Advantages of mutation in passive testing: An empirical study.

Mutation 2009

César Andrés, Mercedes G. Merayo, Carlos Molinero
Universidad Complutense de Madrid

Outline

Formal Testing

- Formal testing techniques are used to check the **`correct behaviour`** of systems.

`What do they do?`
`Functional Behavior`

`How do they do?`
`Non-Functional Properties`

- In real-time systems the `temporal behavior` is considered `critical`.

Formal Testing

Active Testing

Testers are allowed to interact directly with the system.

Passive Testing

Testers analyze traces extracted from the system.

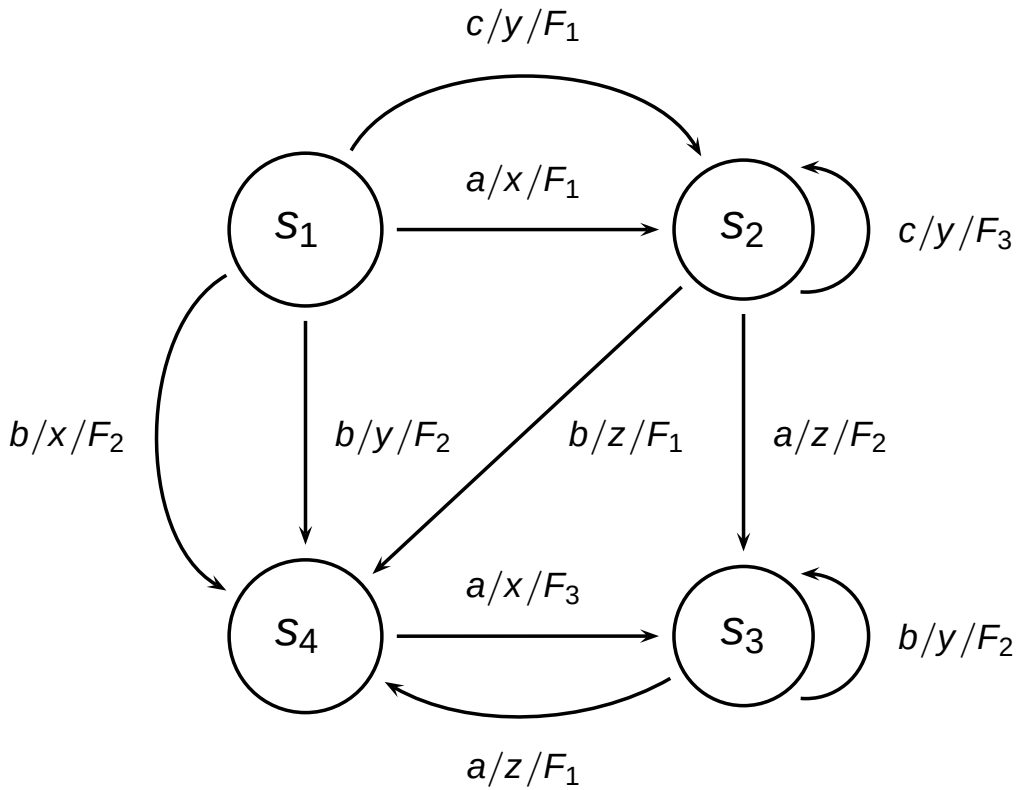
Our approach

- Framework to perform passive testing in systems with temporal restrictions
- Applied on a formal model: Finite State Machines.

Timed Finite State Machines

$$F_2(x) = \begin{cases} 0 & x < 0 \\ \frac{x}{2} & 0 \leq x < 2 \\ 1 & 2 \leq x \end{cases}$$

Uniform distribution in $[0, 2)$



Common conditions

Both specification and implementations:

- Expressed by TFSM.
- Input-enabled.
- Regular stochastic information.
- Observable.

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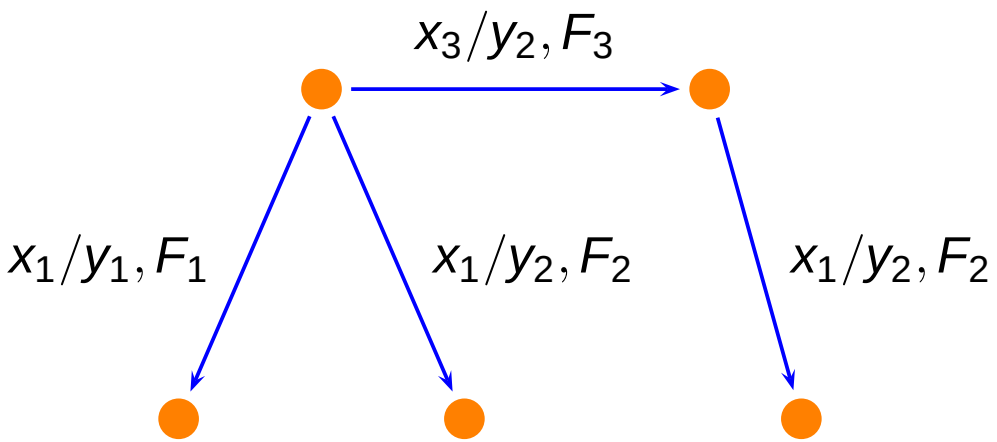
Regular stochastic information



