Leveraging hardware emulation to accelerate SoC verification in multi-physics automotive simulation environment via the Functional Mock-up Interface

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2019 DESIGN AND VERIFICATION™ DVCON CONFERENCE AND EXHIBITION EUROPE

Agenda

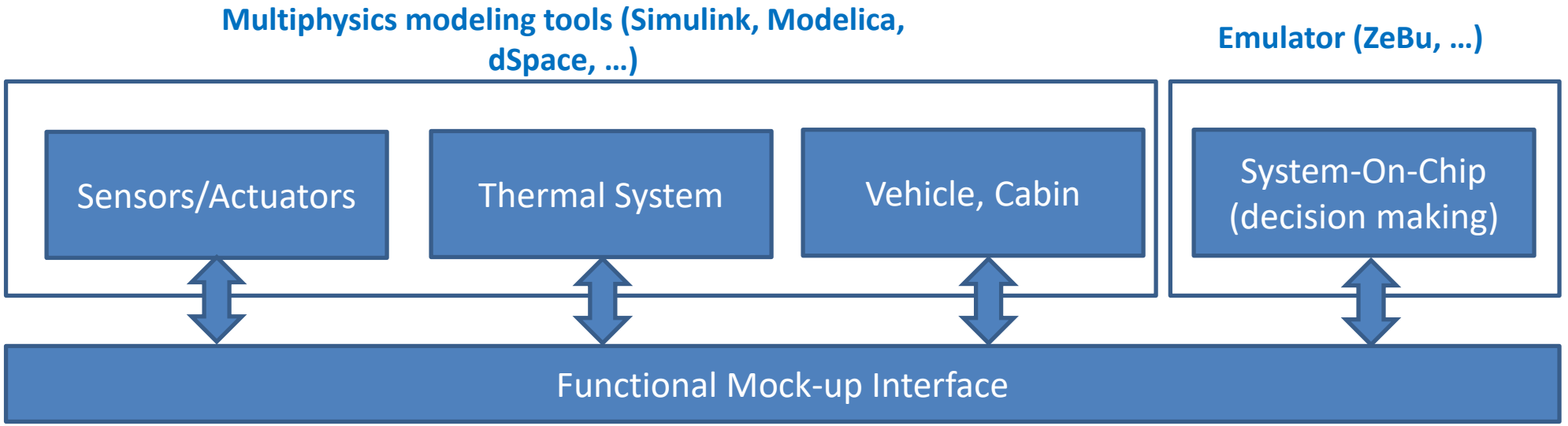
- Context
- Integration of hardware emulation in automotive validation flow
- OpenModelica and ZeBu coupling

Context (1/2)

- The growing complexity and functional demand of automotive HW/SW requires extensive verification effort
  - Verification effort increases to guarantee fault-free functionality to satisfy qualification requirements
  - Development cycles shorten and restrictive time-to-market obligations require advancements for SW development and verification.
  - To meet these needs, hardware emulation solutions have emerged as verification solutions.

- The design of modern automotive SoCs requires also the use of multiple simulation domain tools to validate the system in its future environment with all its external interactions.
  - It is now becoming necessary to build hybrid co-simulation models.

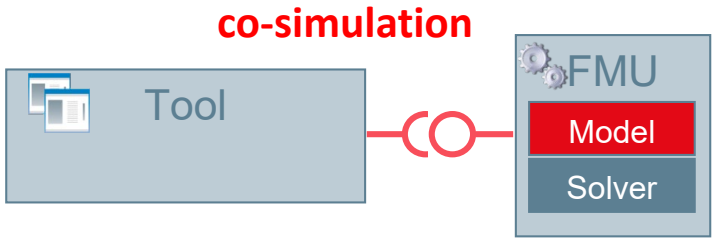
Context (2/2)

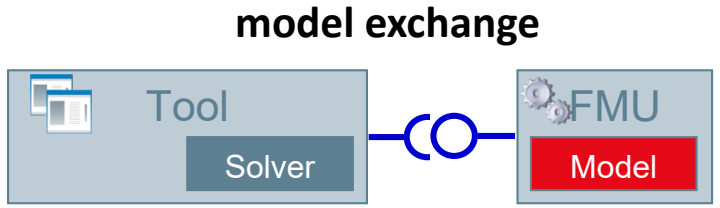


How to integrate hardware emulation like ZeBu in the automotive validation flow?

