Relating Alternating Relations for Conformance and Refinement

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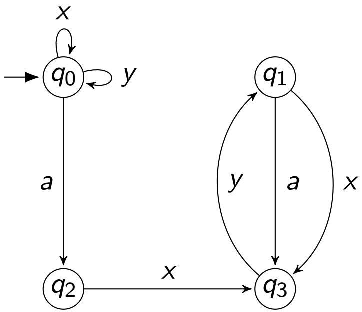
iFM, Bergen, Norway, December 5, 2019

Interface automata

Labeled transition systems with inputs $a, b, ..$ and outputs $x, y, ..$ (Tretmans '96):



A.k.a. *interface automata* (De Alfaro & Henzinger '01) or *I/O automata* (when input enabled) (Lynch & Tuttle '87).

History

Interface Automata

ioco

Tretmans '96

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Alternating Trace Containment

Alternating Simulation

Alur, Henzinger, Kupferman & Vardi '98

Kripke Structure with agents

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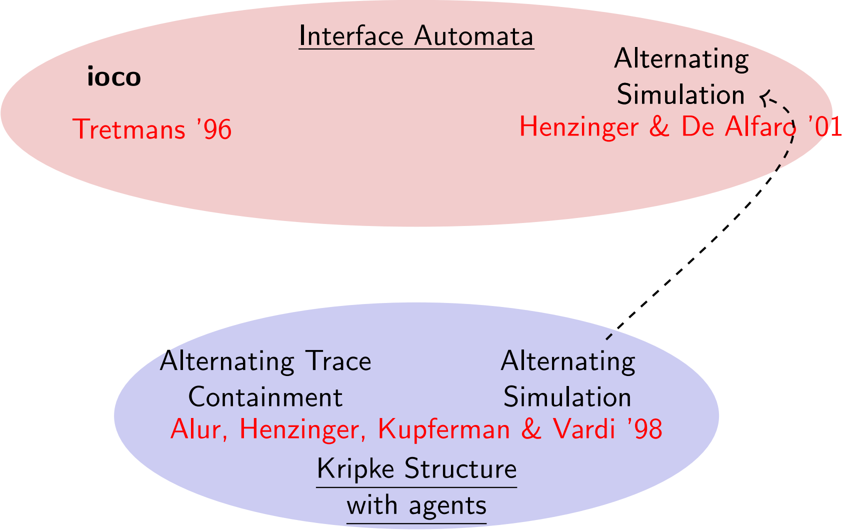
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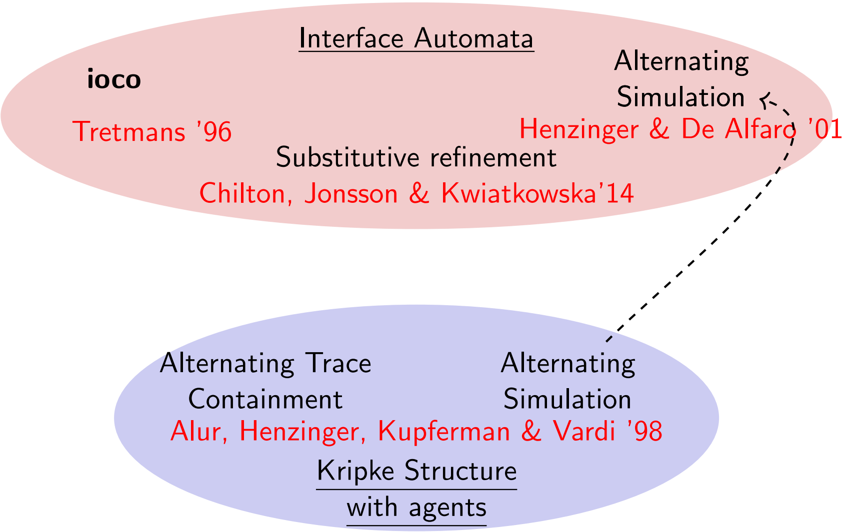
Interface Automata
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Substitutive refinement
Chilton, Jonsson & Kwiatkowska'14
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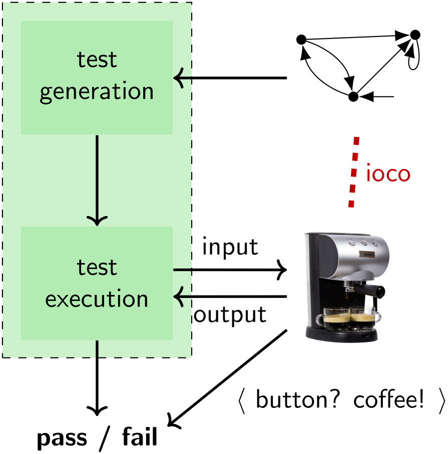
Model-Based Testing