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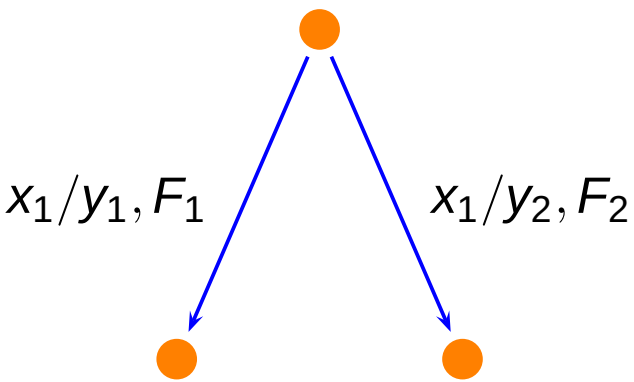
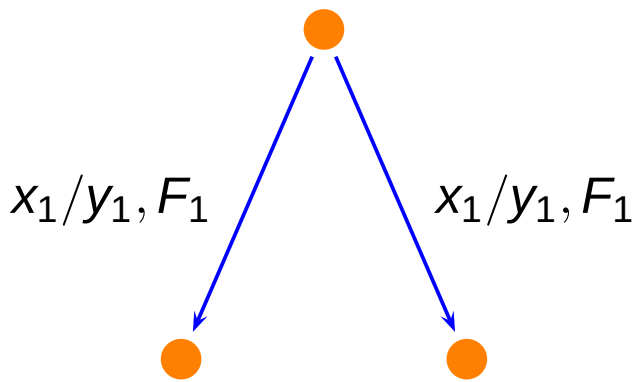
`Observable`



`Non-Observable`



Timed Invariants

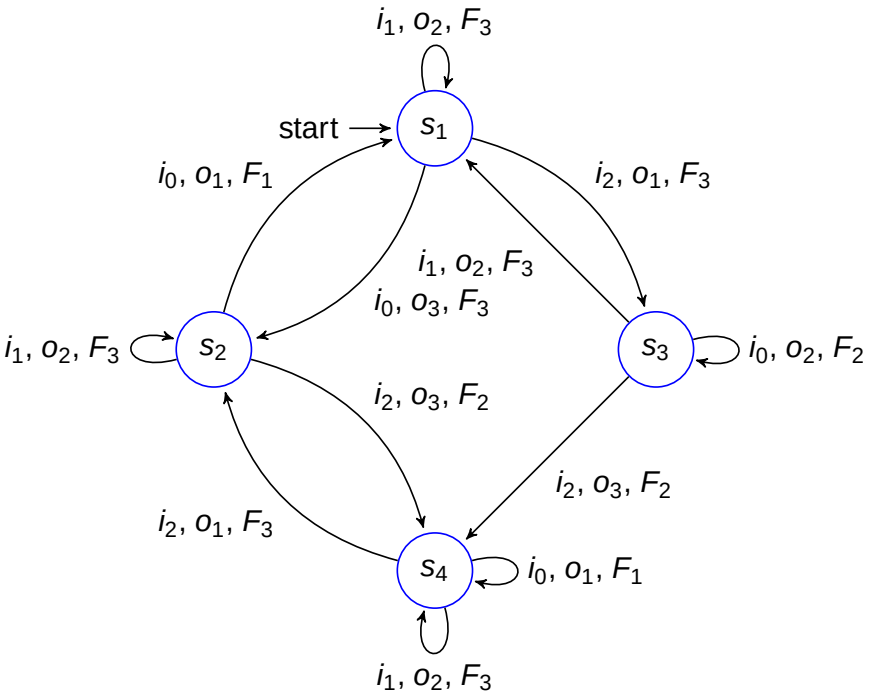
Allow us to express temporal properties that must be fulfilled by the implementation.

- Extracted from the specification.
- Given by the tester from the original requirements.

Correctness

1. Time invariants are correct with respect to the specification.
2. Invariants are satisfied by the traces produced by the implementation.

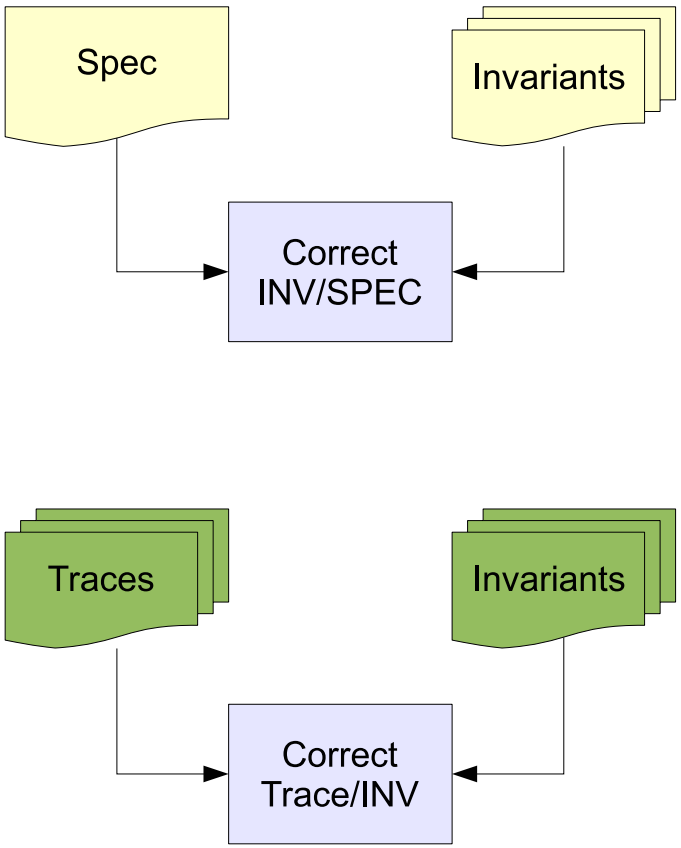
Timed Invariants



$$
\begin{aligned}
\phi_1 &= i_1 \mapsto \{\langle o_2, F_3\rangle\} \\
\phi_2 &= i_2 \mapsto \{\langle o_1, F_3\rangle, \langle o_3, F_2\rangle\} \\
\phi_3 &= i_1/?/F_3, i_1 \mapsto \{\langle o_2, F_3\rangle\} \\
\phi_4 &= i_1/o_2/F_3, i_2/o_3/F_2, *, i_0 \mapsto \{\langle o_1, F_1\rangle\}
\end{aligned}
$$

PASsive TEsting (PASTE)

- Automates our passive testing approach.
- Implements the algorithms defined in our framework.



