Model-Based Conformance Testing of Software Product Lines

23rd CREST Open Workshop

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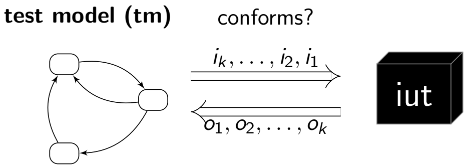
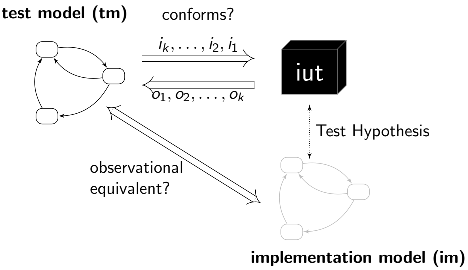
Model-Based Testing [UL07]



- Black-box assumption for implementation under test (iut)
- Automated derivation and application of test cases from a behavioral specification (test model)

Model-Based Conformance Testing [Tre99]



- Test Hypothesis for test result confidence and reproducibility [Ber91]
- Partial verification of the observable behavioral conformance [NH84]

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Implementation relation – equivalent behaviors:

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Parameterized implementation relation – finite set of behaviors:

$$\textbf{im} \sqsubseteq_{te}^{TC} \textbf{tm}$$

Labeled Transition Systems (LTS)

- Labeled State-Transition Graph $(Proc, Act, \rightarrow)$
- LTS trace semantics $tr = (a_1, a_2, \ldots, a_n) \in Tr(s_0, lts) \subseteq Act^*$, iff

$$s_0 \xrightarrow{a_1} s_1 \xrightarrow{a_2} s_2 \cdots \xrightarrow{a_n} s_n = s_0 \xrightarrow{tr} s_n$$

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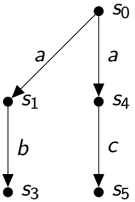

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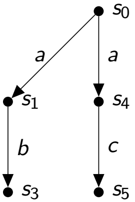

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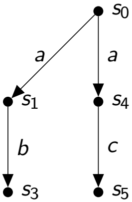

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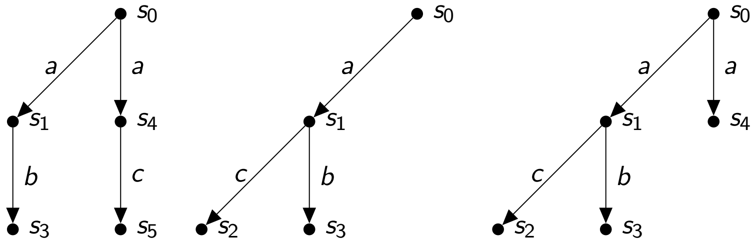
- Parameterized Testing Preorder Relation:

$$im \sqsubseteq_T^{TC} tm \ :\Leftrightarrow \ (Tr(s_0, im) \cap TC) \subseteq (Tr(s_0, tm) \cap TC)$$

where $TC \subseteq Tr(s_0, im)$

Example



(e) lts_1 (f) lts_2 (g) lts_3

- $lts_1 \equiv_T lts_2 \equiv_T lts_3$

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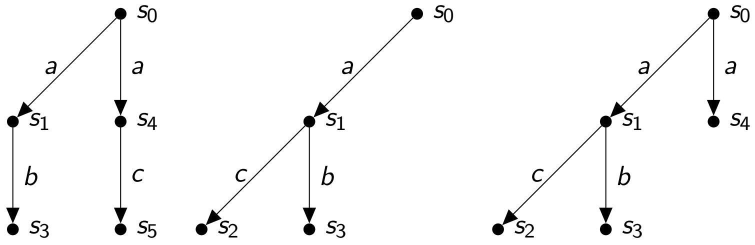

(h) lts_1 (i) lts_2 (j) lts_3

- $lts_1 \equiv_T lts_2 \equiv_T lts_3$
- **But:** different behaviors after composition with environment emitting input action a.