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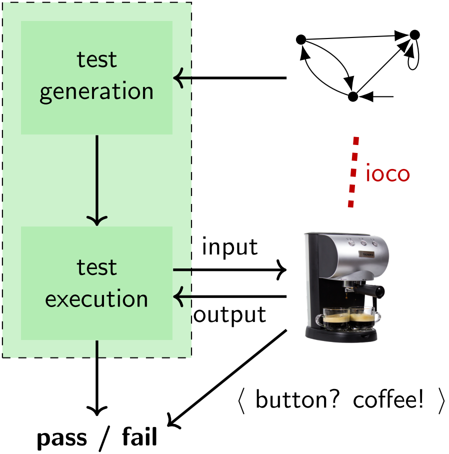

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- Assume SUT can be modeled as *input enabled* IA

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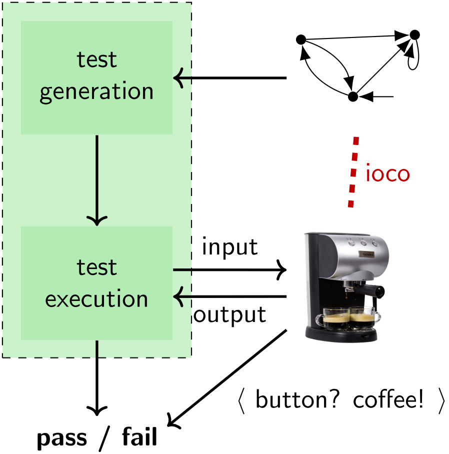

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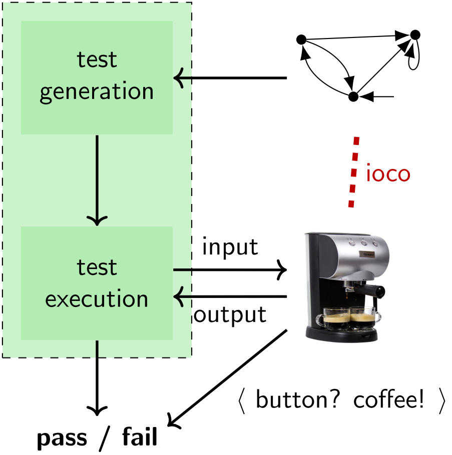
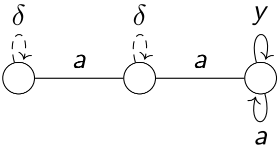


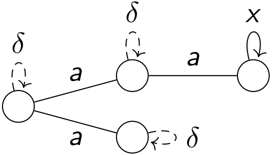
- ioco $\subseteq IA_{i.e.} \times IA$
- Assume SUT can be modeled as *input enabled* IA
- **uioco** fixes problem with compositionality (vd Bijl, Rensink & Tretmans '03)
- **uioco** generalized to preorder on IA's (Volpato & Tretmans '13)
- **ioco** used as conformance relation in many tools

Difference between ioco and uioco



uioco

~~ioco~~



Tester versus bug

There are fundamental connections between model-based testing and 2-player concurrent games.

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Can we lift these connections to general, nondeterministic settting?

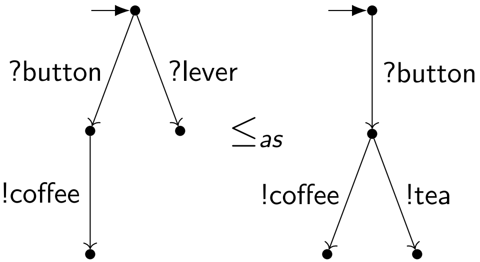
Alternating Refinements

- Kripke structures with *collaborative* and *adversarial* agents
- Refinement restrictse behaviour of collaborative agents, without restricting the adversarial agents
- Two refinements
  - alternating *simulation*
  - alternating *trace containment*

