UNIVERSITÄT ZU LÜBECK
INSTITUTE FOR SOFTWARE ENGINEERING
AND PROGRAMMING LANGUAGES

isp

TOOL PAPER: Tessla-ROS-Bridge Runtime Verification of Robotic Systems

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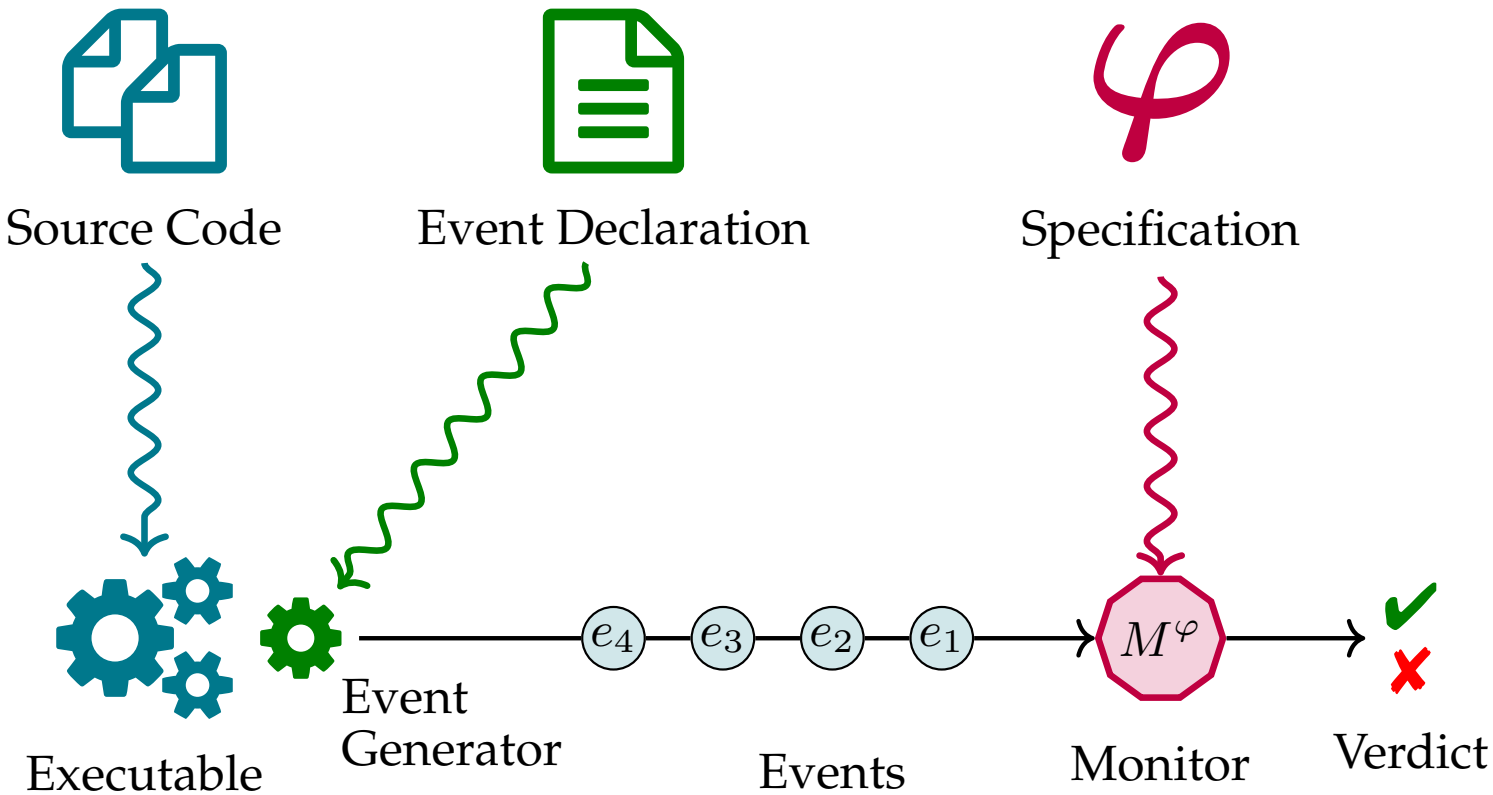
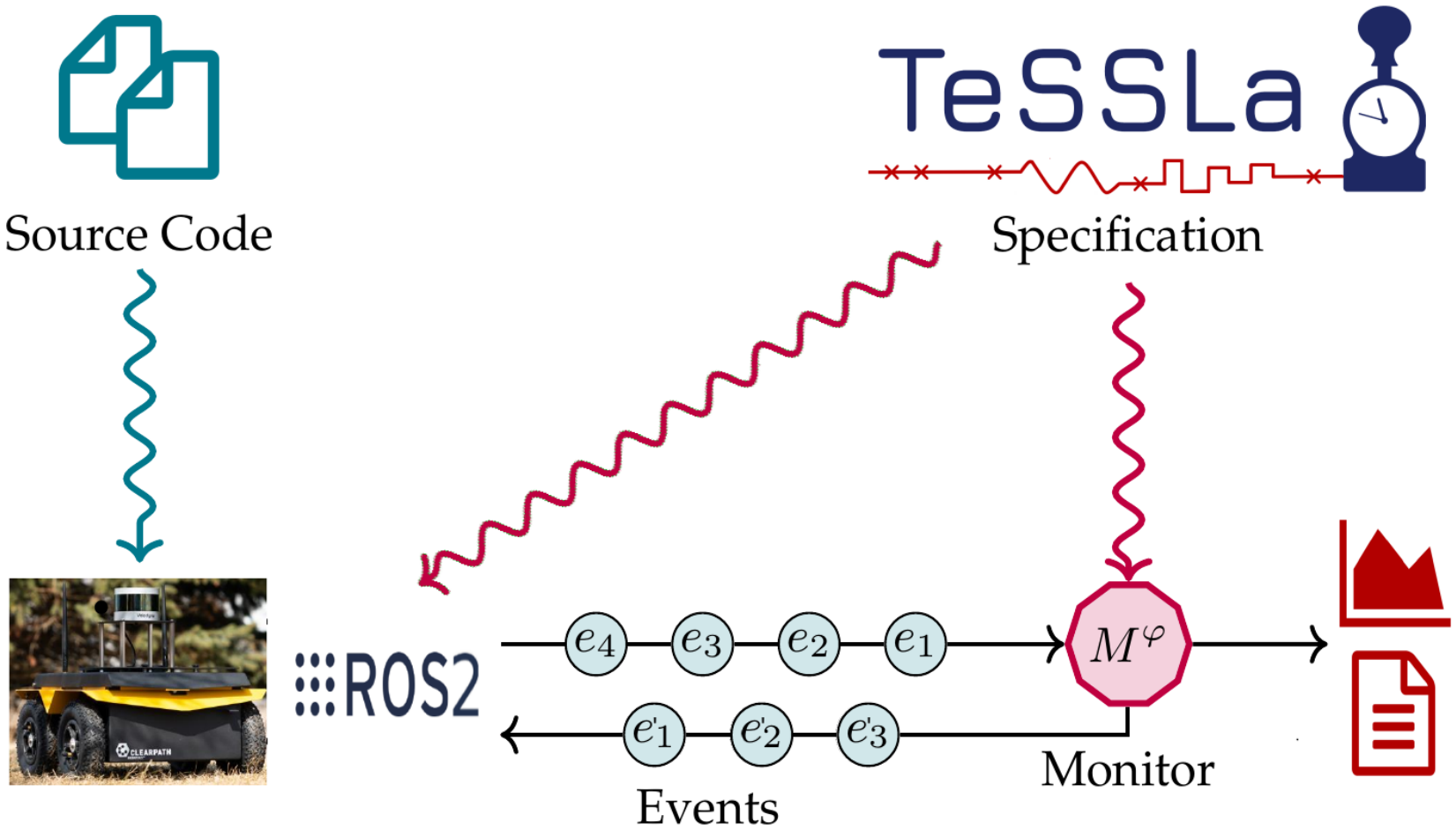
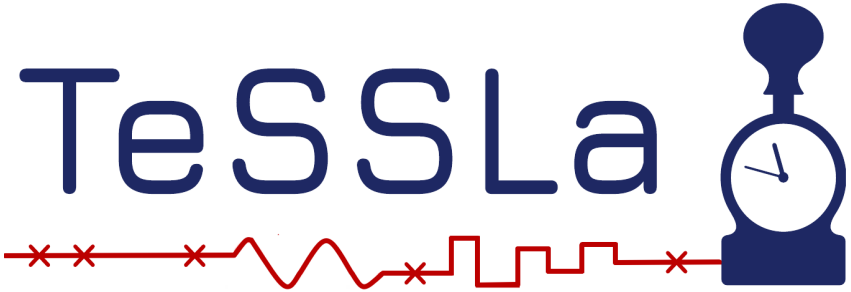
Traditional (Stream) Runtime Verification



