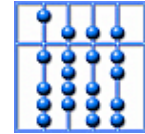


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## **Specification of Distributed Systems**

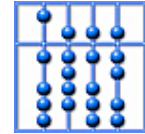
Dr. Bernhard Schätz  
Leopold-Franzens Universität Innsbruck  
Sommersemester 2005



# Overview

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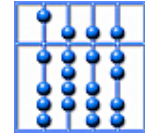
1. Introduction
2. Basics: Behavior, Interaction
  1. Modeling Computation: State Transition Systems
  2. Modeling Interaction: Labeled Transition Systems
  3. Modeling Concurrency: Synchronized Transition Systems
  4. Modeling Behavior: Streams of Observations
  5. Modeling Communication: Synchronized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



## 2.6 Questions

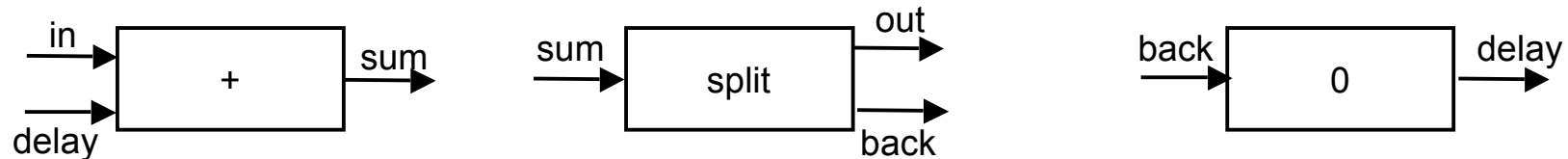
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1. Exercise: Describe the behavior of the adder, doubler, and initializer for values  $-2, \dots, 2$  and traces up to length 3.
2. Exercise: Calculate the behavior of the integrator from those behaviors.
3. What is the difference between the traces of a LTS of a system and a stream-based behavior describing the same system?
4. When does a behavior describe a receptive (i.e. input-enabled system)?
5. When does a behavior describe a deterministic system?
6. Allowing only untimed behavior, what kind of send/receive actions are possible?
7. What kind of untimed structured behavior corresponds to systems obeying Questions 4 and 5



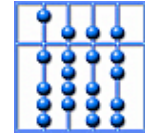
## Exercise 1

Exercise: Describe the behavior of the adder, splitter, and initializer for values  $-2, \dots, 2$  and traces up to length 3.



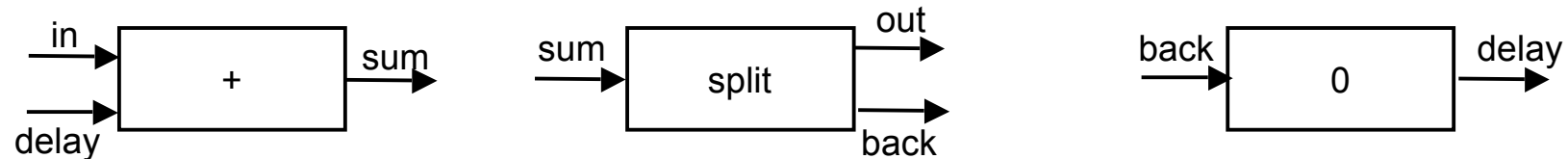
Components:

- Adder: Emits sum of inputs (timed: next round) when provided with two inputs (timed: the same round: )
  - Timed Behavior, e.g.,  $(- \bullet - \bullet -, - \bullet - \bullet -, - \bullet - \bullet -)$ ,  $(-2 \bullet 1 \bullet 2, - \bullet 0 \bullet -1, - \bullet - \bullet 1)$ ,  $(-2 \bullet 1 \bullet 2, 1 \bullet 0 \bullet -1, - \bullet -1 \bullet 1)$
  - Untimed Structured Behavior, e.g.,  $(\langle \rangle, \langle \rangle, \langle \rangle)$ ,  $(-2 \bullet 1 \bullet 2, 0 \bullet -1, -2 \bullet 1)$ ,  $(-2 \bullet 1 \bullet 2, 1 \bullet 0 \bullet -1, -2 \bullet 1 \bullet 1)$
  - Untimed Behavior:  $\langle \rangle$ ,  $(in, -2) \bullet (in, 1) \bullet (delay, 1) \bullet (in, 2) \bullet (delay, 0) \bullet (sum, -2) \bullet (sum, 1)$ ,  $(delay, 1) \bullet (in, -2) \bullet (in, 1) \bullet (delay, 0) \bullet (in, 2) \bullet (sum, -2) \bullet (sum, 1) \bullet (delay, -1) \bullet (sum, 1)$



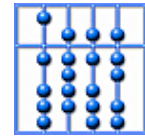
## Exercise 1

Exercise: Describe the behavior of the adder, splitter, and initializer for values  $-2, \dots, 2$  and traces up to length 3.