Alternating Simulation

Adaptation to interface automata:

- Input-choices are adversarial
- Output-choices are collaborative



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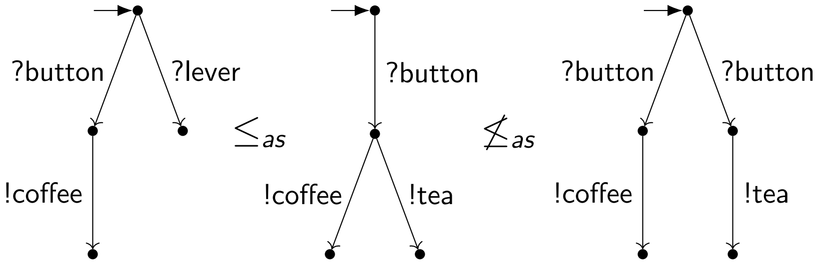
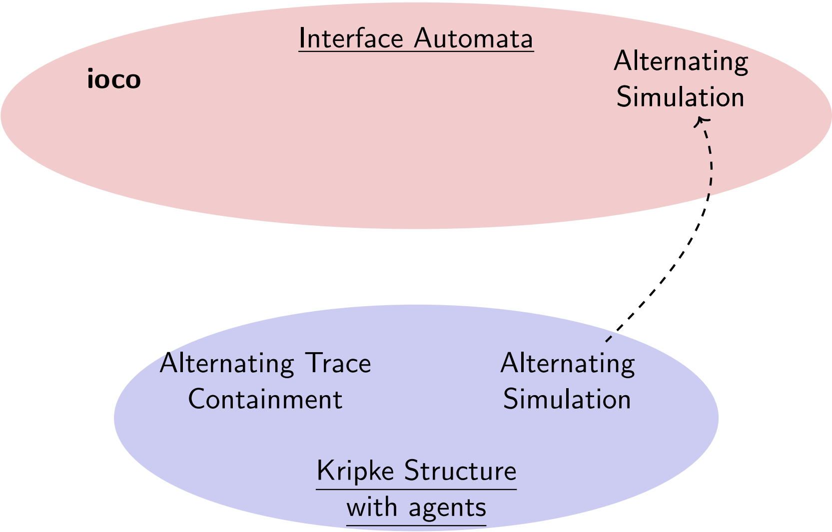


There is no (reasonable) testing scenario for alternating simulation!

Contributions



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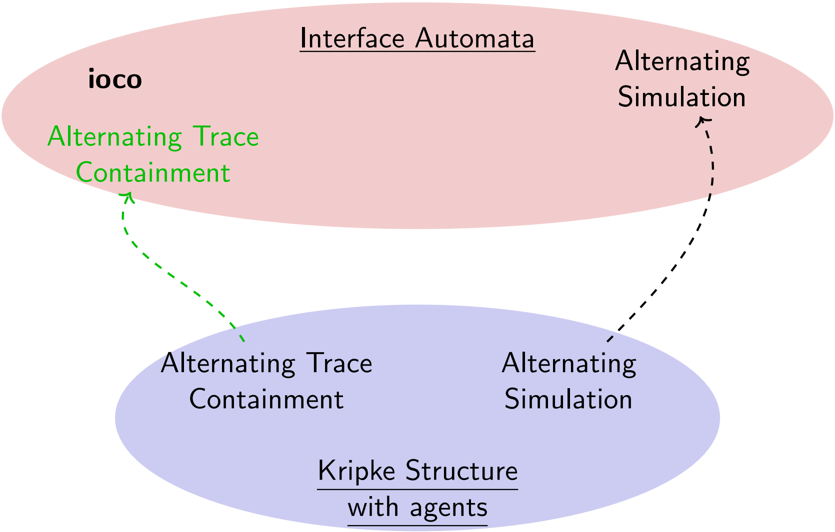