In this paper: Extension to robot systems





TeSSLa is a general purpose Stream-based Specification language:

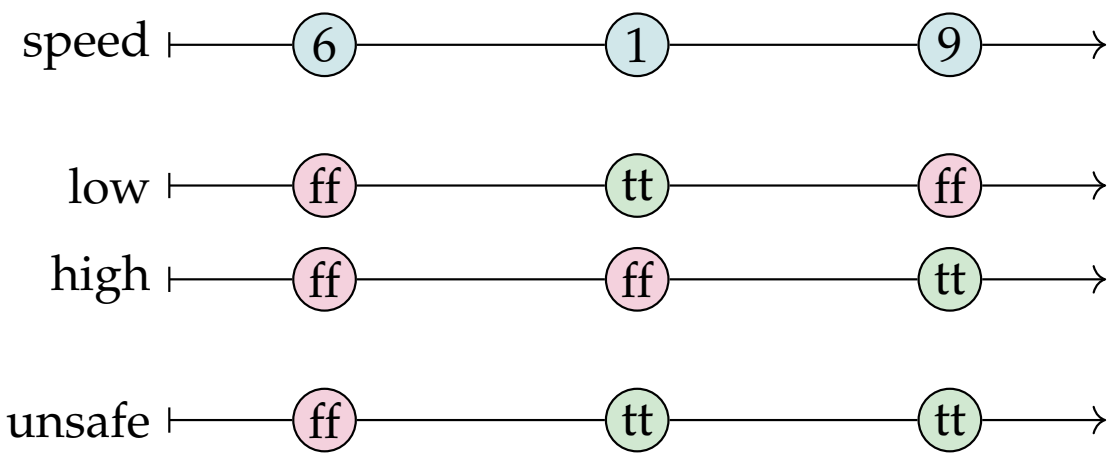
Every monotonous, continuous and future-independent stream transformation function f can be specified in TeSSLa

Possible fields of application:

- Online Monitoring
- Logfile Analysis
- Event pattern generation
- Analysis of the specification
- ...

Basic concept: Combining streams

Correctness property: Speed is between 2 and 8.



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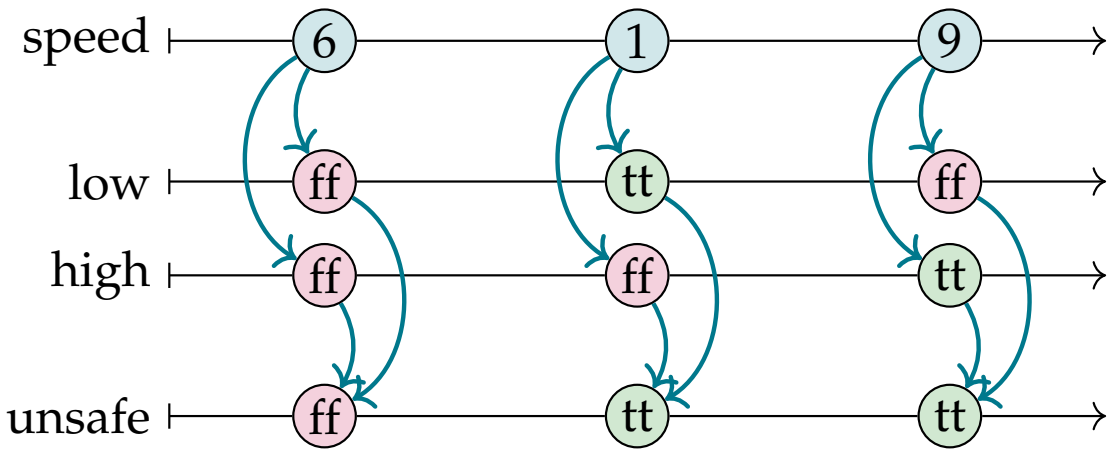


