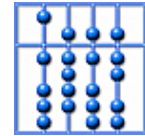


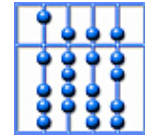
Vorlesung Specification of Distributed Systems

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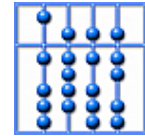
Overview

1. Introduction
2. Basics: Behavior, Interaction, Concurrency
3. Coroutines
4. Communicating Processes
5. Data Flow Models
6. State-Based Models
7. Coordination
8. Executions
9. Property Descriptions



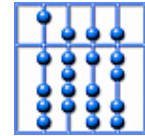
Overview

1. Introduction
2. Basics: Behavior, Interaction, Concurrency
 1. Modeling Computation: State Transition Systems
 2. Modeling Interaction: Labeled Transition Systems
 3. Modeling Concurrency: Synchronized Transition Systems
 4. Modeling Behavior: Streams of Observations
 5. Modeling Communication: Synchronized Behaviors
 6. Modelling Parallelism: Event Structures
3. Coroutines
4. Communicating Processes
5. Data Flow Models
6. State-Based Models
7. Coordination
8. Executions
9. Property Descriptions



2.4 Questions

1. Exercise: Describe the event traces of a two-process system synchronized by a semaphore.
2. What special property holds for the causal order of the event structure of Exercise 1?
3. When is an event trace a prefix of another one?
4. What is the relation between an event trace of a composed system and its sub-systems?
5. What are the event traces of CSP terms
 - STOP
 - $a \rightarrow P$
 - $P \mid Q$
 - $P \parallel Q$
6. Can you tell whether a system consists of concurrent processes by looking at its event traces?



Exercise 1

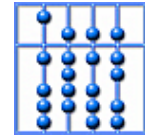
1. Describe the event traces of a two-process system synchronized by a semaphore.

Intuition:

- Actions $P1, V1$ ($P2, V2$) denote completed P/V operation of P1 (P2)
- Events $P1_i, V1_i$ ($P2_i, V2_i$) denote the i -th P/V operation on the semaphore

Formalization: Processes P1, P2

- Alphabet: $\{ P1, V1, P2, V2 \}$
- All possible events: $\{ P1_i, V1_i, P2_i, V2_i \mid i \in \text{Nat} \}$
- Label: $P1_i \rightarrow P1, V1_i \rightarrow V1, P2_i \rightarrow P2, V2_i \rightarrow V2$
- Maximum causal relation:
 - Sequential execution of P1: $P1_i \leq V1_j, P1_j \leq V1_i, V1_i \leq P1_j$, for $0 \leq i < j$
 - Sequential execution of P2: $P2_i \leq V2_j, P2_j \leq V2_i, V2_i \leq P2_j$, for $0 \leq i < j$
 - Cross-synchronization: $V2_i \leq P1_j, V1_i \leq P2_j$, for $0 < i < j$

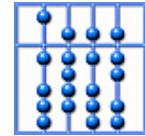


Exercise 1

1. Describe the event traces of a two-process system synchronized by a semaphore.

Intuition: I_1 (I_2) is the set of P/V operations on the semaphore preformed by P1 (P2)

- Event traces:
 - Events $E = E_1 \cup E_2$: Alternative execution of P1 and P2
 - Disjoint sets I_1, I_2 with $I_1 \cup I_2 = [0..n]$
 - Variant 1: Partial trace with final V
 $E_1 = \{P1_i, V1_i \mid i \in I_1\}$, and $E_2 = \{P2_i, V2_i \mid i \in I_2\}$
 - Variant 2: Partial trace without final V
 $E_1 = \{P1_i, V1_i \mid i \in I_1\} \setminus \{V1_n\}$, or $E_2 = \{P2_i, V2_i \mid i \in I_2\} \setminus \{V2_n\}$
 - Variant 3: Complete trace: $n = \infty$
 - Causal relation: Causal relation as prescribed by maximum causal relation



Question 2

What special property holds for the causal order of the event structure of Exercise 1?

