

Modeling Concurrent and Probabilistic Systems

Lecture 9: Observation Congruence

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- 1 Repetition: Weak Bisimulation
- 2 Definition of Observation Congruence
- 3 Properties of Observation Congruence
- 4 Decidability of Observation Congruence

Repetition: Definition of Weak Bisimulation

Definition

- Given $w \in Act^*$, $\widehat{w} \in (N \cup \overline{N})^*$ denotes the sequence of non- τ -actions in w (in particular, $\widehat{\tau^n} = \varepsilon$ for every $n \in \mathbb{N}$).
- For $w = \alpha_1 \dots \alpha_n \in Act^*$ and $P, Q \in Prc$, we let

$$P \xRightarrow{w} Q \iff P (\xrightarrow{\tau})^* \xrightarrow{\alpha_1} (\xrightarrow{\tau})^* \dots (\xrightarrow{\tau})^* \xrightarrow{\alpha_n} (\xrightarrow{\tau})^* Q$$

(and hence: $\xRightarrow{\varepsilon} = (\xrightarrow{\tau})^*$).

- A relation $\rho \subseteq Prc \times Prc$ is called a **weak bisimulation** if $P \rho Q$ implies, for every $\alpha \in Act$,
 - 1 $P \xrightarrow{\alpha} P' \implies \text{ex. } Q' \in Prc \text{ such that } Q \xRightarrow{\widehat{\alpha}} Q' \text{ and } P' \rho Q'$
 - 2 $Q \xrightarrow{\alpha} Q' \implies \text{ex. } P' \in Prc \text{ such that } P \xRightarrow{\widehat{\alpha}} P' \text{ and } P' \rho Q'$
- $P, Q \in Prc$ are called **weakly bisimilar** (notation: $P \approx Q$) if there exists a weak bisimulation ρ such that $P \rho Q$.

Properties

- 1 $P \sim Q \implies P \approx Q$
- 2 \approx is an equivalence relation
- 3 $LTS(P) = LTS(Q) \implies P \approx Q$
- 4 $P \approx Q \implies \widehat{Tr}(P) = \widehat{Tr}(Q)$
- 5 \approx is (non- τ) deadlock sensitive
- 6 For every $P \in Proc$, $P \approx \tau.P$
- 7 \approx is **not a congruence**:

It is true that $b.nil \approx \tau.b.nil$

but $a.nil + b.nil \not\approx a.nil + \tau.b.nil$

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Definition of Observation Congruence I

Goal: introduce an equivalence which has most of the desirable properties of \approx and which is preserved under all CCS operators

Definition 9.1

$P, Q \in \text{Proc}$ are called **observationally congruent** (notation: $P \simeq Q$) if, for every $\alpha \in \text{Act}$,

- ① $P \xrightarrow{\alpha} P' \implies \text{ex. } Q' \in \text{Proc} \text{ such that } Q \xRightarrow{\alpha} Q' \text{ and } P' \approx Q'$
- ② $Q \xrightarrow{\alpha} Q' \implies \text{ex. } P' \in \text{Proc} \text{ such that } P \xRightarrow{\alpha} P' \text{ and } P' \approx Q'$

Remark: \simeq differs from \approx only in the use of $\xRightarrow{\alpha}$ rather than $\xrightarrow{\hat{\alpha}}$, i.e., it requires τ -actions from P or Q to be simulated by at least one τ -step in the other process. This only applies to the first step; the successors just have to satisfy $P' \approx Q'$ (and not $P' \simeq Q'$).

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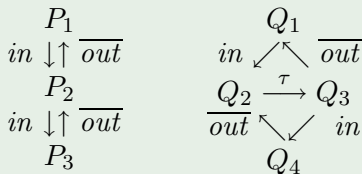
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Example 9.2

- Sequential and parallel two-place buffer:

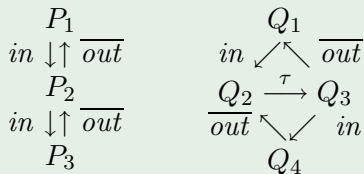


$P_1 \simeq Q_1$ since $P_1 \approx Q_1$ (cf. Example 8.3) and neither P_1 nor Q_1 has initial τ -steps

- $\tau.b.nil \not\approx b.nil$ (since $\tau.b.nil \xrightarrow{\tau}$ but $b.nil \not\xrightarrow{\tau}$)
 \implies counterexample to congruence of \approx does not apply
- $b.\tau.nil \simeq b.nil$ (since $\tau.nil \approx nil$)

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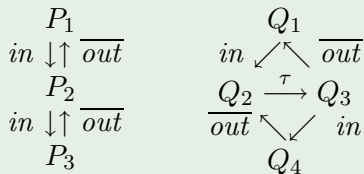


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Corollary 9.3

For every $P, Q \in \text{Proc}$,

- 1 $P \sim Q \implies P \simeq Q$
- 2 $P \simeq Q \implies P \approx Q$

Proof.

