

FMI Meets SystemC: A Framework for Cross-Tool Virtual Prototyping

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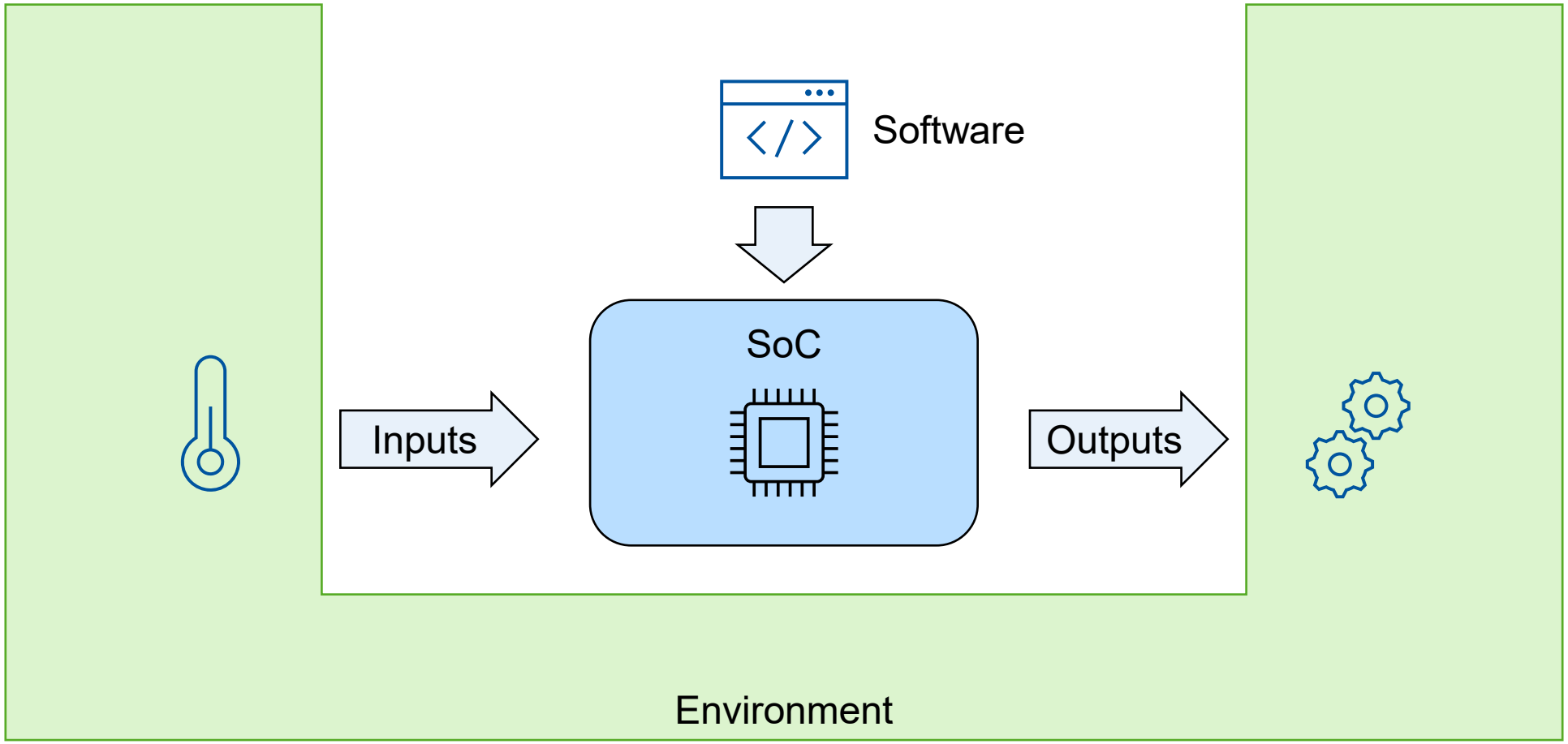
16th Modelica & fmi Conference

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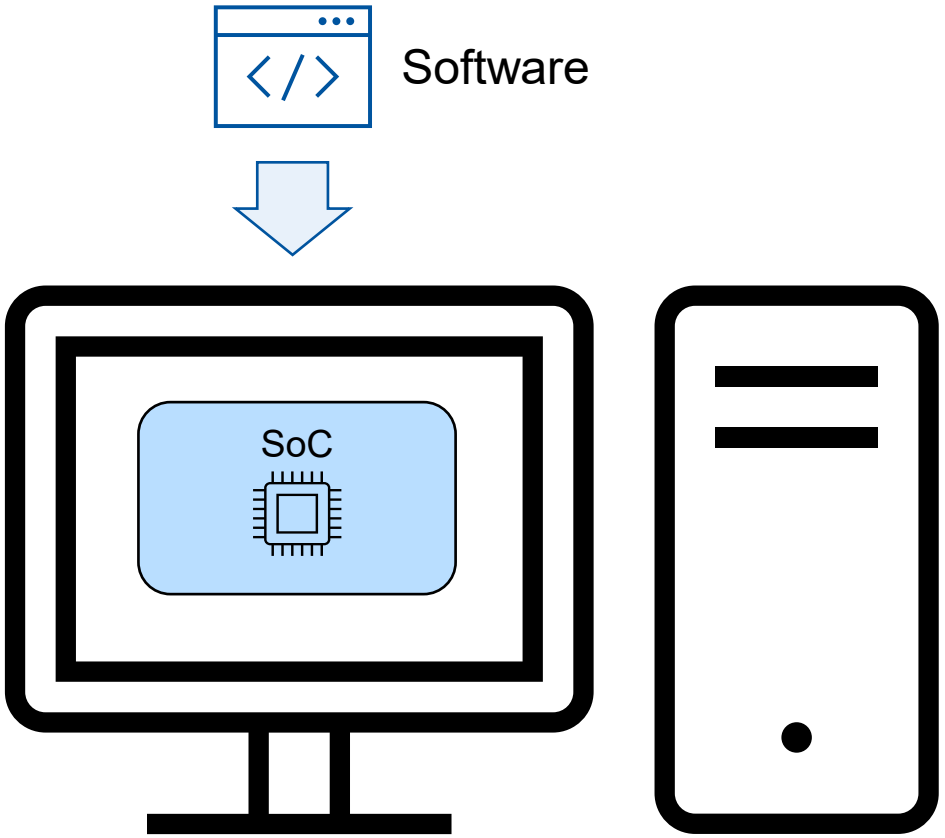
MACHINEWARE