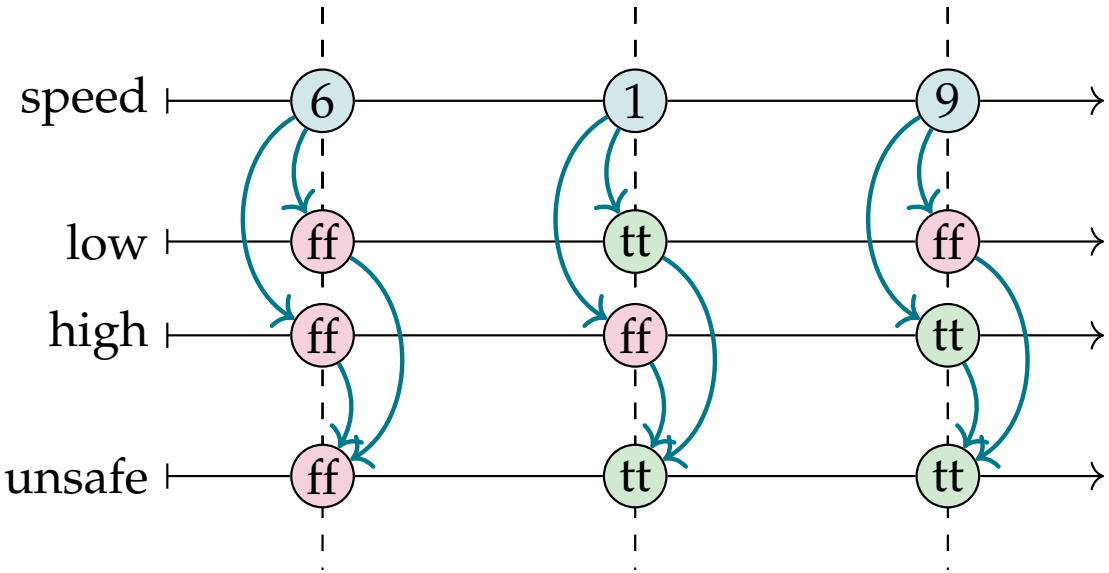

```
in speed: Events[Int]

def low = (speed < 2)
def high = (speed > 8)
def unsafe = low || high

out unsafe
```

Basic concept: Synchronous streams

Correctness property: Speed is between 2 and 8.

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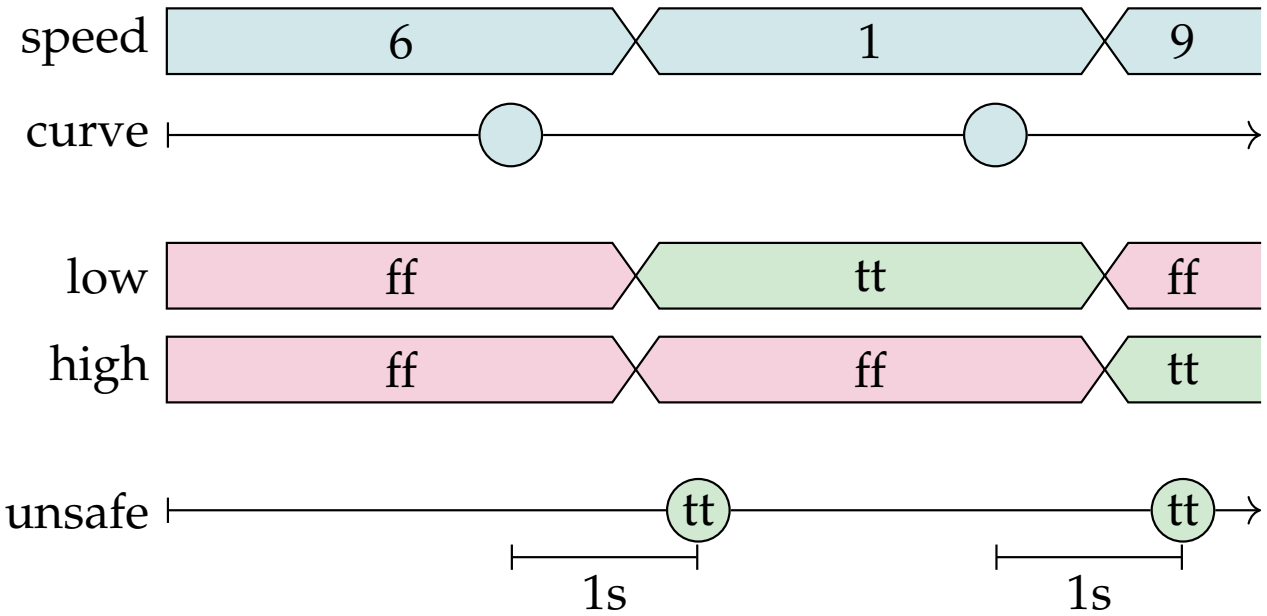
Basic concept: Asynchronous streams

Correctness property: Speed is between 2 and 8, one second after robot intends driving a curve.