What is FMI?

- Open interface standard for model exchange between different modeling and simulation environments
  - A component implementing the FMI interface is known as **Functional Mock-up Unit (FMU)**
- The FMI standard supports





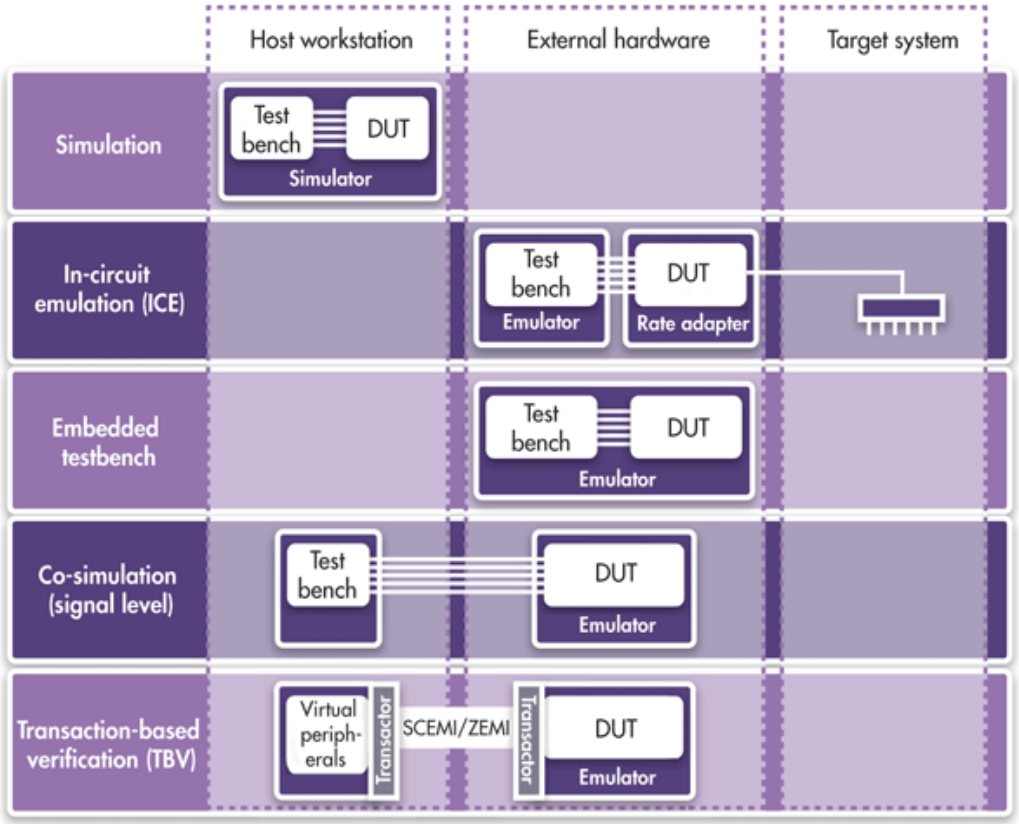
  - Tool: a master which controls the data exchange between FMUs
- A FMU package consists of
  - Model description file
    - a XML file containing the definition of all exposed variables in the FMU and other static information
  - FMU model implementation
    - in form of source code and/or pre-compiled shared libraries.
  - Additional files
    - model icon (bitmap file), documentation files, maps and tables needed by the FMU, and/or all object libraries or dynamic link libraries that are utilized.