tracetronic

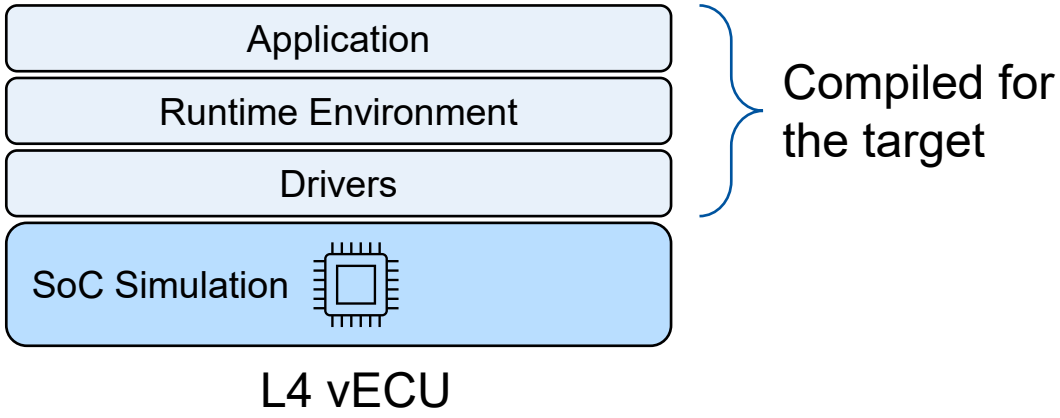
Introduction into Virtual Prototyping



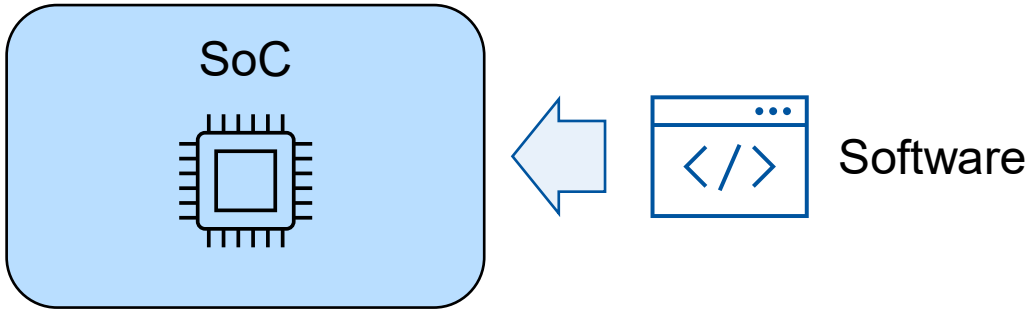
Virtual Prototyping Advantages

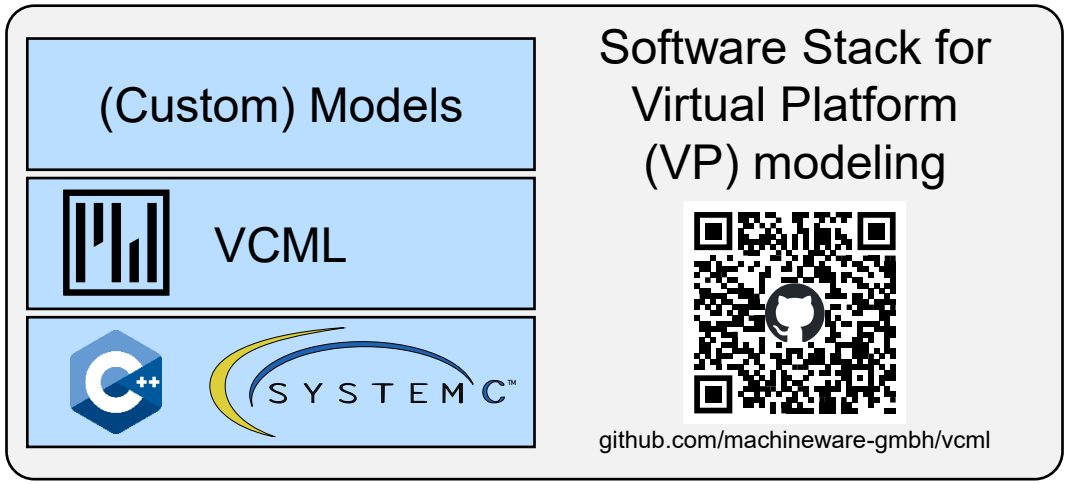


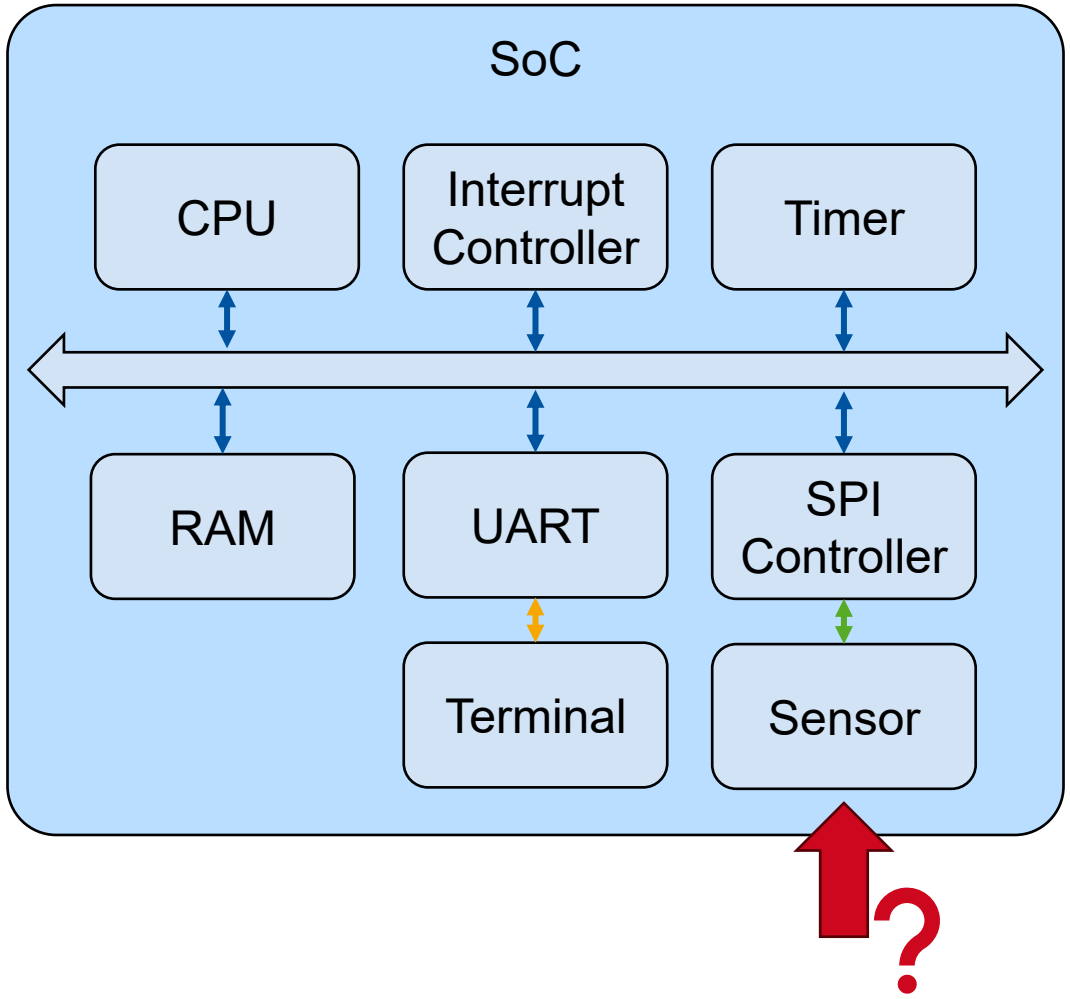
- **Develop, test, and debug** the target software on a desktop PC (e.g., x86)
- Get **detailed introspection** into the device models
- Hardware does not need to be available
- **Scalable**
- Easy & fast **distribution**