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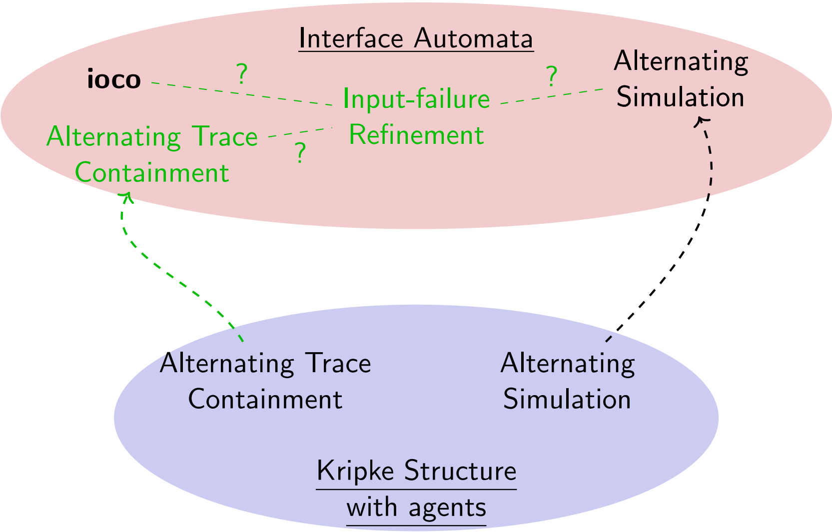
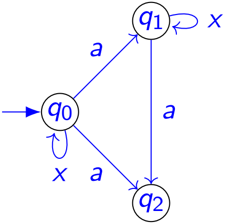


Input-universal and output-existential

Let s be an IA with states Q inputs I and output O. Then



$$\mathrm{out}(Q) = \{x \in O \mid \exists q \in Q : q \xrightarrow{x}\}$$

$$\mathrm{in}(Q) = \{a \in I \mid \forall q \in Q : q \xrightarrow{a}\}$$

$$\mathrm{out}(\{q_1, q_2\}) = \{x\}$$

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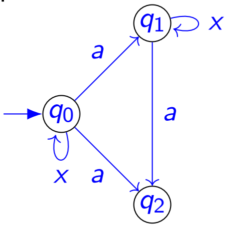

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Let $L = I \cup O$ and $\sigma \in L^*$. Then

σ is *s-output-existential* if $\forall j \in 1 \ldots n : \ell^j \in \mathrm{out}(s \text{ after } \ell^1 \ldots \ell^{j-1}) \cup I$

σ is *s-input-universal* if $\forall j \in 1 \ldots n : \ell^j \in \mathrm{in}(s \text{ after } \ell^1 \ldots \ell^{j-1}) \cup O$

$a\ a$ is output-existential but not input-universal

$a\ x\ a$ is output-existential and input-universal

Input-Universal and Output-Existential refinement

Definition

Let $\mathrm{OE}(s)$ denote the set of s-output-existential words, and $\mathrm{IU}(s)$ the set of s-input-universal words. Then

$$s_1 \leq_{iuoe} s_2 \iff \mathrm{OE}(s_1) \cap \mathrm{IU}(s_2) \subseteq \mathrm{IU}(s_1) \cap \mathrm{OE}(s_2)$$

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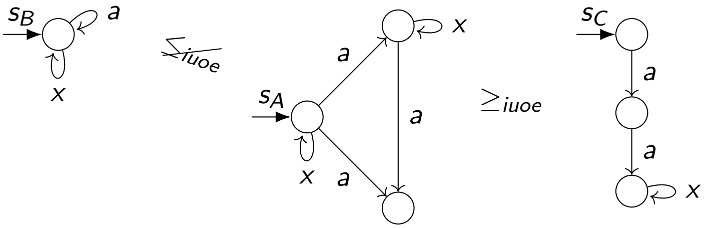

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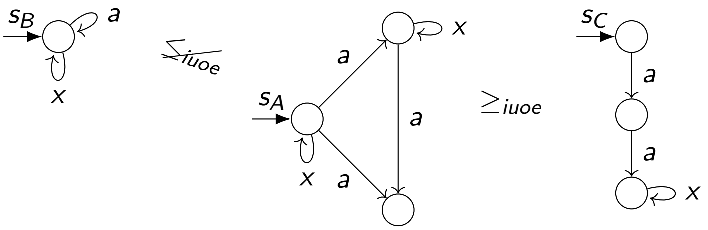


$axax \in \mathrm{OE}(s_B) \cap \mathrm{IU}(s_A)$ and $axax \notin \mathrm{OE}(s_A)$

Relating uioco, $\leq_{if}$ and $\leq_{iuoe}$

If s is an interface automaton then $\Delta(s)$ is the interface automaton obtained by adding a self-loop with output label δ to every state of s that does not enable an output.

