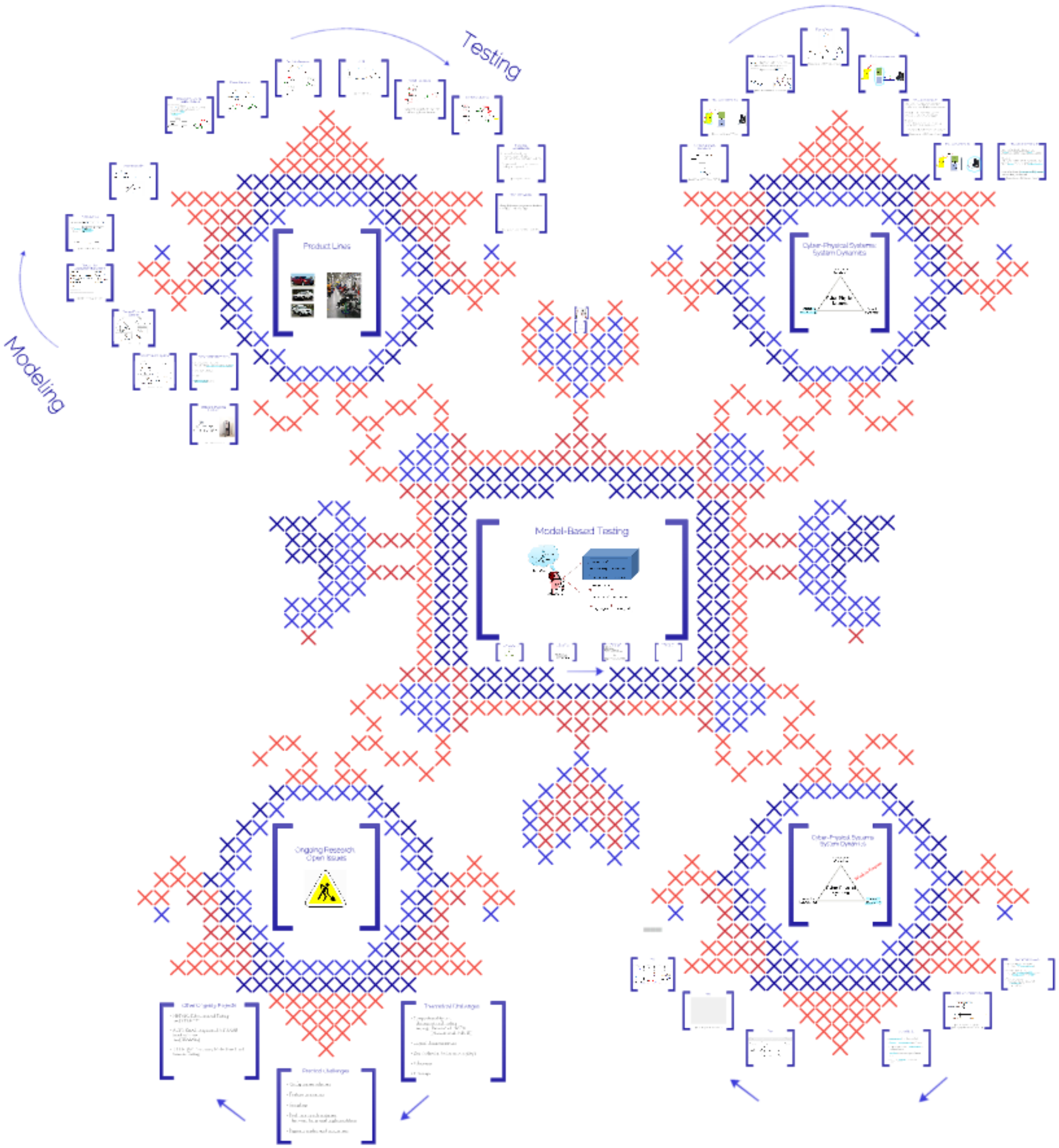
From Concurrency Theory to Model-Based Testing Cyber-Physical Systems

Mohammad Mousavi

HALMSTAD UNIVERSITY

KK-stiftelsen

Vetenskapsrådet



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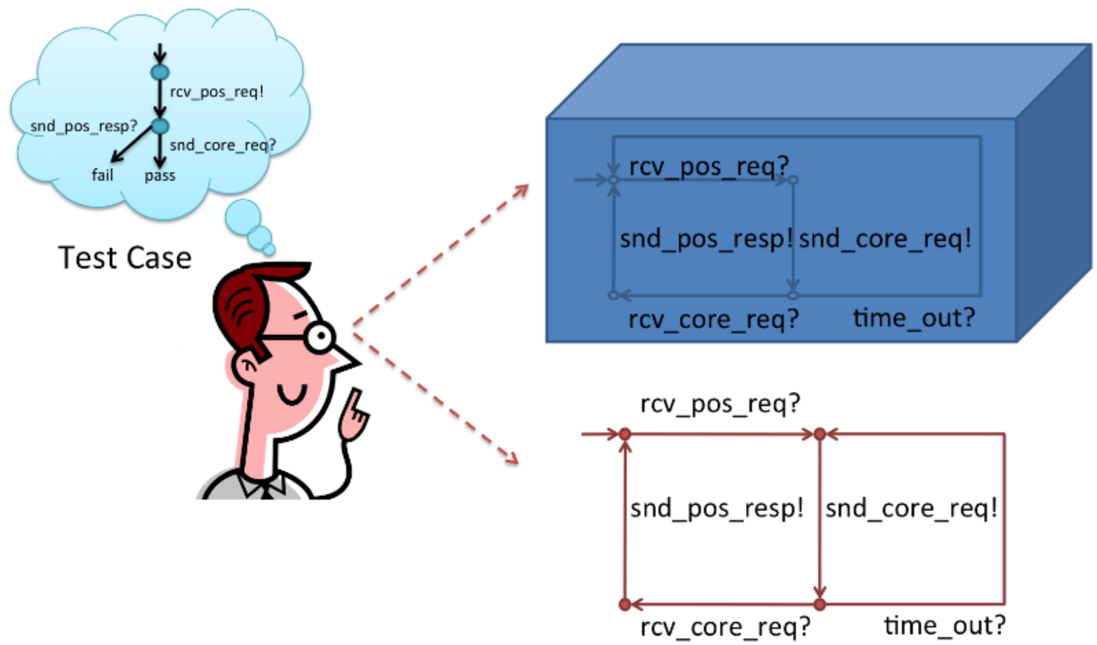

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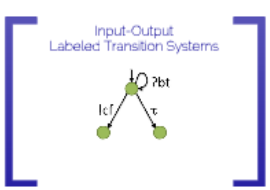
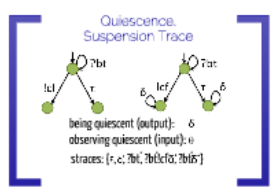
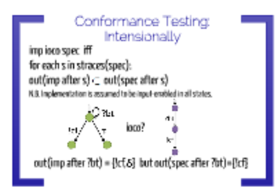
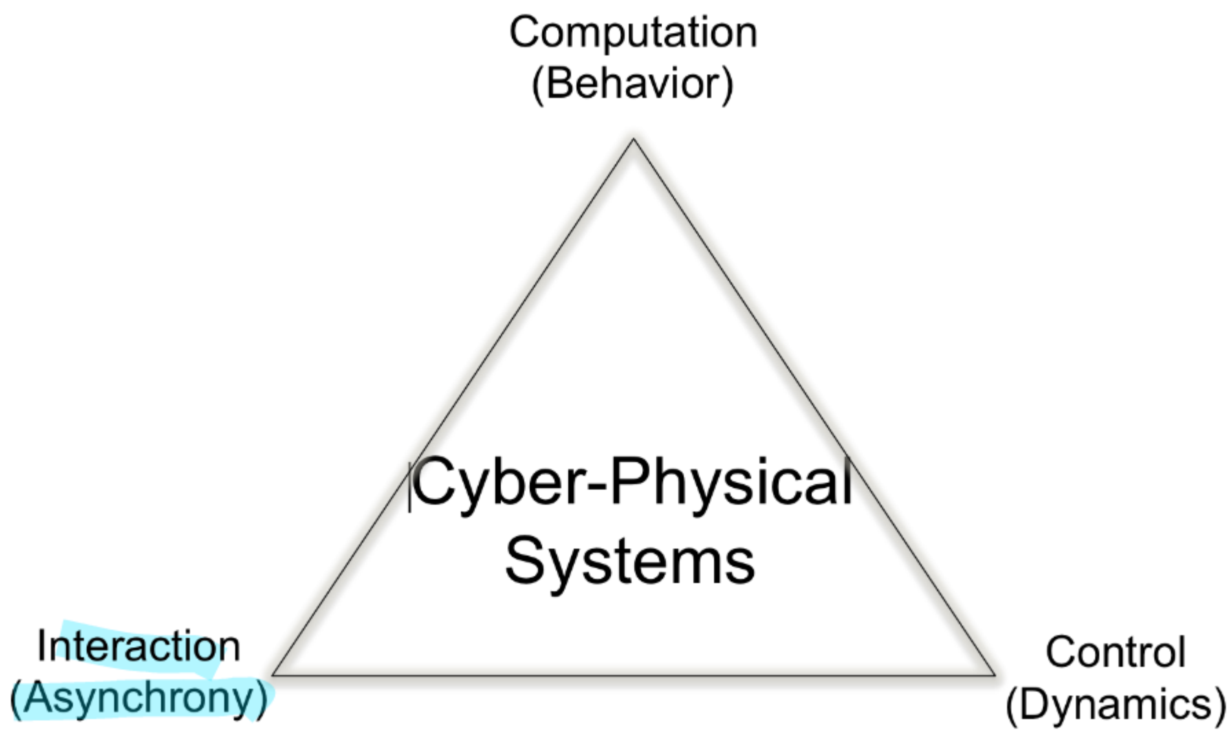