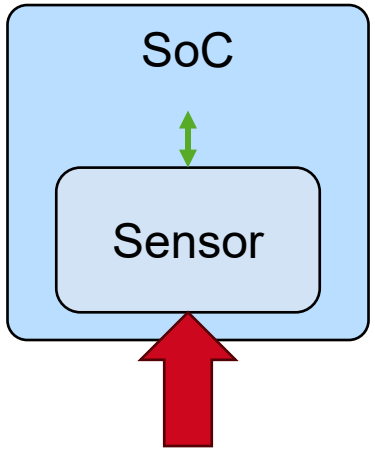
Introduction into Virtual Prototyping







Environmental Inputs



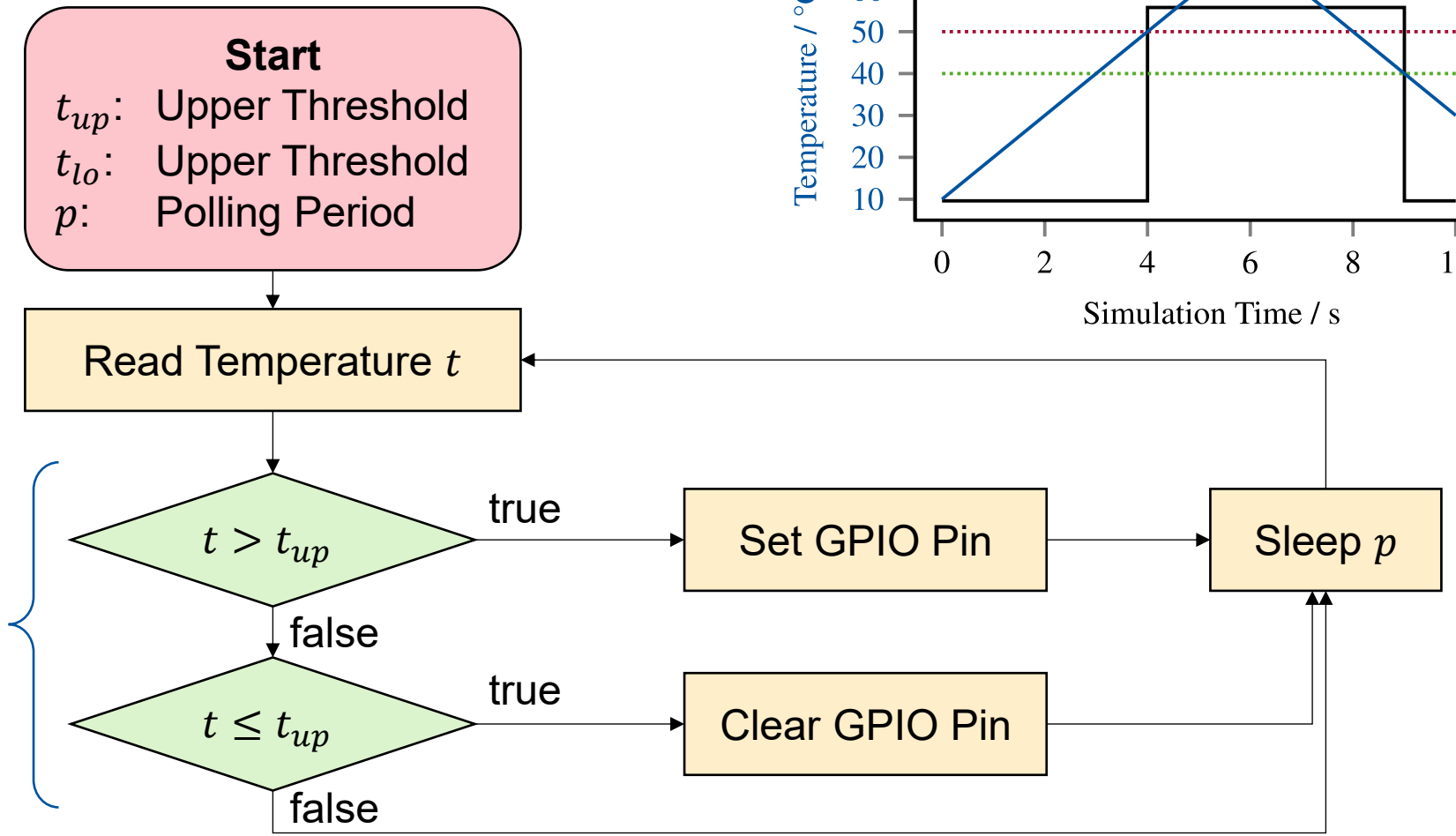
Configuration parameters inside the model

✓ Develop & test software that accesses the sensor

✓ Try different values

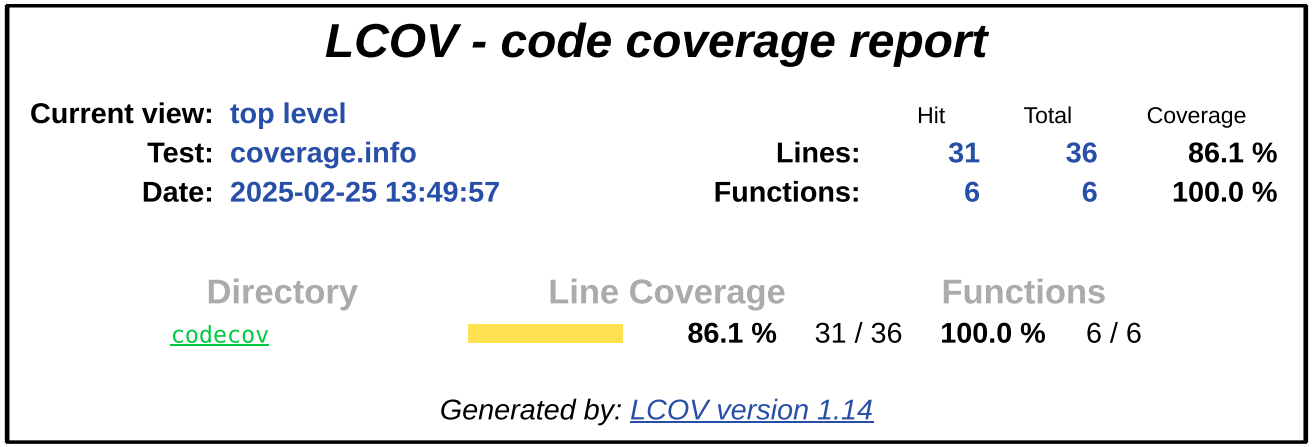
✗ Automatically modify values during runtime

Example – Schmitt-Trigger Application



For a constant temperature input, only a single path can be tested at a time

Example – Schmitt Trigger Application



LCOV - code coverage report

			Hit	Total	Coverage
Current view:	top level				
Test:	coverage.info	**Lines:**	31	36	**86.1 %**
Date:	2025-02-25 13:49:57	**Functions:**	6	6	**100.0 %**

Directory	Line Coverage		Functions	
codecov	**86.1 %**	31 / 36	**100.0 %**	6 / 6

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- Constant environmental inputs can lead to **poor testing**
- Environmental inputs **need to be varied** during simulation
- Environmental models should be **separated from the VP**