PASsive TEsting (PASTE)

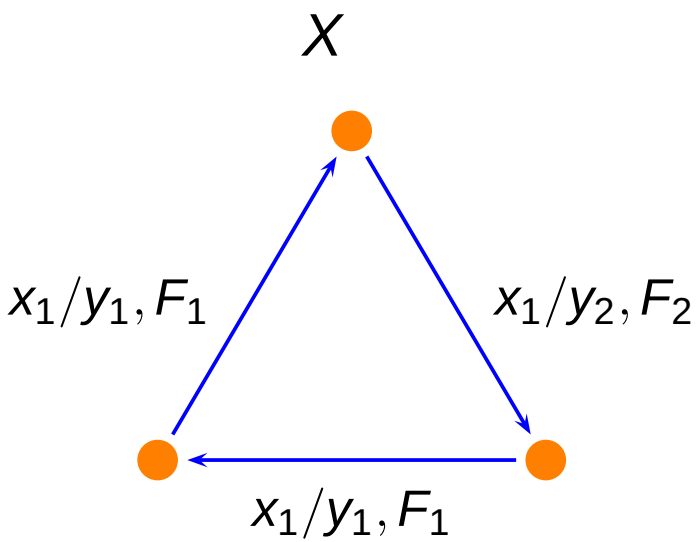
- Some invariants have more power than others for detecting faults.
  - Length of the invariant.
  - Length of the trace.
  - Kind of fault.
- Selection of the *best invariants*.
- Functionality based on mutation techniques.

Mutants Module

Help the tester to select the most efficient invariants to capture the different errors.

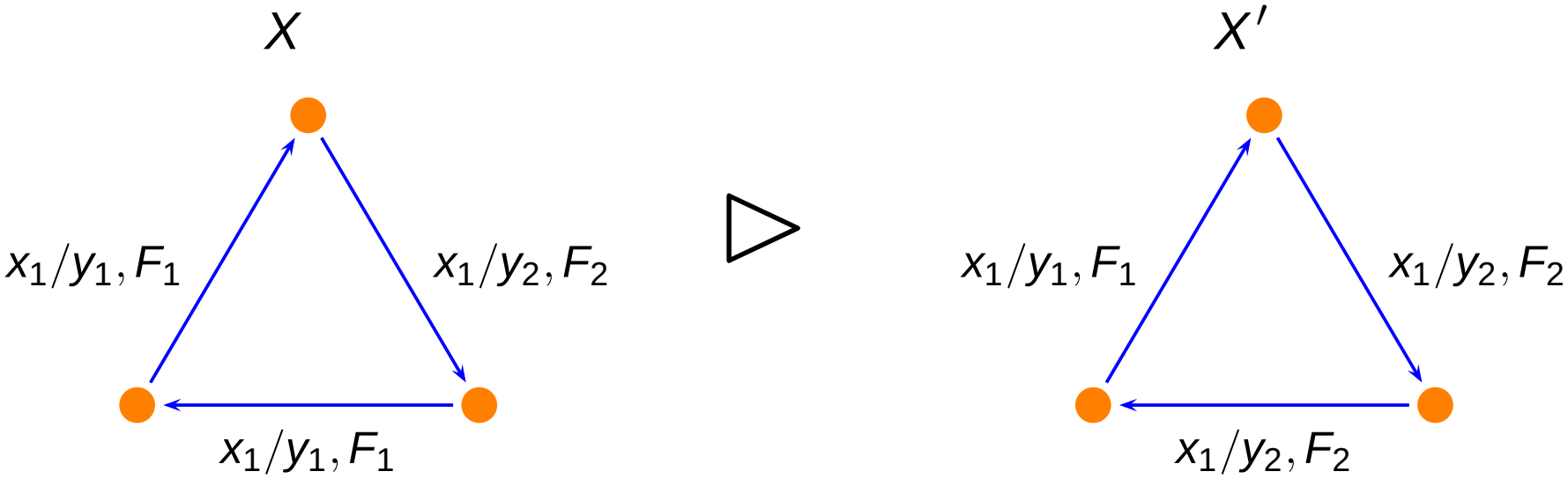
1. Generation of mutants from the specification.
2. Extraction of traces from the produced mutants.
3. Application of invariants to the extracted traces.
4. Analysis of the results for determining the level of effectiveness of the invariants.

Changing an output



- The mutant must be observable.
- The mutant must present regular stochastic information.

