UNIVERSITÄT ZU LÜBECK
INSTITUTE FOR SOFTWARE ENGINEERING
AND PROGRAMMING LANGUAGES

isp

Rapidly Adjustable Non-Intrusive Online Monitoring for Multi-core Systems

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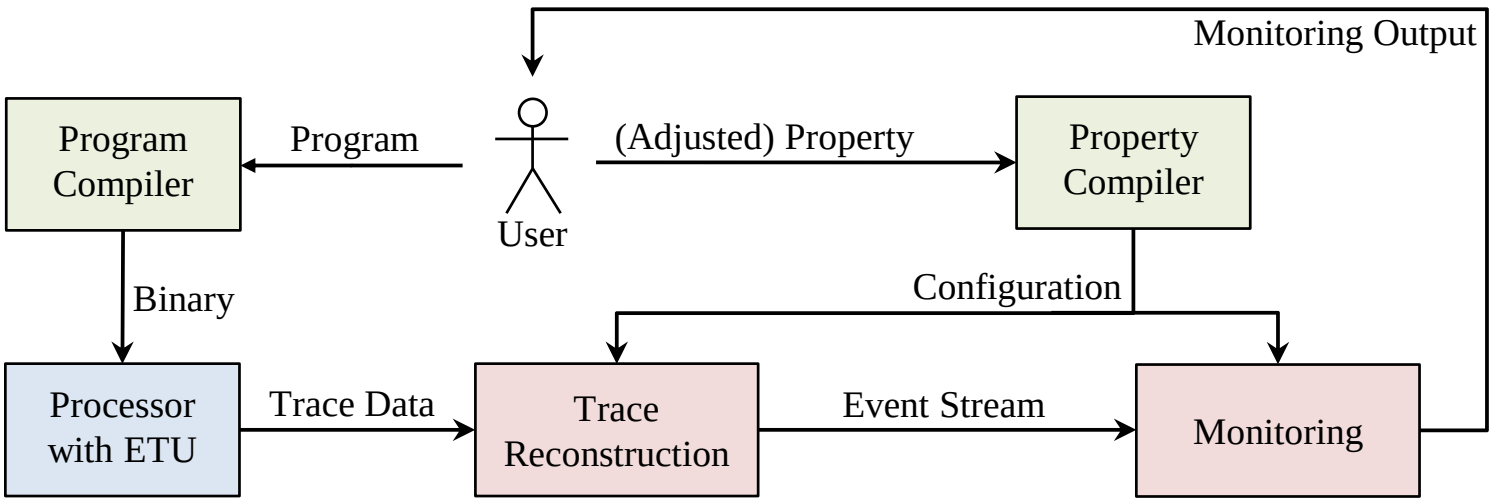
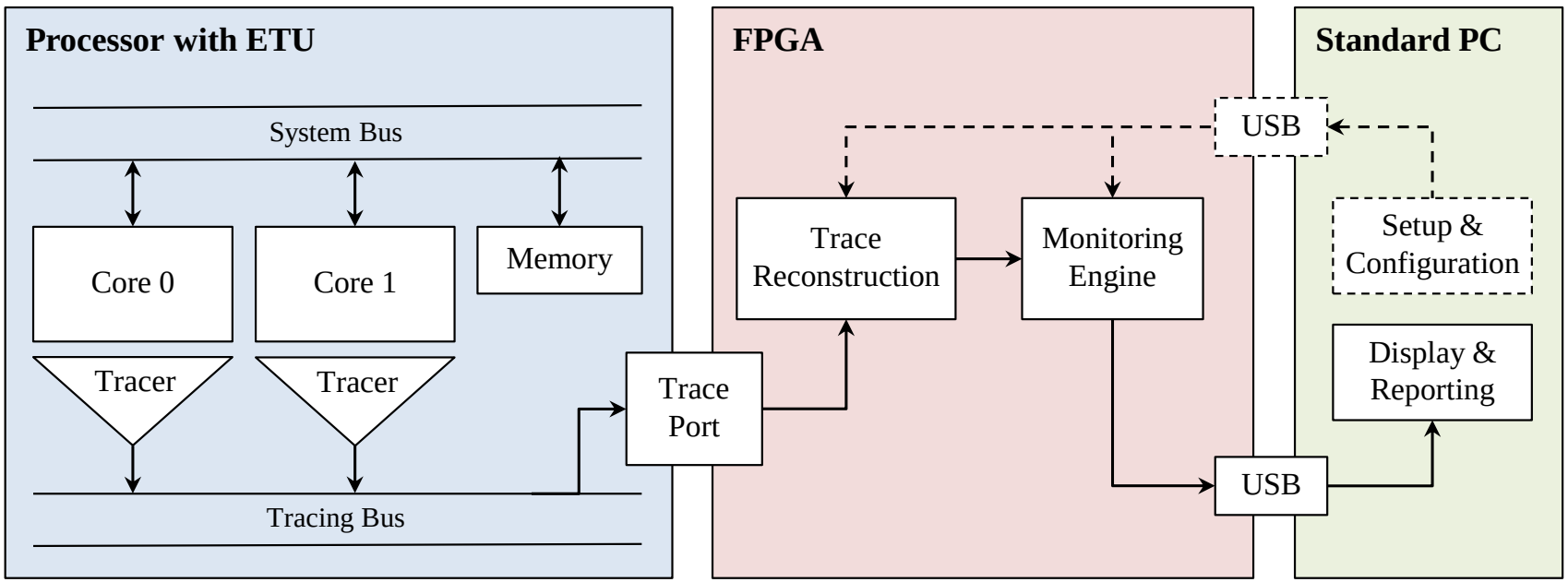
Goals

- Online monitoring
  - $\Rightarrow$ No offline computation
  - $\Rightarrow$ Live trace reconstruction and event processing on FPGA
- Non-intrusive for the system under test
  - $\Rightarrow$ No instrumentation
  - $\Rightarrow$ External trace port
- Rapidly adjustable monitors
  - $\Rightarrow$ Not synthesizing the monitor
  - $\Rightarrow$ Synthesize flexible FPGA architecture which can be configured
- Common trace source
  - $\Rightarrow$ No special hardware
  - $\Rightarrow$ Embedded Trace Unit (ETU)

RETOM Workflow



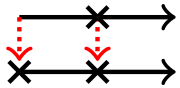
Architecture



Temporal Stream-based Specification Language

Temporal Stream-based Specification Language

default, defaultFrom



- Initialize streams
- Start of recursion

Temporal Stream-based Specification Language

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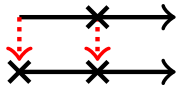

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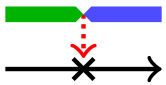
time



- Get timestamps of stream
- Replaces data values with timestamps
- Only way to read timestamps

Temporal Stream-based Specification Language

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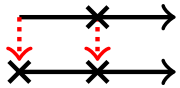

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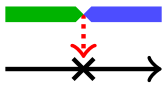

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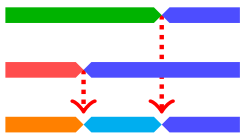
lift



- Lifts standard functions to streams
- Used to manipulate data, events, ...

TeSSLa: Lifted Addition

Lift arbitrary functions to streams with signal semantics.

$$\mathsf{lift}_{\mathbb{D}_1,\ldots,\mathbb{D}_n,\mathbb{D}'} : (\mathbb{D}_1 \times \cdots \times \mathbb{D}_n \rightharpoonup \mathbb{D}') \to (\mathcal{S}_{\mathbb{D}_1} \times \cdots \times \mathcal{S}_{\mathbb{D}_n} \to \mathcal{S}_{\mathbb{D}'})$$

$$\mathsf{add} : \mathbb{Z} \times \mathbb{Z} \to \mathbb{Z},$$
$$z = \mathsf{lift}(\mathsf{add})(x, y)$$

Temporal Stream-based Specification Language

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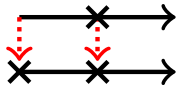

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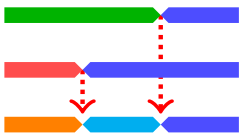

- Lifts standard functions to streams
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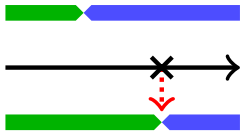
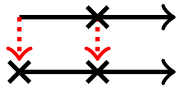
last



- Refers to previous value of a stream
- Recursion

Temporal Stream-based Specification Language

default, defaultFrom



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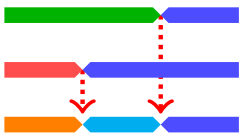
lift



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- Used to manipulate data, events, ...