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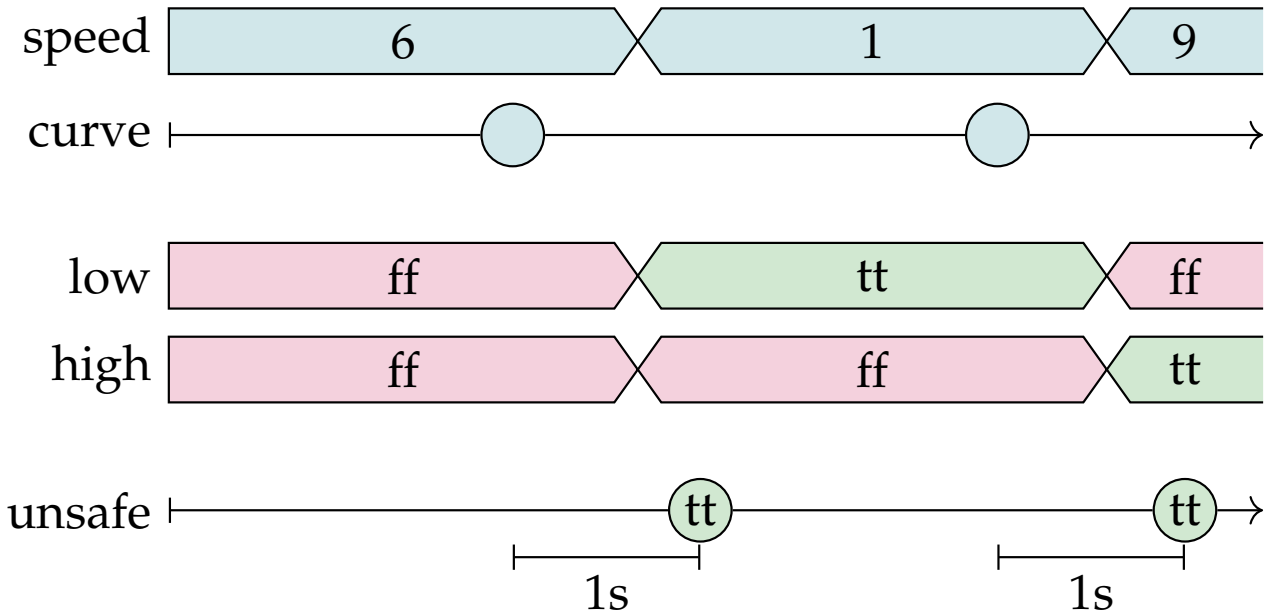
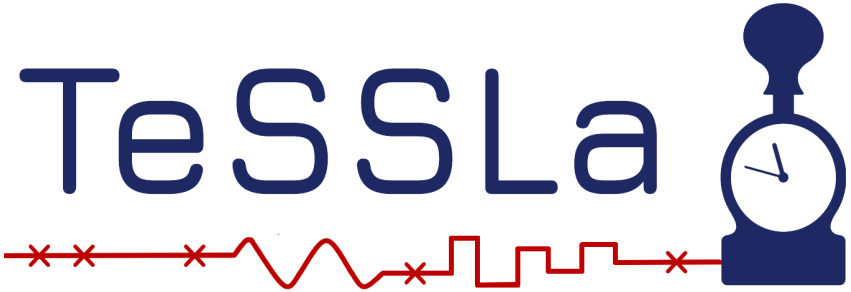


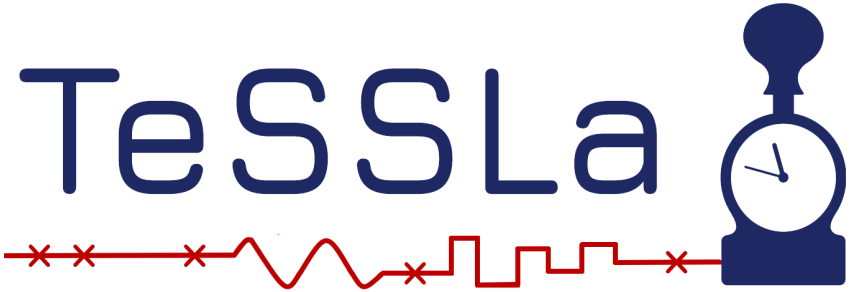

```
in speed: Events[Int]
in curve: Events[Unit]

def low = (speed < 2)
def high = (speed > 8)
def unsafe = on(low || high, delay(1s, curve))

out unsafe
```



- Abstractions for both **events** and **signals**
- Description of **asynchronous streams**
- **Time** as first-class citizen
- Useful for description of **Cyber Physical Systems**



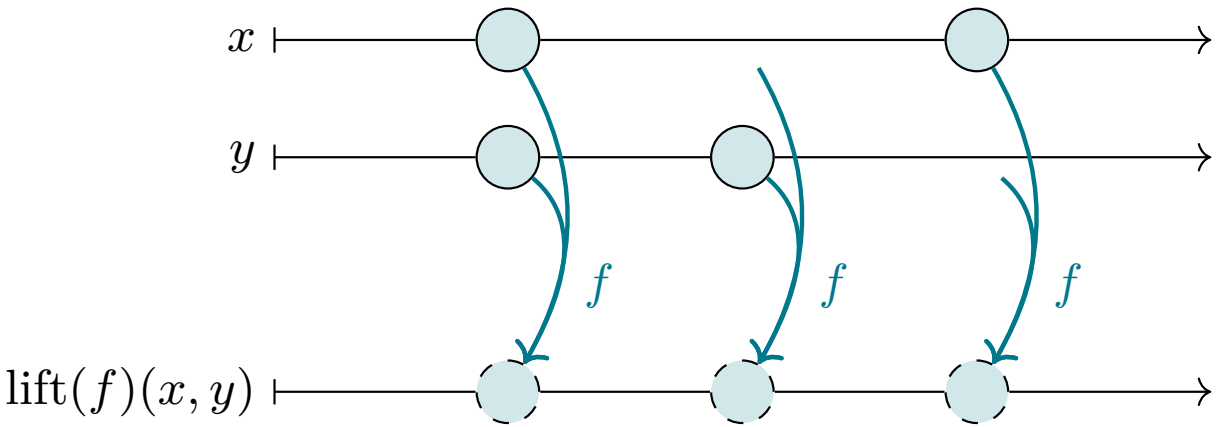
TeSSLa: Language and features

Language based on **five core operations** plus

- Type system
- Macro system
- Module system
- Standard library and several user libraries
- Meta Data/annotation concept

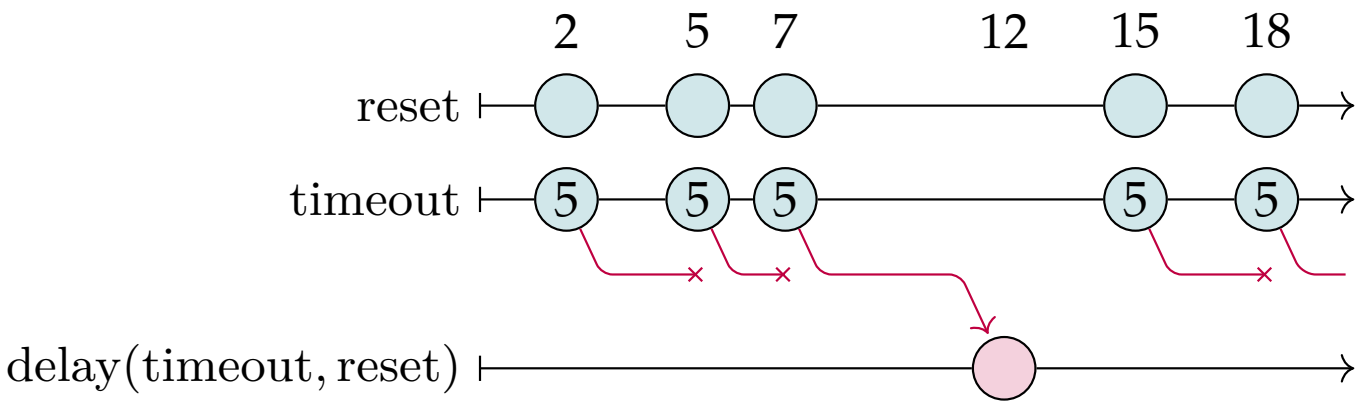
TeSSLa core operations: Lift

- *Lift* applies a function to the current events on a certain number of streams
- e.g. adds two numerical event values