Changing an output



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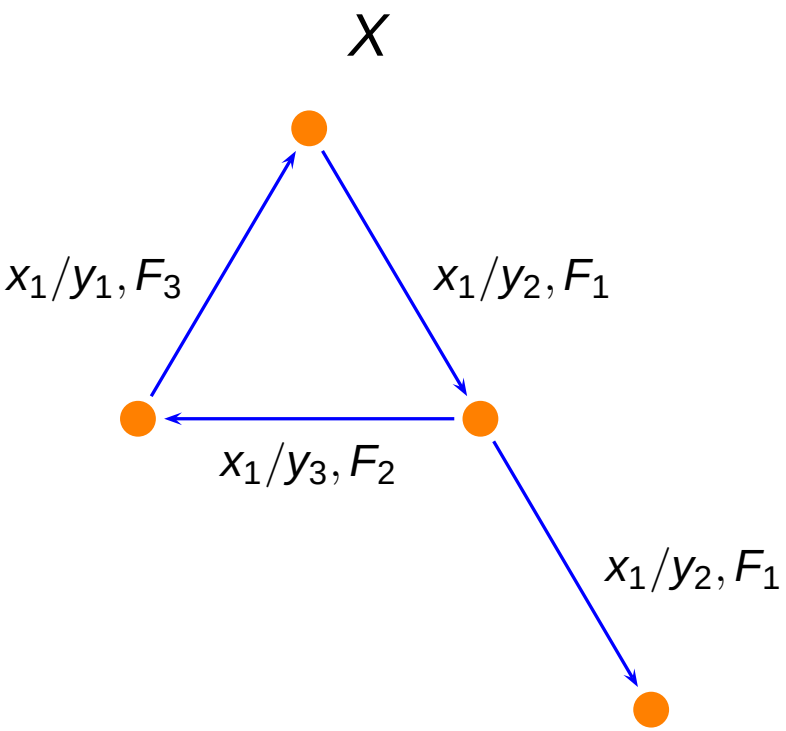
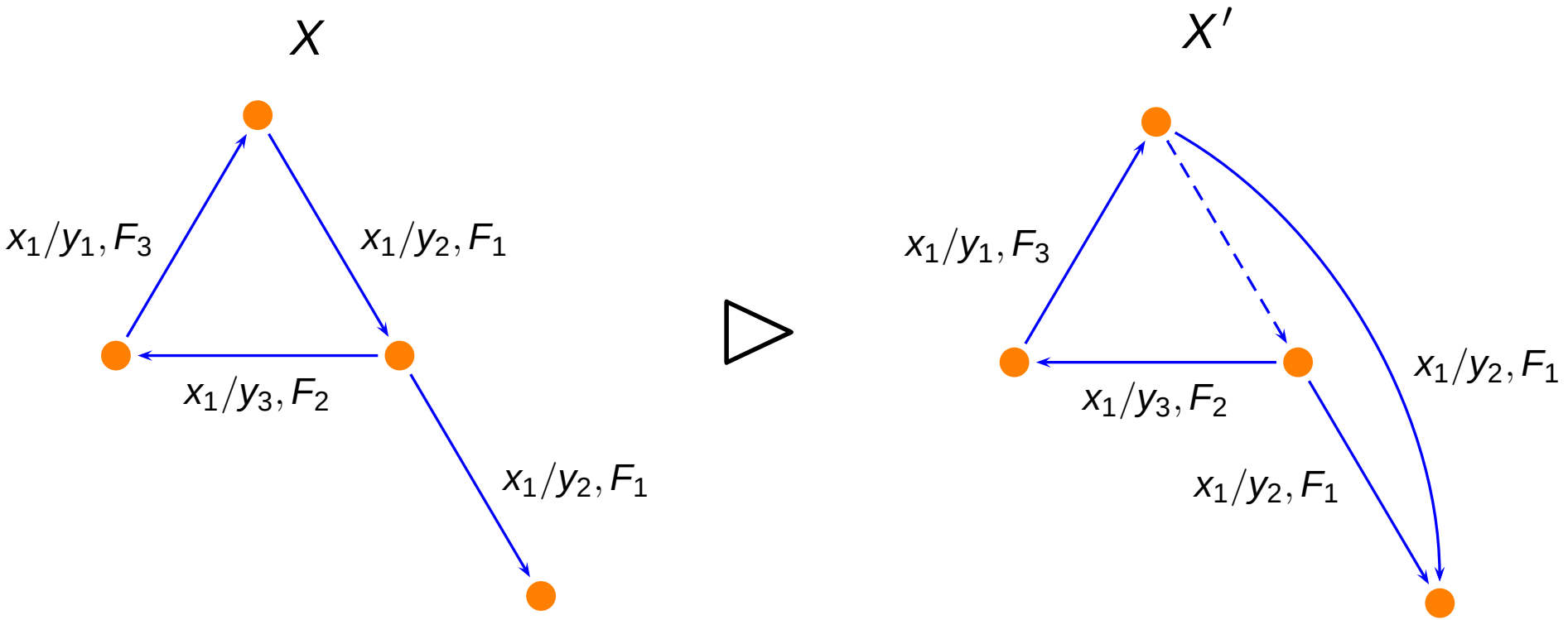
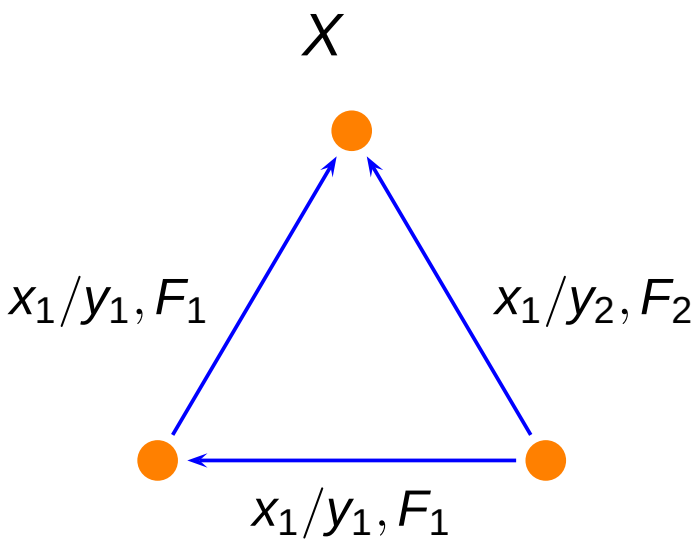
Changing the target state in a transition