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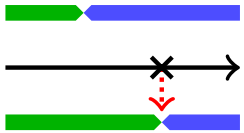
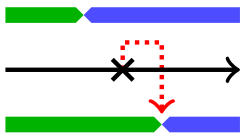


- Refers to previous value of a stream
- Recursion

delayedLast



- Only way to create events
- Takes a stream and delays events by its current value
- Output events have the previous value of another given stream

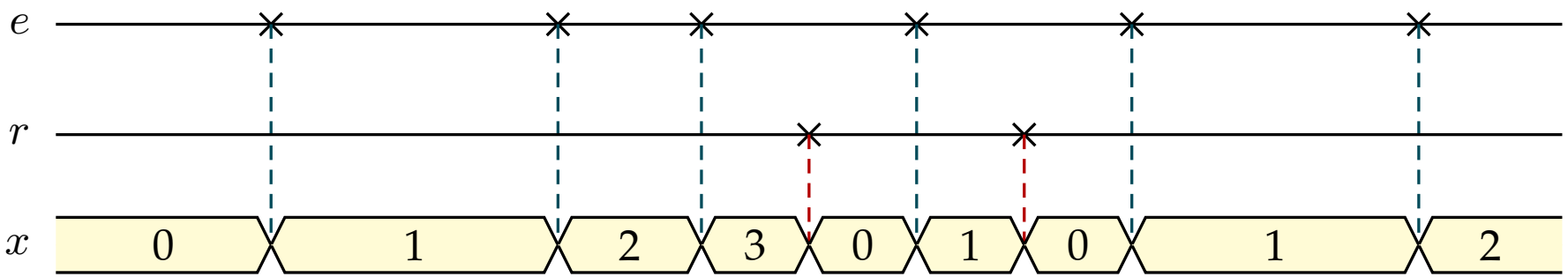
TeSSLa: easy example

Let $a \in \mathcal{S}_{\text{Int}}$ be an input stream, $x, y \in \mathcal{S}_{\text{Int}}$ be intermediate streams and $z \in \mathcal{S}_{\text{Int}}$ be the output stream.

TeSSLa specifications can be seen as a system of equations:

```
x = last(z, a)
y = default(x, 0)
z = y + a
```

TeSSLa by Example



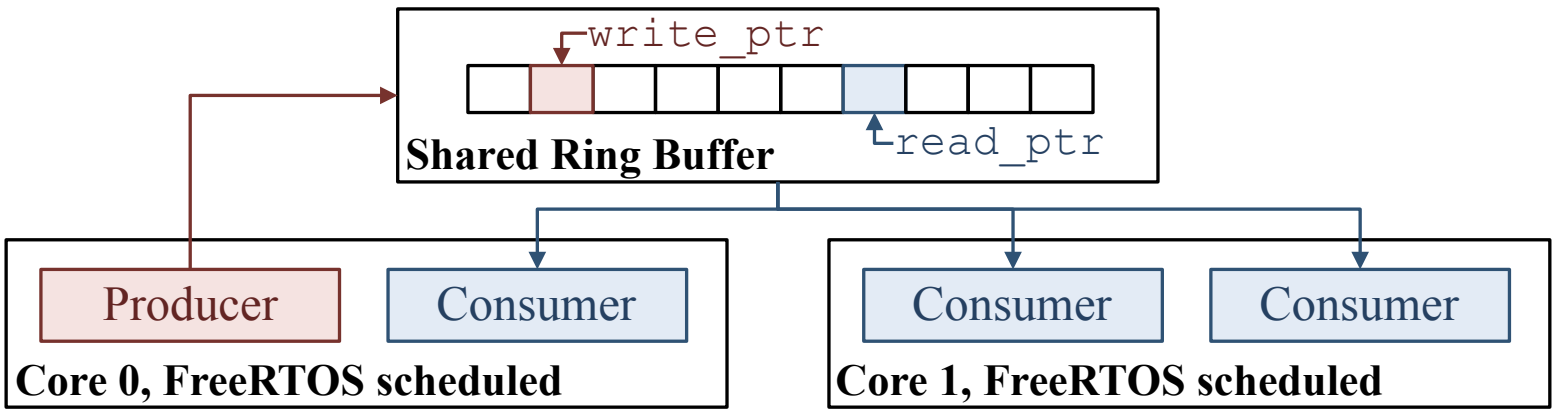

```
def x := eventCount(e, reset = r)
```

TeSSLa Standard Library

Counting events until reset

```
def eventCount(values, reset) :=
  default(
    if default(time(reset) > time(values), false)
    then 0
    else if default(time(reset) == time(values), false)
    then 1
    else last(eventCount, values) + 1
  , 0)
```

FPGA configuration and case study



Case study properties

Property a)

```
-- INPUT STREAM DEFINITION
def ptrChanged := merge(codeLine("core0.c:27"),
                        codeLine("core1.c:27"))
def stop :=  functionCalls("core0.c:stopConsumers")
def start := functionCalls("core0.c:startConsumers")

-- PROPERTY
def clk := merge(stop, ptrChanged, start)
def output :=
  monitor("always(stop implies
     (not(ptrChanged) until start))",
     step := clk)
out output
```