FMI execution steps

Steps	Functions	Description
Instantiation	*fmi2Instantiate()*	FMU instance creation
Initialization mode	*fmi2EnterInitializationMode()*	• FMU notification to perform its internal model's initialization • Possibility to set input variables with ***fmi2SetXXX*** and to get output variables with ***fmi2GetXXX*** (XXX corresponds to the variable type)
Runtime	*fmi2DoStep(fmi2Component c, fmi2Real currentCommunicationPoint, fmi2Real communicationStepSize,…)*	• Slave initialization and co-simulation computation. • The calculation is performed until the next communication point • fmi2DoStep function is called periodically (communication step) by the master until the simulation ends
Termination	*fmi2Terminate()*	Retrieving the simulation solution and terminate the simulation

Commonly used emulation modes (1/2)

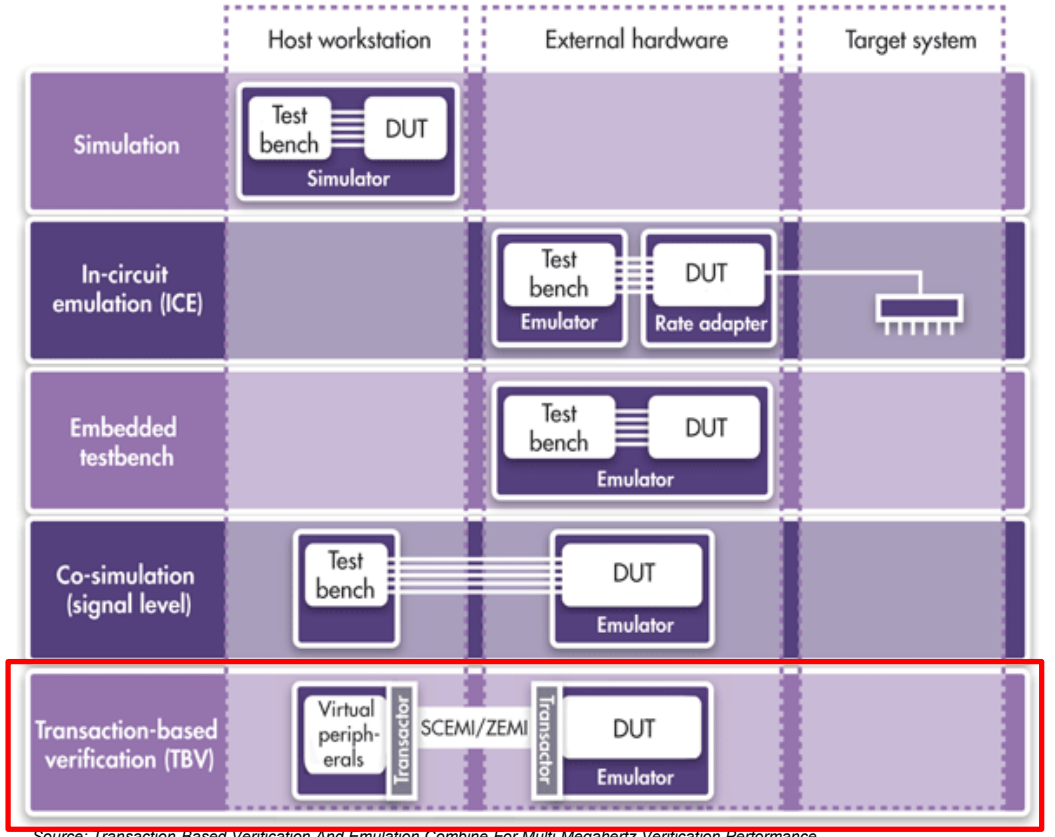
- In-circuit emulation (ICE)
  - Pros
    - Allow to directly connect physical devices to the emulator
    - Eliminate host PC communication
  - Cons
    - Rate adapter development can be complex
- Embedded testbench
  - Pros
    - Eliminate host PC communication
  - Cons
    - Testbench has to be synthesizable



Source: Transaction-Based Verification And Emulation Combine For Multi-Megahertz Verification Performance

Commonly used emulation modes (2/2)

- Co-simulation
  - Pros
    - Easy to set up => use the existing testbench
  - Cons
    - Performance limited by the number of signals to exchange between host and emulator
- Transaction-based verification (TBV)
  - Pros
    - Raises the level of verification abstraction
    - Simplifies the communication between the testbench and DUT
  - Cons
    - Need to develop protocol-specific transactors