Changing the target state in a transition



Altering the distribution function



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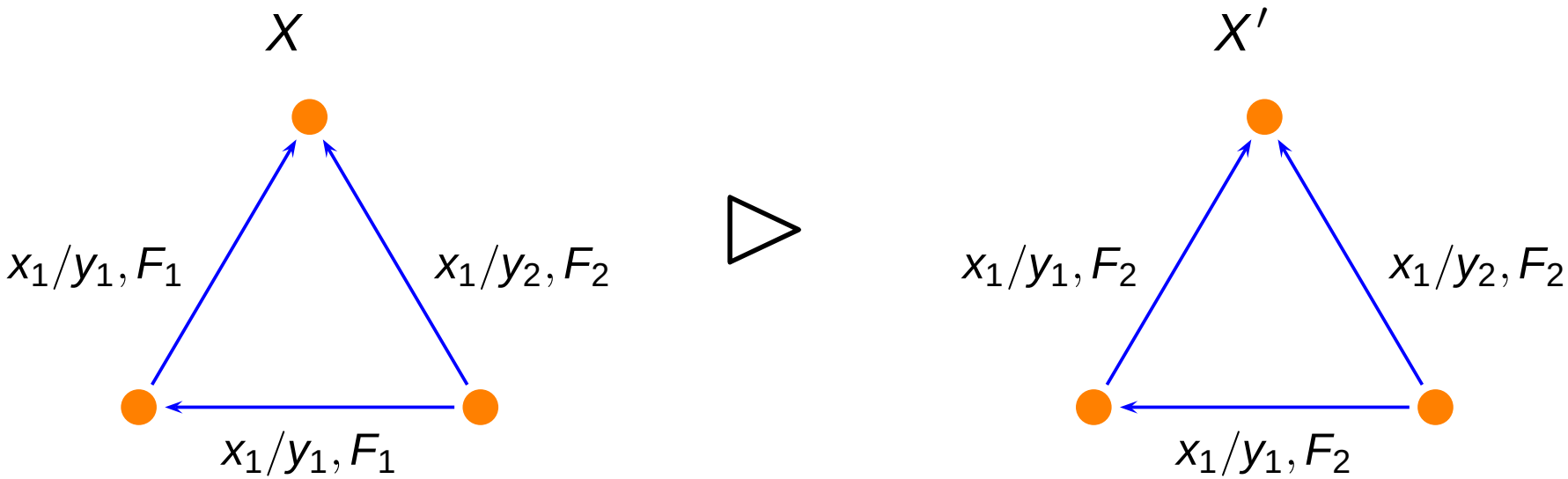
Altering the distribution function



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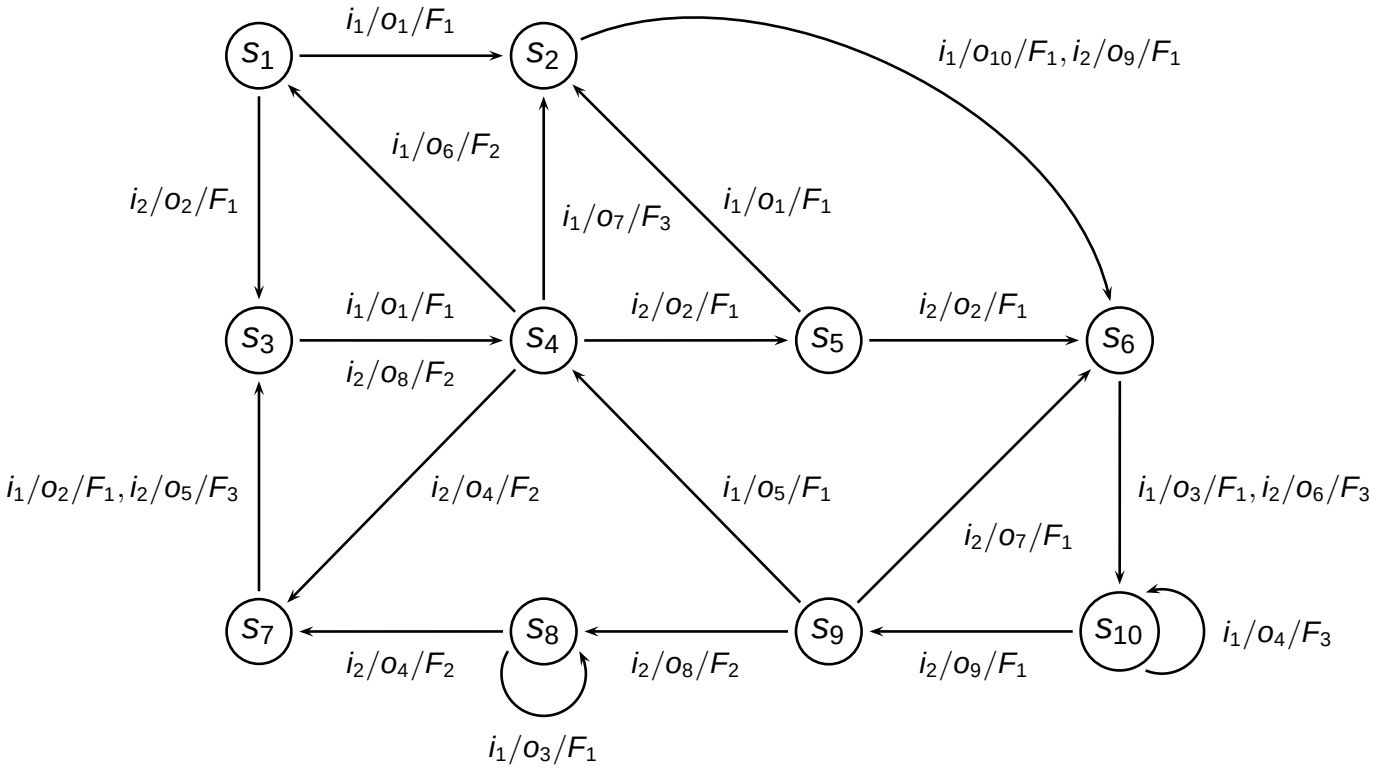
The specification



$$F_1(t) = \begin{cases} 0 & \text{if } t < 0 \\ \frac{t}{2} & \text{if } 0 \leq t < 2 \\ 1 & \text{if } 2 \leq t \end{cases}$$

$$F_2(t) = \begin{cases} 0 & \text{if } t < 4 \\ 1 & \text{if } 4 \leq t \end{cases}$$

$$F_3(t) = \begin{cases} 1 - e^{\frac{-t}{3}} & \text{if } 0 \leq t \\ 0 & \text{if } 0 > t \end{cases}$$