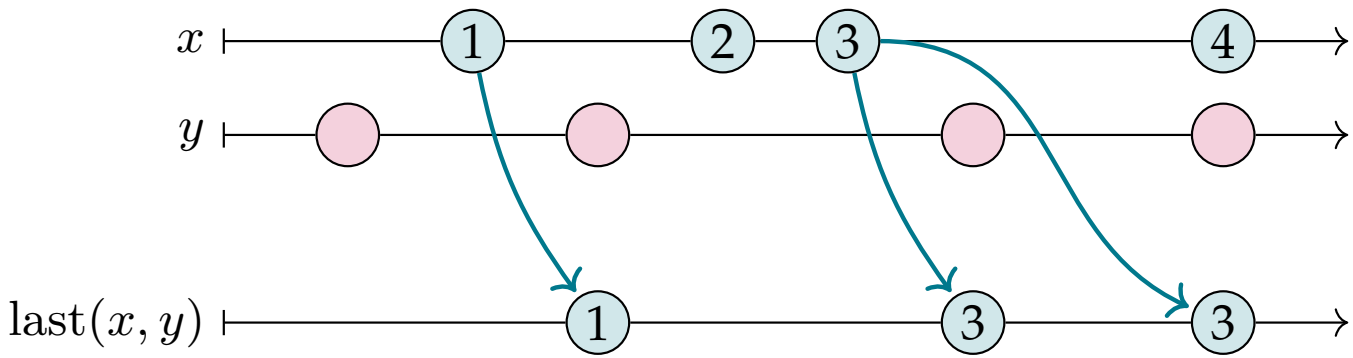
TeSSLa core operations: Delay

- *Delay* creates a new event some time after a reset event
- Possibility to create output events at timestamps without input events



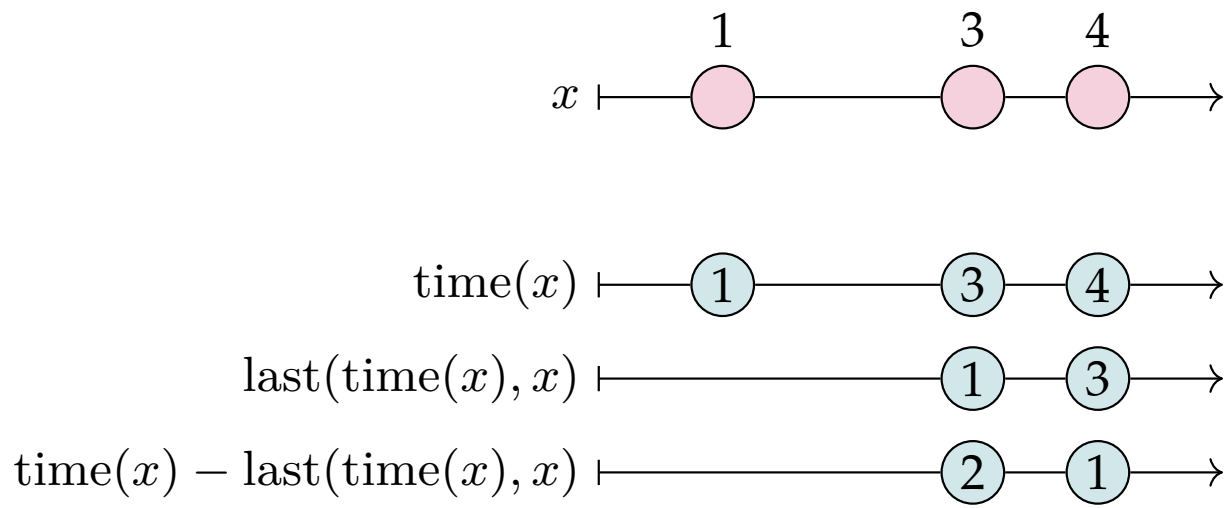
TeSSLa core operations: Last

- *Last* allows to access the values of events on one stream that occurred strictly before the events on another stream
- Important for accessing streams with signal semantics



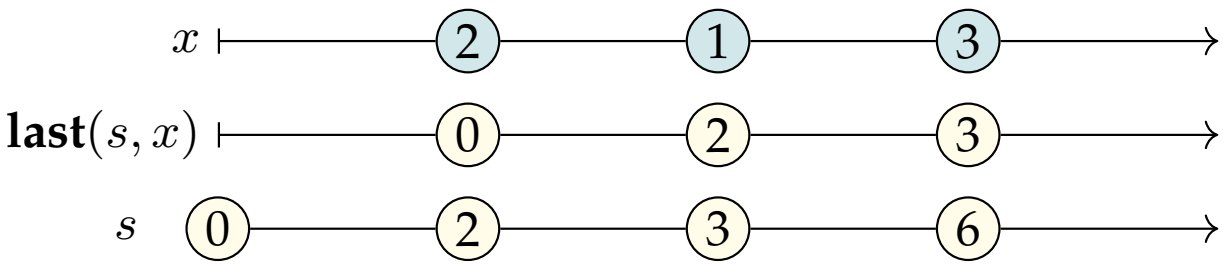
TeSSLa core operations: Time

- *Time* provides access to the timestamps of events
- Produces events carrying their timestamps as data value
- Hence all operators for data values can be applied to timestamps.