Source: Transaction-Based Verification And Emulation Combine For Multi-Megahertz Verification Performance

ZeBu transaction-based verification (TBV) execution steps

Steps	Functions	Description
Initialization	*open(location);* *init();* *getClock("clock");* *connect();*	• Mandatory operations • Open and initialize the ZeBu board • Get the clock driver • Depending on the component used in the design, configuration phases might be required • AXI transactor configuration phase (setting the data bit-width, the address bit-width) etc of the AXI interface. • Several operations, like memory load, signals dump and so on, can be included in this step.
Runtime	*run(cycles);* *speed = InVar;* *OutVar = accel;*	• Running the emulation for a defined amount of cycles. • The current value of variables can be get or set during this step.
Termination	*free(pt);* *close();*	Free pointers, …, close the ZeBu board

FMU to ZeBu adaptation: functions

	FMI functions	ZeBu functions

Initialization	`fmi2Instantiate(…)`
	`fmi2EnterInitializationMode(…)`
		`zebu = Board::open(workLocation);`
		`zebu->init();`
		`zebu->getClock("top.clk");`
		`zebu->getDriver("top.dut_cosim");`
		`driver->connect();`
		`*reg_speed = zebu->getSignal("top.reg_speed");`
		`*reg_accel = zebu->getSignal("top.reg_accel");`
		`*reg_brake = zebu->getSignal("top.reg_brake");`

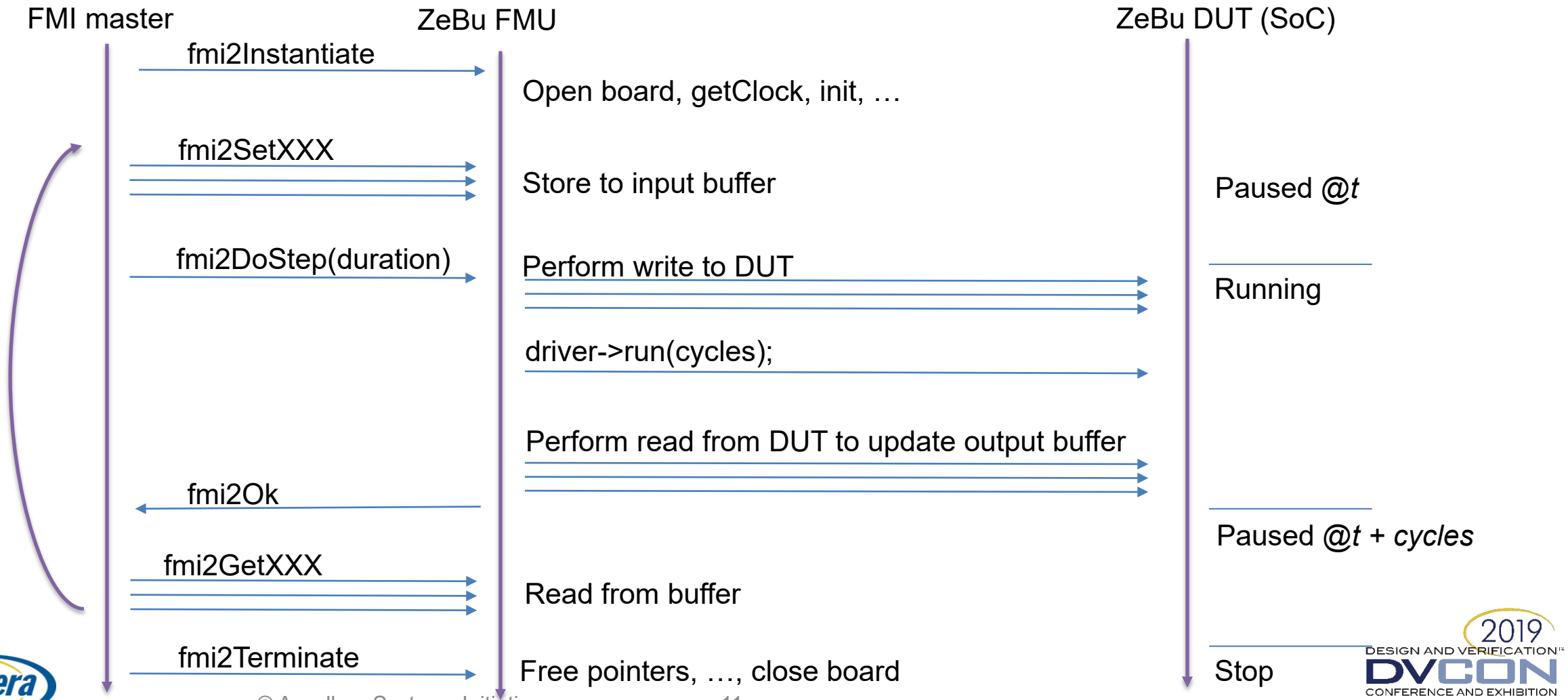
Runtime	`fmi2DoStep(…,duration,…)`	`driver->run(cycles);`