Simplicity

Keep model as simple as possible
→ high performance

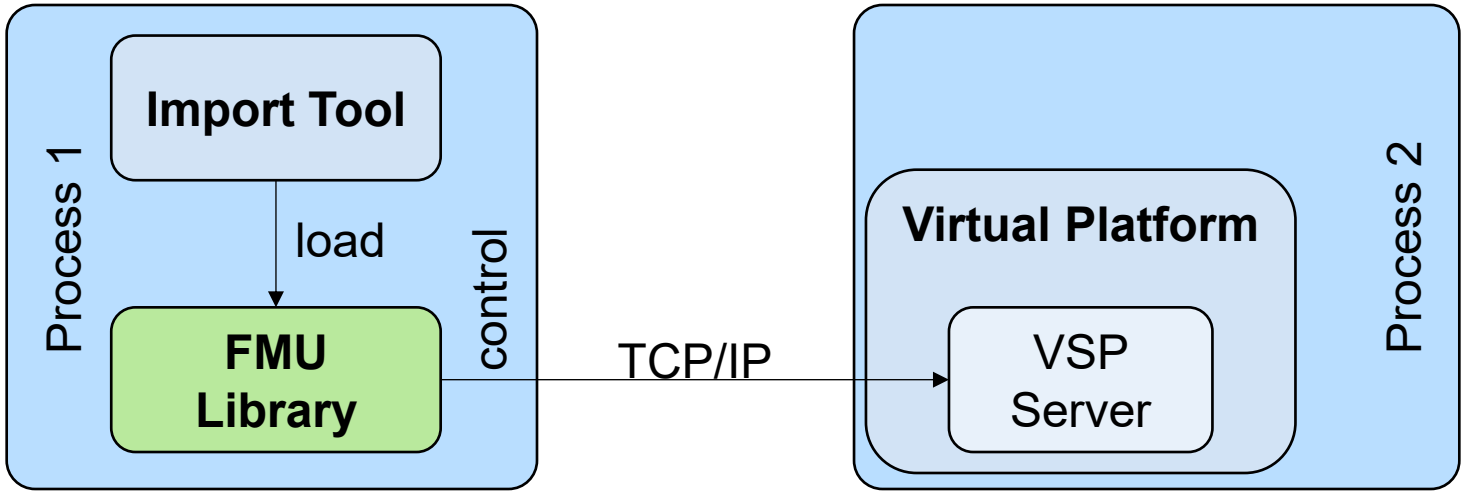
Genericity

Model should only reflect the behavior of the HW
→ reusability

Specialization of Tools

Well-established tool to create environmental models exist

FMI-Based Co-Simulation Approach



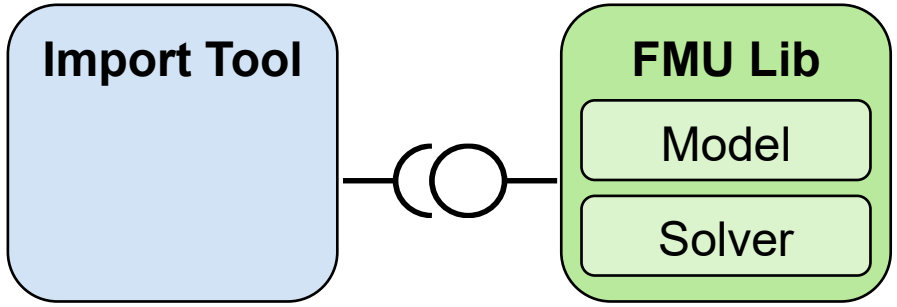
Time synchronization

Synchronize simulation time

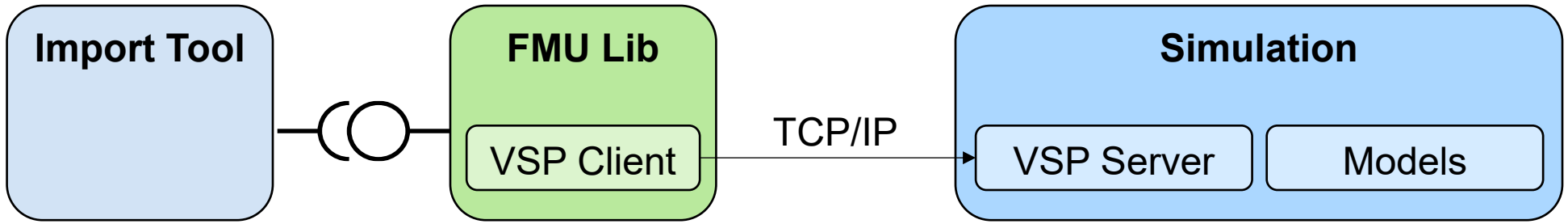
Property control

Expose selected model properties to the import tool

FMI Approach

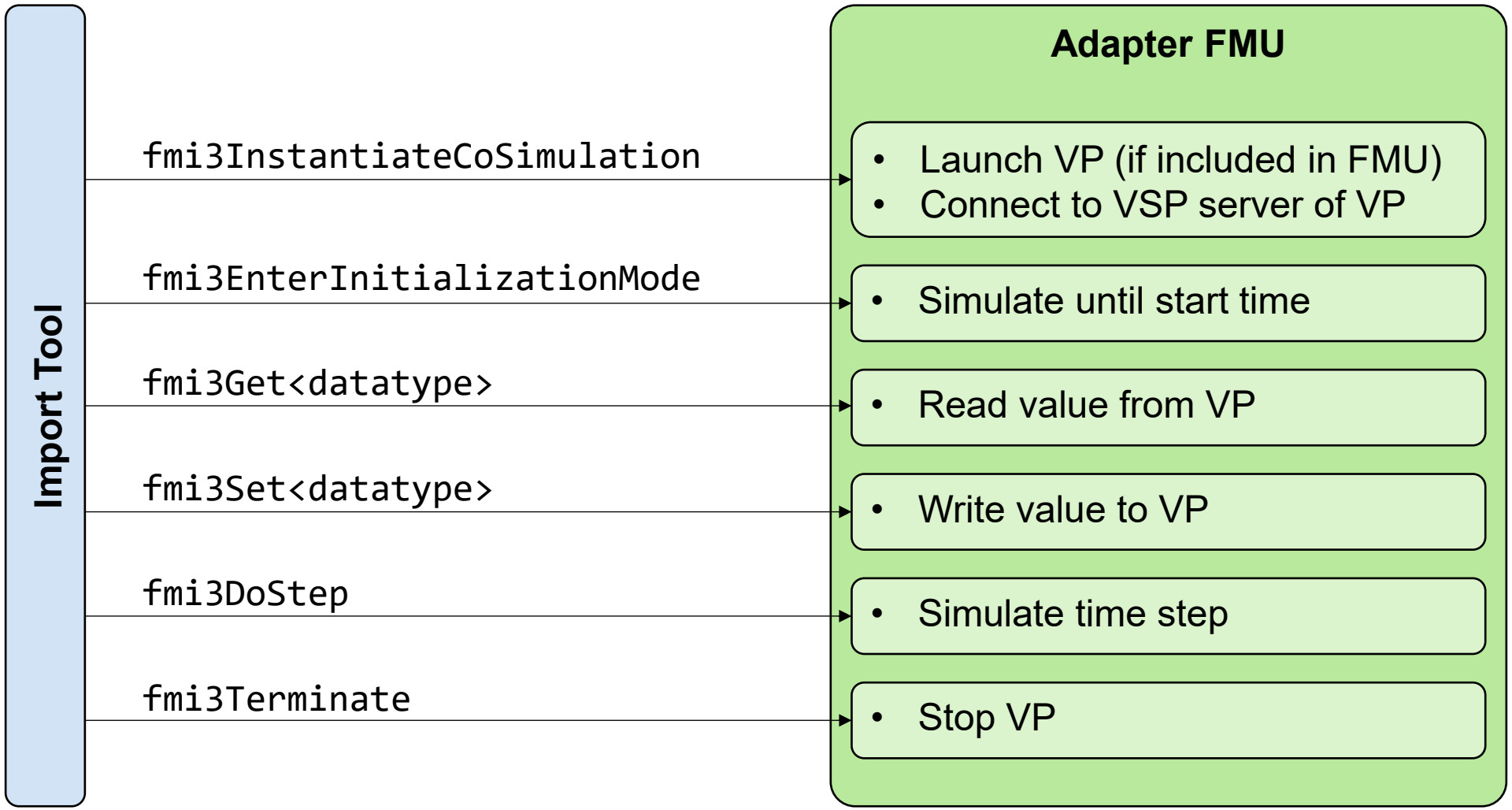


FMI for Co-Simulation



Adapter Approach

FMI Details


Import Tool
fmi3InstantiateCoSimulation
fmi3EnterInitializationMode
fmi3Get<datatype>
fmi3Set<datatype>
fmi3DoStep
fmi3Terminate
Adapter FMU
• Launch VP (if included in FMU)
• Connect to VSP server of VP
• Simulate until start time
• Read value from VP
• Write value to VP
• Simulate time step
• Stop VP

Model-Description File

```
<fmiModelDescription ... fmiVersion="3.0" modelName="myVP" ...>
    <CoSimulation modelIdentifier="myVP" needsExecutionTool="true"
        canHandleVariableCommunicationStepSize="true" ... />
    <DefaultExperiment startTime="3" stopTime="5" stepSize="0.01" />
    <ModelVariables>
        <Float64 name="time" valueReference="0" causality="independent" variability="continuous" />