Theorem

s_1 **uioco** $s_2 \quad \Leftrightarrow \quad \Delta(s_1) \leq_{if} \Delta(s_2)$

Theorem

$s_1 \leq_{if} s_2 \quad \Leftrightarrow \quad s_1 \leq_{iuoe} s_2$

Here $\leq_{if}$ is the substitutive refinement of Chilton, Jonsson & Kwiatkowska '14.

Agents and Strategies

- Alternating trace containment presupposes a set of agents, which are either collaborative or adversarial.
- Agents may restrict possible transitions following an initial path by choosing a strategy.
- Once every agent has chosen a strategy, we obtain a unique path in the interface automaton.
- Collaborative agent choose at most one input action, and adversarial agents choose at most one output action, a determinization strategy, and a race condition strategy.
- Domains of strategies denoted $\Sigma_i(s)$, $\Sigma_o(s)$, $\Sigma_d(s)$ and $\Sigma_r(s)$, respectively.

Two player game

Game of alternating trace containment played by two players, the protagonist and the antagonist, on IAs s_1 and s_2:

1. Antagonist chooses strategy for collaborative agents s_1
2. Protagonist chooses strategy for collaborative agents s_2
3. Antagonist chooses strategy for adversarial agents s_2
4. Protogonist chooses strategy for adversarial agents s_1

Protogonist wins if traces of runs in s_1 and s_2 are the same.

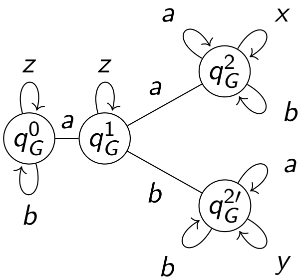
Alternating trace containment

Definition

Let s_1, s_2 be interface automata.
Then s_1 is alternating-trace contained in s_2, denoted $s_1 \leq_{atc} s_2$, if

$$\forall f_o^1 \in \Sigma_o(s_1), \forall f_d^1 \in \Sigma_d(s_1), \forall_r^1 \in \Sigma_d(s_1),$$
$$\exists_o^2 \in \Sigma_o(s_2), \exists f_d^2 \in \Sigma_d(s_2), \exists f_r^2 \in \Sigma_r(s_2),$$
$$\forall f_i^2 \in \Sigma_i(s_2), \exists f_i^1 \in \Sigma_i(s_1) :$$
$$\mathrm{trace}(\mathrm{outcome}(f_i^1, f_o^1, f_d^1, f_r^1)) = \mathrm{trace}(\mathrm{outcome}(f_i^2, f_o^2, f_d^2, f_r^2))$$

Counterexample



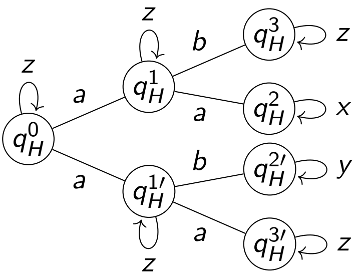
ioco

uioco

$\leq_{if}$

$\leq_{iuoe}$

$\not\leq_{atc}$



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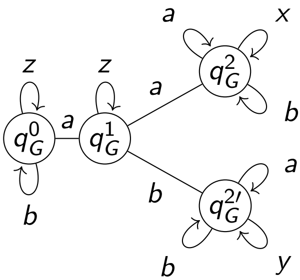

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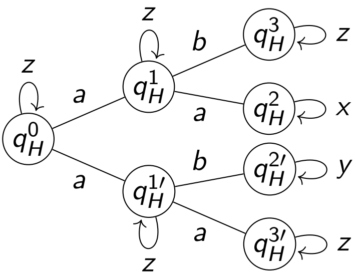


Problems in definition $\leq_{atc}$:

(1) order in which strategies are selected,

(2) input strategies not trace based.