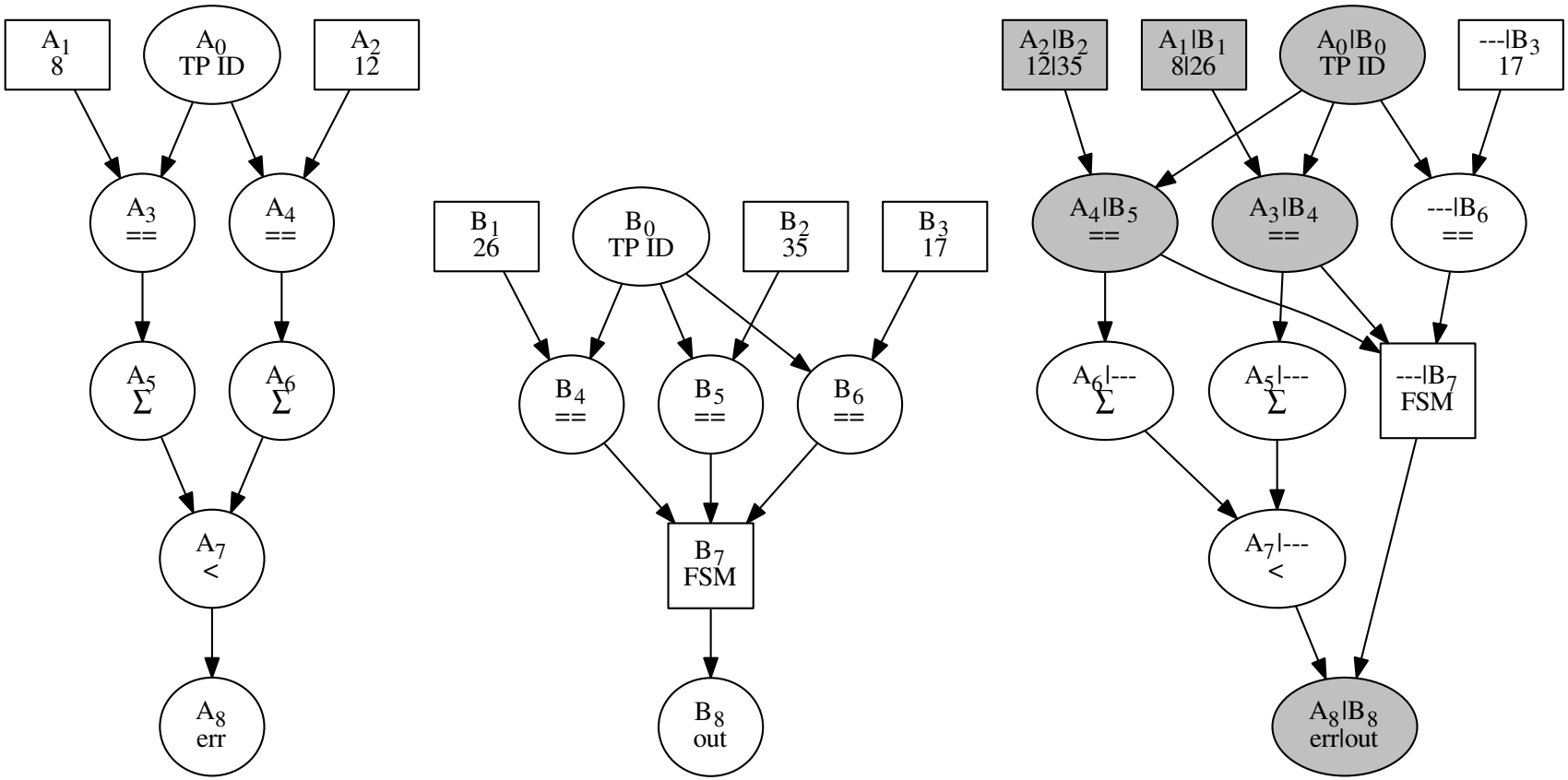
Case study properties

Property b)

```
-- INPUT STREAM DEFINITION
def write := codeLine("core0.c:37")
def read0 := codeLine("core0.c:24")
def read1 := codeLine("core1.c:24")

-- PROPERTY
def err :=
eventCount(read0) + eventCount(read1) > eventCount(write)
out err
```

FPGA configuration example



FPGA reconfiguration

Property c)

```
-- MACRO CALL
out doubleRead(
  read := codeLine("core0:24"),
  ptrChanged := codeLine("core0:27"))
```

where `doubleRead` is a macro defined as follows:

```
-- MACRO DEFINITION
def doubleRead(read, ptrChanged) := {
  def clk := merge(read, ptrChanged)
  monitor("always(read implies
    next(not(read) until ptrChanged))",
    step := clk)
}
```

Same for core 1 by replacing the zeros with ones.

Outlook – TeSSLa

In the future, the following features would be desirable for TeSSLa:

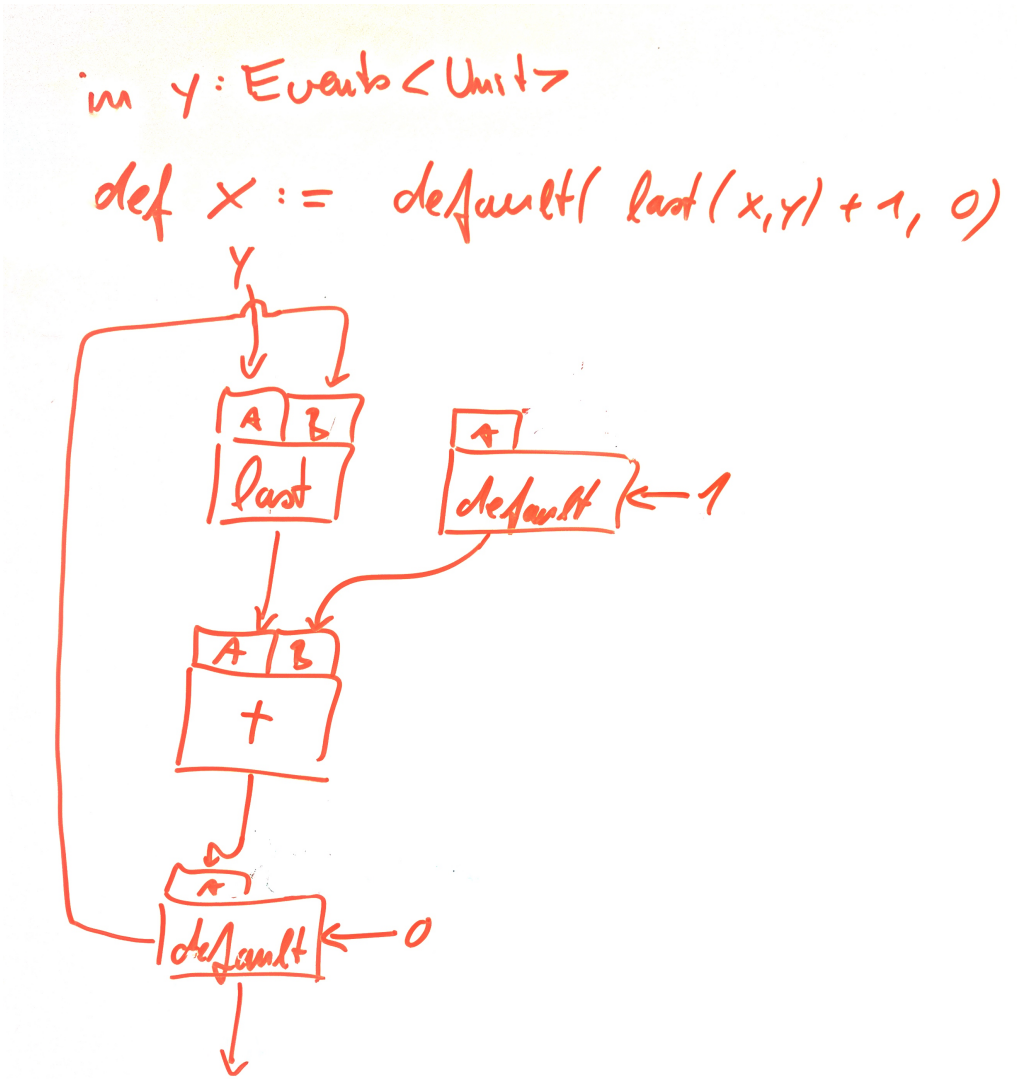
- High level data structures like maps and queues
- Possibility to handle gaps and uncertainties in streams
- ...

This will result in

$$\underset{\text{Bounded maps / queues, ...}}{\text{TeSSLa}_{\text{Hardware}}} \subset \underset{\text{Effectively monitorable}}{\text{TeSSLa}_{\text{Software}}} \subseteq \text{TeSSLa}$$

Outlook – FPGA Monitors

- More flexible approach
- Configurable RV-Engines instead of graphs
- Core functions instead of high level ones



Appendix

Temporal Stream-based Specification Language

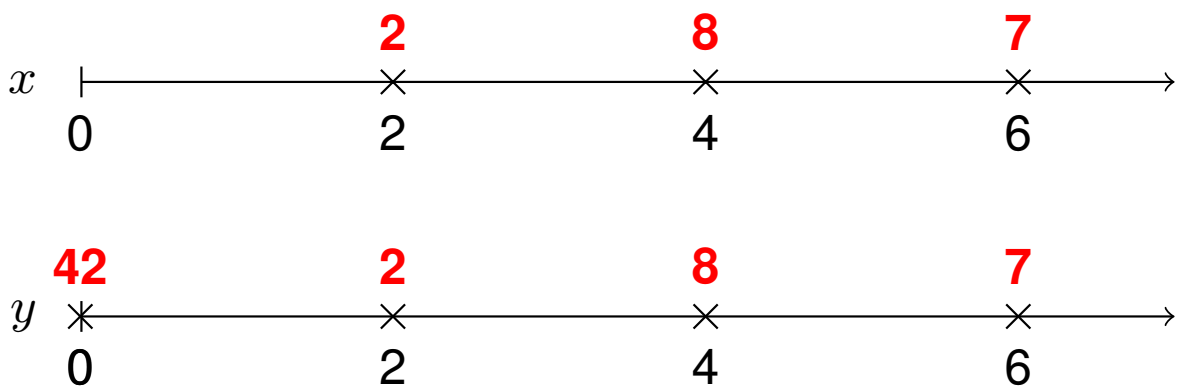
- Reasons over a set of **non-synchronized real-time streams**
- **Declarative** style: Specification rather than implementation
- **Modularity**: Allowing abstractions based on six core operators
- **Time** as first-class citizen
- Abstraction for both, **events** and **signals**
- **Recursion** to reason about the past
- Implementable with **finite memory**