Decorated Trace Semantics

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- Stricter notions of behavioral equivalence discriminate different decision structures within the state-transition graphs [Abr87]

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Example: Failures and Readies

- A pair (tr, X) with $tr \in Act^*$ and $X \subseteq Act$ is a *failure* of state s_0 if $s_0 \xrightarrow{tr} s_n$ for some state s_n and $initials(s_n) \cap X = \emptyset$.

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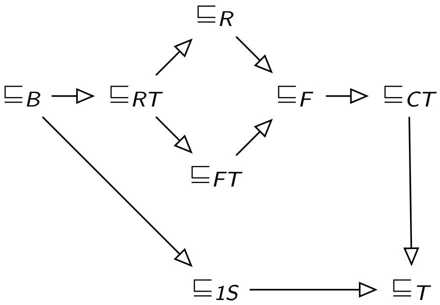
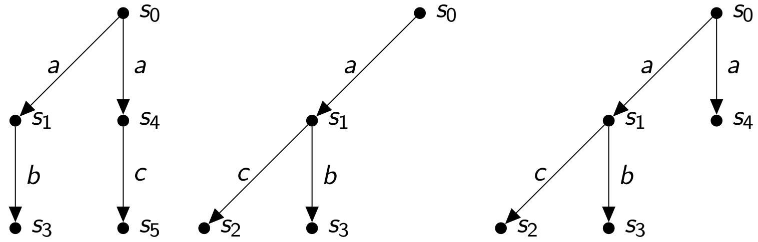
- A pair (tr, X) with $tr \in Act^*$ and $X \subseteq Act$ is a *ready* of state s_0 if $s_0 \xrightarrow{tr} s_n$ for some state s_n and $initials(s_n) = X$.

Preorder Relation Inclusion Hierarchy [BFvG04]



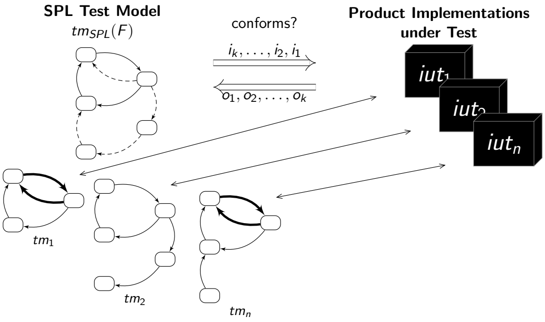
Example – Revisited



(k) lts_1 (l) lts_2 (m) lts_3

- lts_3 has completed trace a
- $lts_2 \sqsubseteq_F lts_1$
- lts_2 and lts_1 are incomparable under $\sqsubseteq_R$

Model-Based SPL Testing



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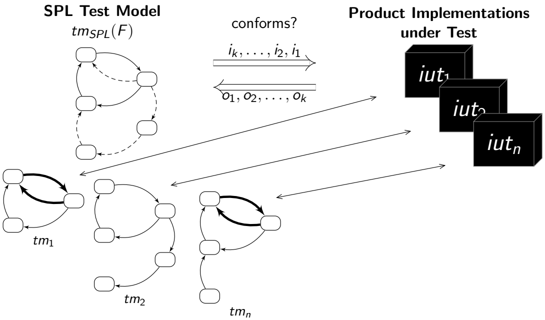

- Reusable generic test model specification parameterized over features F
- Reuse of test cases $TC' \subseteq TC$ of product *iut* for product *iut'* if

$$tm \sqsubseteq_{te}^{TC'} tm'$$

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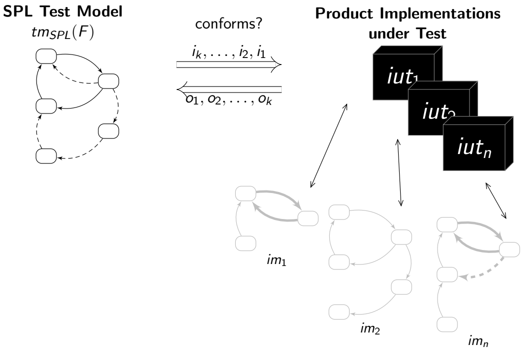