        <Float32 name="system.max31855.temp" valueReference="1" causality="input"
            variability="continuous" start="10.0" />
        <UInt32 name="system.gpio.data" valueReference="2" causality="output" variability="discrete" />
    </ModelVariables>
    <ModelStructure>
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        <Output valueReference="2" />
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    <Annotations>
        <Annotation type="VCML">
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```

Model-Description File

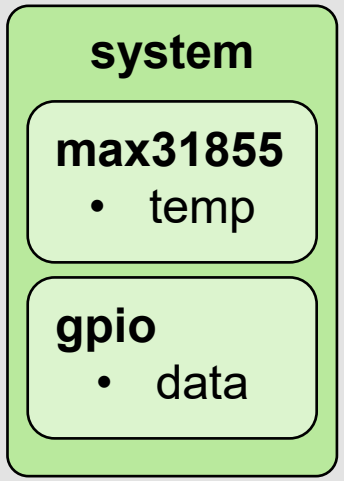
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        </Annotation>
    </Annotations>
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```

Define start and end time, and step size

Model-Description File

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        <Output valueReference="2" />
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    <Annotations>
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```

Define in- and outputs that should be exposed.
Reference by hierarchical name

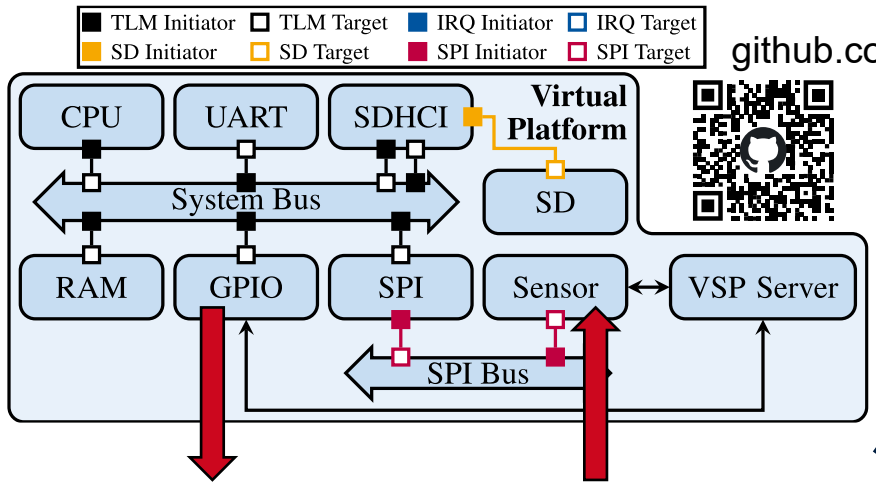


Model-Description File

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</fmiModelDescription>
```

