On the Unification of Process Semantics: Observational Semantics

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Introduction

- A large collection of semantics for processes.
- Most are classified in van Glabbeek's spectrum:
  - Observational/testing framework.
  - Axiomatic framework.
  - Logical framework.
- No uniform scenario:
  - Different kinds of observations.
  - Unrelated axioms.
  - Different testing scenarios.

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Our proposal

- A uniform observational framework:
  - Branching observations for simulation (branched) semantics.
  - Linear observations for the linear semantics.
  - Closure operations to generate the observations for the linear semantics.

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BCCSP processes

Definition

The set BCCSP(Act) of processes is defined by:

$$p ::= \mathbf{0} \mid ap \mid p + q$$

where $a \in Act$; $\mathbf{0}$ represents the process that performs no action; for every action in Act, there is a prefix operator; and $+$ is a choice operator.

Definition

The operational semantics for BCCSP terms is defined by

$$ap \xrightarrow{a} p \qquad \frac{p \xrightarrow{a} p'}{p + q \xrightarrow{a} p'} \qquad \frac{q \xrightarrow{a} q'}{p + q \xrightarrow{a} q'}$$

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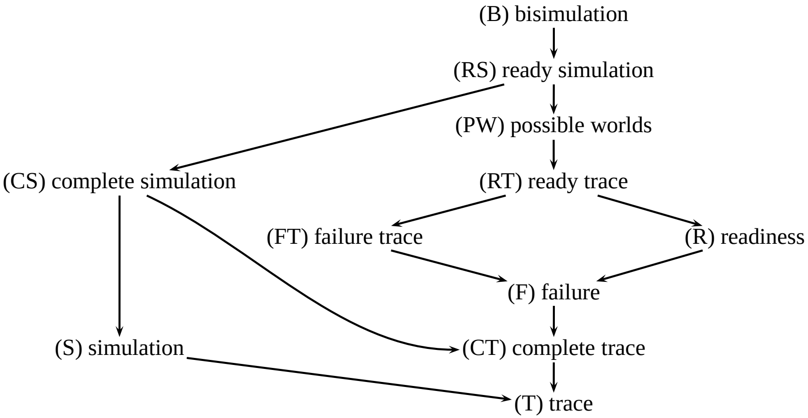
The classical van Glabbeek's ltbt spectrum



Constrained simulations

Definition

Given a relation N, an *N-constrained simulation* is a relation S_N such that pS_Nq implies:

- For every a, if $p \xrightarrow{a} p'$ there exists q', $q \xrightarrow{a} q'$ and $p'S_Nq'$, and
- pNq.

Notation: $p \sqsubseteq_{NS} q$.

- The universal relation U relating all processes gives rise to the simulation semantics;
- Relation I, relating processes with the same initial actions, corresponds to ready simulation;
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Local observations L_N

We observe locally at each state of the process the information needed to decide the corresponding constraint.

- Plain simulation: $L_U = \{\cdot\}$, $L_U(p) = \cdot$.
- Ready simulation: $L_I = \mathcal{P}(Act)$, $L_I(p) = I(p)$.
- Complete simulation: $L_C = Bool$, $L_C(p)$ is *true* if $p \equiv \mathbf{0}$ and *false* otherwise.
- Trace simulation: $L_T = \mathcal{P}(Act^*)$, $L_T(p) = T(p)$, the set of traces of p.
- 2-nested simulation: $L_S = \{[\![p]\!]_S \mid p \in \text{BCCSP}\}$, $L_S(p) = [\![p]\!]_S$.

Branching general observations

The domain BGO_N of branching general observations of p corresponding to the constraint N contains the finite trees doubly labelled, at their nodes by local observations in L_N, and at their arcs by actions in Act.

Definition

The set $BGO_N(p)$ can be compositionally defined as

$$BGO_N(p) = \{\langle L_N(p), S\rangle \mid S \subseteq \{(a, bgo) \mid bgo \in BGO_N(p'), p \xrightarrow{a} p'\}\}\,.$$

Any $bgo \in BGO_N(p)$ can be interpreted as a partial aggregated view of a collection of computations of p, by observing L_N at their states.

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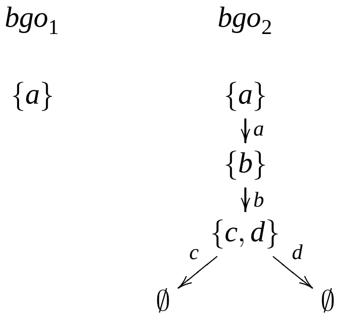
Examples: $N = I$



For $p = a(b(c + d) + bc + bd)$, $bgo_k \in BGO_I(p)$, for $k \in \{1, 2, 3\}$.

Results

Theorem

For all $N \in \{U, I, C, T, S\}$ and any two processes p and q,
$p \sqsubseteq_{NS} q$ iff $p \leq^b_N q$.

Key facts to obtain this characterisation:

- We may include, but no must!, in a *bgo* several partial computations that start executing several transitions.
- We may *duplicate* a single transition by including different computations starting with the same transition.