- 1 since $\xrightarrow{\alpha} \subseteq \xRightarrow{\alpha}$ and $\sim \subseteq \simeq$
- 2 since $\xRightarrow{\alpha} \subseteq \xRightarrow{\hat{\alpha}}$



Remark: this implies that

- processes with **identical LTSs** are \simeq -equivalent,
- \simeq -equivalent processes are (non- τ) **trace equivalent**, and
- \simeq is (non- τ) **deadlock sensitive**.

Exercise 5 shows that both inclusions are proper.

Properties of Observation Congruence I

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Theorem 9.4

\simeq is a *CCS congruence*.

Proof.

- 1 “equivalence” part: see Theorem 9.6
- 2 “congruence” part: omitted



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Properties of Observation Congruence II

A characterization of \simeq in terms of \approx :

Theorem 9.5

For every $P, Q \in \text{Prc}$,

$$P \simeq Q \iff P + R \approx Q + R \text{ for every } R \in \text{Prc}.$$

Proof.

on the board □

Remark: together with Corollary 9.3 and Theorem 9.4, this shows that \simeq is the **largest congruence contained in \approx**

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Theorem 9.6

\simeq is an equivalence relation.

Proof.

on the board ☐

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A characterization of \approx in terms of \simeq (reversal of Theorem 9.5):

Theorem 9.7

For every $P, Q \in \text{Prc}$,

$$P \approx Q \iff P \simeq Q \text{ or } P \simeq \tau.Q \text{ or } \tau.P \simeq Q.$$

Proof.

see Exercise 5



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The Problem

We now show that the **word problem for observation congruence**

Problem (Word problem for observation congruence)

Given: $P, Q \in Proc$

Question: $P \simeq Q$?

is decidable for finite-state processes (i.e., for those with $|S(P)|, |S(Q)| < \infty$ where $S(P) := \{P' \in Proc \mid P \longrightarrow^* P'\}$) (in general it is undecidable).

Since the definition of \simeq directly relies on \approx (cf. Def. 9.1), we first extend the partitioning algorithm from \sim (Theorem 7.1) to \approx .

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The Partitioning Algorithm I

Theorem 9.8 (Partitioning algorithm for \sim)

Input: *LTS* $(S, Act, \longrightarrow)$ (S finite)

Procedure: ❶ *Start with initial partition $\Pi := \{S\}$*

❷ *Let $B \in \Pi$ be a block and $\alpha \in Act$ an action*

❸ *For every $P \in B$, let*

$$\alpha(P) := \{C \in \Pi \mid \text{ex. } P' \in C \text{ with } P \xrightarrow{\alpha} P'\}$$

be the set of P 's α -successor blocks

❹ *Partition $B = \sum_{i=1}^k B_i$ such that*

$$P, Q \in B_i \iff \alpha(P) = \alpha(Q) \text{ for every } \alpha \in Act$$

❺ *Let $\Pi := (\Pi \setminus \{B\}) \cup \{B_1, \dots, B_k\}$*

❻ *Continue with (2) until Π is stable*

Output: *Partition $\hat{\Pi}$ of S*

Then, for every $P, Q \in S$,

$$P \sim Q \iff \text{ex. } B \in \hat{\Pi} \text{ with } P, Q \in B$$

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Then, for every $P, Q \in S$,

$$P \approx Q \iff \text{ex. } B \in \hat{\Pi} \text{ with } P, Q \in B$$

Remarks:

- 1 Since S is finite, $\alpha^*(P)$ is effectively computable in step (3) of the algorithm.
- 2 The \approx -partitioning algorithm can be interpreted as the application of the \sim -partitioning algorithm to an appropriately modified LTS:

$$\begin{aligned} & \text{Theorem 9.8 for } (S, Act, \longrightarrow) \\ \hat{=} & \text{Theorem 7.1 for } (S, Act, \longrightarrow') \\ & \text{where } \longrightarrow' := \bigcup_{\alpha \in Act} \xrightarrow{\hat{\alpha}} \end{aligned}$$

Proof.

similar to Theorem 7.1 (\sim -partitioning algorithm) □

The Partitioning Algorithm II

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Decidability of Observation Congruence

Since the definition of \simeq requires the weak bisimilarity of the intermediate states after the first step, Theorem 9.8 yields the decidability of \simeq :

Theorem 9.9 (Decidability of \simeq)

*Let $(S, Act, \longrightarrow)$ and $\hat{\Pi}$ as in Theorem 9.8. Then, for every $P, Q \in S$,
$$P \simeq Q \iff \alpha^+(P) = \alpha^+(Q) \text{ for every } \alpha \in Act$$

where $\alpha^+(P) := \{C \in \hat{\Pi} \mid \text{ex. } P' \in C \text{ with } P \xRightarrow{\alpha} P'\}$.*

Proof.

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Example 9.10

on the board

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