Define connection parameters

Case Study



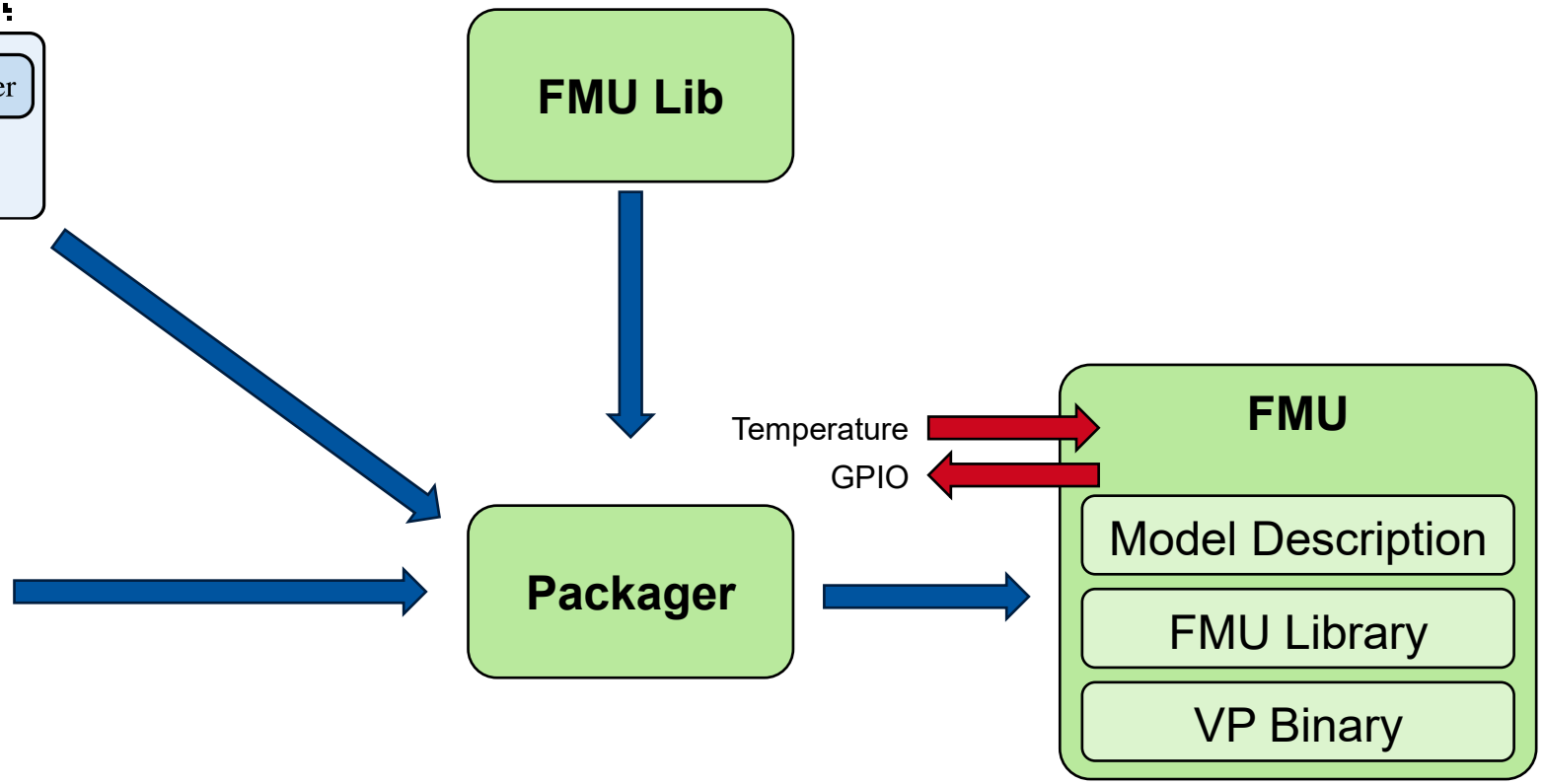
github.com/aut0/avp64

GPIO Pin Output

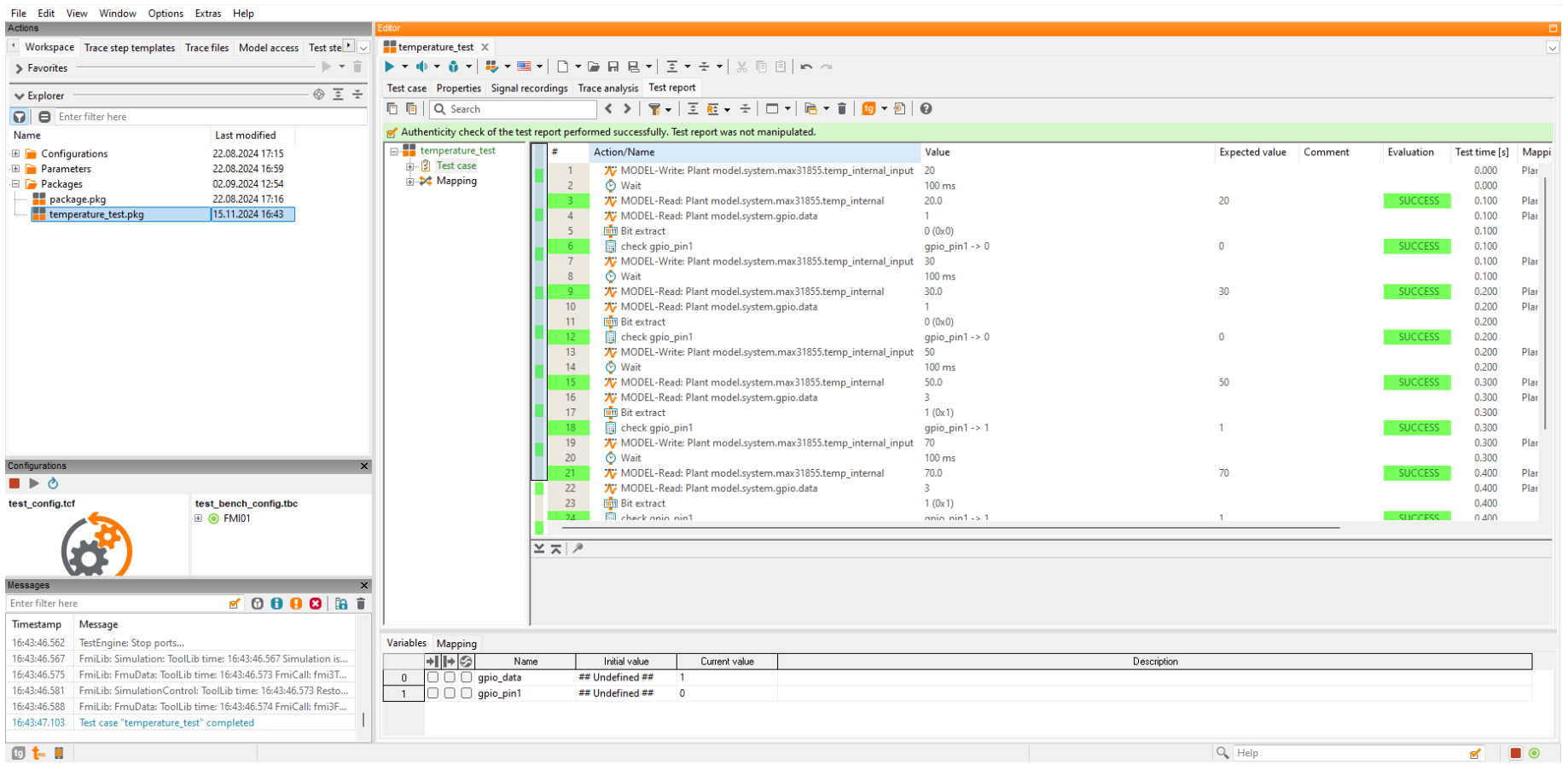
Temperature Input

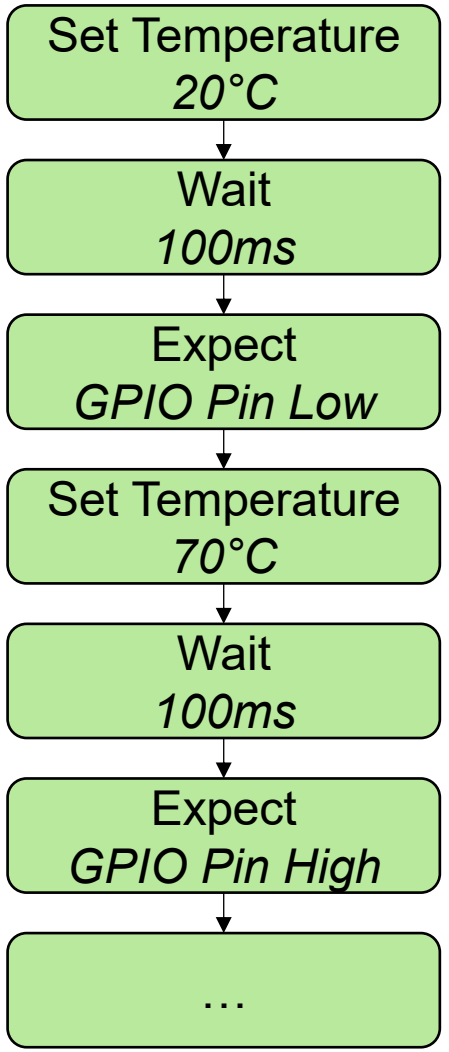
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Model Description

