

Modeling Concurrent and Probabilistic Systems

Lecture 7: Decidability of Strong Bisimulation & Definition of Strong Simulation

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- 1 Repetition: Strong Bisimulation
- 2 Decidability of Strong Bisimulation
- 3 Summary: Properties of Strong Bisimulation
- 4 Strong Simulation

Repetition: Definition of Strong Bisimulation

Definition (Strong bisimulation)

A relation $\rho \subseteq Prc \times Prc$ is called a **strong bisimulation** if $P\rho Q$ implies, for every $\alpha \in Act$,

$$\textcircled{1} \quad P \xrightarrow{\alpha} P' \implies \text{ex. } Q' \in Prc \text{ such that } Q \xrightarrow{\alpha} Q' \text{ and } P'\rho Q'$$

$$\textcircled{2} \quad Q \xrightarrow{\alpha} Q' \implies \text{ex. } P' \in Prc \text{ such that } P \xrightarrow{\alpha} P' \text{ and } P'\rho Q'$$

$P, Q \in Prc$ are called **strongly bisimilar** (notation: $P \sim Q$) if there exists a strong bisimulation ρ such that $P\rho Q$.

Theorem

\sim is an equivalence relation.

Proof.

on the board



Congruence Property of Strong Bisimulation

Definition (CCS congruence)

An equivalence relation $\cong \subseteq \text{Prc} \times \text{Prc}$ is said to be a **CCS congruence** if it is preserved by the CCS constructs; that is, if $P \cong Q$ then

$$\alpha.P \cong \alpha.Q$$

$$P + R \cong Q + R$$

$$R + P \cong R + Q$$

$$P \parallel R \cong Q \parallel R$$

$$R \parallel P \cong R \parallel Q$$

$$\text{new } a P \cong \text{new } a Q$$

for every $\alpha \in \text{Act}$, $R \in \text{Prc}$, and $a \in N$.

Theorem 7.3

\sim is a CCS congruence.

Proof.

on the board



Deadlock Sensitivity of Strong Bisimulation

Definition (Deadlock)

Let $P, Q \in \text{Prc}$ and $w \in \text{Act}^*$ such that $P \xrightarrow{w} Q$ and $Q \not\rightarrow$. Then Q is called a **w-deadlock** of P .

An equivalence relation $\cong \subseteq \text{Prc} \times \text{Prc}$ is called **deadlock sensitive** if for every $P \cong Q$ such that P has a w -deadlock, Q also has a w -deadlock.

Theorem 7.4

\sim is deadlock sensitive.

Proof.

on the board



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The Problem

We now show that the **word problem for strong bisimulation**

Problem (Word problem for strong bisimulation)

Given: $P, Q \in \text{Prc}$

Question: $P \sim Q?$

is **decidable for finite-state processes** (i.e., for those with $|S(P)|, |S(Q)| < \infty$ where $S(P) := \{P' \in \text{Prc} \mid P \longrightarrow P'\}$)
(in general it is undecidable – see 4th ex. sheet).

To this aim we give an algorithm which **iteratively partitions** the state set of an LTS such that the single blocks correspond to the \sim -equivalence classes.

The Partitioning Algorithm I

Theorem 7.1 (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 $B = \bigcup_{i=1}^k B_i$ 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 becomes stable*

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

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

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

The Partitioning Algorithm II

Remark: if states from two disjoint LTSs $(S_1, Act_1, \longrightarrow_1)$ and $(S_2, Act_2, \longrightarrow_2)$ (where $S_1 \cap S_2 = \emptyset$) are to be compared, their union $(S_1 \cup S_2, Act_1 \cup Act_2, \longrightarrow_1 \cup \longrightarrow_2)$ is chosen as input (here usually $Act_1 = Act_2$)

Example 7.2

Binary semaphore (on the board)

Proof.

(Theorem 7.1; on the board)



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Summary: Properties of Strong Bisimulation

Properties of strong bisimulation

- ① \sim is an equivalence relation
- ② $LTS(P) = LTS(Q) \implies P \sim Q$
- ③ $P \sim Q \implies Tr(P) = Tr(Q)$
- ④ \sim is a CCS congruence
- ⑤ \sim is deadlock sensitive
- ⑥ \sim is decidable for finite-state processes

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Strong Simulation

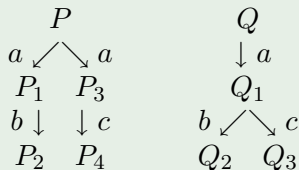
Observation: sometimes, the concept of strong bisimulation is **too strong** (example: extending a system by new features)

Definition 7.3 (Strong simulation)

A relation $\rho \subseteq Prc \times Prc$ is called a **strong simulation** if, whenever $P \rho Q$ and $P \xrightarrow{\alpha} P'$, there exists $Q' \in Prc$ such that $Q \xrightarrow{\alpha} Q'$ and $P' \rho Q'$. We say that Q **strongly simulates** P if there exists a strong simulation ρ such that $P \rho Q$.

Thus: if Q strongly simulates P , then whatever transition path P takes, Q can match it by a path which retains all of P 's options.

Example 7.4



Q strongly simulates P ,
but not vice versa

Strong Simulation and Bisimulation

Corollary 7.5

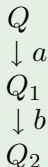
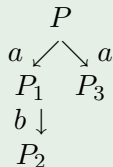
If $P \sim Q$, then Q strongly simulates P , and P strongly simulates Q .

Proof.

A strong bisimulation $\rho \subseteq \text{Proc} \times \text{Proc}$ for $P \sim Q$ is a strong simulation for both directions. □

Caveat: the converse does generally not hold!

Example 7.6



Q simulates P and vice versa,
but $P \not\sim Q$