The causal order (of a specific event structure) of exercise 1 forms a linear order:

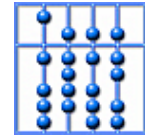
- Disjoint sets I_1, I_2 with $I_1 \cup I_2 = [0..n]$
- (Variant 1) $E_1 = \{P_{1_i}, V_{1_i} \mid i \in I_1\}$, $E_2 = \{P_{2_i}, V_{2_i} \mid i \in I_2\}$
- Sequential execution of P_1 : $P_{1_i} \leq V_{1_j}$, $P_{1_j} \leq V_{1_i}$, $V_{1_i} \leq P_{1_j}$, for $0 \leq i < j$
- Sequential execution of P_2 : $P_{2_i} \leq V_{2_j}$, $P_{2_j} \leq V_{2_i}$, $V_{2_i} \leq P_{2_j}$, for $0 \leq i < j$
- Cross-synchronization: $V_{2_i} \leq P_{1_j}$, $V_{1_i} \leq P_{2_j}$, for $0 < i < j$

Since I_1, I_2 disjoint, we ignore the process labels and obtain:

- Events: $E = \{P_i, V_i \mid i \in [0..n]\}$
- Causal order: $P_i \leq V_j$, $P_j \leq V_i$, $V_{1_i} \leq P_{1_j}$, for $0 \leq i < j$

This corresponds to $P_0 \leq V_0 \leq P_1 \leq V_1 \leq P_2 \leq V_2 \leq \dots$

Therefore: The event structures form (sequential) execution traces



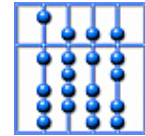
Question 3

When is an event trace a prefix of another event trace?

Intuition: A trace of a process is a prefix of another trace of a process if both describe the same execution and the former is a beginning of the later

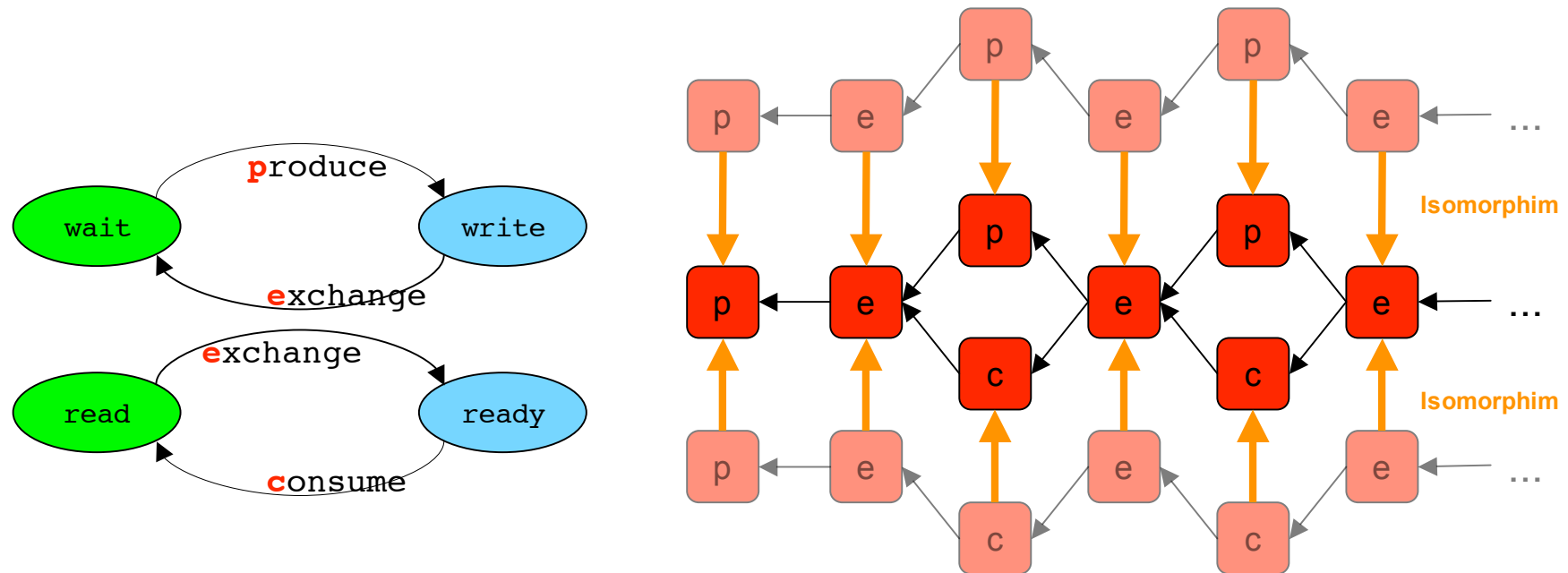
Formal prefix property: $(A1, E1, L1, C1) \leq (A2, E2, L2, C2)$