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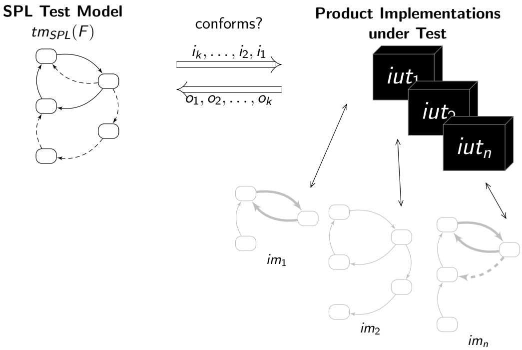

- Extending the Test Hypothesis to SPLs under test
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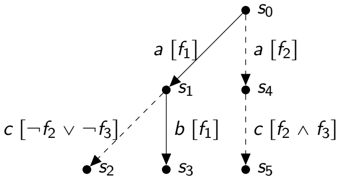
$$im \sqsubseteq_{te}^{TC''} im'$$

Feature-Annotated LTS [CHSL11]



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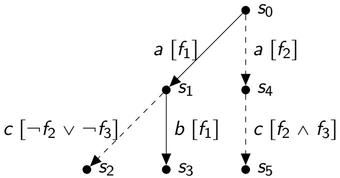
- LTS with transition annotations $\sigma(s, a, s') \in \mathbb{B}(F)$



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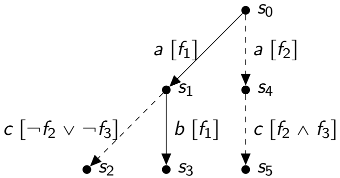

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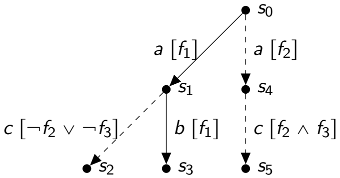

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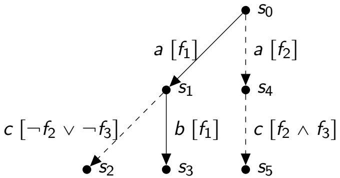

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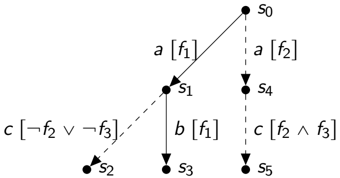

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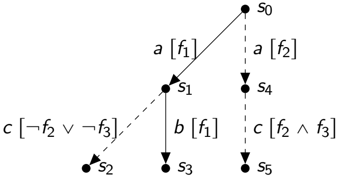
- Product space $PC_{fm} = \{\Gamma : F \to \mathbb{B} \mid \Gamma \models fm\}$
- Feature model refinement $fm' \sqsubseteq_{fm} fm$ is product space refinement

Transition Modalities [LT88]



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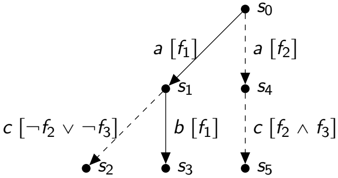

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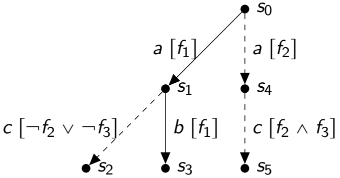

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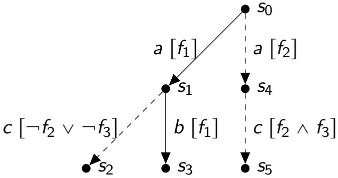

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- *prohibited*-transitions $\nrightarrow \subseteq Proc \times Act \times Proc$, where
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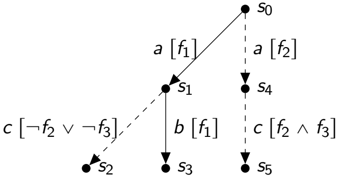

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- $\longrightarrow_{must} \subseteq \longrightarrow_{may}$
- $\nrightarrow \cap \longrightarrow_{may} = \emptyset$