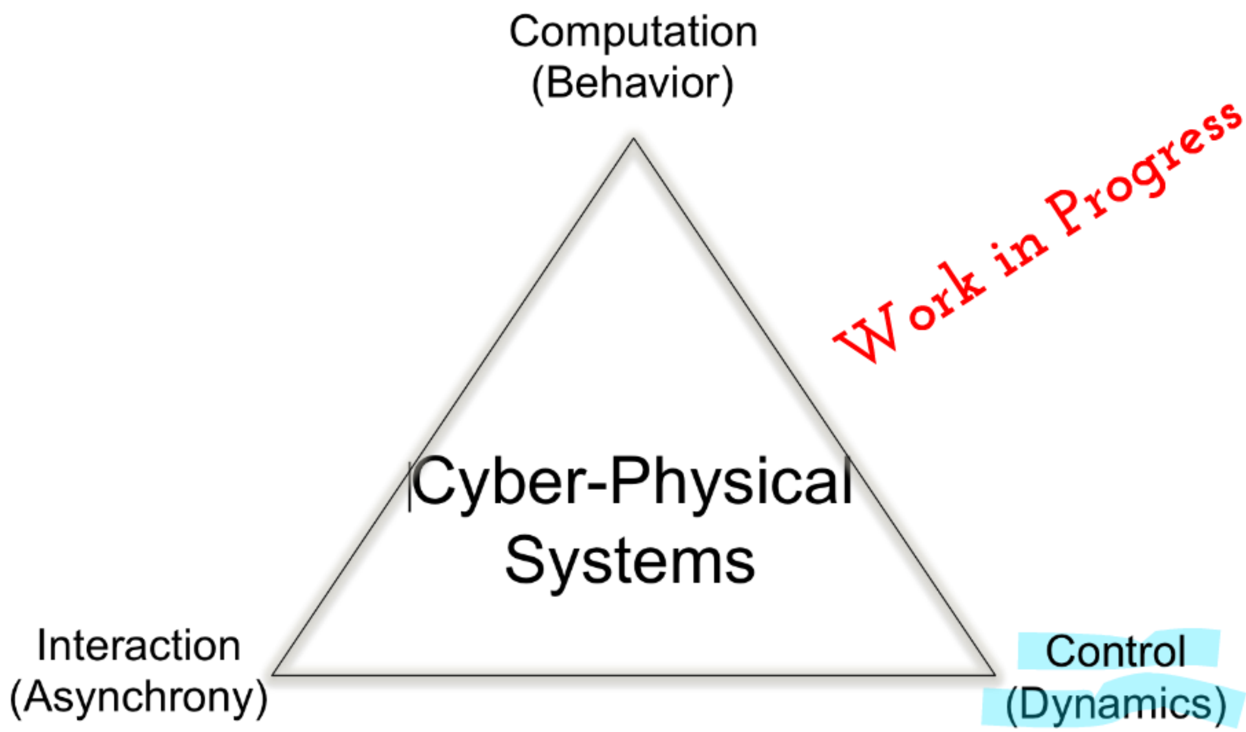


Product Lines

Cyber-Physical Systems: System Dynamics

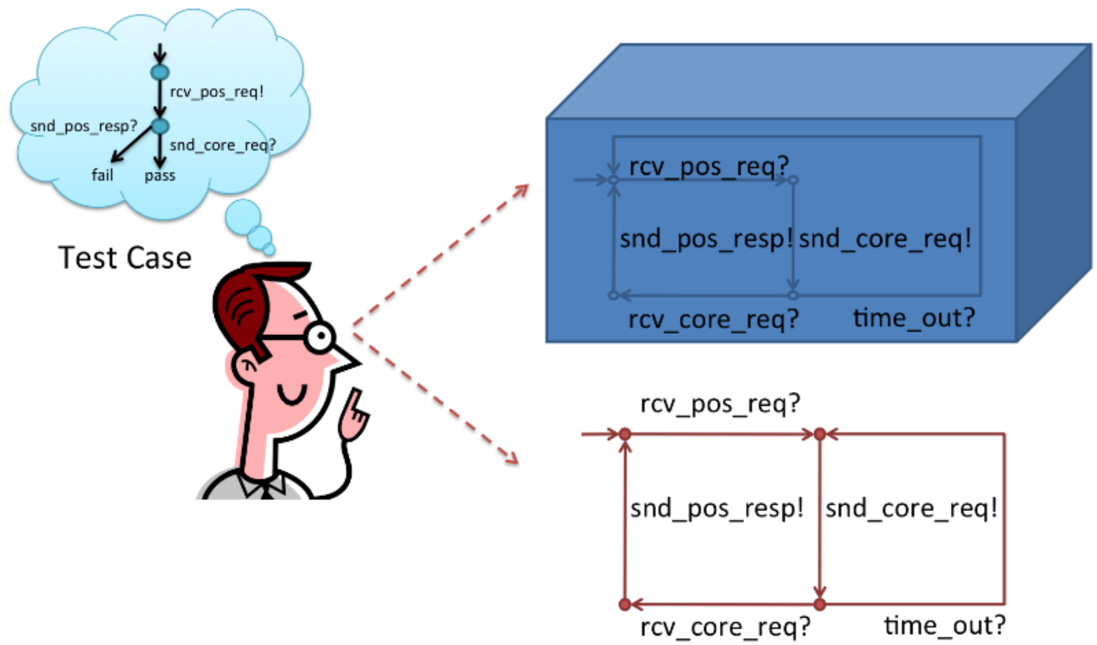


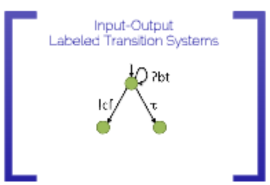
Cyber-Physical Systems: System Dynamics

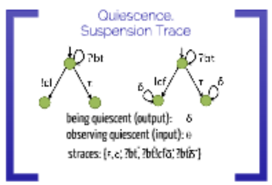


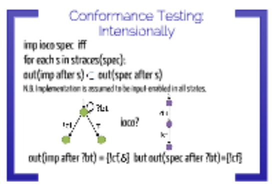
Ongoing Research, Open Issues

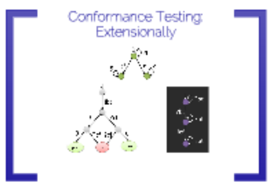
Model-Based Testing



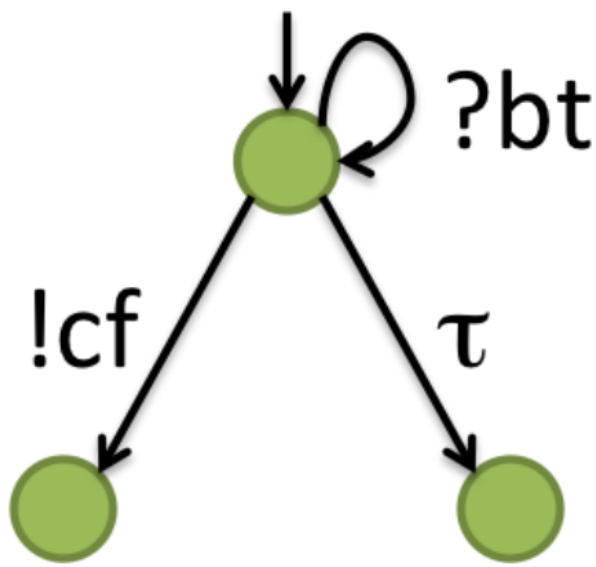




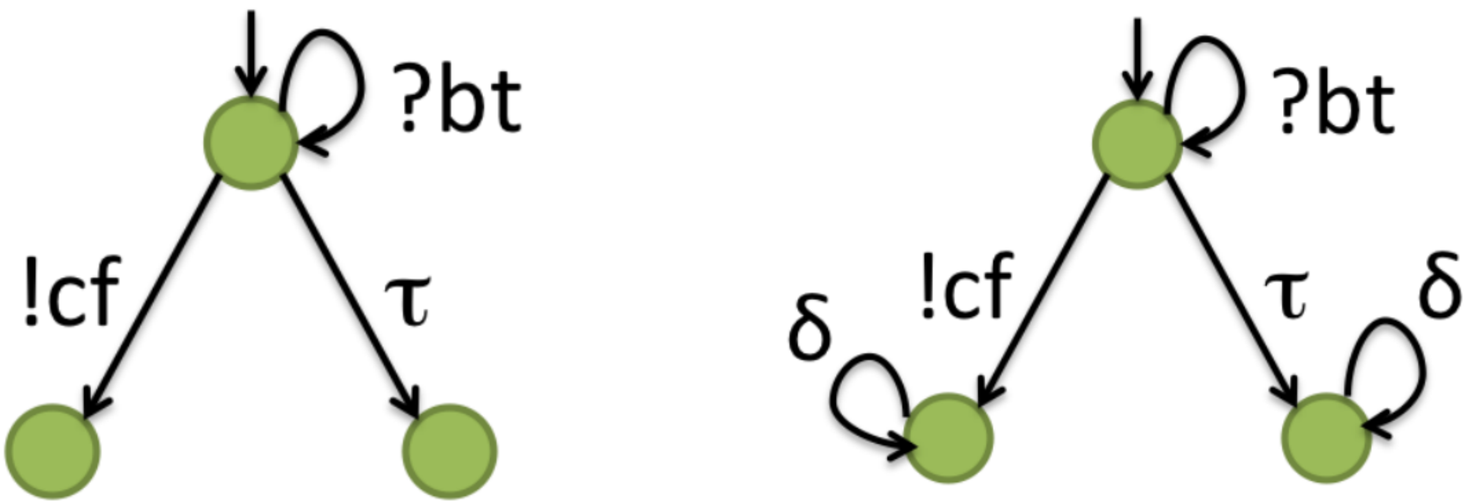




Input-Output Labeled Transition Systems



Quiescence, Suspension Trace



being quiescent (output): δ

observing quiescent (input): θ

straces: $\{\varepsilon, \delta^*, ?bt^*, ?bt^*!cf\delta^*, ?bt^*\delta^*\}$

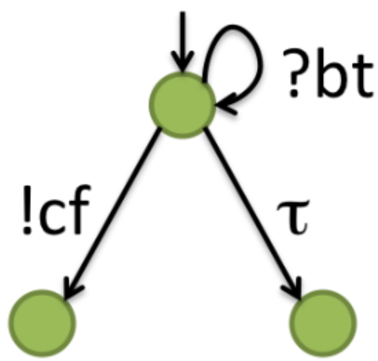
Conformance Testing: Intensionally

imp ioco spec iff

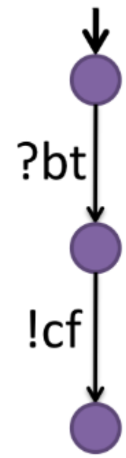
for each s in straces(spec):

out(imp after s) $\subseteq$ out(spec after s)

N.B. Implementation is assumed to be input-enabled in all states.

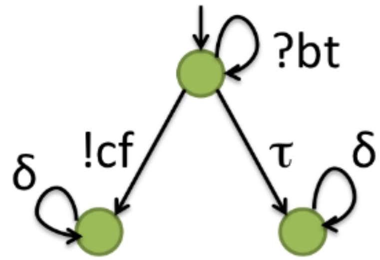


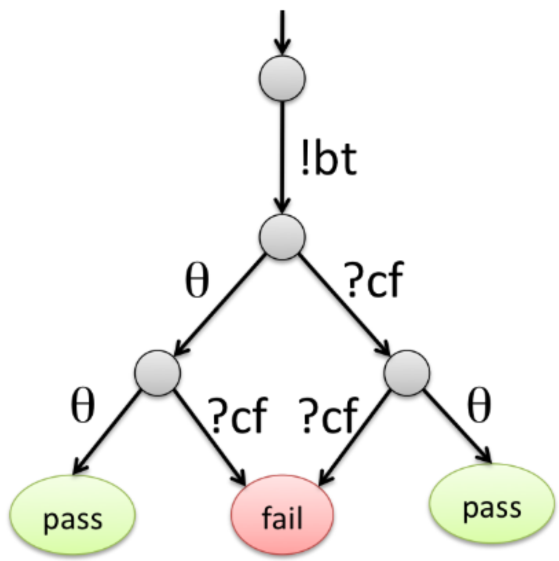
ioco?

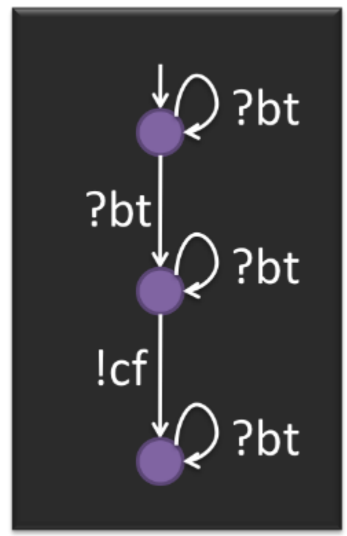


out(imp after ?bt) = {!cf,δ} but out(spec after ?bt)={!cf}

Conformance Testing: Extensionally

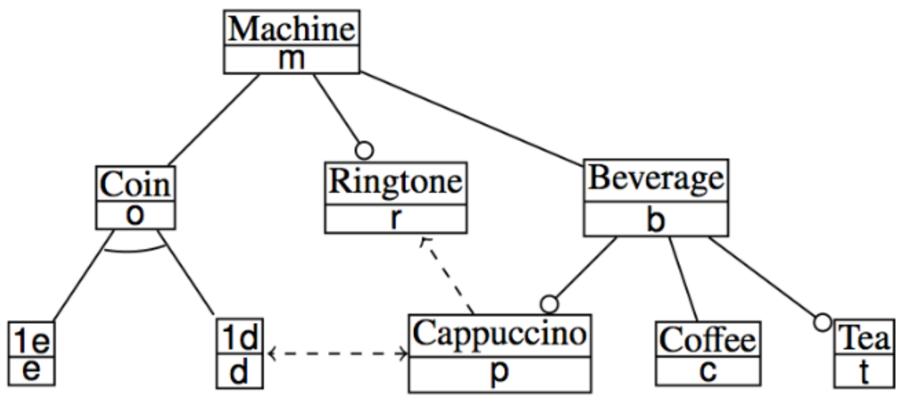






Product Lines

Structural Modeling: Features



[Schobbens, Heymans, and Trigaux, RE'06]