- Alphabets in subset relation: $A1 \subseteq A2$
- Events in subset relation: $E1 \subseteq E2$
- Labeling in subset relation: $L1 \subseteq L2$
- Causal relation in subset relation: $C1 \subseteq C2$

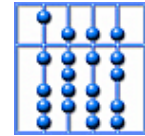


Question 4

What is the relation of the event structures of a composed system to the event structures of its sub-systems?



Note: To identify common events of the subsystems, an isomorphism relates the events of the combined system to the events of each sub-system, respecting the alphabet of the actions and the causal orders



Question 4

What is the relation of the event structures of a composed system to the event structures of its sub-systems?

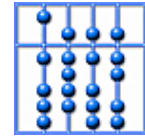
Subsystems:

- Subsystem 1: $(A1, E1, L1, C1)$
- Subsystem 2: $(A2, E2, L2, C2)$

Combined system: $(A1 \cup A2, E1' \cup E2', L1' \cup L2', C1' \cup C2')$ with

- $(A1, E1, L1, C1)$ is isomorphic (concerning $E1$ and $E1'$) to $(A1, E1', L1', C1')$
- $(A2, E2, L2, C2)$ is isomorphic (concerning $E2$ and $E2'$) to $(A2, E2', L2', C2')$

Note: This principle applies to sequential composition and parallel composition

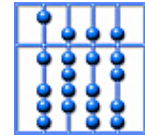


Question 5

What are the event traces of the CSP terms STOP , $a \rightarrow P$?

Event traces:

- Deadlock: STOP_A
 - Alphabet: A
 - Events: \emptyset
 - Labels: \emptyset
 - Causal order: \emptyset
- Prefix: $a \rightarrow P$
 - Alphabet: $\{ a \} \cup \text{Alphabet of } P$
 - Events: $\{ e \} \cup \text{Events of } P$
 - Labels: $\{ e \rightarrow a \} \cup \text{Labels of } P$
 - Causal order: $\{ e \leq e' \mid e' \in \text{Events of } P \} \cup \text{Causal order of } P$

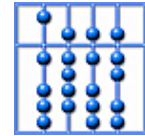


Question 5

What are the event traces of CSP terms $P \mid Q$ and $P \parallel Q$?

Event traces:

- Choice: $P \mid Q$
 - Alphabet: Alphabet of $P \cup$ Alphabet of Q
 - Events: Events of P or Events of Q
 - Labels: Labels of P or Labels of Q
 - Causal order: Order of P or order of Q
- Parallel composition: As described in Question 3



Question 6

Can you tell whether a system consists of concurrent processes by looking at its event traces?

Event traces describe causal dependencies, they distinguish between independent actions and sequentialized actions.

Therefore: They explicitly distinguish between concurrent and sequential execution.

Example: Arbitrary sequentialization vs parallel execution of actions “a” and “b”:

- Parallel execution: $(\{e_1, e_2\}, \{a, b\}, \{e_1 \rightarrow a, e_2 \rightarrow b\}, \emptyset)$
- Sequentialization: $(\{e_1, e_2\}, \{a, b\}, \{e_1 \rightarrow a, e_2 \rightarrow b\}, \{e_1 \leq e_2\})$ or $(\{e_1, e_2\}, \{a, b\}, \{e_1 \rightarrow a, e_2 \rightarrow b\}, \{e_2 \leq e_1\})$