TeSSLa Core: Default

Add a value at time zero if not present.

$$\mathsf{default}_{\mathbb{D}} : \mathbb{D} \times \mathcal{S}_{\mathbb{D}} \to \mathcal{S}_{\mathbb{D}}$$

$$y = \mathsf{default}(42, x)$$

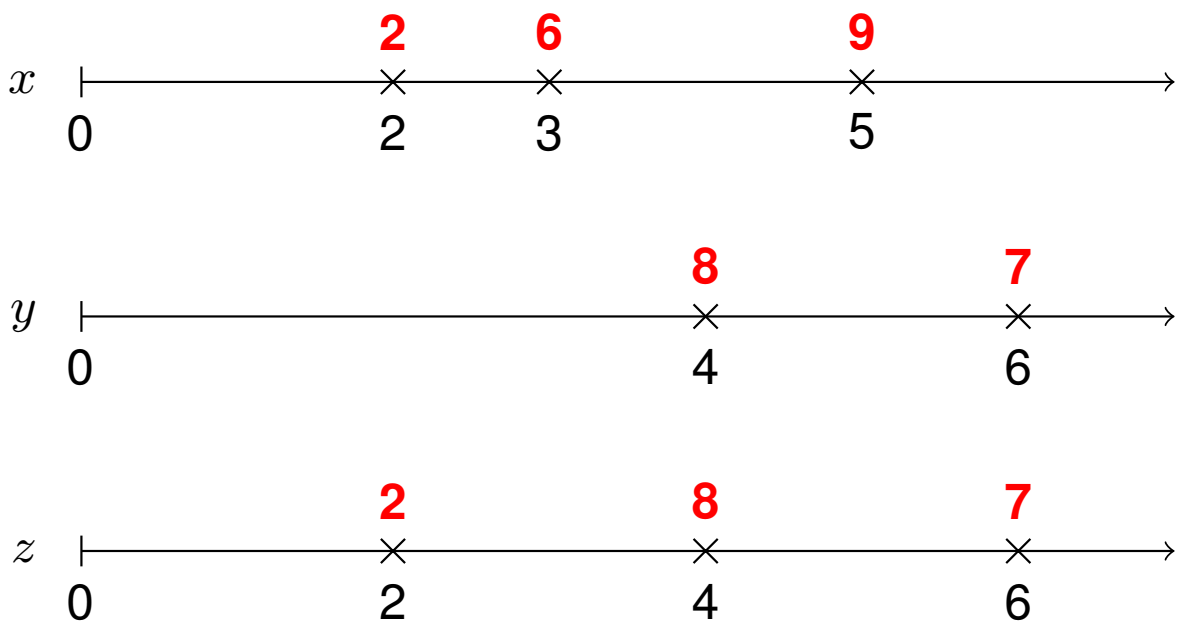


TeSSLa Core: Default From

Add first value from another stream if nothing happened before.

$$\mathsf{defaultFrom}_{\mathbb{D}} : \mathcal{S}_{\mathbb{D}} \times \mathcal{S}_{\mathbb{D}} \to \mathcal{S}_{\mathbb{D}}$$

$$z = \mathsf{defaultFrom}(x, y)$$

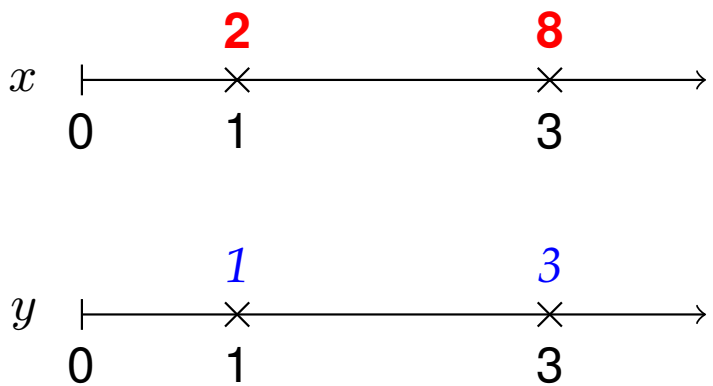


TeSSLa Core: Time

Get the time of events.

$$\mathsf{time}_{\mathbb{D}} : \mathcal{S}_{\mathbb{D}} \to \mathcal{S}_{\mathbb{T}}$$

$$y = \mathsf{time}(x)$$



TeSSLa Core: Lifted Addition

Lift arbitrary functions to streams with signal semantics.

$$\mathsf{lift}_{\mathbb{D}_1,\ldots,\mathbb{D}_n,\mathbb{D}'} : (\mathbb{D}_1 \times \cdots \times \mathbb{D}_n \rightharpoonup \mathbb{D}') \to (\mathcal{S}_{\mathbb{D}_1} \times \cdots \times \mathcal{S}_{\mathbb{D}_n} \to \mathcal{S}_{\mathbb{D}'})$$

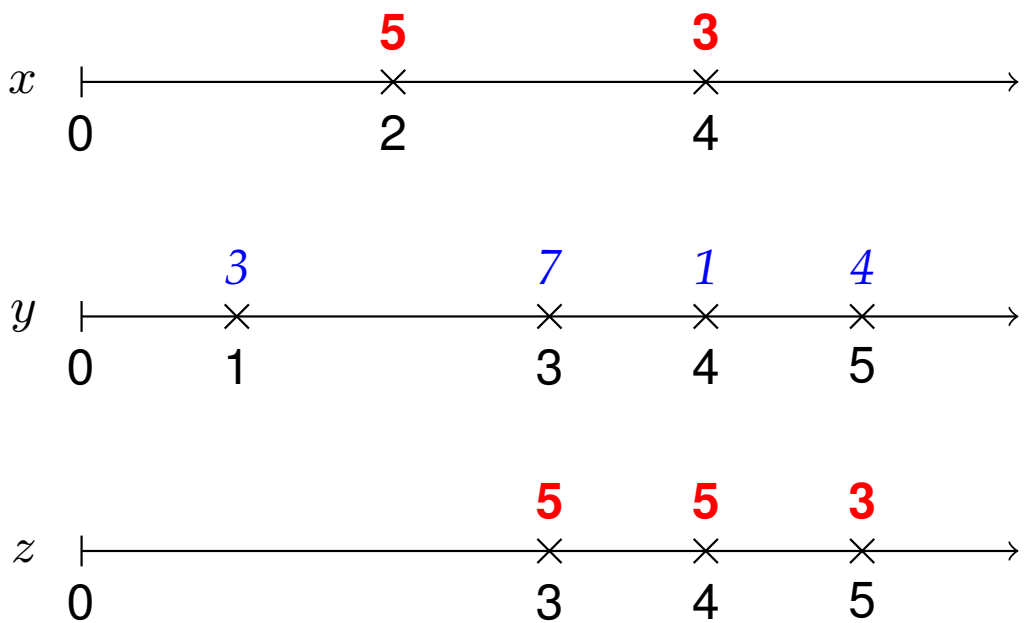
$$\mathsf{add} : \mathbb{Z} \times \mathbb{Z} \to \mathbb{Z},$$
$$z = \mathsf{lift}(\mathsf{add})(x, y)$$

TeSSLa Core: Last

Get the last value of a stream at a certain point in time.