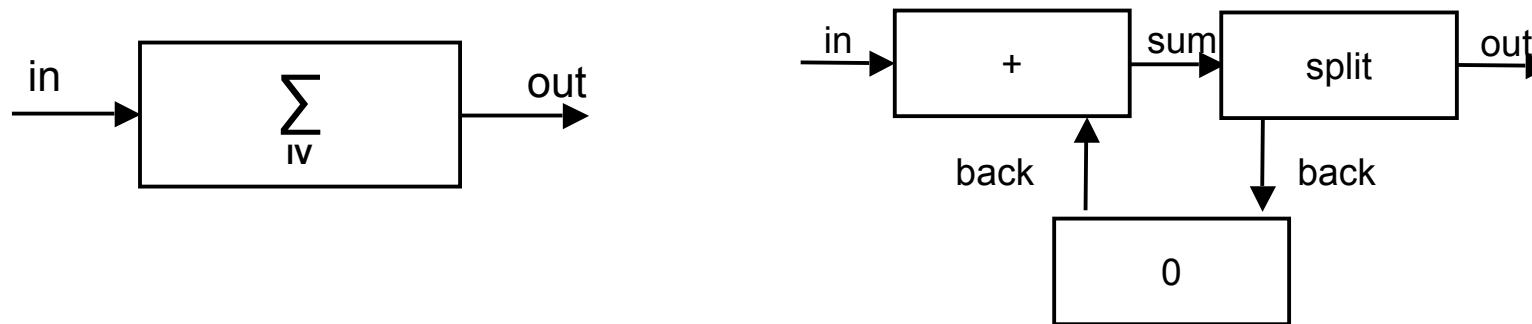
Components:

- Splitter: Emits the input on both output ports (timed: same round):
  - Timed Behavior, e.g.,  $(- \cdot - \cdot - \cdot -, - \cdot - \cdot - \cdot -, - \cdot - \cdot - \cdot -)$ ,  $(-2 \cdot 1 \cdot -, -2 \cdot 1 \cdot -, -2 \cdot 1 \cdot -)$
  - Untimed Structured Behavior, e.g.,  $(\langle \rangle, \langle \rangle, \langle \rangle)$ ,  $(-2 \cdot 1, -2 \cdot 1, -2 \cdot 1)$
  - Untimed Behavior:  $\langle \rangle$ ,  $(\text{sum}, -2) \cdot (\text{out}, -2) \cdot (\text{sum}, 1) \cdot (\text{back}, -2) \cdot (\text{back}, 1) \cdot (\text{out}, 1)$
- Initializer: Emits 0 (timed: in the first round), then its input
  - Timed Behavior, e.g.,  $(- \cdot - \cdot - \cdot -, 0 \cdot - \cdot - \cdot -)$ ,  $(-2 \cdot 1 \cdot -, 0 \cdot -2 \cdot 1)$
  - Untimed Structured Behavior, e.g.,  $(\langle \rangle, 0)$ ,  $(-2 \cdot 1, 0 \cdot -2 \cdot 1)$
  - Untimed Behavior:  $(\text{delay}, 0)$ ,  $(\text{delay}, 0) \cdot (\text{back}, -2) \cdot (\text{delay}, -2) \cdot (\text{back}, 1) \cdot (\text{delay}, -2)$



## Exercise 2

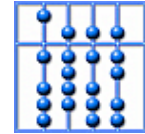
Exercise: Calculate the behavior of the integrator from those behaviors.