Behavioral Models for SPLs

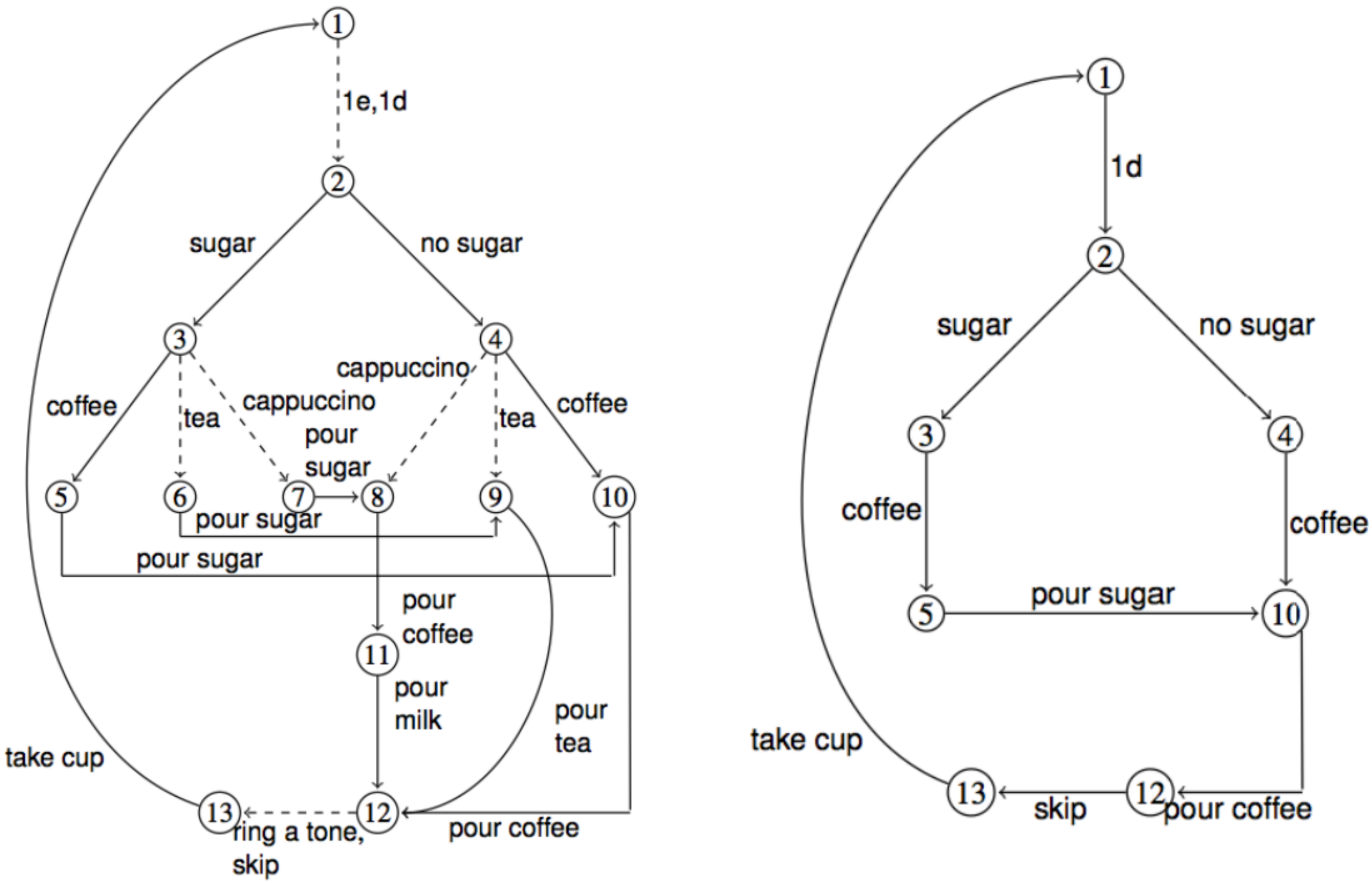
- Various extensions of LTSs:
  Modal- and **Featured Transitions Systems**

- Feature(d) Petri Nets

- PL-CCS

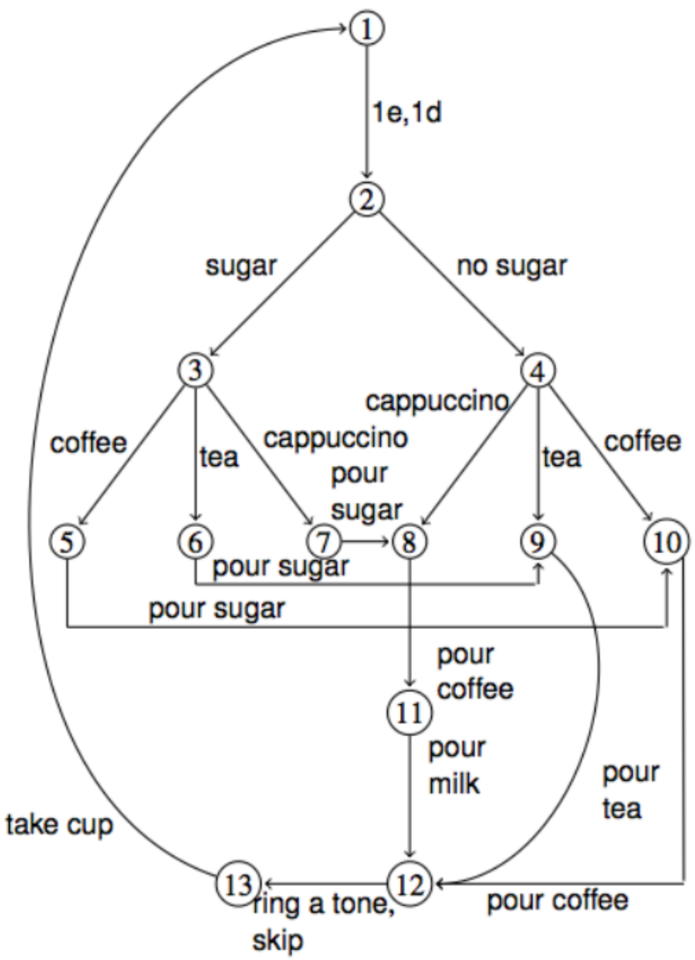
- **Delta-Oriented** FSMs

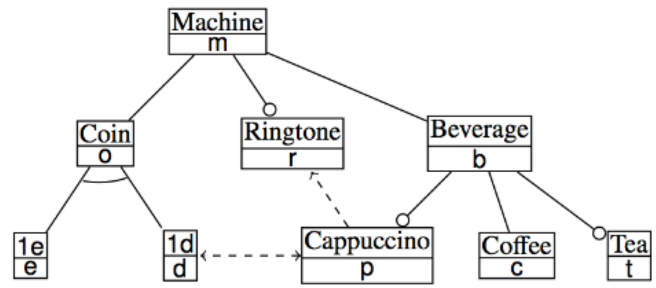
Modal Transition Systems



[Larsen and Thomsen. LICS'98]

Featured Transition Systems





Transitions	*Features*
$s_1 \xrightarrow{1e} s_2$	e
$s_1 \xrightarrow{1d} s_2$	d
$s_2 \xrightarrow{coffee} s_5$	c
$s_2 \xrightarrow{tea} s_6$	t

Transitions	*Features*
$s_2 \xrightarrow{cappuccino} s_7$	p
$s_{12} \xrightarrow{ring\ a\ tone} s_{13}$	$p \Rightarrow r$
remaining transitions	m

[Classen et al., ICSE 2010]

Product Line Labeled Transition Systems

$s_1 = \textit{1e}.s_2 \oplus \textit{1d}.s_2$

$s_2 = \textit{sugar}.s_3 + \textit{no sugar}.s_4$

$s_3 = \textit{coffee}.s_5 + \langle \textit{tea}.s_6 + \textit{cappuccino}.s_7 \rangle$

$s_4 = \textit{coffee}.s_{10} + \langle \textit{tea}.s_9 + \textit{cappuccino}.s_8 \rangle$

$s_5 = \textit{pour sugar}.s_{10}$

$s_6 = \textit{pour sugar}.s_9$

$s_7 = \textit{pour sugar}.s_8$

$s_8 = \textit{pour coffee}.s_{11}$

$s_9 = \textit{pour tea}.s_{12}$

$s_{10} = \textit{pour coffee}.s_{12}$

$s_{12} = \textit{ring tone}.s_{13} + \textit{skip}.s_{13}$

$s_{13} = \textit{take cup}.s_1 \quad .$

$\langle P \rangle = P \oplus \mathbf{Nil}.$

$(\mathbb{P} \times \{L, R, ?\}^I, A, I, \rightarrow)$

$\rightarrow \subseteq (\mathbb{P} \times \{L, R, ?\}^I) \times (A \times \{L, R, ?\}^I) \times (\mathbb{P} \times \{L, R, ?\}^I)$

[Gruler, Leucker, and Scheidemann., FMOODS'08]

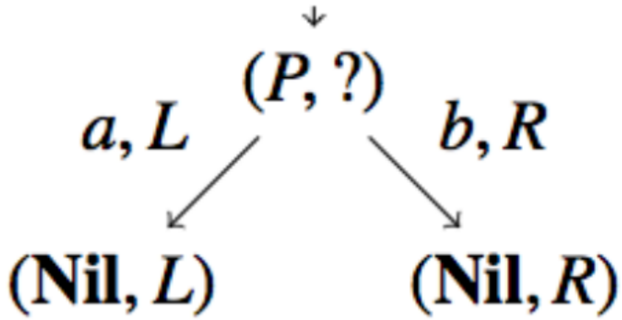
Expressiveness

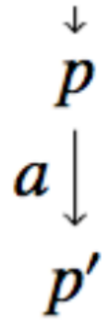
- SPL Formalism: $\mathbf{M} = (\mathbb{M}, [\![\ ]\!])$, $[\![\ ]\!] : \mathbb{M} \rightarrow 2^{\mathbf{P}}$
- Given $\mathbf{M} = (\mathbb{M}, [\![\ ]\!])$, $\mathbf{M}' = (\mathbb{M}', [\![\ ]\!]')$
  an encoding is $E : \mathbb{M} \rightarrow \mathbb{M}'$
  such that $[\![\ ]\!] = E \circ [\![\ ]\!]'$

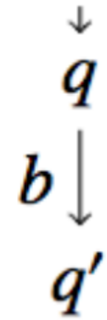
$$\textbf{MTSs} \longrightarrow \textbf{PL-LTSs} \longrightarrow \textbf{FTSs}$$

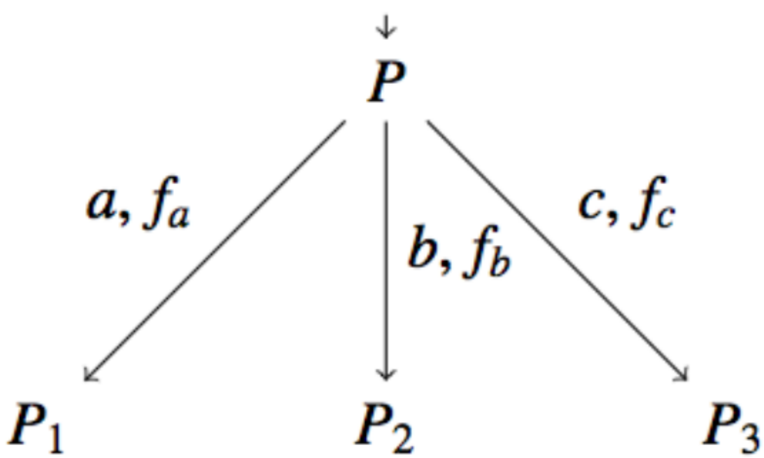
[Beohar, Varshosaz, MRM, SCP'15]

Counterexamples





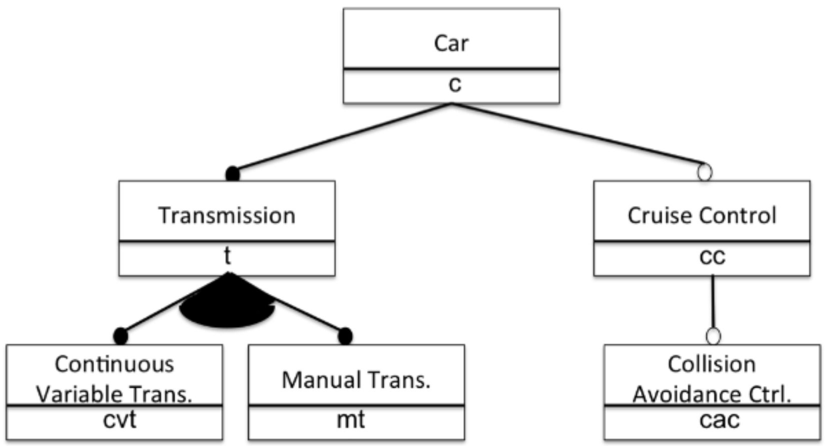


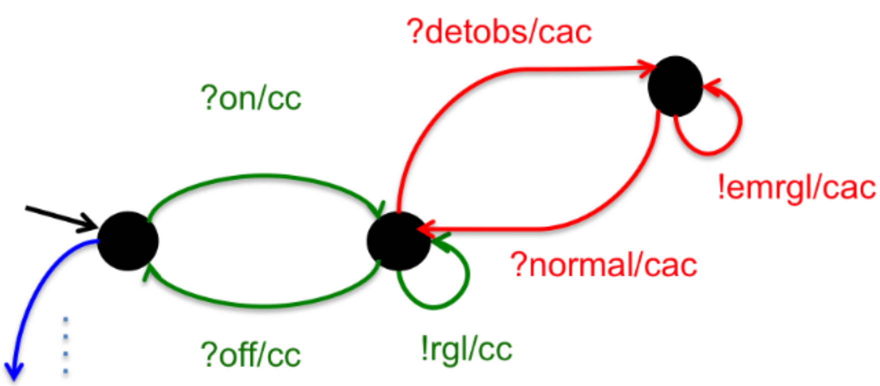


Featured Input-Output Transition Systems

$(S, s, A_\tau, F, T, \Lambda)$, where:

- S, s, A_τ have the same intuition as in IOLTS,
- F is a set of propositions (features),
- $T \subseteq S \times A_\tau \times \mathbb{B}(F) \times S$
- $\Lambda \subseteq \{\lambda : F \to \mathbb{B}\}$

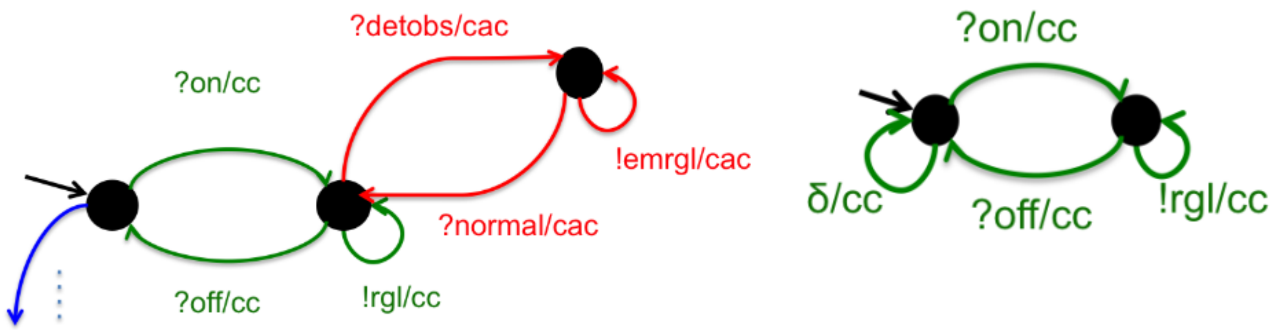




Product Derivation

$$\frac{\exists_{\lambda}\ \lambda \models (\gamma(s,a,s') \wedge \varphi)}{\Delta_{\varphi}(s) \xrightarrow{a}_{\gamma(s,a,s') \wedge \varphi} \Delta_{\varphi}(s')} \quad (1)$$

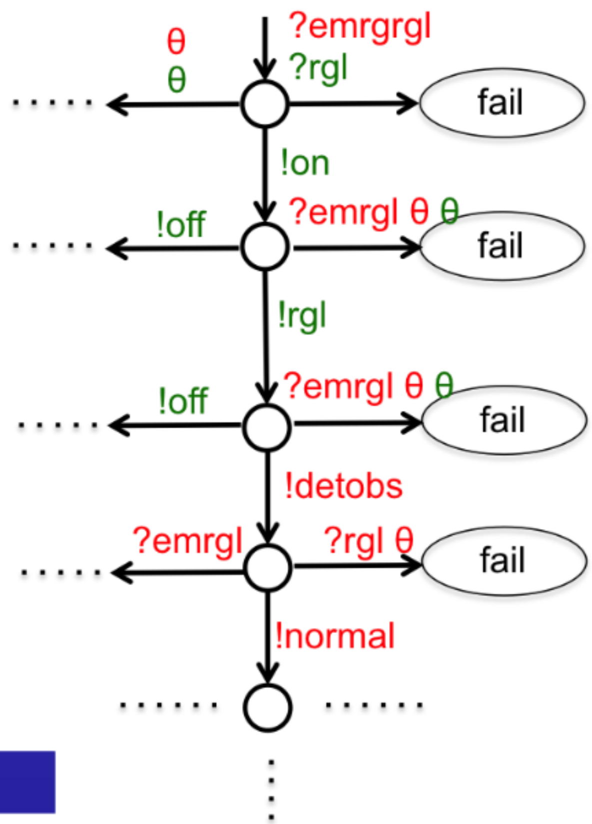
$$\frac{\nexists_{\lambda,s',a}\ \lambda \models (\gamma(s,a,s') \wedge \varphi) \wedge a \in A_{\mathcal{O}} \cup \{\tau\}}{\Delta_{\varphi}(s) \xrightarrow{\delta}_{\varphi} \Delta_{\varphi}(s)} \quad (2)$$

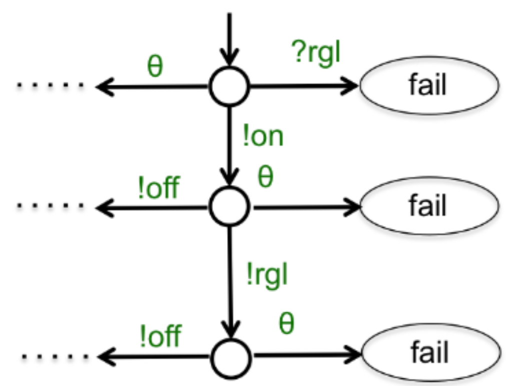


Test-Suite Derivation

$$\frac{X, Y \neq \emptyset \quad (X,\sigma), (Y, \sigma a) \in \mathbf{X}_s^{\varphi}}{(X,\sigma) \xrightarrow{f(a)}_{\varphi} (Y, \sigma a)} \quad (3) \qquad \frac{a \in A_{\mathcal{O}} \cup \{\theta\} \quad (X,\sigma) \xrightarrow{a}_{\varphi} (Y, \sigma')}{(X,\sigma) \xrightarrow{a}_{\varphi} \mathbf{pass}} \quad (4)$$

$$\frac{(X,\sigma) \not\xrightarrow{a}_{\varphi} \mathbf{pass}}{(X,\sigma) \xrightarrow{a}_{\varphi} \mathbf{fail}} \quad (5) \qquad \frac{a \in A_{\mathcal{O}} \cup \{\theta\}}{\mathbf{pass} \xrightarrow{a}_{\varphi} \mathbf{pass} \quad \mathbf{fail} \xrightarrow{a}_{\varphi} \mathbf{fail}} \quad (6)$$



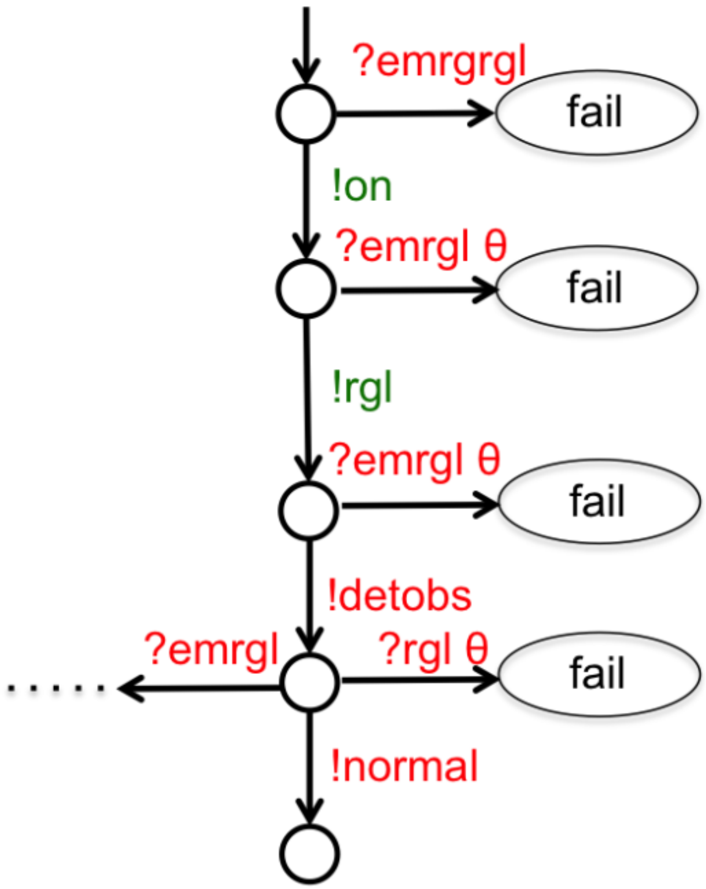


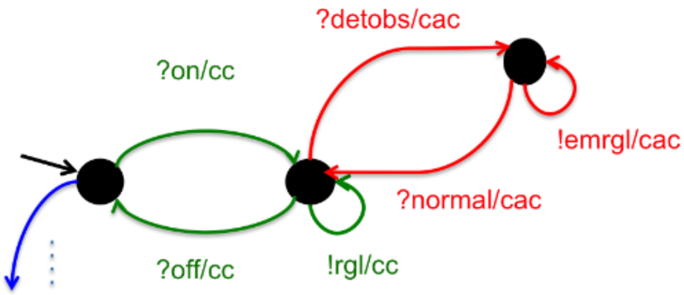
Click!

$$
\begin{array}{ccc}
\Delta_{\varphi}(s) & \xrightarrow{\textbf{test generation}} & (\hat{\mathbf{X}}_s, \varepsilon) \\
\Delta_{\varphi'}(\_) \downarrow & & \downarrow \Delta^{\mathbf{t}}_{\varphi'}(\_) \\
\Delta_{\varphi \wedge \varphi'}(s) & \xrightarrow[\textbf{test generation}]{} & (\hat{\mathbf{X}}_s^{\varphi \wedge \varphi'}, \varepsilon) \cong \Delta^{\mathbf{t}}_{\varphi'}(\hat{\mathbf{X}}_s, \varepsilon)
\end{array}
$$

[Beohar and MRM. SVT'14]

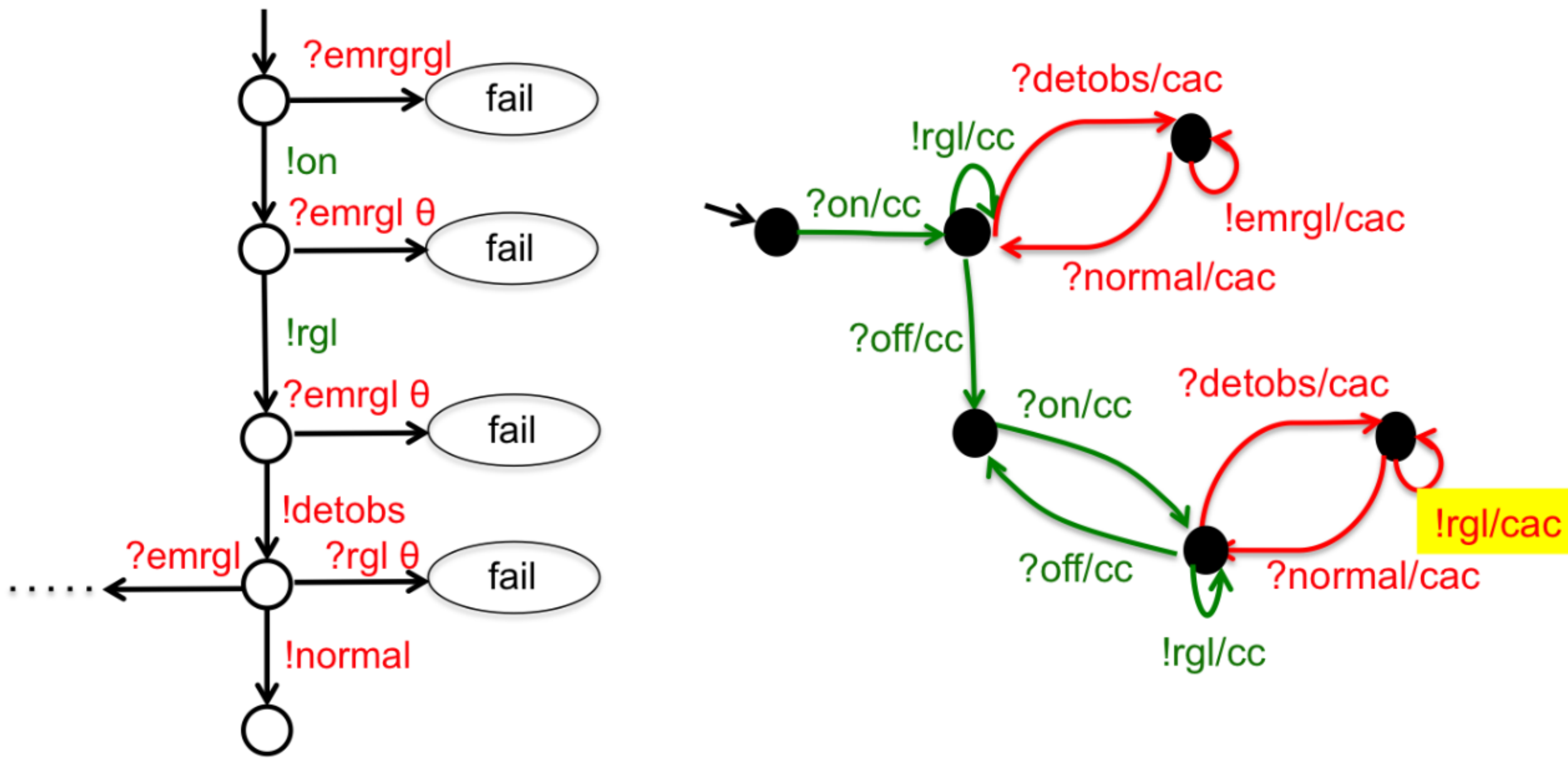
Spinal Test Suites





Spines: Simple paths through test suite leading to new behavior

Non-Exhaustiveness



Recovering Exhaustiveness

Orthogonal implementations:

interacting with old features
does not influence new features' behavior

Theorem: Spinal test suites are exhaustive for orthogonal implementations

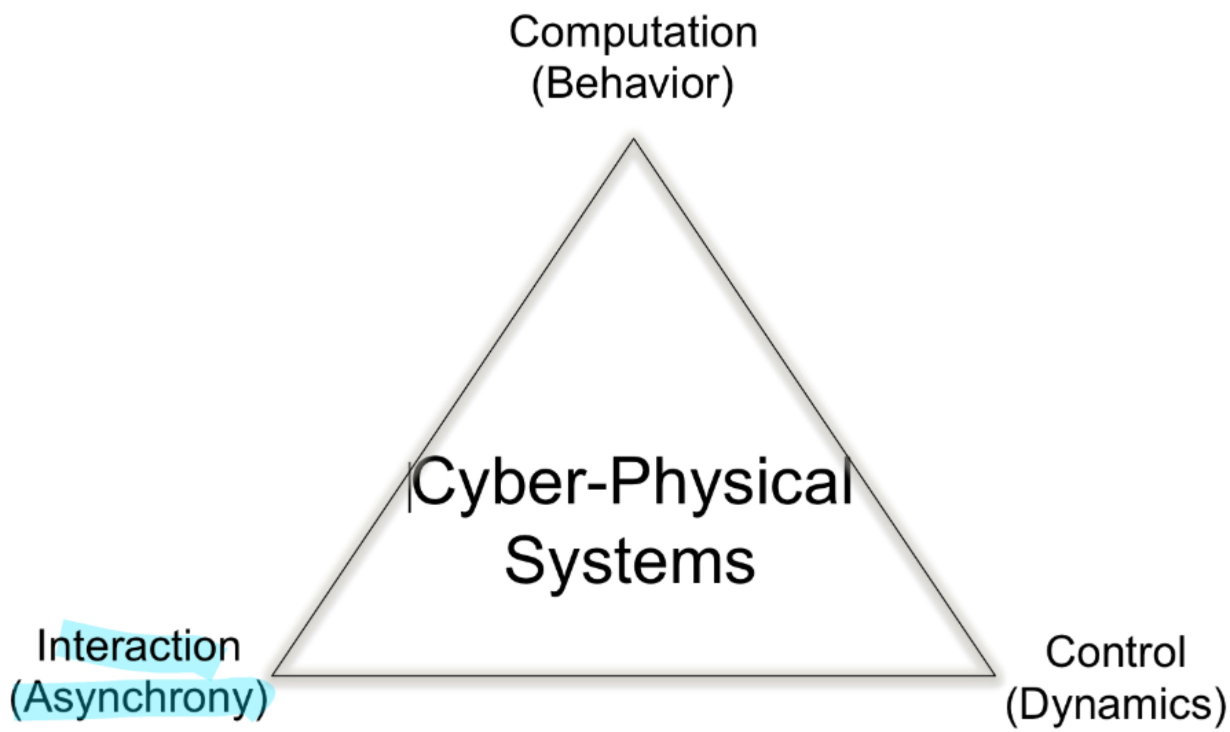
[Beohar and MRM. MBT'14]

Work in Progress

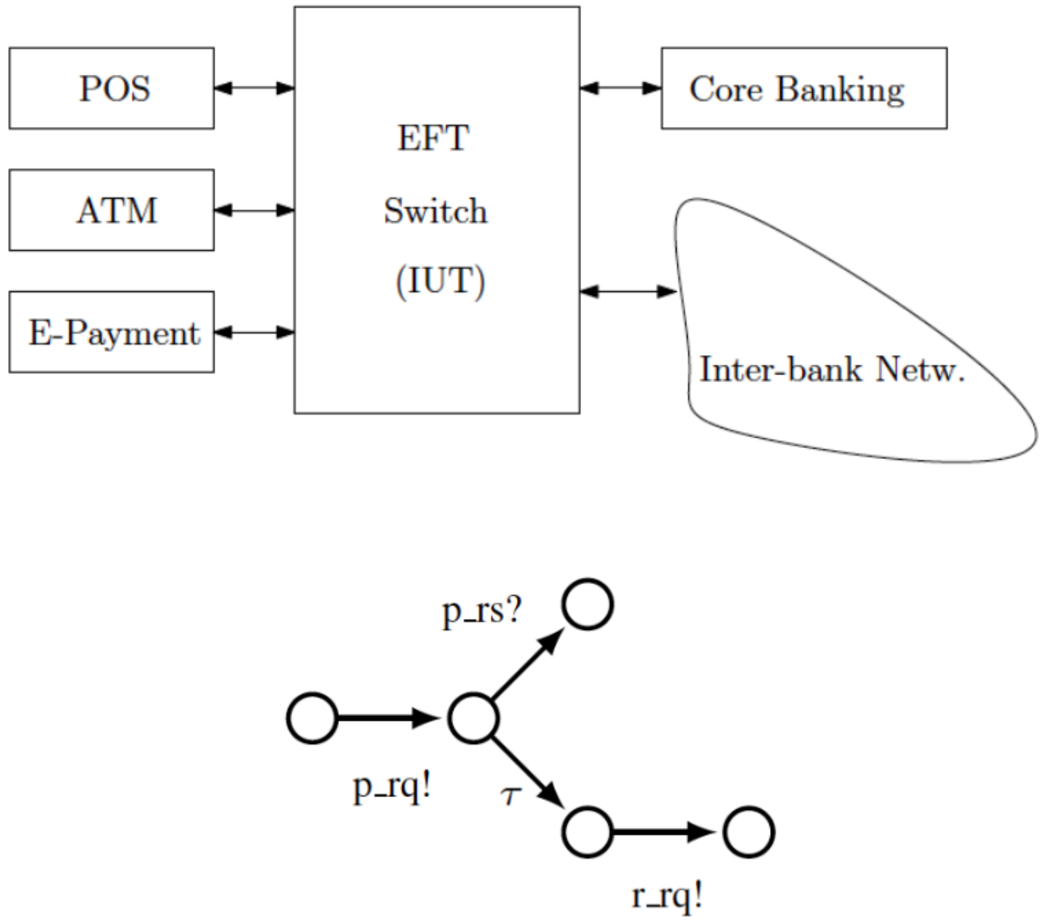
Using differential program verification to establish orthogonality

[Logozzo, Lahiri, Fahndrich, and Blackshear. PLDI'14]

Cyber-Physical Systems: System Dynamics

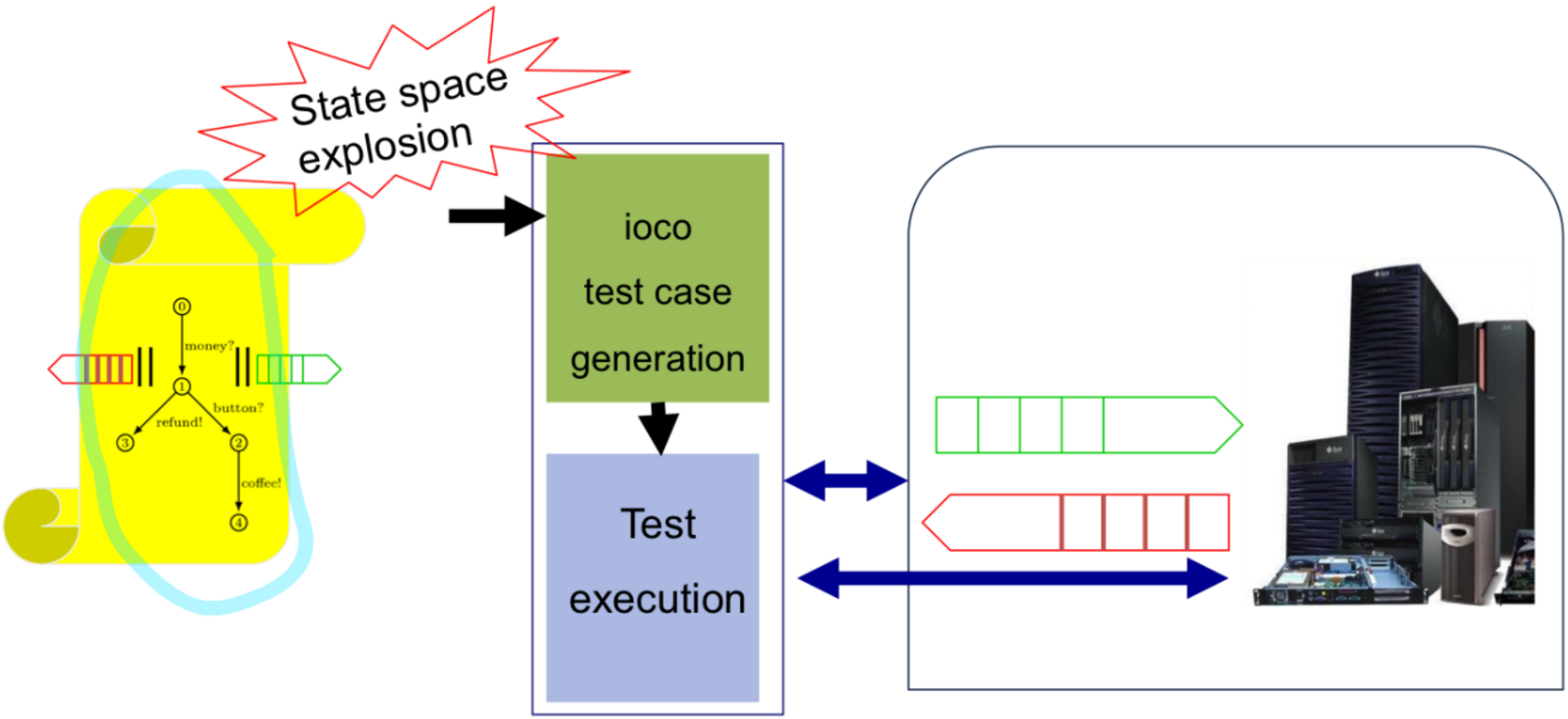


Our Encounter with Asynchrony



[Asadi, Khosravi, MRM, Noroozi. FSEN'11]