Set of Invariants

$$
\begin{array}{lllll}
\phi_1 = & & & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle\} \\
\phi_2 = & & & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle, \langle o_1, F_1\rangle\} \\
\phi_3 = & & & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_3, F_1\rangle, \langle o_2, F_1\rangle\} \\
\phi_4 = & & & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_3, F_1\rangle, \langle o_2, F_1\rangle, \langle o_1, F_1\rangle\} \\
\phi_5 = & & & i_2 \mapsto & \{\langle o_{10}, F_3\rangle, \langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle\} \\
\phi_6 = & & & i_2 \mapsto & \{\langle o_{10}, F_3\rangle, \langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle, \langle o_1, F_1\rangle\} \\
\phi_7 = & & & i_2 \mapsto & \{\langle o_{10}, F_3\rangle, \langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_3, F_1\rangle, \langle o_2, F_1\rangle\} \\
\phi_8 = & & & i_2 \mapsto & \{\langle o_{10}, F_3\rangle, \langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_3, F_1\rangle, \langle o_2, F_1\rangle, \langle o_1, F_1\rangle\} \\
\phi_9 = & & & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_7, F_3\rangle, \langle o_6, F_2\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_2, F_3\rangle, \langle o_1, F_1\rangle\} \\
\phi_{10} = & & & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_3\rangle, \langle o_6, F_2\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_2, F_3\rangle, \langle o_1, F_1\rangle\} \\
\phi_{11} = & & i_2/o_8/F_2, & i_2 \mapsto & \{\langle o_{10}, F_3\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle, \langle o_1, F_2\rangle\} \\
\phi_{12} = & & i_2/o_8/F_2, & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_3\rangle, \langle o_6, F_2\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle\} \\
\phi_{13} = & & i_2/o_8/F_2, & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_3\rangle, \langle o_6, F_2\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_1, F_1\rangle\} \\
\phi_{14} = & & i_2/o_8/F_2, & i_2 \mapsto & \{\langle o_{10}, F_3\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_3, F_1\rangle, \langle o_2, F_1\rangle\} \\
\phi_{15} = & & i_1/o_3/F_1, & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_7, F_1\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_3, F_1\rangle, \langle o_2, F_1\rangle, \langle o_1, F_2\rangle\} \\
\phi_{16} = & & i_1/o_3/F_1, & i_1 \mapsto & \{\langle o_9, F_3\rangle, \langle o_7, F_3\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_2, F_3\rangle, \langle o_1, F_1\rangle\} \\
\phi_{17} = & i_2/o_8/F_2, & i_1/o_3/F_1, & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle\} \\
\phi_{18} = & i_2/o_8/F_2, & i_1/o_3/F_1, & i_2 \mapsto & \{\langle o_9, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_1\rangle, \langle o_6, F_3\rangle, \langle o_5, F_3\rangle, \langle o_4, F_2\rangle, \langle o_2, F_1\rangle, \langle o_1, F_1\rangle\} \\
\phi_{19} = & i_2/o_8/F_2, & i_1/o_3/F_1, & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_7, F_3\rangle, \langle o_6, F_2\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_2, F_3\rangle, \langle o_1, F_1\rangle\} \\
\phi_{20} = & i_2/o_8/F_2, & \star, & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_9, F_1\rangle, \langle o_7, F_3\rangle, \langle o_6, F_2\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_2, F_3\rangle, \langle o_1, F_1\rangle\} \\
\phi_{21} = & i_1/o_3/F_1, & i_1/o_3/F_1, & i_1 \mapsto & \{\langle o_{10}, F_1\rangle, \langle o_8, F_2\rangle, \langle o_7, F_3\rangle, \langle o_6, F_3\rangle, \langle o_5, F_1\rangle, \langle o_4, F_3\rangle, \langle o_3, F_1\rangle, \langle o_2, F_3\rangle, \langle o_1, F_1\rangle\}
\end{array}
$$

Non equivalent mutants			Total
CO	CGS	CT	638
201	230	207	

Mutants generated

- All mutants were generated for CO and CGS operators.
- Different levels of deviation for CT operator.