$$\mathsf{last}_{\mathbb{D},\mathbb{D}'} : \mathcal{S}_{\mathbb{D}} \times \mathcal{S}_{\mathbb{D}'} \to \mathcal{S}_{\mathbb{D}}$$

$$z = \mathsf{last}(x, y)$$

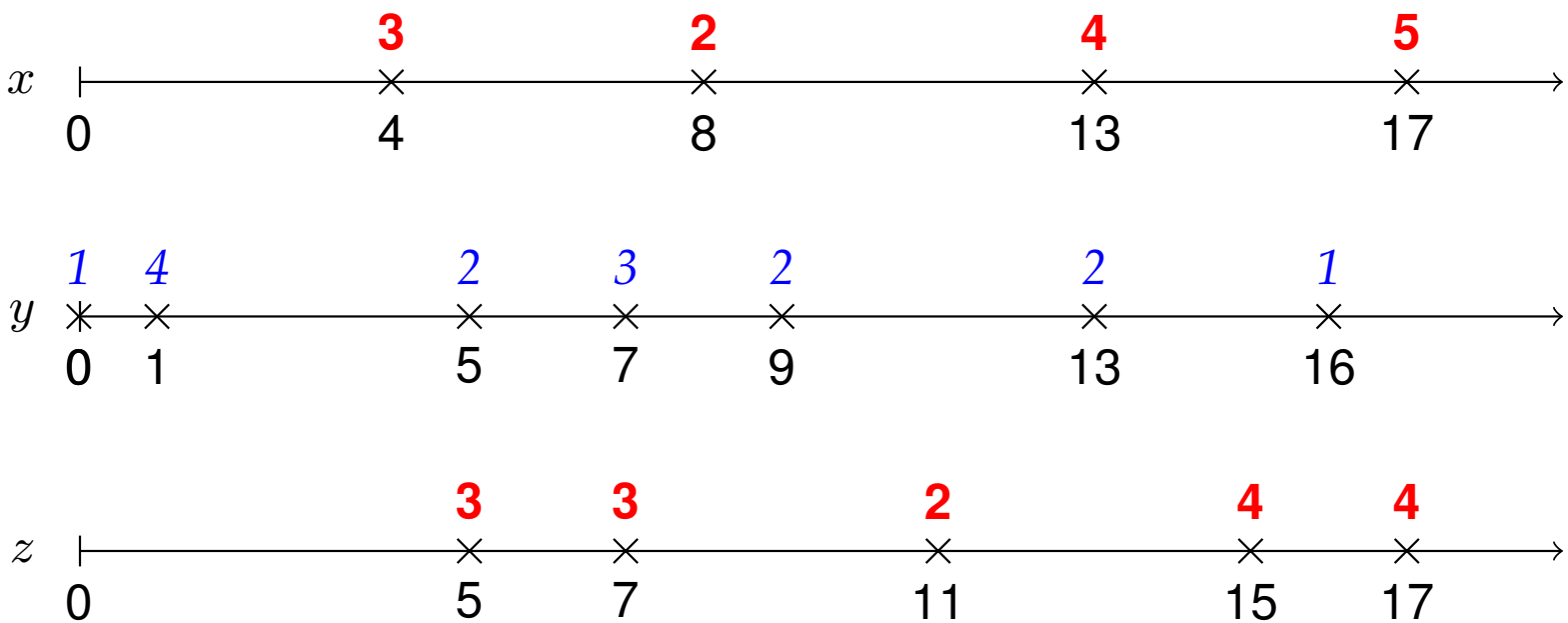


TeSSLa Core: Delayed Last

Delay a stream by delays given in a stream.

$$\mathsf{delayedLast}_{\mathbb{D}} : \mathcal{S}_{\mathbb{D}} \times \mathcal{S}_{\mathbb{T}\setminus\{0\}} \to \mathcal{S}_{\mathbb{D}}$$