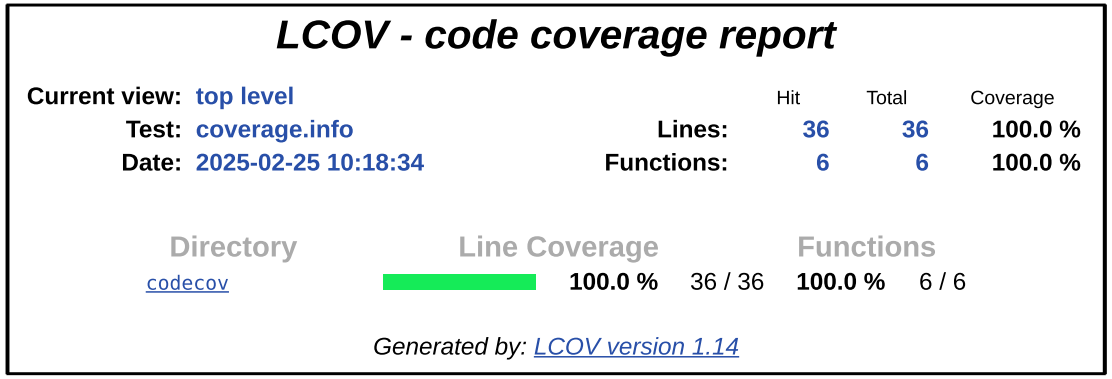


Test Setup


File Edit View Window Options Extras Help
Actions
Workspace Trace step templates Trace files Model access
Favorites
Explorer
Enter filter here
Name Last modified
Configurations 22.08.2024 17:15
Parameters 22.08.2024 16:59
Packages 02.09.2024 12:54
package.pkg 22.08.2024 17:16
temperature_test.pkg 15.11.2024 16:43
Configurations
test_config.tcf
test_bench_config.tbc
FMI01
Messages
Enter filter here
Timestamp Message
16:43:46.562 TestEngine: Stop ports...
16:43:46.567 FmiLib: Simulation: ToolLib time: 16:43:46.567 Simulation is...
16:43:46.575 FmiLib: FmuData: ToolLib time: 16:43:46.573 FmiCall: fmi3T...
16:43:46.581 FmiLib: SimulationControl: ToolLib time: 16:43:46.573 Resto...
16:43:46.588 FmiLib: FmuData: ToolLib time: 16:43:46.574 FmiCall: fmi3F...
16:43:47.103 Test case "temperature_test" completed
Editor
temperature_test
Test case Properties Signal recordings Trace analysis Test report
Search
Authenticity check of the test report performed successfully. Test report was not manipulated.
temperature_test
Test case
Mapping
Action/Name Value Expected value Comment Evaluation Test time [s] Mappi
1 MODEL-Write: Plant model.system.max31855.temp_internal_input 20 0.000 Plar
2 Wait 100 ms 0.000
3 MODEL-Read: Plant model.system.max31855.temp_internal 20.0 20 SUCCESS 0.100 Plar
4 MODEL-Read: Plant model.system.gpio.data 1 0.100 Plar
5 Bit extract 0 (0x0) 0.100
6 check gpio_pin1 gpio_pin1 -> 0 0 SUCCESS 0.100
7 MODEL-Write: Plant model.system.max31855.temp_internal_input 30 0.100 Plar
8 Wait 100 ms 0.100
9 MODEL-Read: Plant model.system.max31855.temp_internal 30.0 30 SUCCESS 0.200 Plar
10 MODEL-Read: Plant model.system.gpio.data 1 0.200 Plar
11 Bit extract 0 (0x0) 0.200
12 check gpio_pin1 gpio_pin1 -> 0 0 SUCCESS 0.200
13 MODEL-Write: Plant model.system.max31855.temp_internal_input 50 0.200 Plar
14 Wait 100 ms 0.200
15 MODEL-Read: Plant model.system.max31855.temp_internal 50.0 50 SUCCESS 0.300 Plar
16 MODEL-Read: Plant model.system.gpio.data 3 0.300 Plar
17 Bit extract 1 (0x1) 0.300
18 check gpio_pin1 gpio_pin1 -> 1 1 SUCCESS 0.300
19 MODEL-Write: Plant model.system.max31855.temp_internal_input 70 0.300 Plar
20 Wait 100 ms 0.300
21 MODEL-Read: Plant model.system.max31855.temp_internal 70.0 70 SUCCESS 0.400 Plar
22 MODEL-Read: Plant model.system.gpio.data 3 0.400 Plar
23 Bit extract 1 (0x1) 0.400
Variables Mapping
Name Initial value Current value Description
0 gpio_data ## Undefined ## 1
1 gpio_pin1 ## Undefined ## 0
Help


Set Temperature
20°C
Wait
100ms
Expect
GPIO Pin Low
Set Temperature
70°C
Wait
100ms
Expect
GPIO Pin High
...

Coverage Results



LCOV - code coverage report

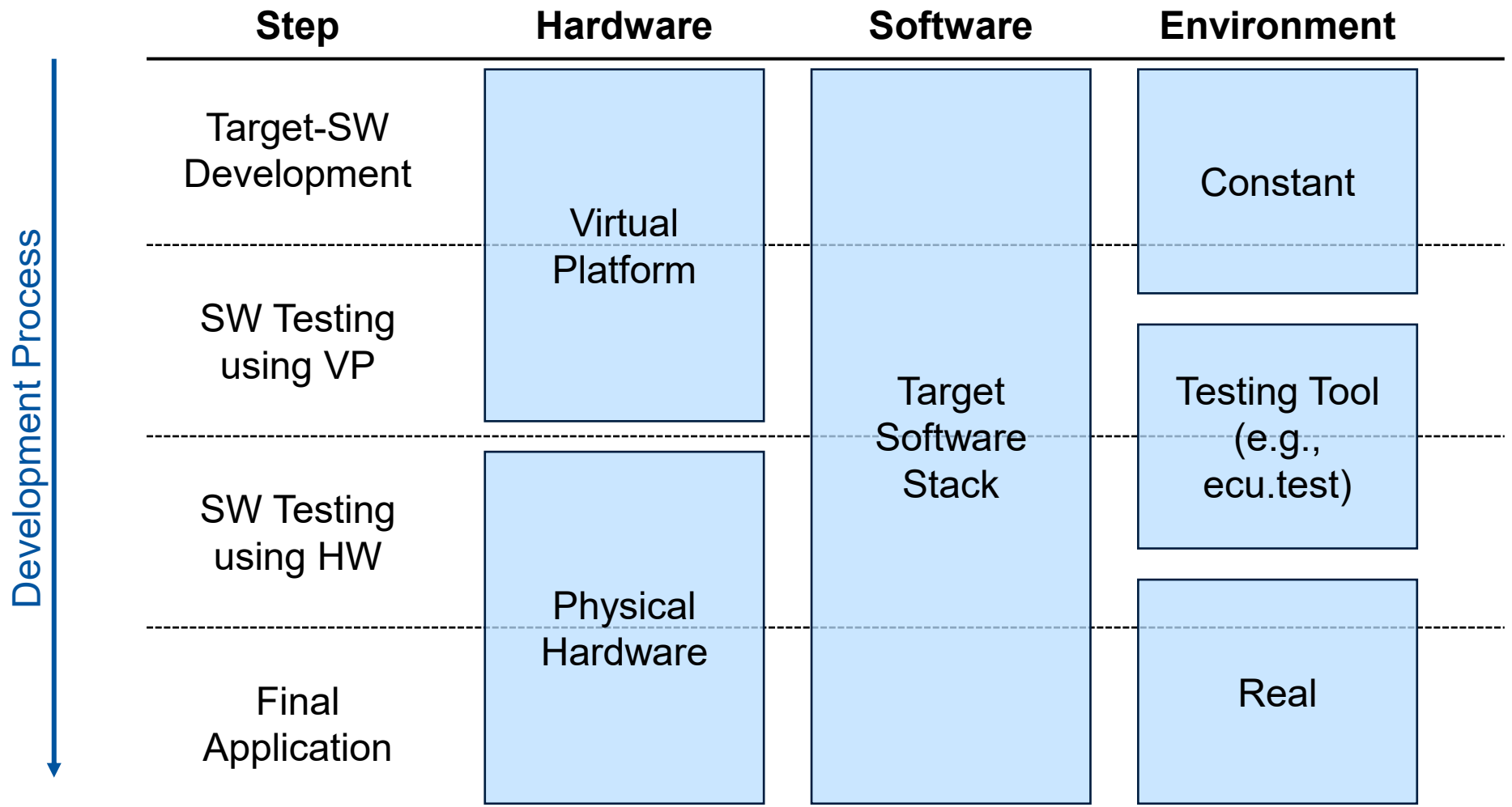
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Current view:	top level				
Test:	coverage.info	**Lines:**	36	36	100.0 %
Date:	2025-02-25 10:18:34	**Functions:**	6	6	100.0 %