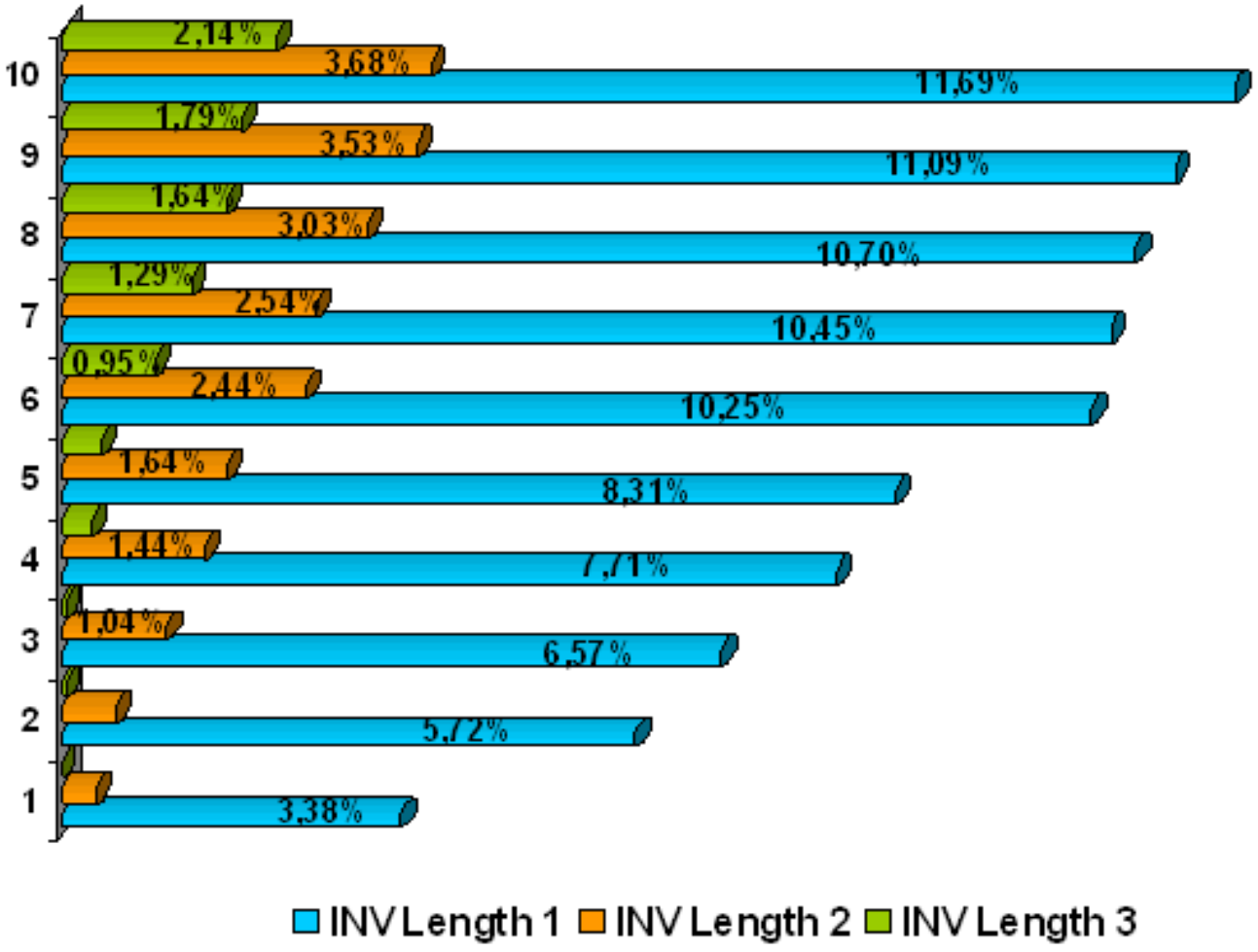
Traces extracted

- From each mutant 10 traces are extracted.
- Different length: $k \cdot |\mathcal{S}|$ where $k \in \{1.,10\}$

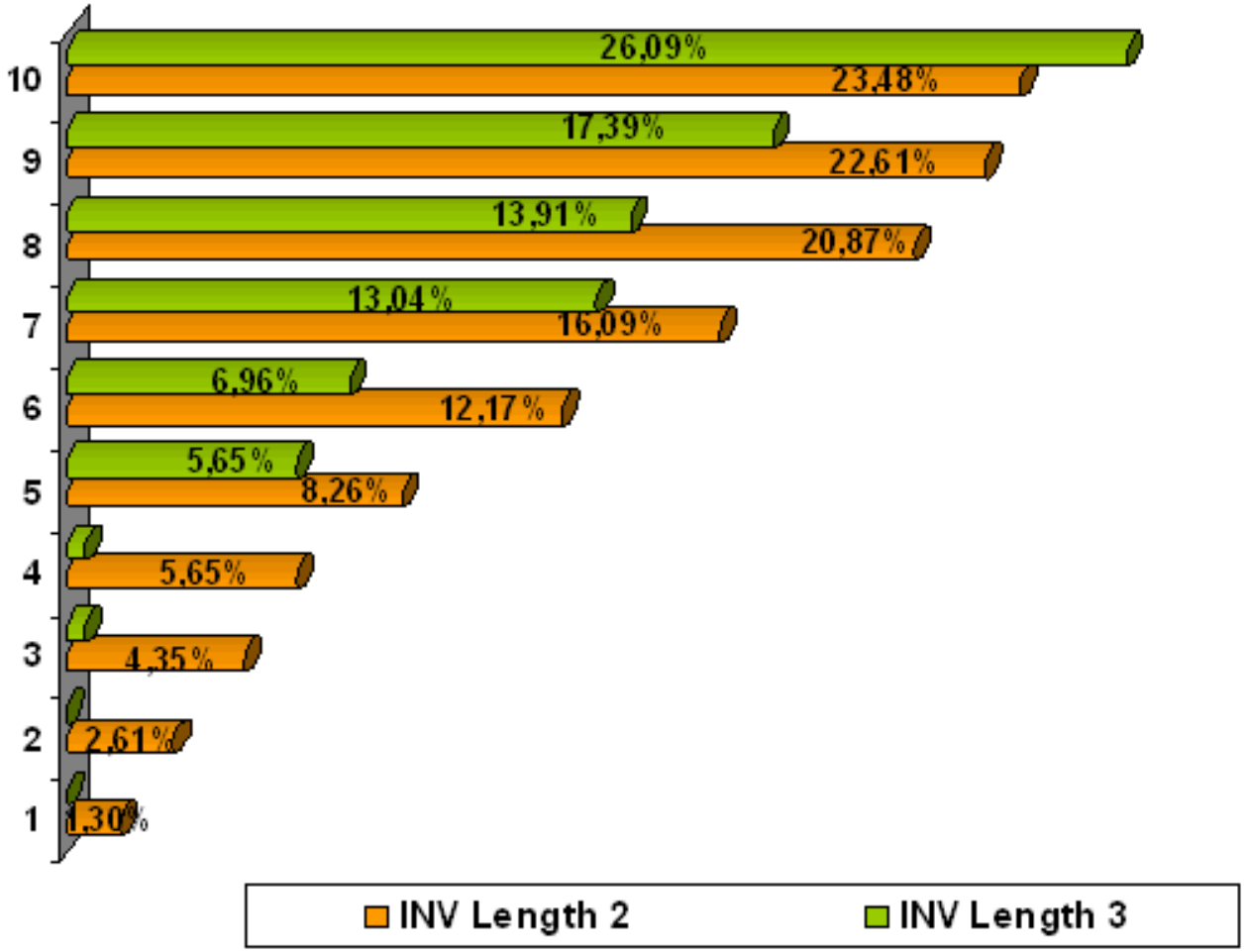
Analysis of results

- Length of traces
- Length of the invariants.
- Kind of mutant from which the trace was extracted.