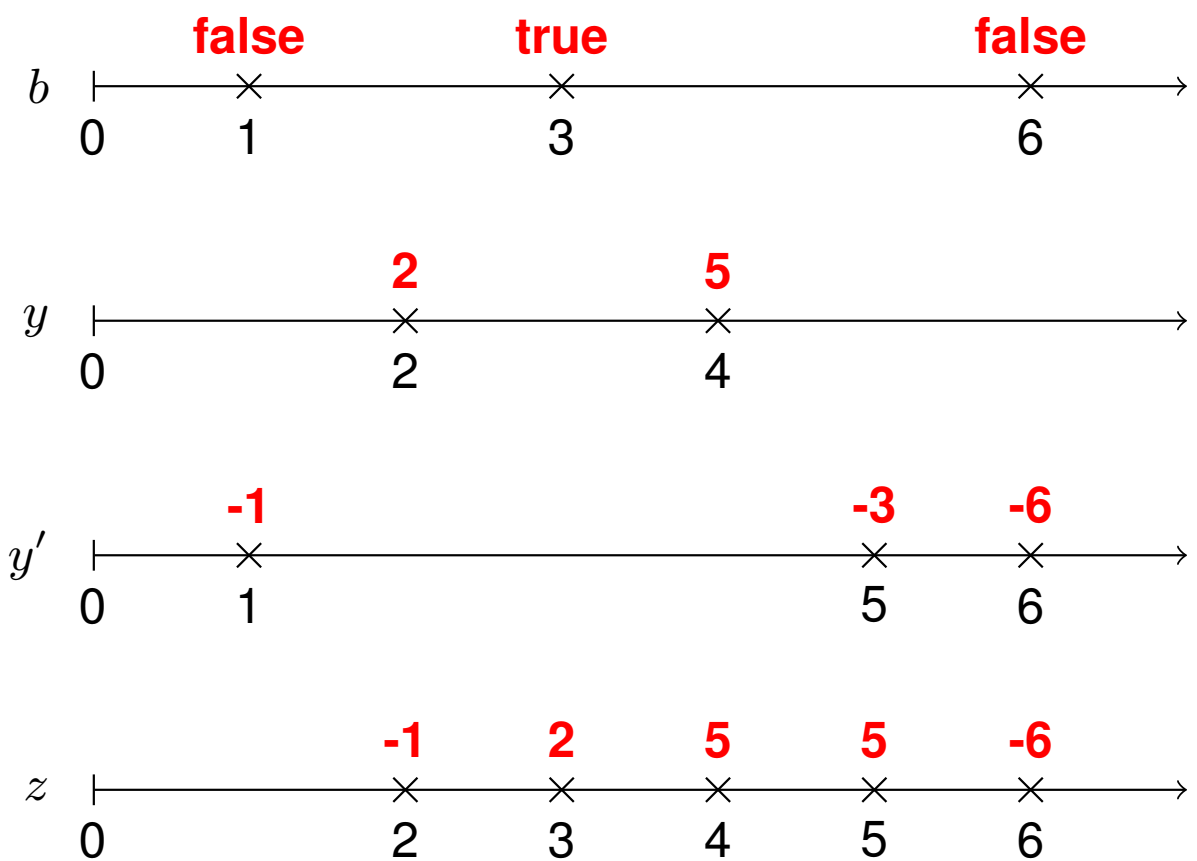
$$z = \mathsf{delayedLast}(x, y)$$



TeSSLa Core: Lifted If-Then-Else

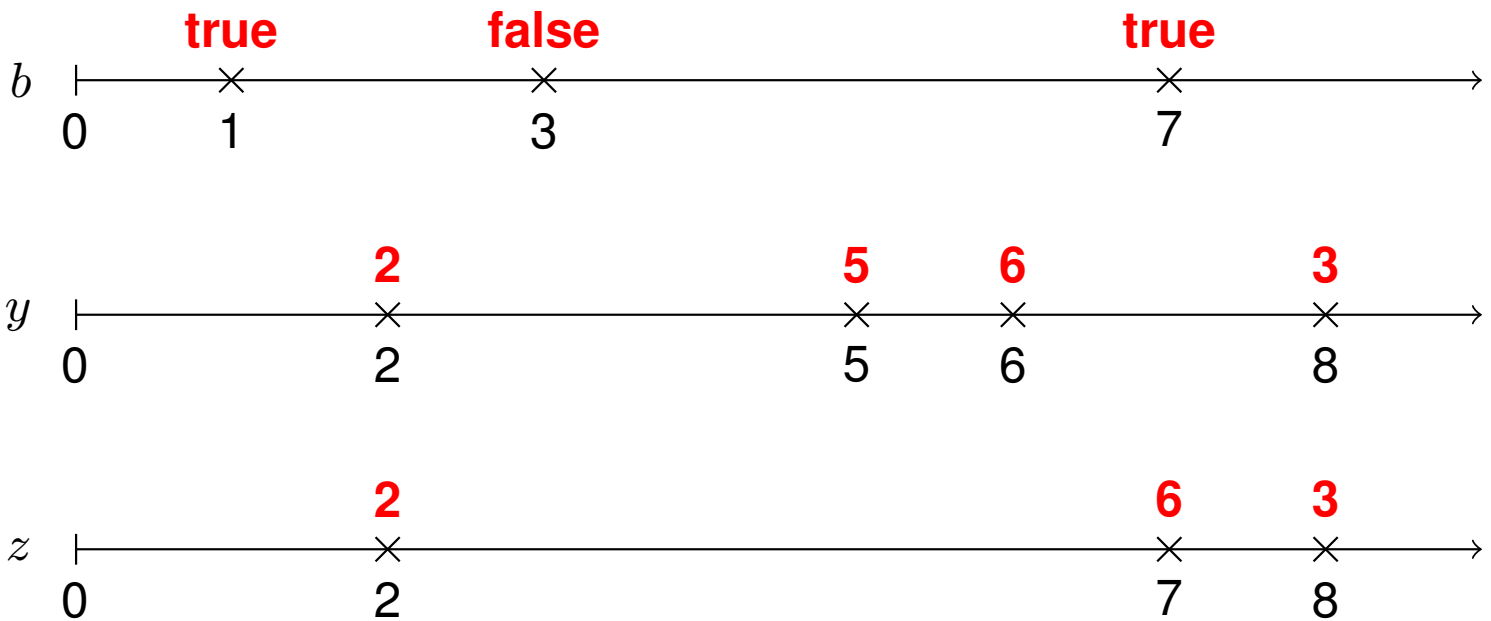
$$\mathsf{ifthenelse}_A : \mathbb{B} \times A \times A \to A$$

$$z = \mathsf{lift}(\mathsf{ifthenelse})(b, y, y')$$

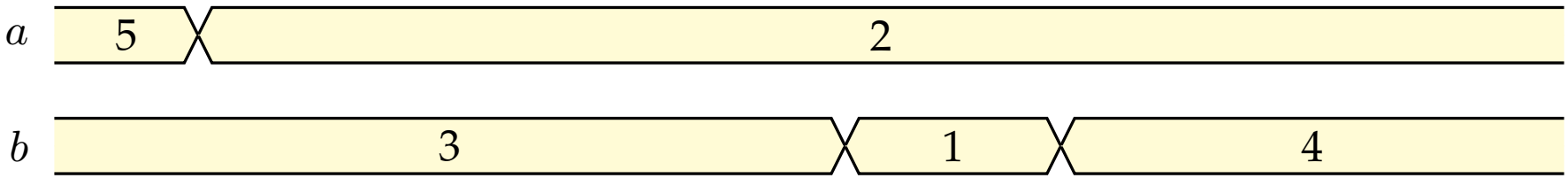


TeSSLa Core: Lifted If-Then

$$\mathsf{ifthen}_A : \mathbb{B} \times A \rightharpoonup A$$
$$z = \mathsf{lift}(\mathsf{ifthen})(b, y)$$

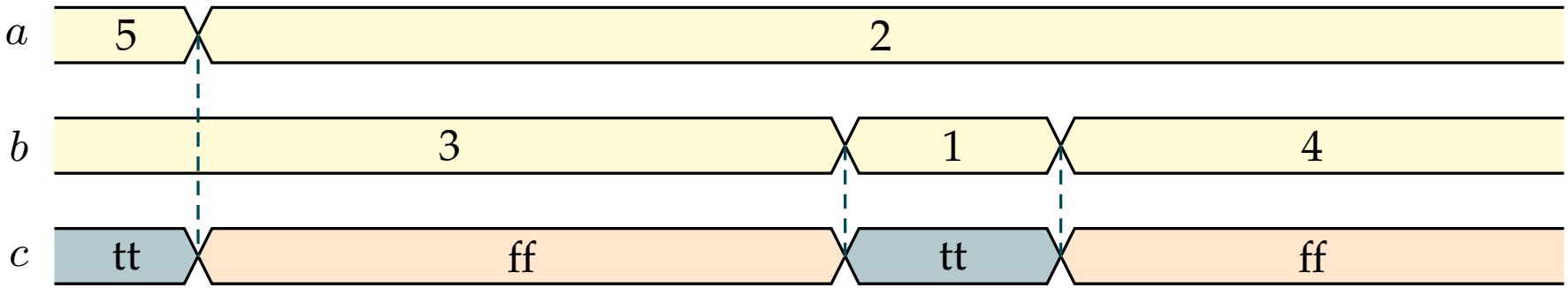


TeSSLa by a More Complex Example




```
slide<2->def c := a > b->def p := if c
 noEvent(e, since = rising(c))
```

TeSSLa by a More Complex Example

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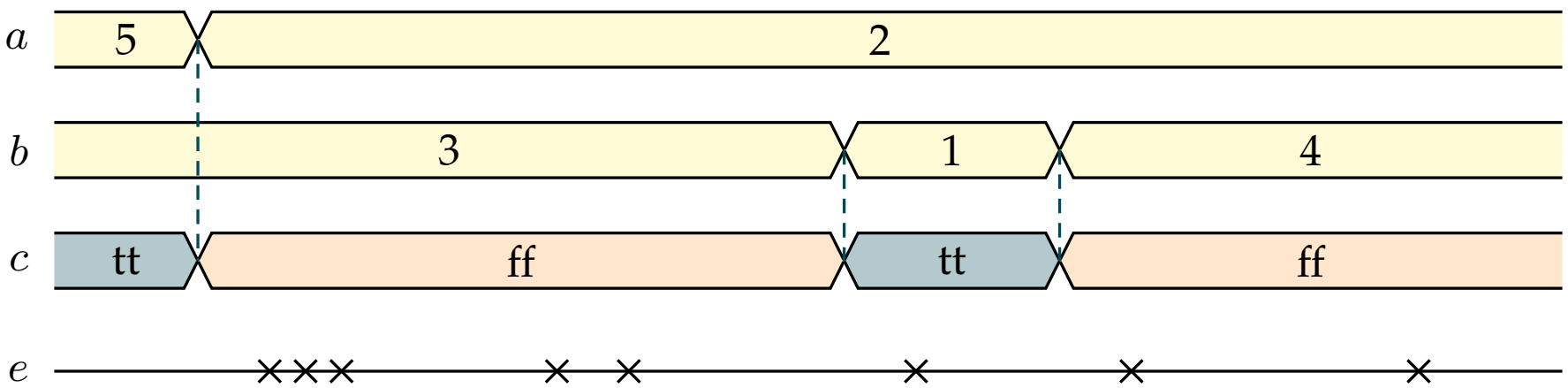