Recursive Equations in TeSSLa

$$s = \mathbf{lift}(merge)(\mathbf{last}(s, x) + x, 0)$$



Macro-System

- Possibility to extend minimal language core by arbitrary functions

Macro Definition Fold

```
def fold[T,R](stream: Events[T], init: R,
              f: (Events[R],Events[T]) => Events[R]) = result
where
{
    def result: Events[R] = merge(f(last(result, stream),
                                     stream), init)
}
```

Usage of Fold

```
def y = fold(x, 0, (c: Int, x: Int) => c+x)
```

Module System

Modules

```
module myModule {
  module mySubmodule {
    def myCount[A](a: Events[A]) := c where {
      def c: Events[Int] := merge(last(c, a) + 1, 0)
    }
  }
}

in x: Events[Unit]
def y := myModule.mySubmodule.myCount(x)
out y
```

Module System

Modules

```
module myModule {
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    def myCount[A](a: Events[A]) := c where {
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  }
}

in x: Events[Unit]
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```

⇒ Possibility to create TeSSLa libraries.

Standard & User Libraries

Standard Library Defines a high number of macros to make the usage of TeSSLa comfortable

- Basic operations: `Merge, Signal Lift, Const, Filter, ...`
- Aggregation functions: `Minimum, Maximum, Fold, Reduce, ...`
- Common datastrucutre functions: `Set.contains, Map.getOrElse, ...`
- Application specific functions: `Burst-Pattern recognition, Event-Chain recognition, ...`

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User Libraries e.g. for

- special logics
- AUTOSAR Timex extension

TeSSLa Language: Typesystem

- Built-in basic types can be extended by user-defined types
- Supports externally defined nominal types
- Record types
- Generics

Supported basic types:

- Unit
- Int
- Float
- Boolean
- String

Supported complex datastructures:

- Lists
- Sets
- Maps

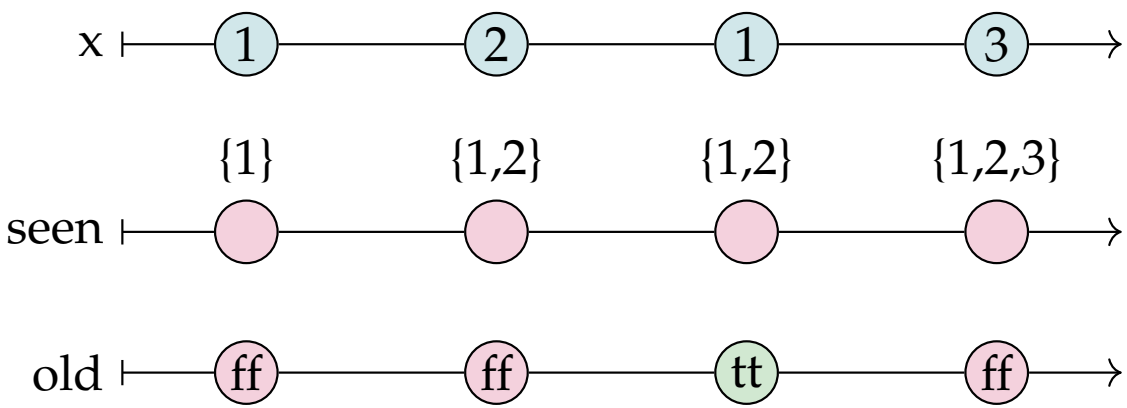
Complex datastructures

Complex datastructures

```
in x: Events[Int]

def seen: Events[Set[Int]] := fold(x, Set.empty[Int], Set.add)

out Set.contains(last(seen, x), x) as old
```



Meta Data/Annotations

Possibility to pass event declaration to connected tools:

- `@InstFunctionCall(func\_name)`
- `@VisSignal`
- `@RosSubscription(topic, datatype, qos_profile)`
- `@RosPublisher(topic, datatype, qos_profile)`
- ...

```
@RosSubscription("/sensor1", "int64", "10")
in x : Events[Int]

[...]