Integrator: If presented with an input, the integrator produces the sum of all inputs received so far (including the last input)

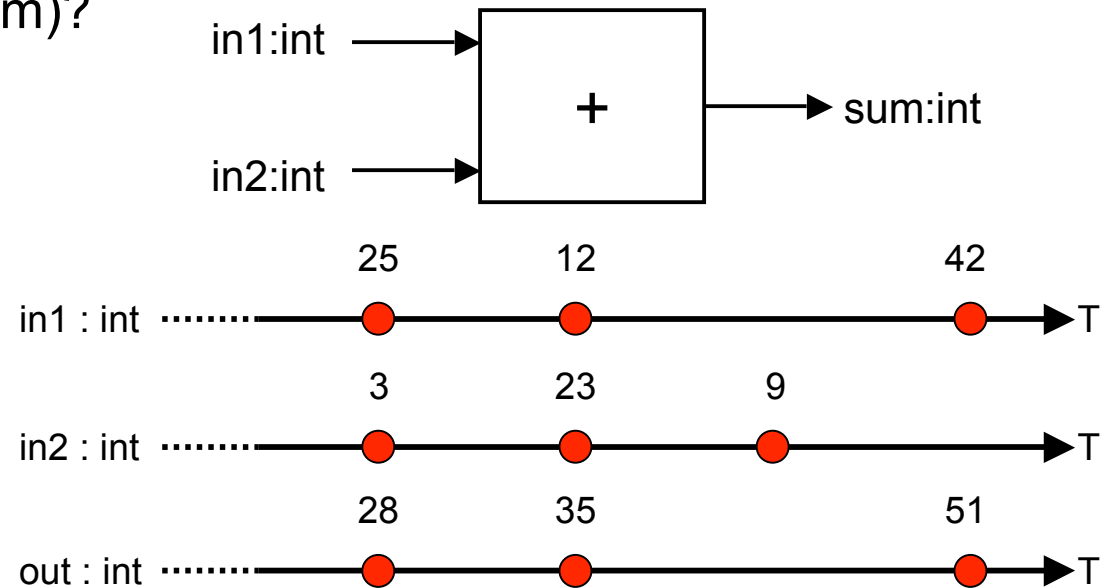
Combined behavior:

- Timed Behavior, e.g.,  $(- \bullet - \bullet - , - \bullet - \bullet -)$ ,  $(-2 \bullet 1 \bullet - , -2 \bullet -1 \bullet -)$
- Untimed Structured Behavior, e.g.,  $(\langle \rangle , \langle \rangle)$ ,  $(-2 \bullet 1 , -2 \bullet -1)$
- Untimed Behavior, e.g.,  $\langle \rangle$ ,  $(in, -2) \bullet (out, -2) \bullet (in, 1) \bullet (out, -1)$



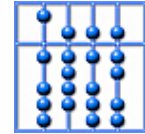
## Question 4

When does a behavior describe a receptive (i.e. input-enabled system)?



Receptiveness: Input cannot be blocked

- Timed observations: for all  $i \in \text{In}^\omega$ . exists  $o \in \text{Out}^\omega$ .  $(i,o) \in B$
- Untimed structured observations: for all  $i \in \text{In}^\omega$ . exists  $o \in \text{Out}^\omega$ .  $(i,o) \in B$
- Untimed observations: if  $t \cdot o \in B$  for  $o \in \text{Out}^\omega$  then  $t \cdot i \cdot o \in B$  for  $i \in \text{In}$



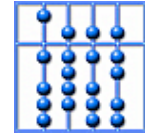
## Question 5

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When does a behavior describe a deterministic system?

Deterministic behavior:

- Interpretation: The system does not offer choices controlled by the system
- Data flow systems: The system does not offered different output to the environment given the same input
- Models:
  - Timed model: forall  $(i,o),(i',o') \in B$ . if  $i = i'$  then  $o = o'$
  - Untimed structured model: forall  $(i,o),(i',o') \in B$ . if  $i = i'$  then  $o = o'$
  - Untimed model: forall  $b,b' \in B$ . if  $b \odot I = b' \odot I$  then  $b \odot O = b' \odot O$



## Question 6

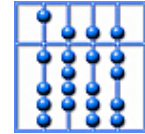
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Allowing only untimed structured behavior, what kind of send/receive actions are possible?