Test-Case Generation

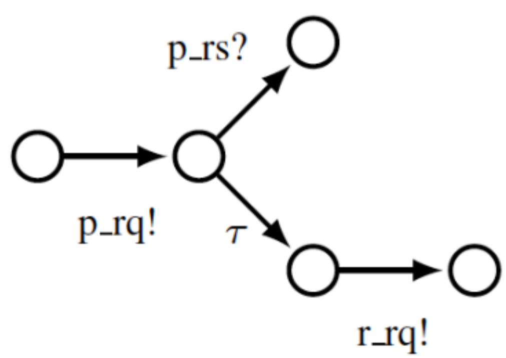


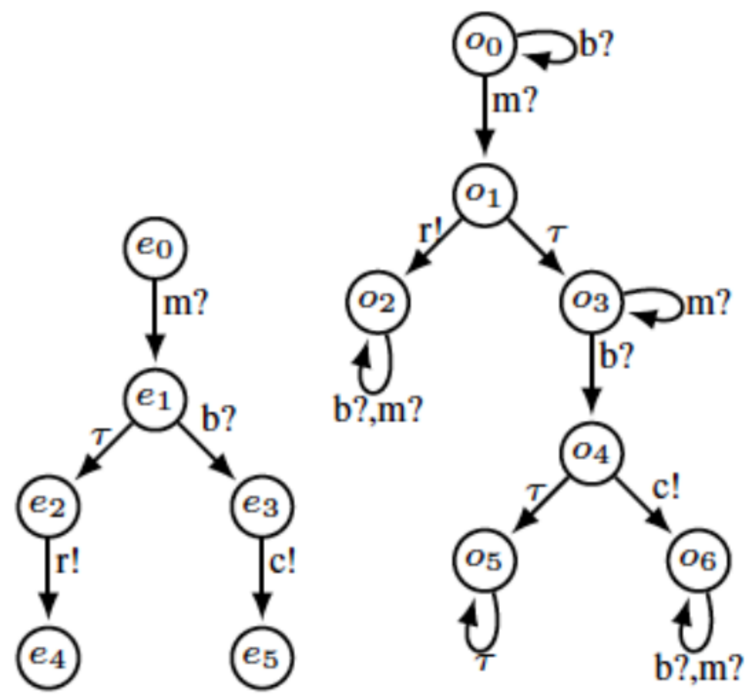
[Tretmans and Verhaard. PSTV'92]

Internal Choice IO(L)TS

IOLTS$^{\sqcap}$: Inputs are only enabled when no output action is weakly enabled

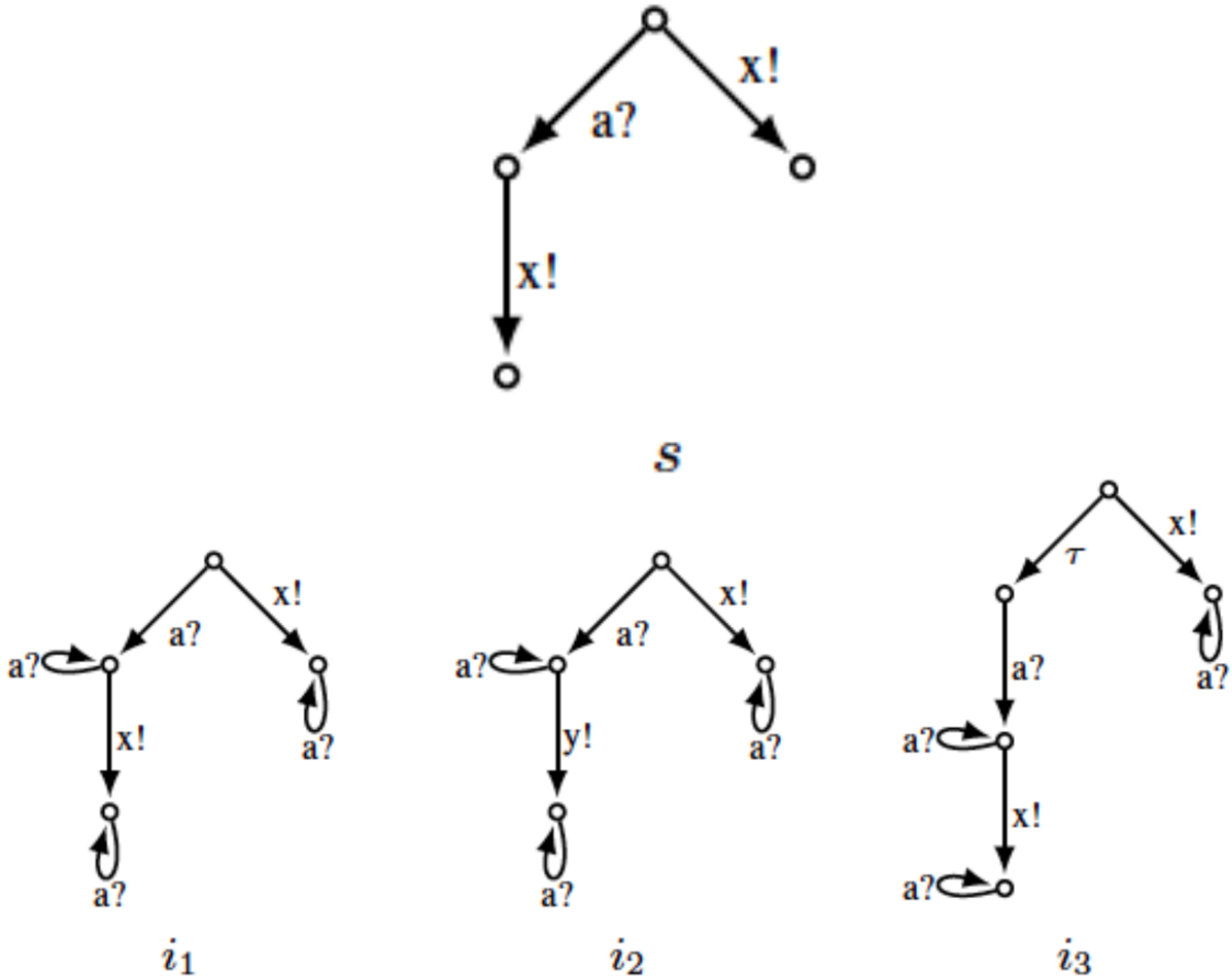
IOTS$^{\sqcap}$: Input-enabled **IOLTS**$^{\sqcap}$





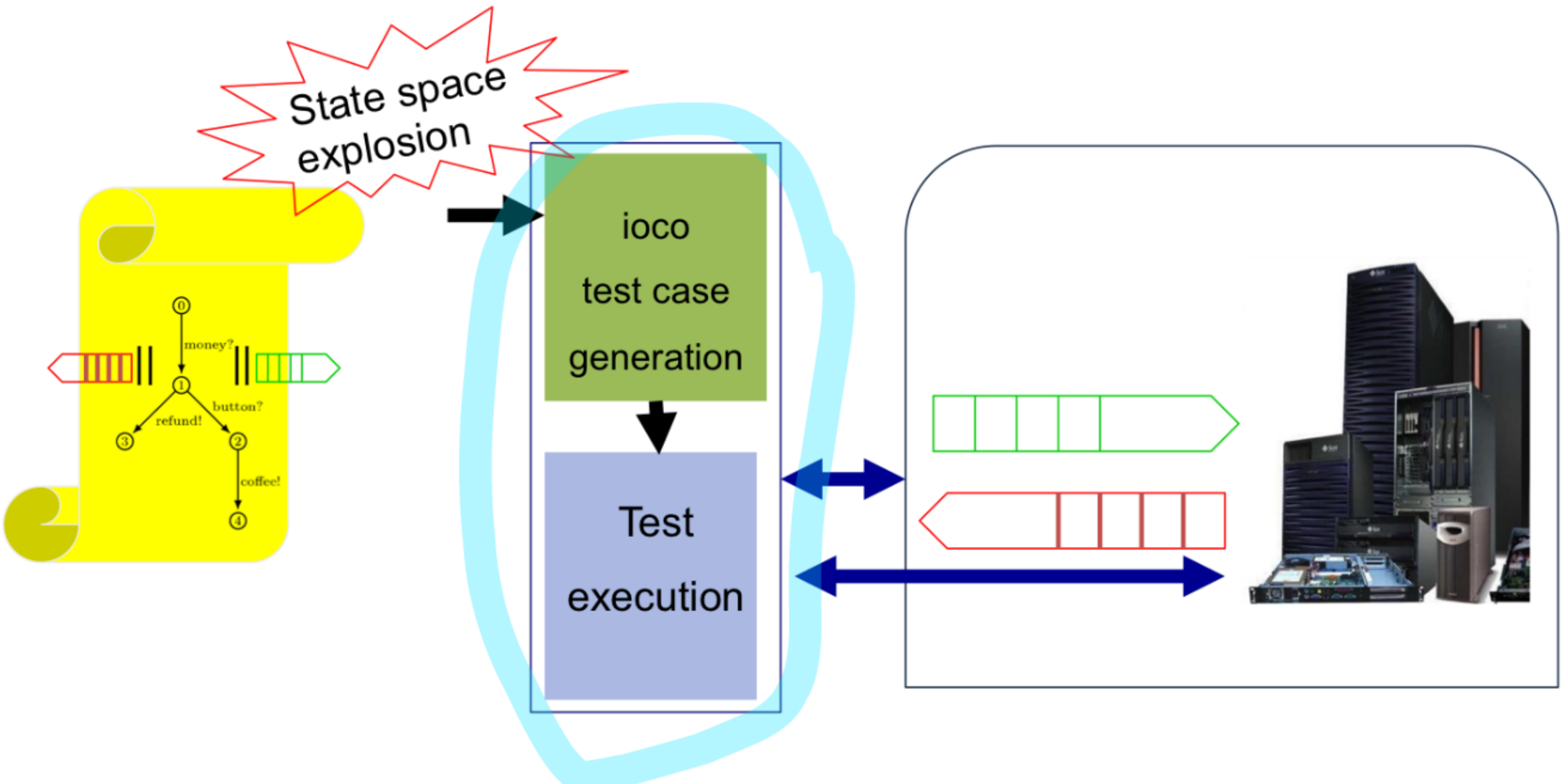
[Weiglhofer and Wotawa. COMPSAC'09]

Testing Power



[Noroozi, Khosravi, MRM, Willemse. SoSym'15]

Test-Case Generation



Test Case Generation

Challenge: selecting test cases that lead to sound verdicts in queue context

Internal choice test cases: observe quiescence before feeding input

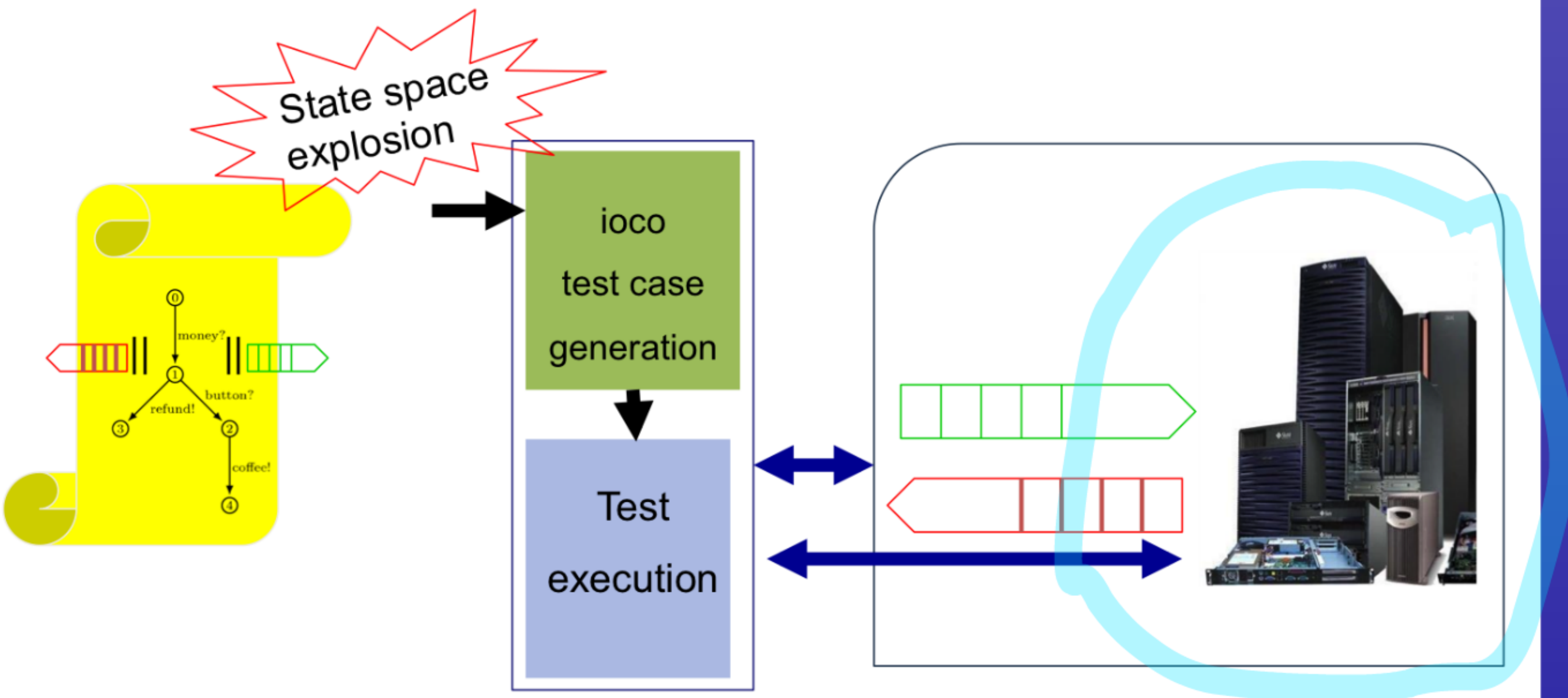
Theorem:

for a non-divergent spec s, internal choice imp. i,
for each internal choice test case t of s,

i passes t if and only if Q(i) passes t

[Noroozi, Khosravi, MRM, Willemse. SoSym'15]