@RosPublisher("/actor1", "int64", "10") @VisSignal
out y
```

TeSSLa-ROS-Integration

Idea: Use TeSSLa to monitor robot systems

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ROS (Robot Operating System):

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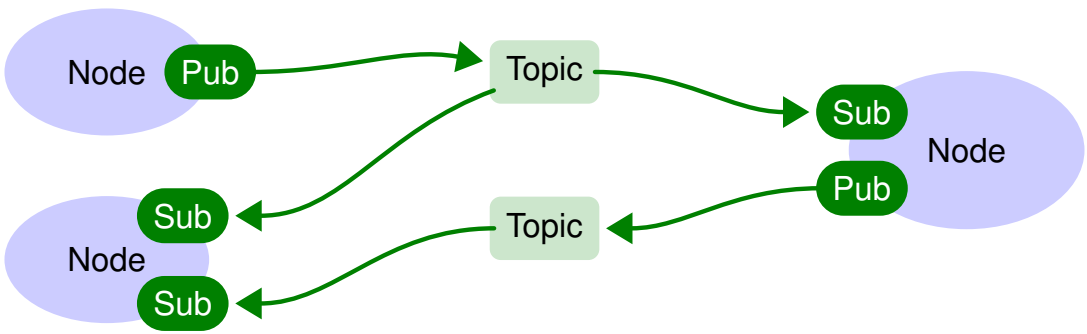
ROS (Robot Operating System):

Basic concept:

- Tasks of a robot (motor control, image recognition etc.) are running parallel in nodes



TeSSLa-ROS-Integration

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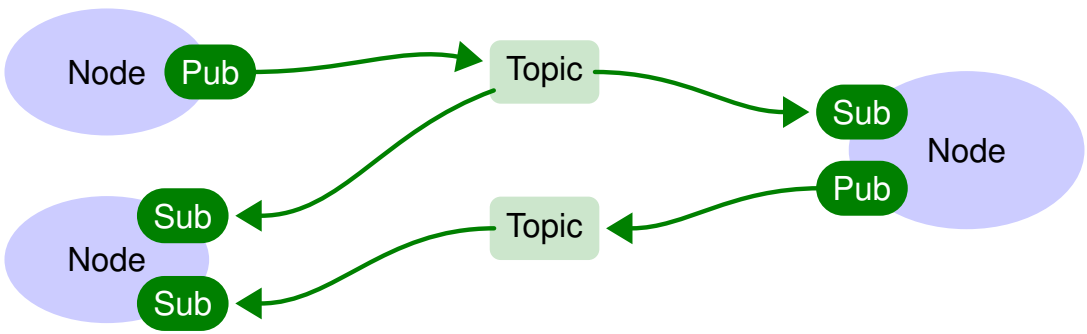
ROS (Robot Operating System):

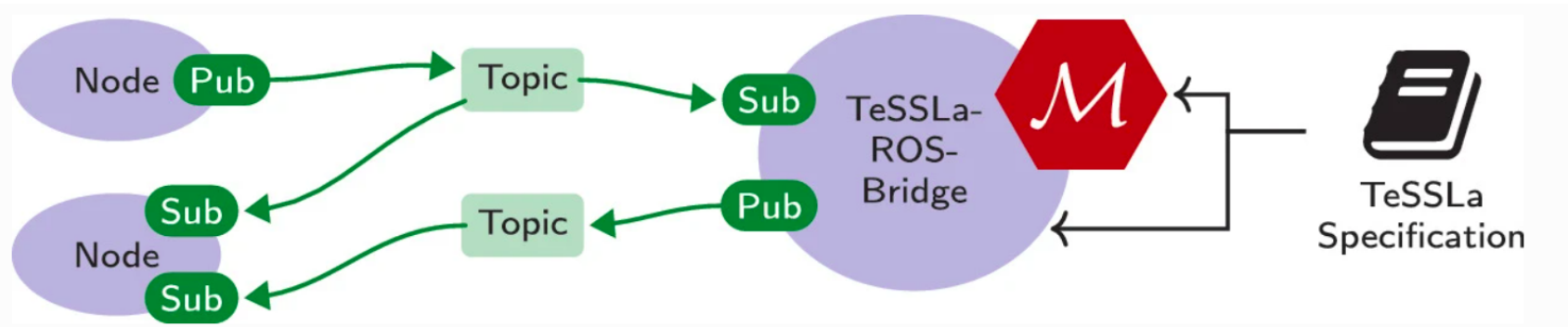
Basic concept:

- Tasks of a robot (motor control, image recognition etc.) are running parallel in nodes
- Communication between nodes via publisher/subscriber pattern



TeSSLa-ROS-Integration: Architecture

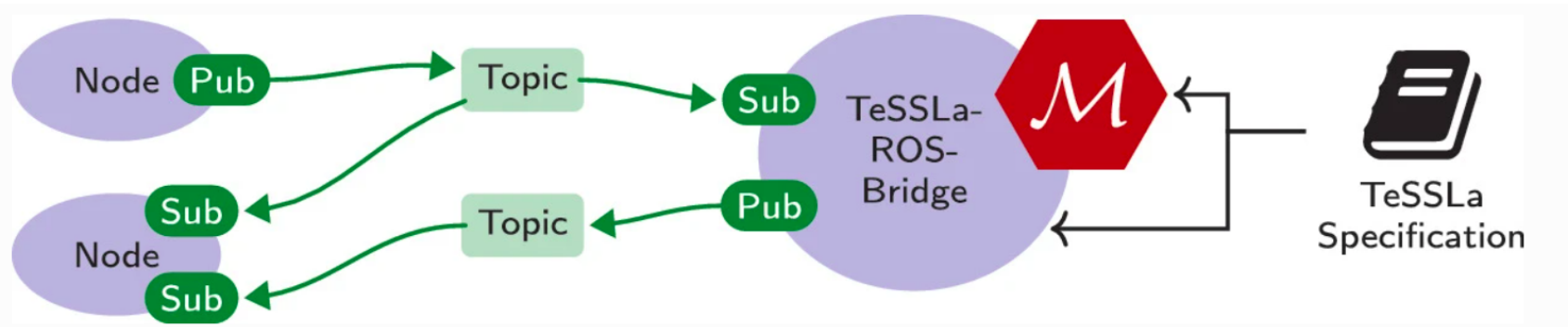
Idea:



TeSSLa-ROS-Integration: Architecture

Idea:

- Use TeSSLa-to-Rust compilation to generate **TeSSLa monitor** from specification



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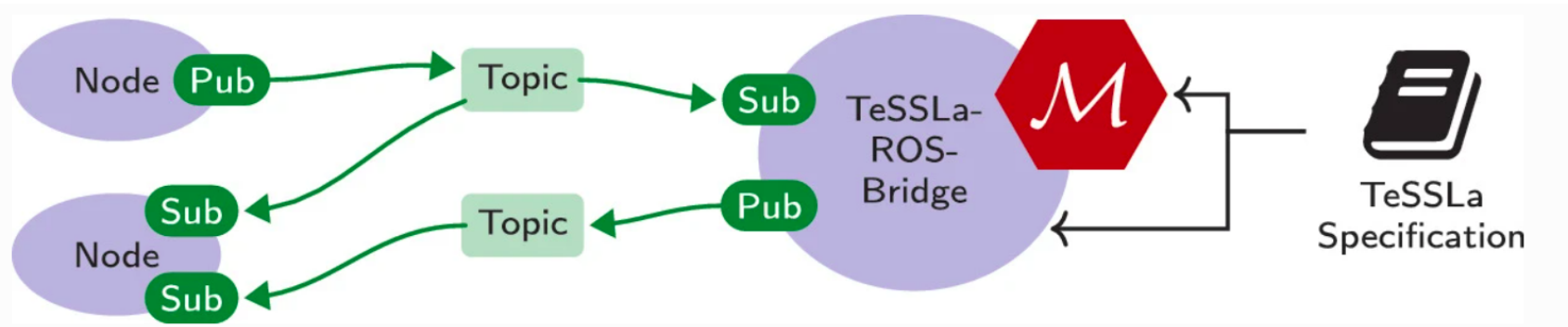
- Use TeSSLa-to-Rust compilation to generate **TeSSLa monitor** from specification
- Run monitor in **separate node** for **shielding** of safety-critical part of the system

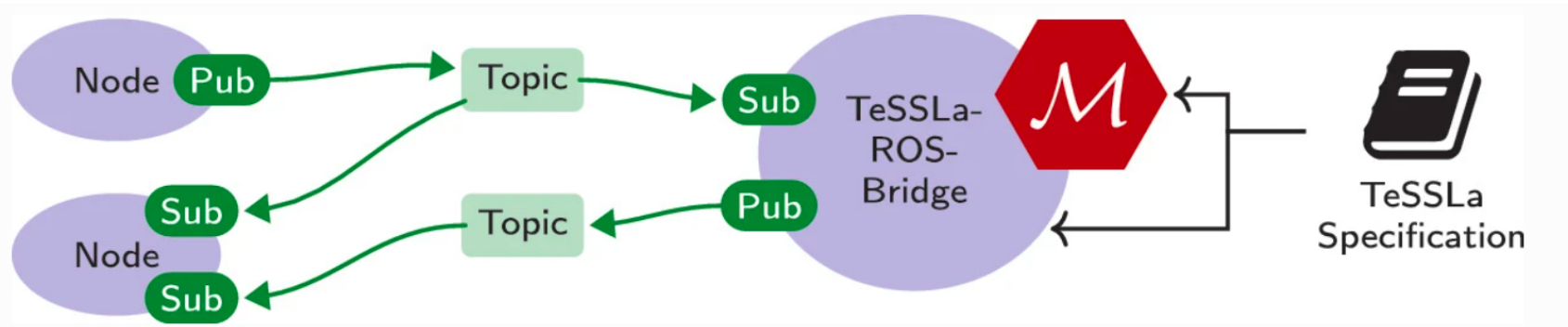


TeSSLa-ROS-Integration: Architecture

Idea:

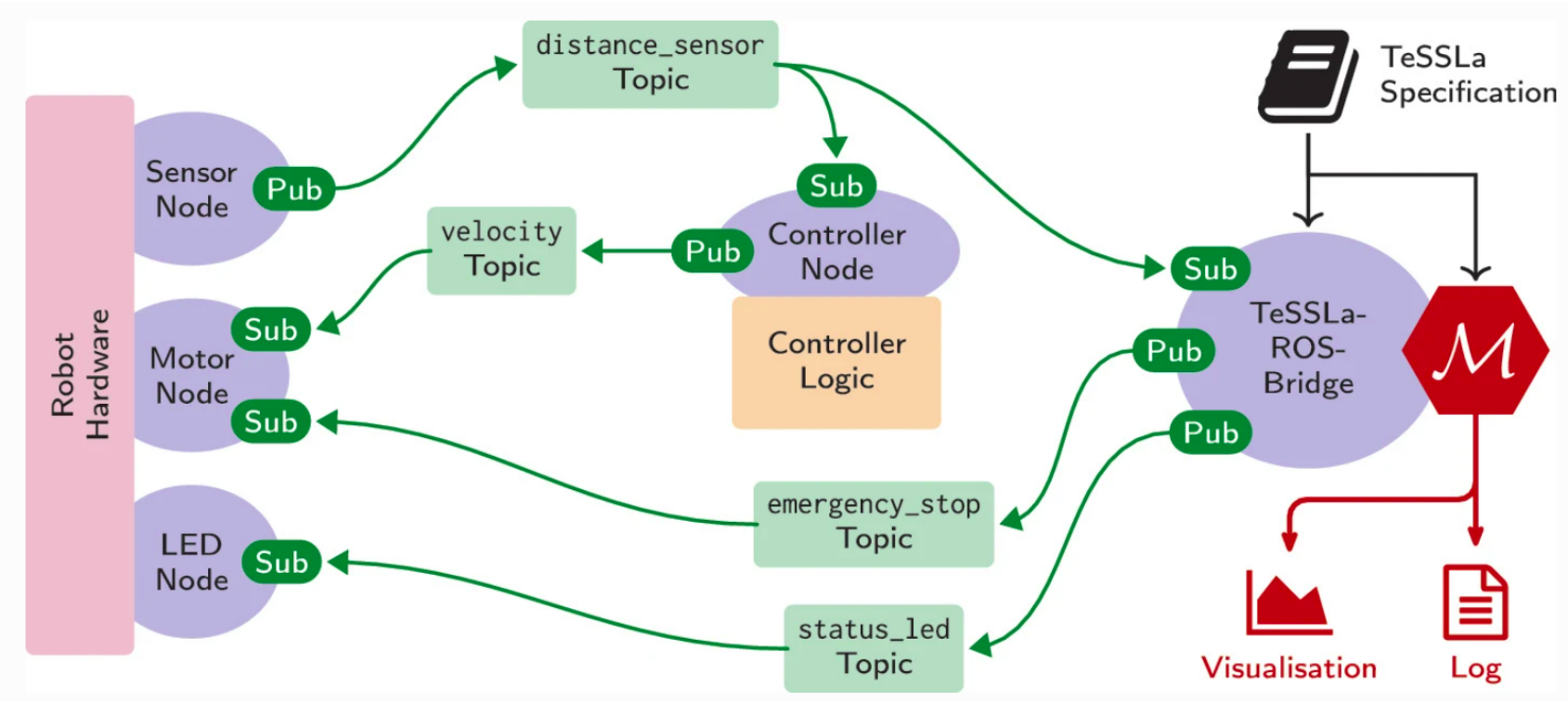
- Use TeSSLa-to-Rust compilation to generate **TeSSLa monitor** from specification
- Run monitor in **separate node** for **shielding** of safety-critical part of the system
- Connect monitor automatically to other nodes via **annotations**