Untimed behavior:

- Interpretation: Temporal causality of input/output not recognizable
- Send actions: Non-blocking send
- Receive actions: Blocking received

Improved versions: Non-blocking send vs. Timeouts (e.g., SDL)



## Question 7

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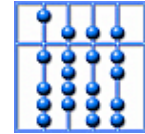
What kind of untimed structured behavior corresponds to systems obeying Questions 4 and 5

Restrictions:

- Receptive behavior: For each input of the environment, there is at least one output of the system
- Deterministic behavior: For each input of the environment, there is at most one output of the system

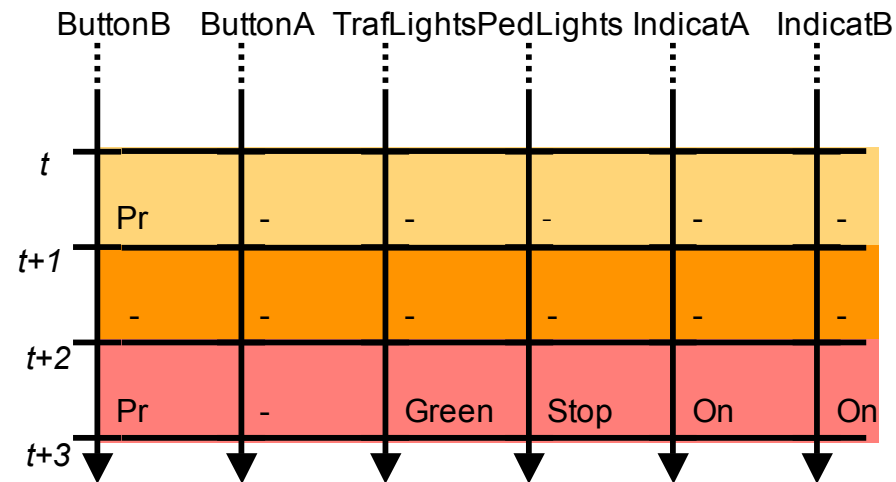
Model: Untimed structured behavior:  $B \subseteq \text{In}^\omega \times \text{Out}^\omega$

- Receptive Behavior: for all  $i \in \text{In}^\omega$ . exists  $o \in \text{Out}^\omega$ .  $(i, o) \in B$
- Deterministic Behavior: for all  $(i, o), (i', o') \in B$ . if  $i = i'$  then  $o = o'$
- Formal: Function from input streams to output streams



## Question 8

Can you tell whether an asynchronous system is atomic/compound by looking at its observation traces?

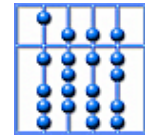


Observation trace:

- Signal for each port (i.e., value of each port for each round)
- Parallel assignment to all interface ports for each round

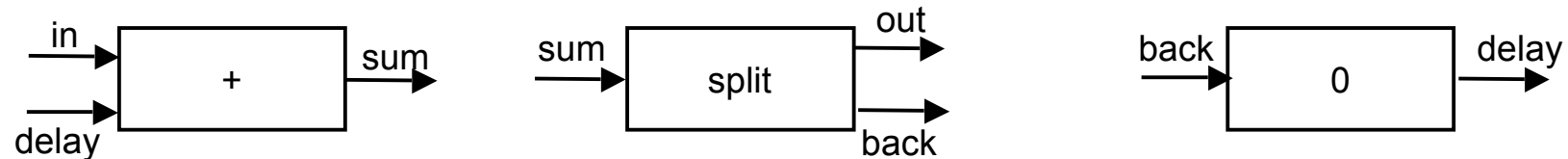
Therefore: Compound/atomic system not distinguishable

- Construction: Output-factored behaviors



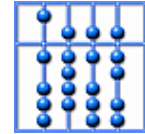
## Question 9

What behavior is obtained for the integrator in the untimed model using an undelayed feedback (i.e., using a simple copy function instead of an initializer) for input  $0 \cdot 0 \cdot \dots$ , ?



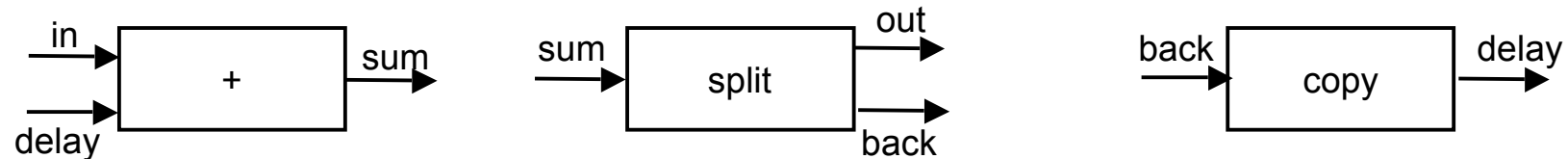
Components:

- Adder: (in,delay, sum), e.g., ( $\langle \rangle$ ,  $\langle \rangle$ ,  $\langle \rangle$ ), (0, 0, 0), ( $0 \cdot 1$ ,  $0 \cdot 1$ ,  $0 \cdot 1$ )
- Splitter: (sum,out,back), e.g., ( $\langle \rangle$ ,  $\langle \rangle$ ,  $\langle \rangle$ ), ( $0 \cdot 1$ ,  $0 \cdot 1$ ,  $0 \cdot 1$ )
- Initalizer: (back, delay), e.g., ( $\langle \rangle$ ,  $\langle \rangle$ ), (0, 0), ( $0 \cdot 1$ ,  $0 \cdot 1$ )
  
- Combined Behavior: (in, delay, sum, out, back), e.g., ( $0 \cdot 0 \cdot \dots$ ,  $0 \cdot 0 \cdot \dots$ ,  $0 \cdot 0 \cdot \dots$ ,  $0 \cdot 0 \cdot \dots$ ,  $0 \cdot 0 \cdot \dots$ )



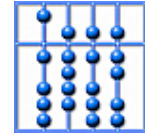
## Question 10

Does the obtained behavior make sense from an operational point of view?  
Explain the answer? If not, is there a possible cure for that case?



Combined Behavior:

- Obtained behavior: (in, delay, sum, out, back), e.g.,  
(0 • 0 • ..., 0 • 0 • ..., 0 • 0 • ....., 0 • 0 • ....., 0 • 0 • ...)
- Operational interpretation: Pathological case
  - Input of initializer is caused by its output
  - Operational behavior:
    - Copy function has only observation (<>, <>)
    - Integrator function has only observation (0 • 0 • ..., <>)
- Cure: If there are multiple solutions, use shortest satisfying solution



## Question 11

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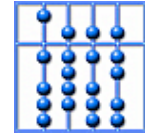
Which model is more abstract - untimed or untimed structured traces?  
Define a mapping from the more concrete to the more abstract model.

Abstraction: Abstract model has less information than concrete model

Order abstraction: Structured model loses information about relative ordering on ports

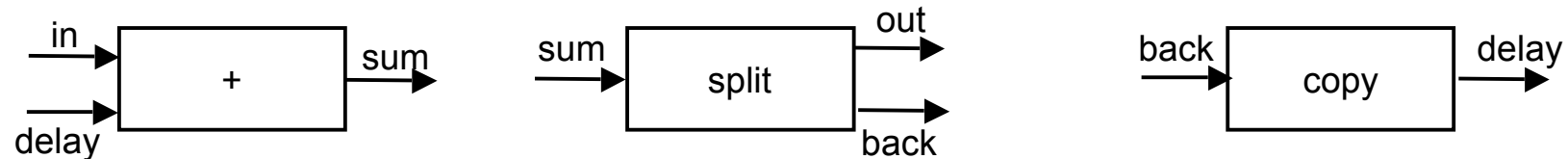
Mapping: Structured behavior  $s$  is obtained from unstructured behavior  $t$  by projection on individual ports

- Splitter component:  $s = (t \textcircled{C} \text{sum}, t \textcircled{C} \text{out}, t \textcircled{C} \text{back})$
- Example:  $(-2 \cdot 1, -2 \cdot 1, -2 \cdot 1) = (\text{sum}, -2) \cdot (\text{out}, -2) \cdot (\text{sum}, 1) \cdot (\text{back}, -2) \cdot (\text{back}, 1) \cdot (\text{out}, 1), (\text{sum}, -2) \cdot (\text{out}, -2) \cdot (\text{sum}, 1) \cdot (\text{back}, -2) \cdot (\text{back}, 1) \cdot (\text{out}, 1), (\text{sum}, -2) \cdot (\text{out}, -2) \cdot (\text{sum}, 1) \cdot (\text{back}, -2) \cdot (\text{back}, 1) \cdot (\text{out}, 1)$



## Question 12

Can the same anomaly appear in the unstructured untimed model? Explain your answer.



Combined Behavior:

- Pathological case: In untimed model e.g.,  
(in,0) • (sum,0) • (in,0) • (sum,0) • ....
- Untimed unstructured model: Pathological case not possible because
  - Adder: (sum,0) must be preceded by (delay,0) in its traces
  - Copy: (delay,0) must be preceded by (back,0) in its traces
  - Split: (back,0) must be preceded by (sum,0) in its traces
  - Integrator: Combined behavior
    - In a legal trace, each (sum,0) must be preceded by a (sum,0)
    - Only legal trace: <>