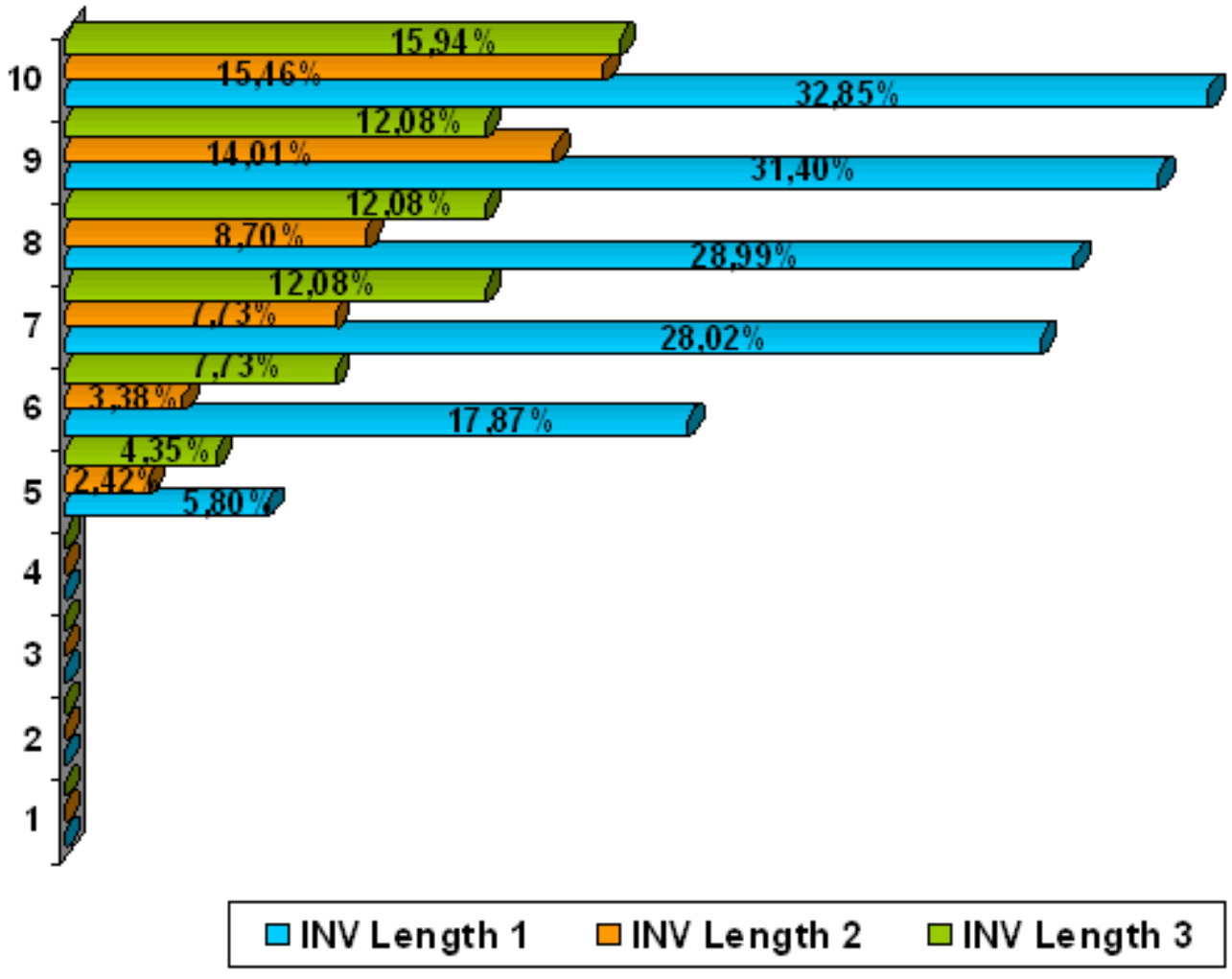
Results I: Output mutants



Results II: Transfer mutants



Results III: Time mutants



Measuring effectiveness

$$\frac{w_{CO} \cdot M_{CO}(\phi_i) + w_{CT} \cdot M_{CT}(\phi_i) + w_{CGS} \cdot M_{CGS}(\phi_i)}{NumTracesMut \cdot M_{TOT}}$$

where $\sum_{i \in \{CO,CT,CGS\}} w_i = 1$

- $M_{CO}(\phi_i)$, $M_{CGS}(\phi_i)$ and $M_{CT}(\phi_i)$: number of errors detected by the invariant ϕ_i.
- M_{TOT}: number of mutants generated.
- *NumTracesMut*: number of traces extracted from each mutant.
- w_{CO}, w_{CT} and w_{CGS} are selected by the tester.

Measuring effectiveness

w_{co}	w_{ct}	w_{cgs}	*Set of Invariants*
$\frac{1}{3}$	$\frac{1}{3}$	$\frac{1}{3}$	$\phi_1 > \phi_3 > \phi_2 > \phi_5 > \phi_9 > \phi_{15} > \phi_{12} > \phi_{16} > \phi_4 \simeq \phi_7$
1	0	0	$\phi_1 > \phi_3 > \phi_2 > \phi_5 > \phi_9 > \phi_4 > \phi_7 > \phi_6 > \phi_{10} > \phi_{16}$
0	0	1	$\phi_{15} > \phi_{12} > \phi_{18} > \phi_{17} > \phi_{16} > \phi_{14} \simeq \phi_{19} > \phi_{21} > \phi_{11} > \phi_{13}$

Conclusions

- Application of mutation techniques to PASTEtool in order to check the effectiveness of the invariants for detecting errors,.
- Mutation operators for obtaining mutants from the specification.
- Different traces are extracted from the mutants that simulate real faults.
- The traces are used to test if the invariants proposed by the tester can find the errors and a measure of its effectiveness is estimated.

Thanks for your attention!