F-LTS Refinement

From $fm' \sqsubseteq_{FM} fm$ it follows that $lts_{\Gamma'} \sqsubseteq_T lts_{\Gamma}$

- $\longrightarrow'_{may} \subseteq \longrightarrow_{may}$
- $\longrightarrow_{must} \subseteq \longrightarrow'_{must}$
- $\not\twoheadrightarrow \subseteq \not\twoheadrightarrow'$

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But: this does not hold for decorated trace semantics

- Set of failures increases under refinement
- Set of readies is not subset closed

$\Rightarrow$ May-transitions may become failures as well as readies after refinement

Decorated May-Trace Semantics

- A pair (tr, X) with $s_0 \xrightarrow{tr} s$ and $X \subseteq Act$ is a *may-failure* of state s_0 if for each $a \in Act$ with $s \xrightarrow{a}_{must} s'$ it holds that $a \notin X$

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From $fm' \sqsubseteq_{FM} fm$ it follows that $lts_{\Gamma'} \sqsubseteq_{te\text{-}may} lts_{\Gamma}$ holds.

- **But:** full product configurations are incomparable under $\sqsubseteq_{te\text{-}may}$

Must-Trace Semantics

- A pair (tr, X) with $s_0 \xrightarrow{tr} s$, where $s_i \xrightarrow{a}_{must} s_{i+1}$, for $0 \leqslant i < n$, and $X \subseteq Act$ is a *must*-failure of state s_0 if for each $a \in Act$ with $s \xrightarrow{a}_{may} s'$ it holds that $a \notin X$
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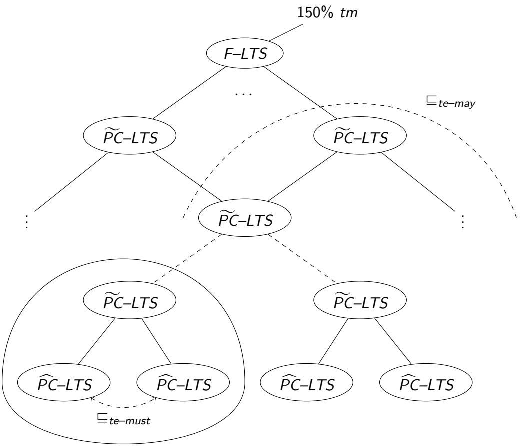
$\Rightarrow$ From $fm' \sqsubseteq_{FM} fm$ it follows that $lts_\Gamma \sqsubseteq_{te\text{-}must} lts_{\Gamma'}$ holds.

$\Rightarrow$ From $\Gamma'' = lub(\Gamma, \Gamma')$ and $TC = Tr_{te\text{-}must}(s_0, f\text{-}lts'')$ it follows that $lts_\Gamma \sqsubseteq_{te}^{TC} lts_{\Gamma'}$ holds.

F-LTS Refinement Hierarchy



FM-constraint May-Trace Semantics

- A trace $s_0 \xrightarrow{tr} s_n$ is an *fm-constraint may-trace* if $\bigwedge_{1 \leqslant i \leqslant n} \sigma(s_{i-1}, a_i, s_i) \models fm$ holds
- A may-failure (tr, X) is an *fm-constraint may-failure* if (1) $s_0 \xrightarrow{tr} s_n$ is an *FM-constraint may-trace*, and (2) $\bigwedge_{a \in X} \neg\sigma(s_n, a, s') \models fm$ holds
- A may-ready (tr, X) is an *fm-constraint may-ready* if (1) $s_0 \xrightarrow{tr} s_n$ is an *FM-constraint may-trace*, and (2) $\bigwedge_{a \in X} \sigma(s_n, a, s') \models fm$ holds

Conclusions & Future Work

- Sample implementation for trace preorder semantics [LSKL12, LLSG12]
- Test result reuse via test model slicing [KLB12]

Future Work

- Variability-aware test result reuse criteria
- Feature-Unit testing
- Testing Equivalences with τ-sensitivity $\rightarrow$ **pl-ioco**
- Automated SPL test suite generation

Thanks for Your Attention

Any Questions?

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