Changing the rules of the game

Definition

Let s_1, s_2 be interface automata.
Then $s_1 \leq^{tb}_{\forall\forall\exists\exists} s_2$, if

$$\forall f_i^2 \in \Sigma_{i,tb}(s_2), \forall f_o^1 \in \Sigma_o(s_1), \forall f_d^1 \in \Sigma_d(s_1), \forall_r^1 \in \Sigma_d(s_1),$$
$$\exists f_i^1 \in \Sigma_{i,tb}(s_1), \exists_o^2 \in \Sigma_o(s_2), \exists f_d^2 \in \Sigma_d(s_2), \exists f_r^2 \in \Sigma_r(s_2) :$$
$$\mathrm{trace}(\mathrm{outcome}(f_i^1, f_o^1, f_d^1, f_r^1)) = \mathrm{trace}(\mathrm{outcome}(f_i^2, f_o^2, f_d^2, f_r^2))$$

Theorem

$s_1 \leq_{as} s_2 \implies s_1 \leq_{atc} s_2.$

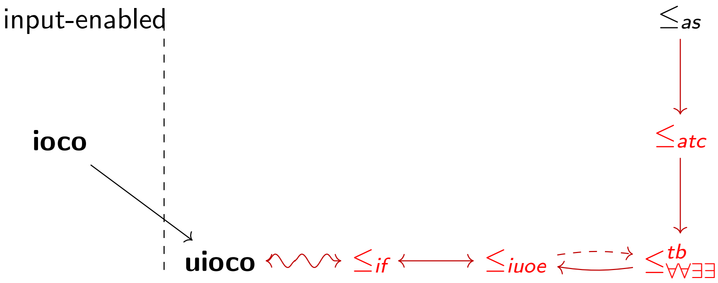
Theorem

$s_1 \leq_{atc} s_2 \implies s_1 \leq^{tb}_{\forall\forall\exists\exists} s_2.$

Theorem

$s_1 \leq^{tb}_{\forall\forall\exists\exists} s_2 \implies s_1 \leq_{iuoe} s_2.$
Furthermore, if s_2 is image-finite, then
$s_1 \leq^{tb}_{\forall\forall\exists\exists} s_2 \impliedby s_1 \leq_{iuoe} s_2.$

Conclusions



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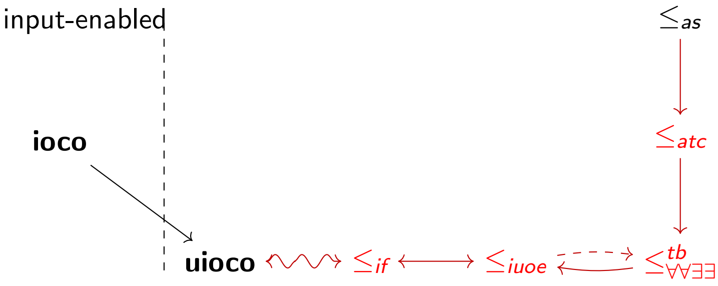

1. use $\leq_{if}$ rather than $\leq_{as}$ as refinement relation

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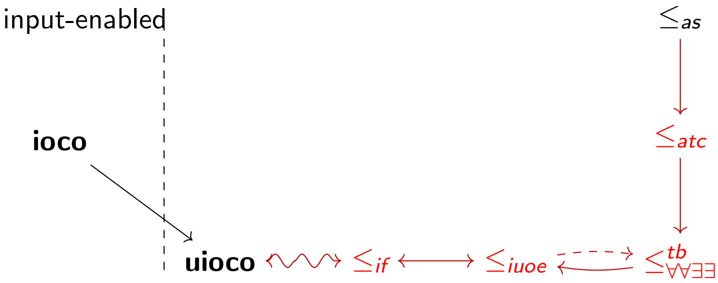

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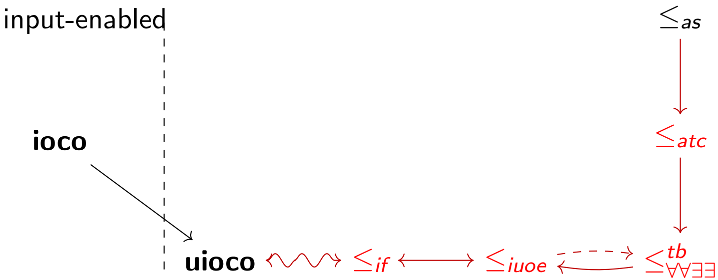

1. use $\leq_{if}$ rather than $\leq_{as}$ as refinement relation
2. use **uioco** rather than **ioco** as conformance relation
3. $\leq_{atc}$ not a sensible notion of trace containment