```
@RosSubscription(topic, datatype, qos_profile)
@RosPublisher(topic, datatype, qos_profile)
```



TeSSLa-ROS-Integration: Usage Example

- Robot driving around with distance sensor
- Must stop temporarily whenever something is too close
- Must stop permanently if something was close several times in short period of time



TeSSLa-ROS-Integration: Usage Example

Example specification

```
include "TesslaROSBridge.tessla"

def RED = 0; def YELLOW = 1; def GREEN = 2

module MyModule {
    def cntTimeReset[A](cnt: Events[A], resetTime: Int) =
        resetCount(cnt, delay(const(resetTime, cnt), cnt))
}

@RosSubscription("/distance_sensor", "int64", "10")
in distance: Events[Int]

def tooClose = default(distance < 20, false)
def tooManyErrors = cntTimeReset(rising(tooClose), 30s) > 5
def stop = tooClose || LTL.once(tooManyErrors)
def ledCode = if tooClose then RED else if stop then YELLOW else GREEN

@RosPublisher("/emergency_stop", "bool", "10") @VisBool
out stop

@RosPublisher("/status_led", "int64", "10") @VisSignal
out ledCode

@VisSignal
out tooClose
```

TeSSLa-ROS-Integration: Usage Example

Recap & Future Work

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  $\Rightarrow$ well suited for specification of CPS

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- Small case study to evaluate convenience of approach

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Future Work

- Try extended RV approaches with robotic domain (e.g. uncertainty)

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Future Work

- Try extended RV approaches with robotic domain (e.g. uncertainty)
- TeSSLa macros specially suited for robotic context
- Use TeSSLa for control tasks of the monitor

Find out more

TeSSLa Website:
www.tessla.io
www.tessla.io/blog/ros-bridge

TeSSLa Playground:
play.tessla.io

TeSSLa Sourcecode:
git.tessla.io