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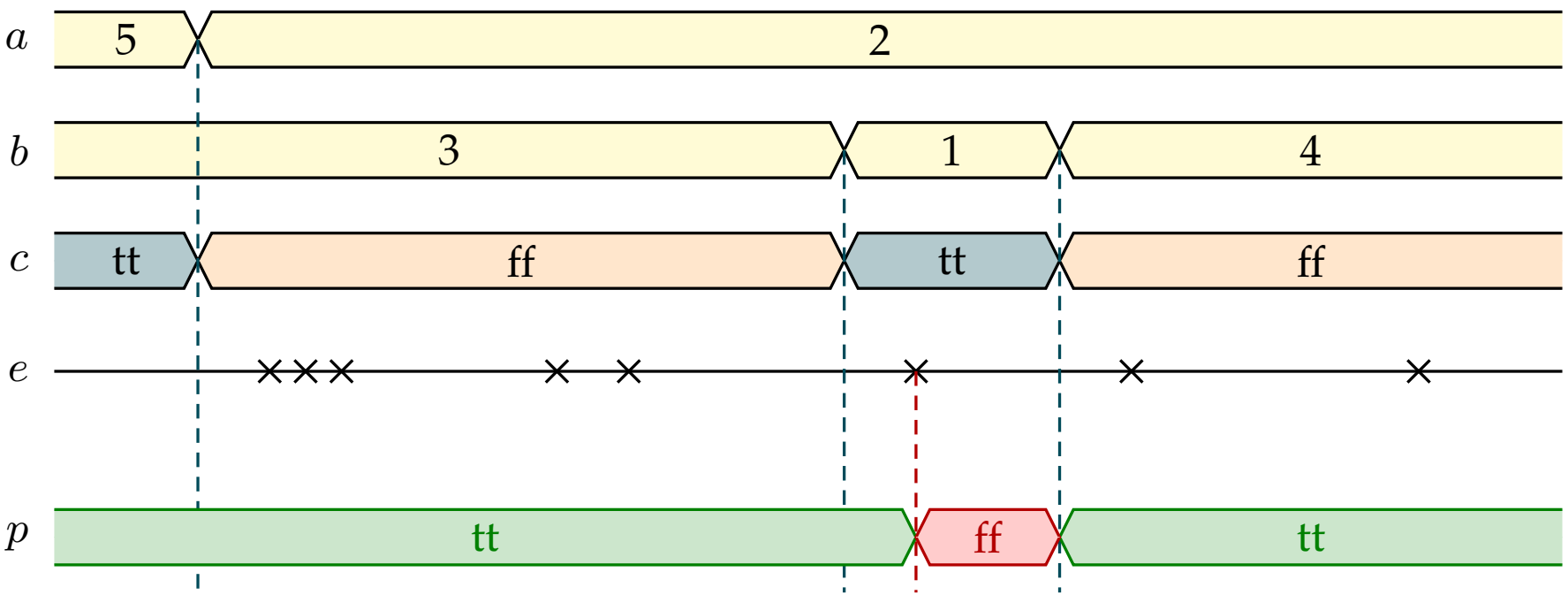
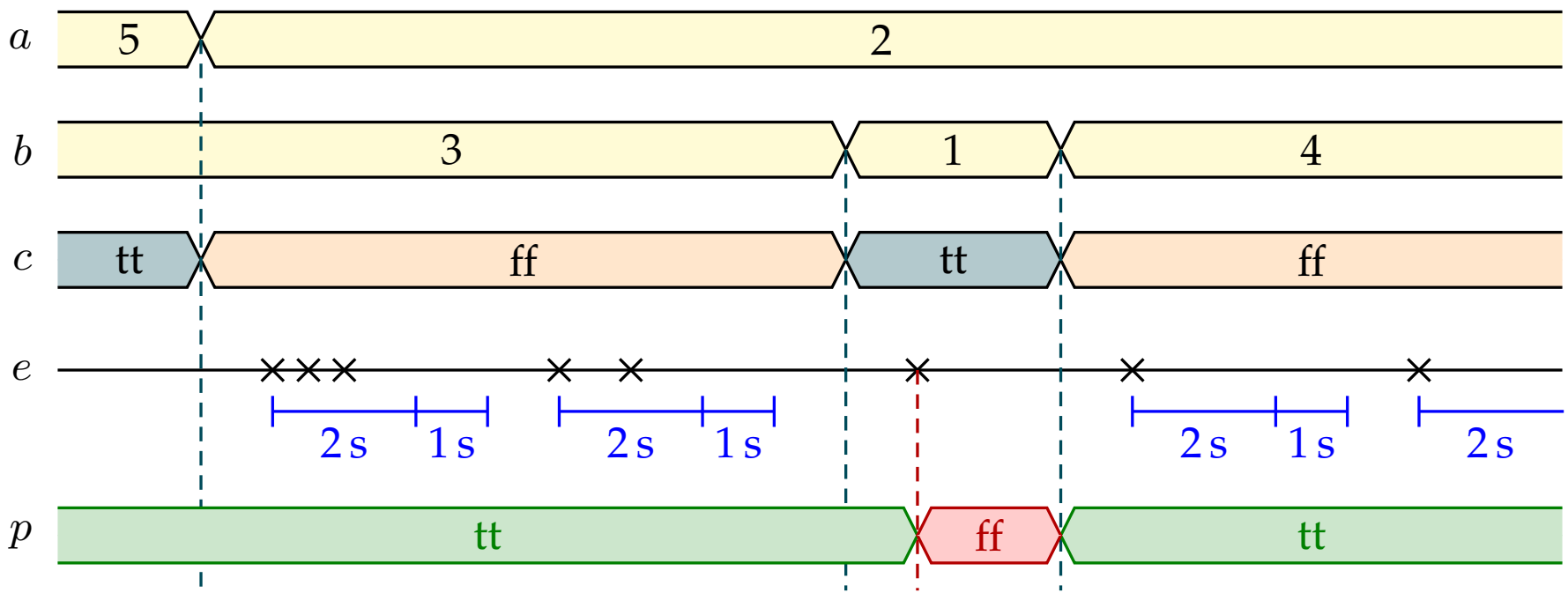


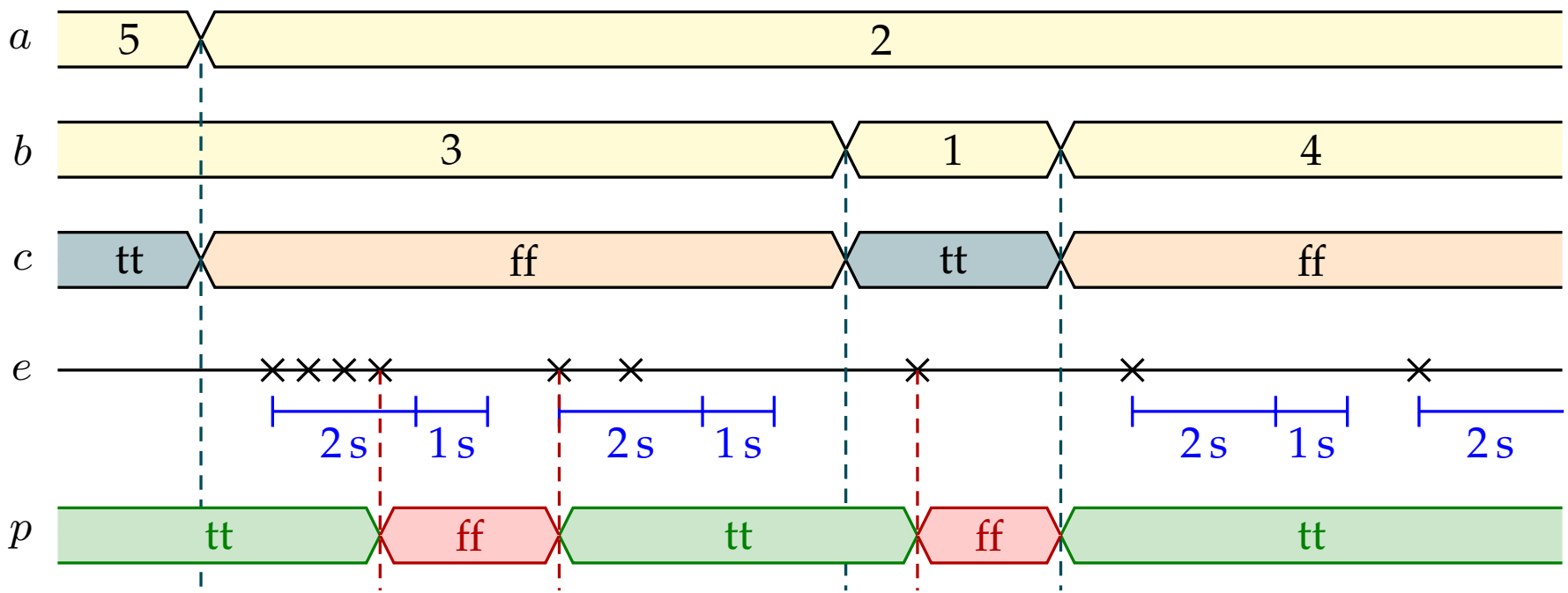

```
slide<2->def c := a > b->def p := if c
 noEvent(e, since = rising(c))
 true
```

TeSSLa by a More Complex Example




```
slide<2->def c := a > b->def p := if c
 noEvent(e, since = rising(c))
 bursts(e, burstLength = 2s,
ingPeriod = 1s,
tAmount = 3s)
```