Directory	Line Coverage		Functions	
codecov	100.0 %	36 / 36	100.0 %	6 / 6

Generated by: LCOV version 1.14

- **Increased code coverage** by testing different environmental inputs
- Simple scenario, can be extended to real-world applications
  - Transient signal waveforms
  - Other, external FMUs to provide physical models

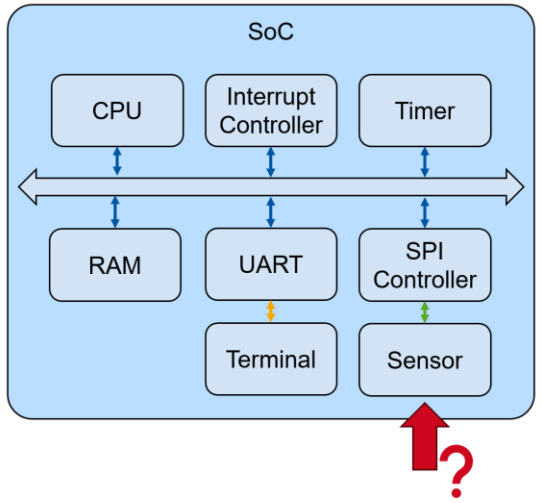
Design Process



Advantages

- Standalone VP can be used for **early SW development**
- FMI co-simulation **adds environmental inputs** to VP
- Test can be **developed using the VP**; SW can be tested early
- Developed tests can be **reused** for real HW testing

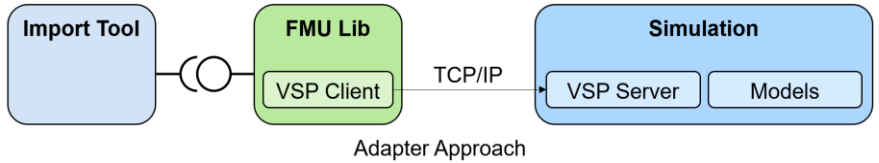
Summary

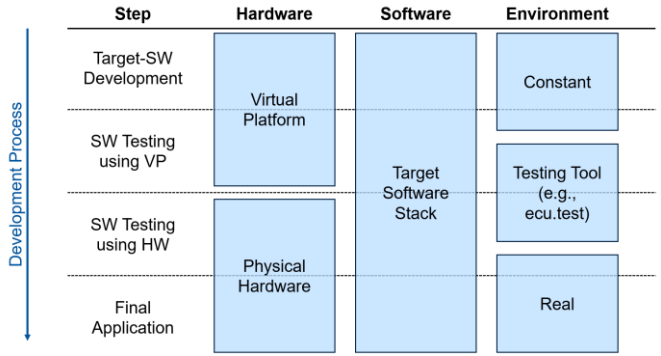


- VPs are a great tool for early SW development
- Lack of environmental simulation
  - Stimuli are usually not part of a VP

→ Needed for thorough SW testing

- FMI-based co-simulation approach
- Separate HW and environment simulation

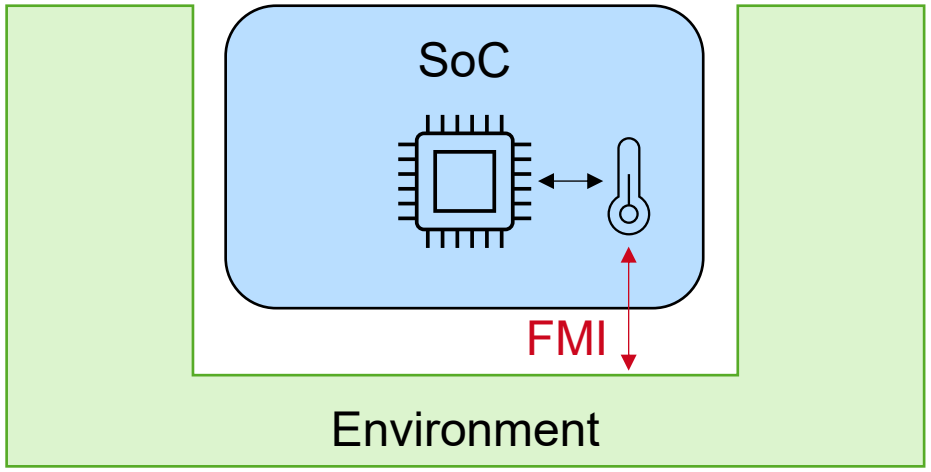




- Design-flow integration
- Early SW and test development
- Re-use of developed tests

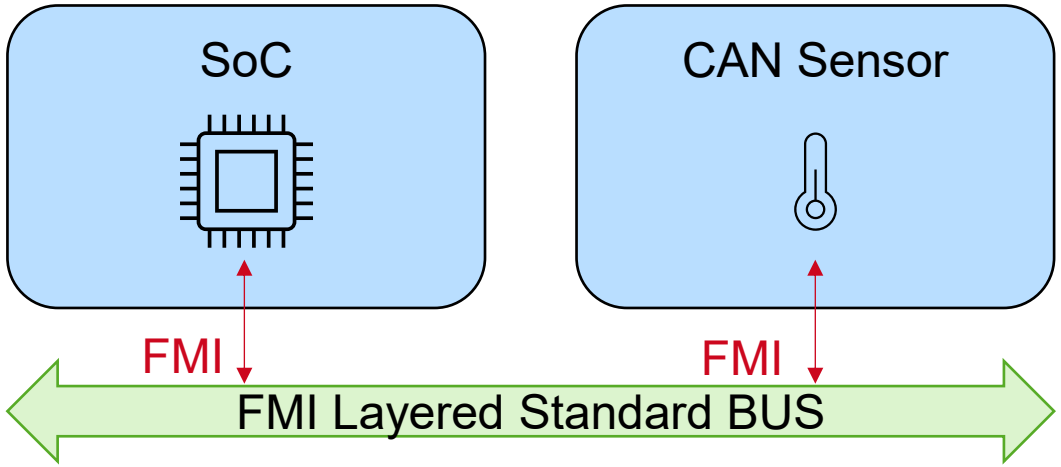
Future Work

By now



- Input/outputs connected to FMI

Next step



- Use FMI LS Bus to connect different simulations
- Connected via a bus (CAN/Ethernet)