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Linear observations

- The set LGO_N of linear general observations for a local observer L_N is the subset of BGO_N defined as:
  - $\langle l, \emptyset \rangle \in LGO_N$ for each $l \in L_N$.
  - $\langle l, \{(a, lgo)\} \rangle$, whenever $a \in A$ and $lgo \in LGO_N$.
- The set of linear general observations of a process p with respect to the local observer L_N is $LGO_N(p) = BGO_N(p) \cap LGO_N$.

Since lgo's are linear they can be presented as decorated traces:

$$LGO_N(p) ::= \{\langle L_N(p) \rangle\} \cup \{\langle L_N(p), a \rangle \circ lgo \mid p \xrightarrow{a} p',\ lgo \in LGO_N(p')\}$$

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Characterizing (some) linear semantics

We write $p \leq_N^l q$, if $LGO_N(p) \subseteq LGO_N(q)$.

Proposition

(1) $\leq_U^l = \sqsubseteq_T$
(2) $\leq_I^l = \sqsubseteq_{RT}$
(3) $\leq_C^l = \sqsubseteq_{CT}$

The linear semantics corresponding to decorated traces observing L_N is the strongest linear semantics definable via L_N

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The rest of linear semantics for $N = I$

There are other coarser semantics for which a different way of treating the linear observations is needed.

For $\mathcal{T}, \mathcal{T}' \subseteq LGO_I$ we define the orders $\leq_I^{l\supseteq}$, $\leq_I^{lf}$, and $\leq_I^{lf\supseteq}$:

- $\mathcal{T} \leq_I^{l\supseteq} \mathcal{T}' \iff \forall X_0 a_1 X_1 \ldots X_n \in \mathcal{T}\ \exists Y_0 a_1 Y_1 \ldots Y_n \in \mathcal{T}'$ $\forall i \in 0..n\ X_i \supseteq Y_i$
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Then, we write $p \leq_I^{lX} q$ if $LGO_I(p) \leq_I^{lX} LGO_I(q)$.

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Observational characterisations of the linear semantics

Proposition

- $\leq_I^{lf}$ *generates the readiness preorder;*
- $\leq_I^{lf\supseteq}$ *generates the failures preorder;*
- $\leq_I^{l\supseteq}$ *generates the failures trace preorder.*

Closure operations characterising the linear orders

A closure operation can be associated to each preorder so that the observational semantics are directly defined in terms of set inclusion.

Definition

For $\mathcal{T} \subseteq LGO_I$, the following three closures are defined:

- $\overline{\mathcal{T}}^{\supseteq} = \{X_0 a_1 X_1 \ldots a_n X_n \mid \exists Y_0 a_1 Y_1 \ldots a_n Y_n \in \mathcal{T}\ \forall i \in 0..n\ X_i \supseteq Y_i\}$.
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For $X \in \{\supseteq, f, f\supseteq\}$ and $p \in BCCSP$, we define $LGO_I^X(p) = \overline{LGO_I(p)}^X$.

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Generalisations to cover other semantics

The preorders $\leq_I^X$ can be generalised substituting I by an arbitrary constraint thus getting $\leq_N^X$.

The new preorders allow us to characterise:

- two semantics recently added to the spectrum: possible futures preorder and the impossible futures preorder.
- two new semantics: possible futures trace semantics and the impossible futures trace semantics.

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The possible worlds semantics and deterministic branching observations

A bgo is deterministic if for every node in it, its set of children $\{(a_i, bgo_i)\}$ satisfies $a_i \neq a_j$ whenever $i \neq j$.

- The set of deterministic branching observations of a process p is $dBGO_N(p) = BGO_N(p) \cap dBGO_N$.
- We write $p \leq_N^{db} q$ if $dBGO_N(p) \subseteq dBGO_N(q)$.

Deterministic branching observations capture the possible worlds semantics plus many other (a bit strange) ones.

Proposition

$$p \leq_I^{db} q \Leftrightarrow p \leq_{PW} q$$

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Unification of the algebraic semantics of processes

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$$(ND)\ M(x,y,w) \Rightarrow a(x+y) \preceq ax + a(y+w)$$

$$\begin{array}{lll} (ND^F) & M_F(x,y,w) \iff \text{true} \\ (ND^R) & M_R(x,y,w) \iff I(x) \supseteq I(y) \\ (ND^{FT}) & M_{FT}(x,y,w) \iff I(w) \subseteq I(y) \\ (ND^{RT}) & M_{RT}(x,y,w) \iff I(x) = I(y)\ \wedge\ I(w) \subseteq I(y) \end{array}$$

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Conclusions

- We have clearly established the three mechanisms to characterise the process semantics by means of observations:
  - Branching observations characterise the simulation semantics.
  - Linear observations characterise the linear semantics.
  - A closure operation is needed to characterise each of the four linear semantics coarser than each constrained simulation semantics.
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The new linear time-branching time spectrum