TeSSLa by a More Complex Example

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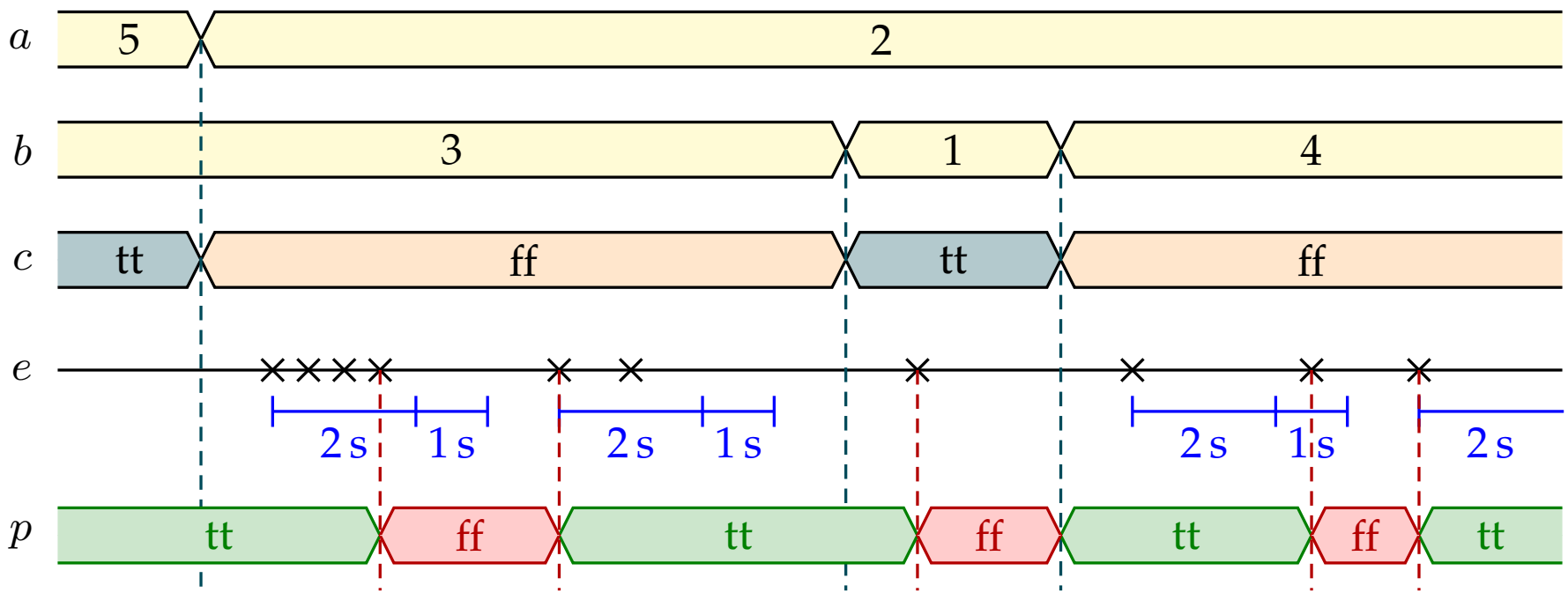


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 noEvent(e, since = rising(c))
 bursts(e, burstLength = 2s,
ingPeriod = 1s,
tAmount = 3s)
```

TeSSLa Standard Library

Detect rising edge of a signal

```
rising(condition) :=
ondition && !last(condition) then ()
```

No event happened since last reset

```
noEvent(on, since) :=
tCount(on, reset = since) == 0
```

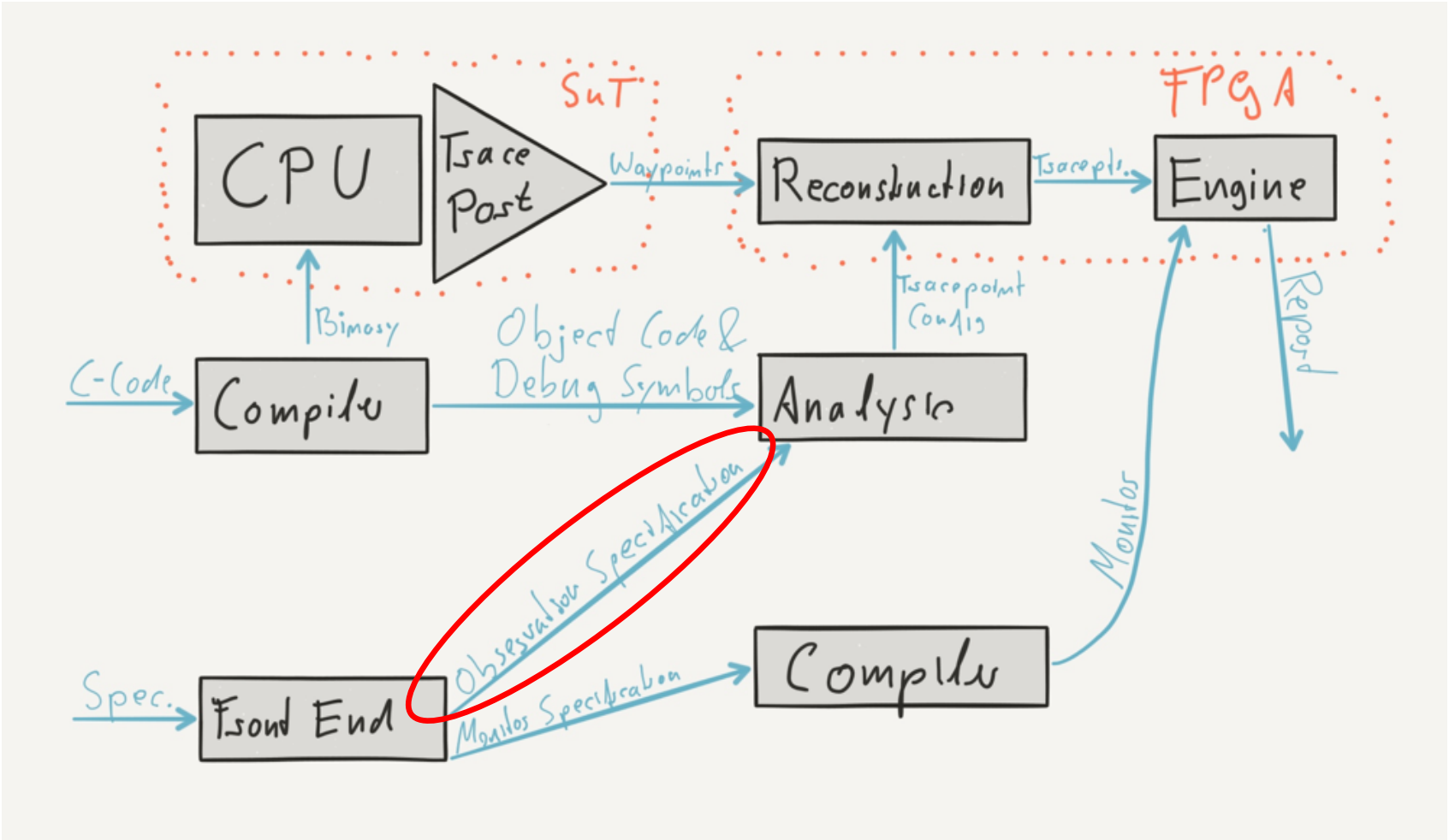
TeSSLa Standard Library

Burst Pattern based on AUTOSAR Timing Extension

```
bursts(e, burstLength, waitingPeriod,
urstAmount) := {
burstStarts :=
ultFrom(
ime(e) - last(time(burstStarts), e) >=
tLength + waitingPeriod
 e,

tCount(e, reset = burstStarts) <= burstAmount &&
(e) < time(burstStarts) + burstLength
```

Outlook: Observation Specification



Outlook: Observation Specification

Elements of the Source Code

- Program Line
- Entering / Leaving a Function
- Reading / Writing Variables
- ...

Elements of the Binary

- Program Counter Address
- CALLS and RETURNS
- Specific Operations (e.g. Floating Point Operations)
- ...