Test-Case Generation



Testable Implementations

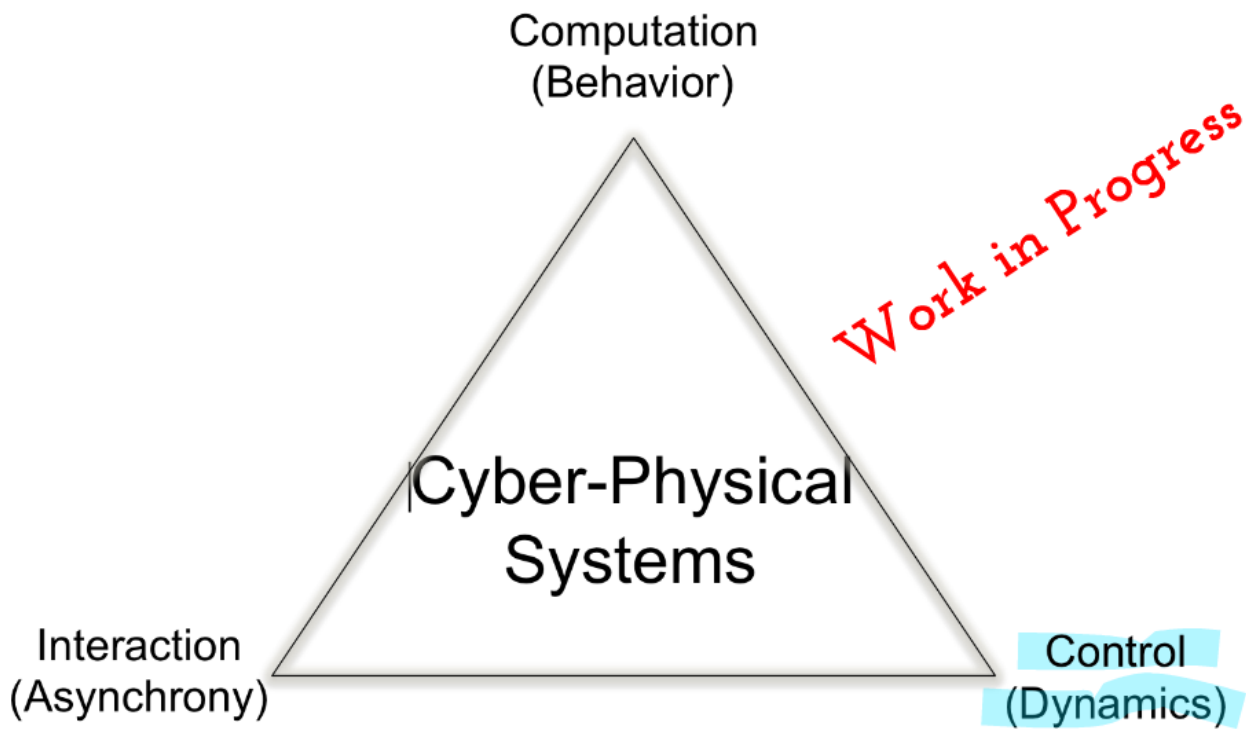
Delay right-closed implementations:
if t.x!.a? in straces(i) then t.a?.x! in straces(i)

Theorem:
If implementation i is delay right-closed,
then i ioco s if and only if Q(i) ioco s

If for all test cases t, i passes t iff Q(i) passes t
then i is delay right-closed.

[Noroozi, Khosravi, MRM, Willemse. SoSym'15]

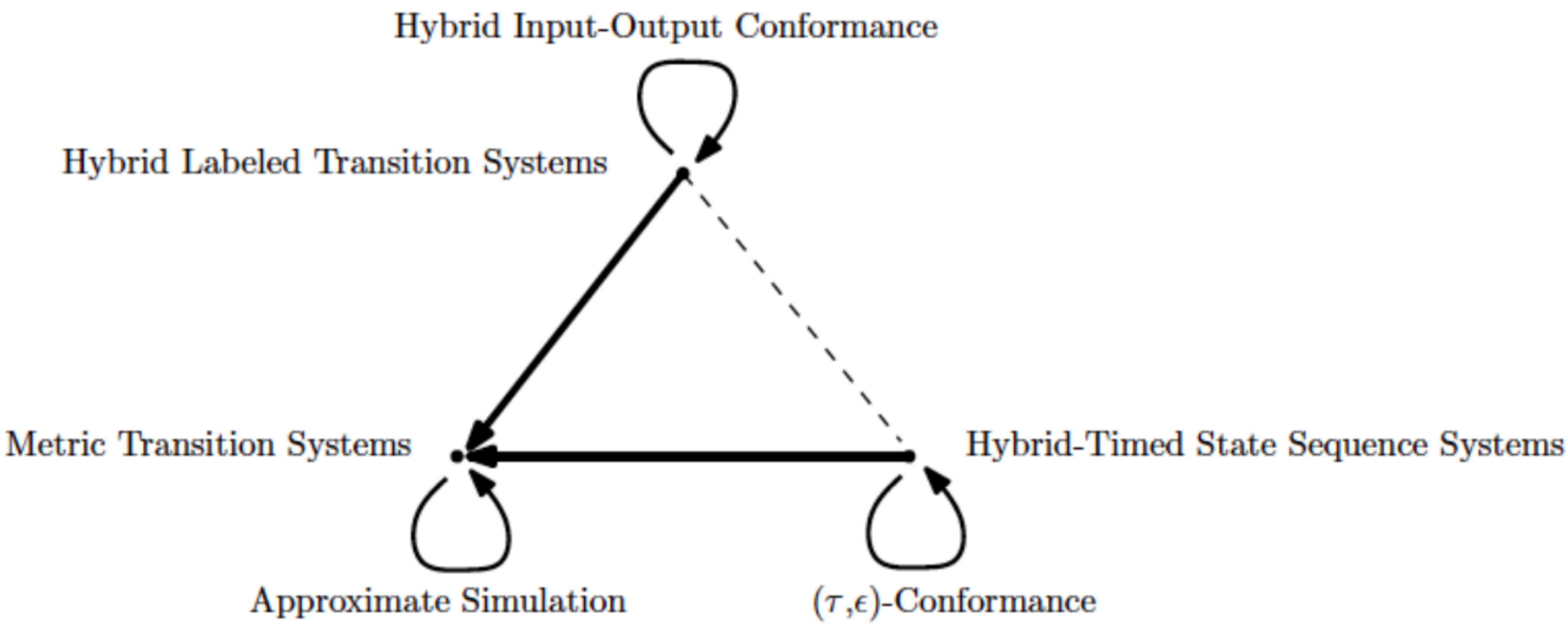
Cyber-Physical Systems: System Dynamics



Semantics Models

- Hybrid Labeled Transition System:
  - LTS with continuous trajectory labels
- Metric Transition Systems:
  - LTS with observation functions on states and metrics on states and transition
- Timed State Sequences:
  - Mappings of initial conditions and discretized inputs to discretized outputs

Models and Conformance



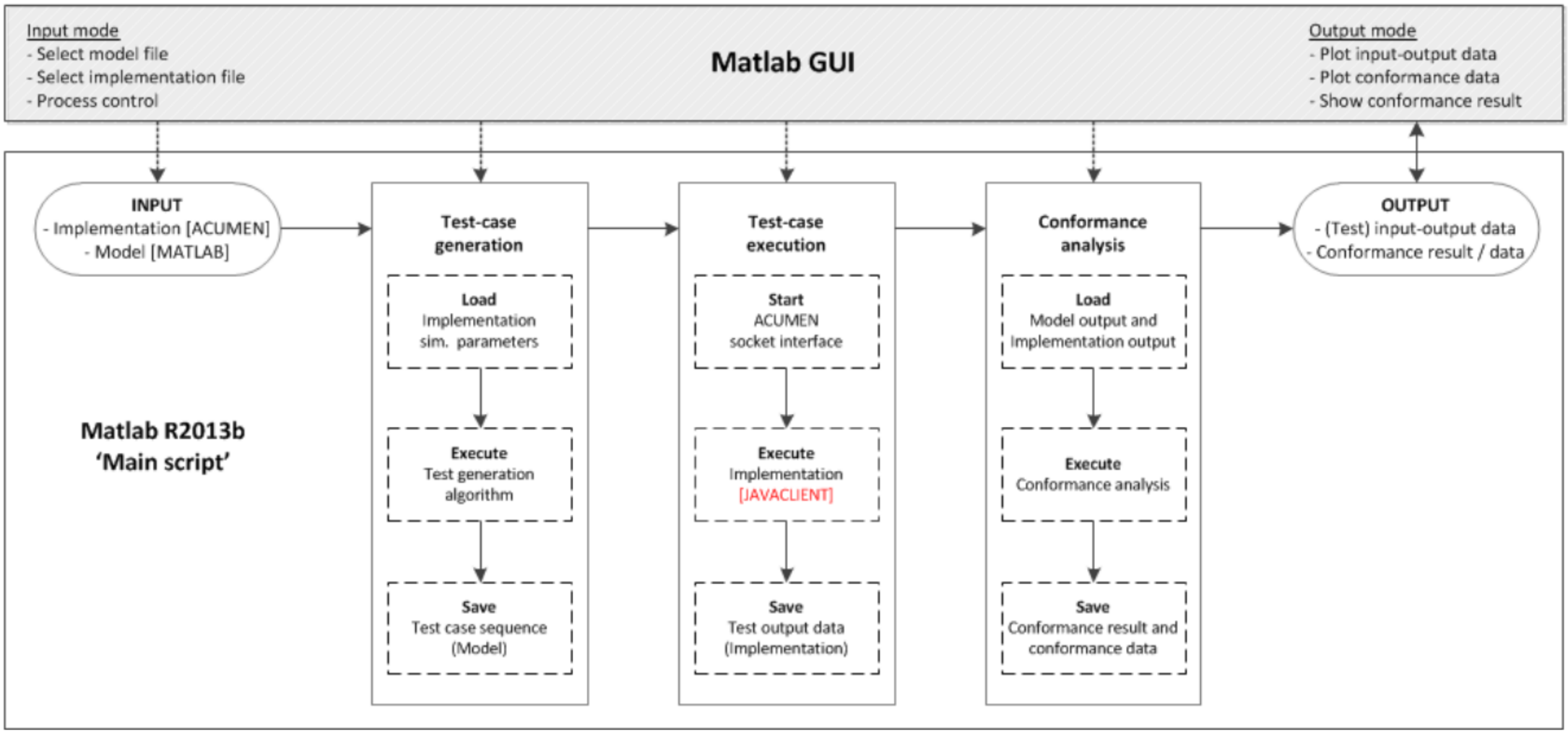
[Khakpour and MRM. CONCUR'15]
[Mohaqeqi, MRM, and Taha. AVoCS'14]

Our Wish List

A pre-congruence for a hybrid model with:

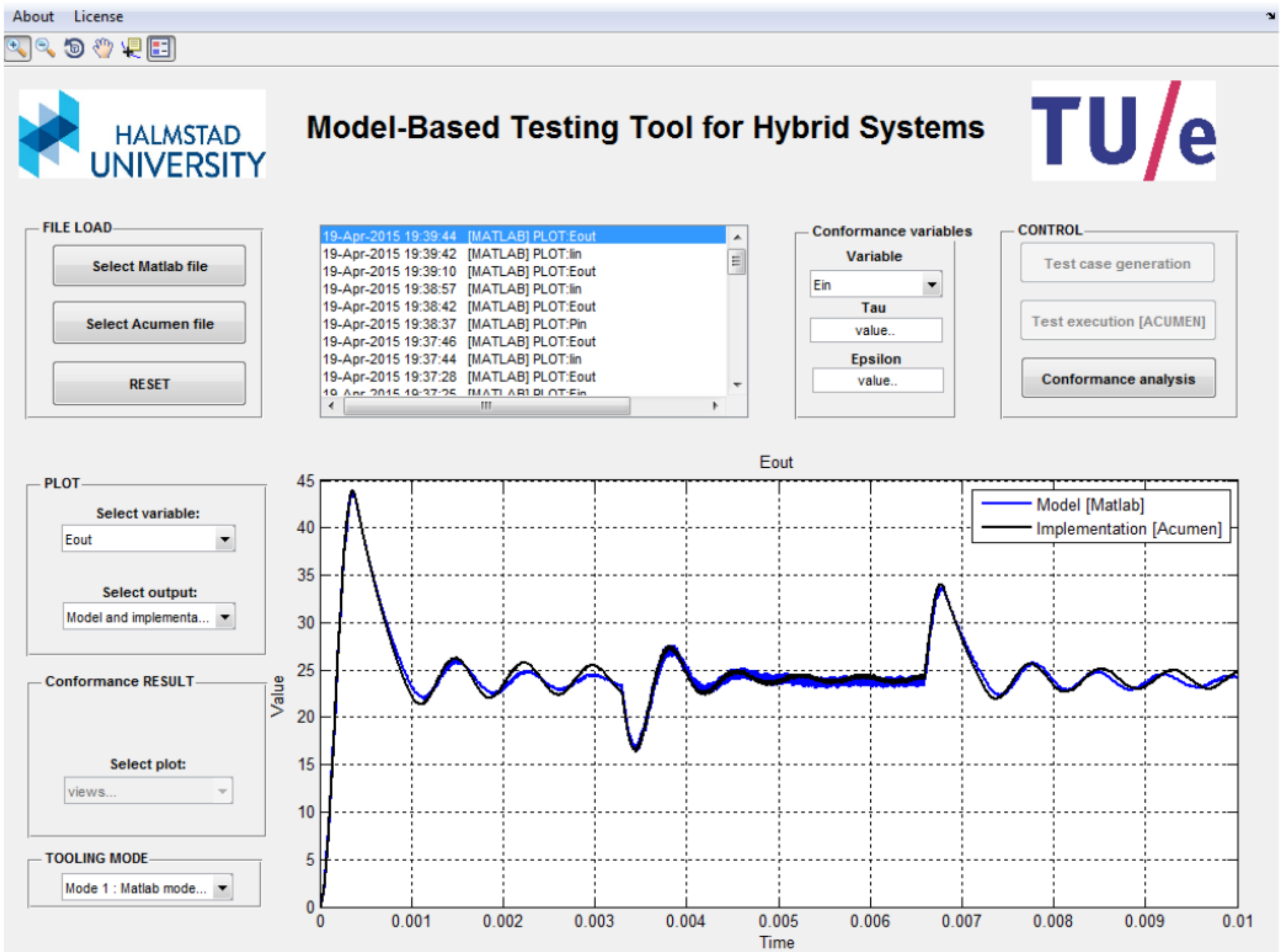
- Partial and non-deterministic specifications,
- Explicit input and output discrete actions and continuous signals,
- Sampling of continuous input and output, and
- A notion of proximity for comparing sampled outputs.

Tool



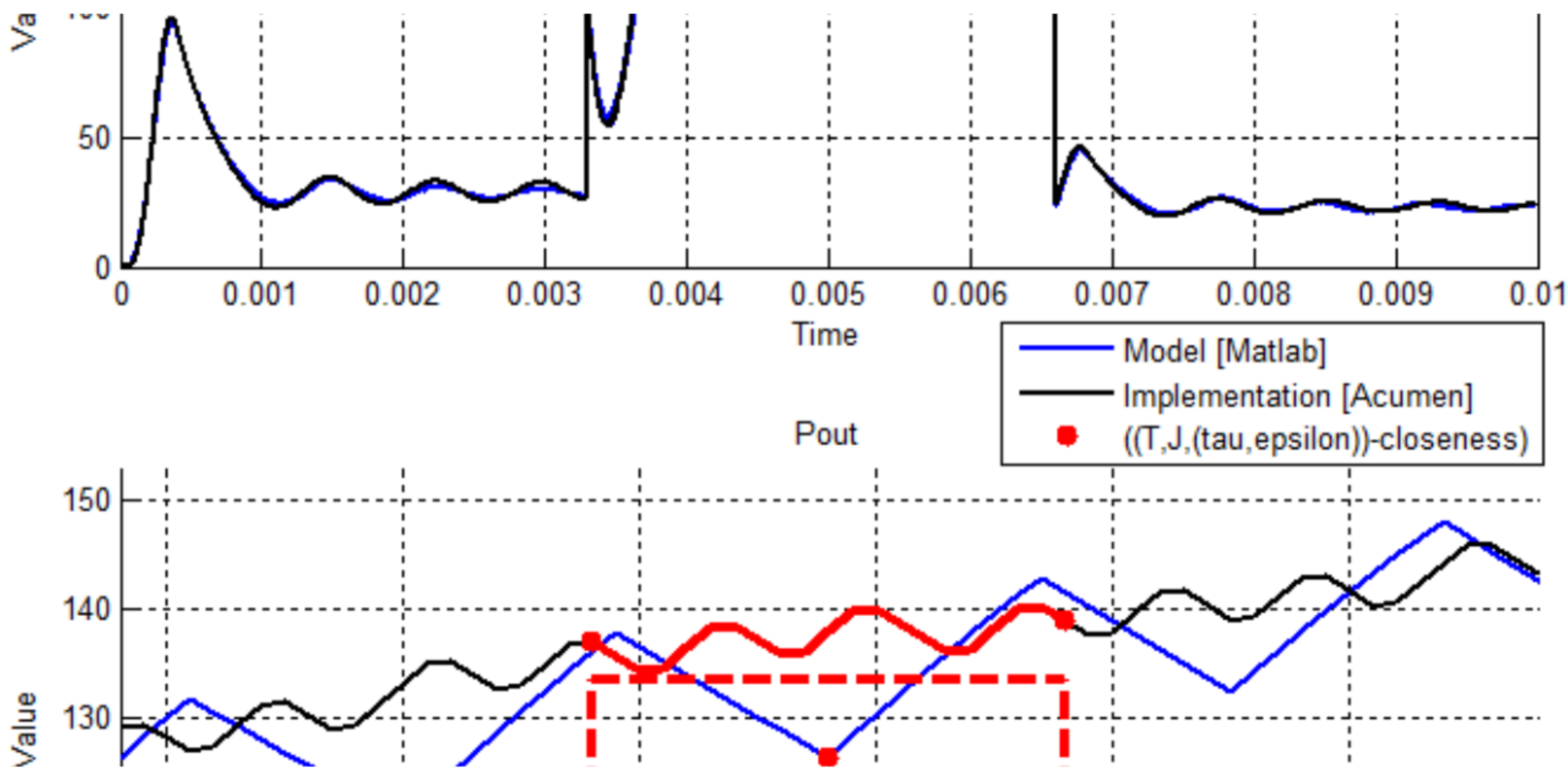
Input mode
- Select model file
- Select implementation file
- Process control
Matlab GUI
Output mode
- Plot input-output data
- Plot conformance data
- Show conformance result
INPUT
- Implementation [ACUMEN]
- Model [MATLAB]
Test-case generation
Load
Implementation sim. parameters
Execute
Test generation algorithm
Save
Test case sequence (Model)
Test-case execution
Start
ACUMEN socket interface
Execute
Implementation
[JAVACLIENT]
Save
Test output data (Implementation)
Conformance analysis
Load
Model output and Implementation output
Execute
Conformance analysis
Save
Conformance result and conformance data
OUTPUT
- (Test) input-output data
- Conformance result / data
Matlab R2013b
'Main script'

Tool



[Aerts, MRM, and Reniers. ICTAC'15]

Tool



Va
50
0
0
0.001
0.002
0.003
0.004
0.005
0.006
0.007
0.008
0.009
0.01
Time
Model [Matlab]
Implementation [Acumen]
((T,J,(tau,epsilon))-closeness)
Pout
150
140
130
Value

Ongoing Research, Open Issues

Theoretical Challenges

- Compositionality and decompositional testing
  see, e.g., [Benes et al. CBSE'15]
  [Noroozi et al. MBT'13]
- Logical characterizations
- Zeno behavior (quiescence, agility)
- Robustness
- Coverage

Practical Challenges

- Configuration selection
- Feature interaction
- Sampling
- Real-time synchronization between tester and implementation
- Rigorous models and simulations

Other Ongoing Projects

- MBT4SPL: Delta-Oriented Testing
  see [ICFEM '15]
- AUTO-CAAS: Diagnosis of AUTOSAR-based software
  see [WASA'15]
- EFFEMBAC: Combining Model-Based- and Concolic Testing

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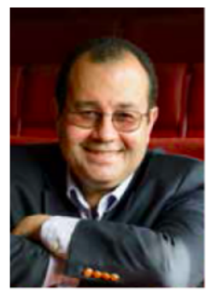

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Thank You!

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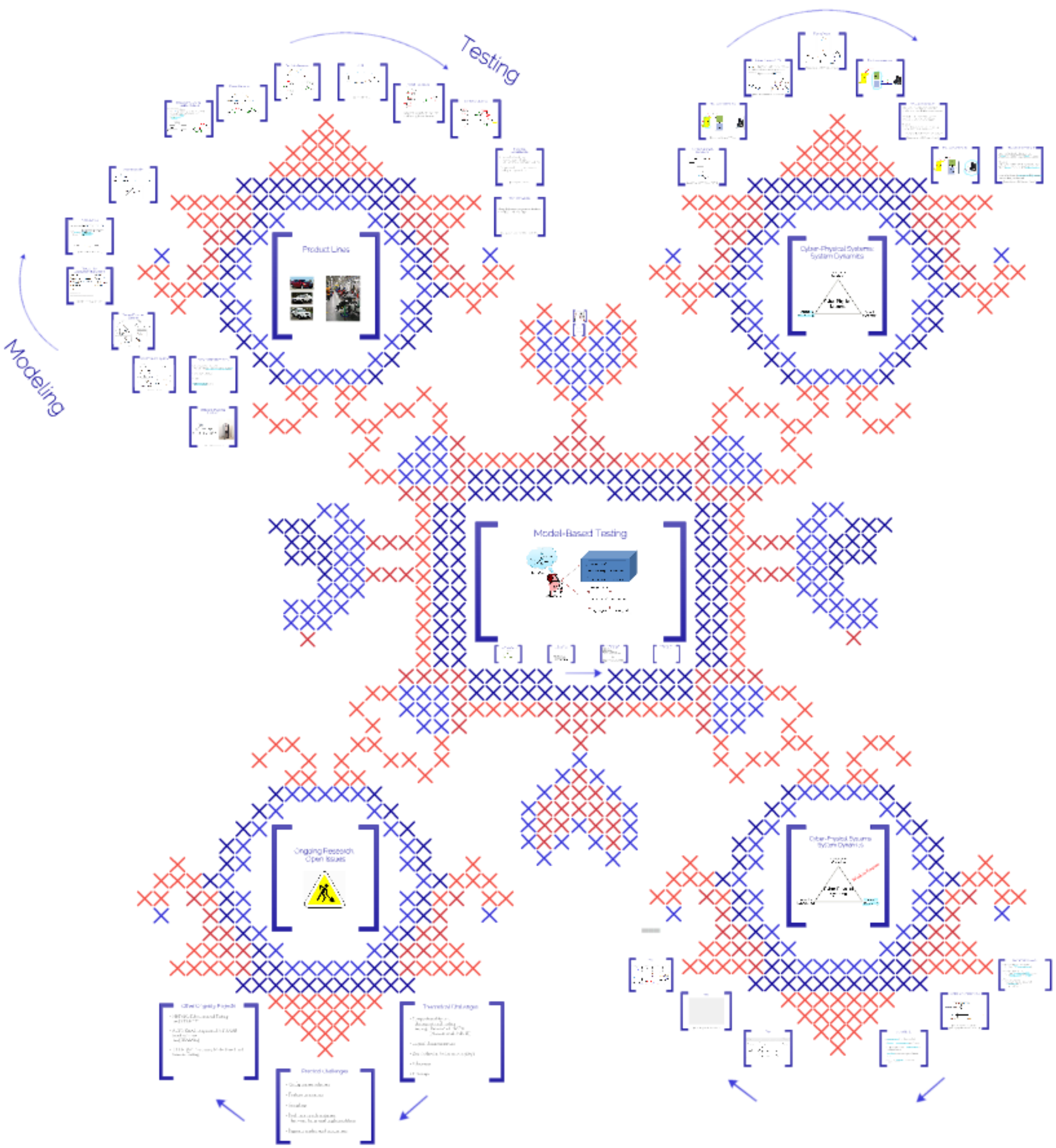

From Concurrency Theory to Model-Based Testing Cyber-Physical Systems

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