Reading data	`fmi2GetInteger(…)`
	`fmi2GetReal(…)`
	…
		`OutVar[1] = *reg_accel;`
		`OutVar[3] = *reg_brake;`

Writing data	`fmi2SetInteger(…)`
	`fmi2SetReal(…)`
	…
		`speed = InVar[2];`
		`*reg_speed = speed;`

Termination	`fmi2Terminate()`	`zebu->close();`

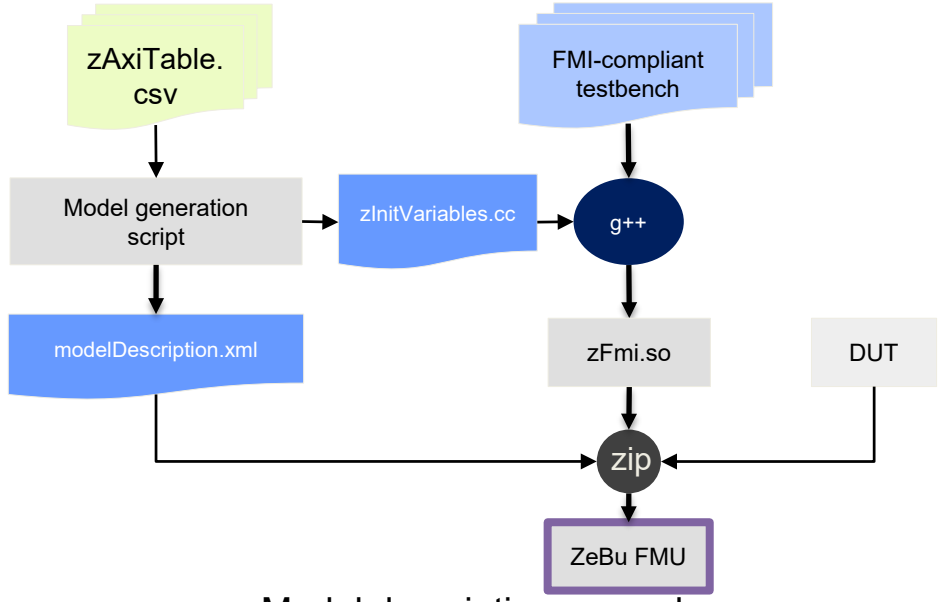
FMU to ZeBu adaptation: synchronization



Automatic generation of ZeBu FMU

- Inputs
  - zAxiTable.csv contains
    - Name, address, direction (input or output), type, intial value, description and dependency between variables
  - FMI-compliant testbench
    - Specialization of the FMI functions to implement the testbench
- Model generation script generates
  - C++ file (zInitVariables.cc)
    - Set the address and initialize the value of all variables
  - XML file (modelDescription.xml)
    - FMI description of available interfaces
- ZeBu FMU package
  - zFmi.so – shared library
  - modelDescription.xml – XML-based model description
  - DUT backend folder – optional other resources
    - FPGA bitstreams

Automatic FMU generation flow



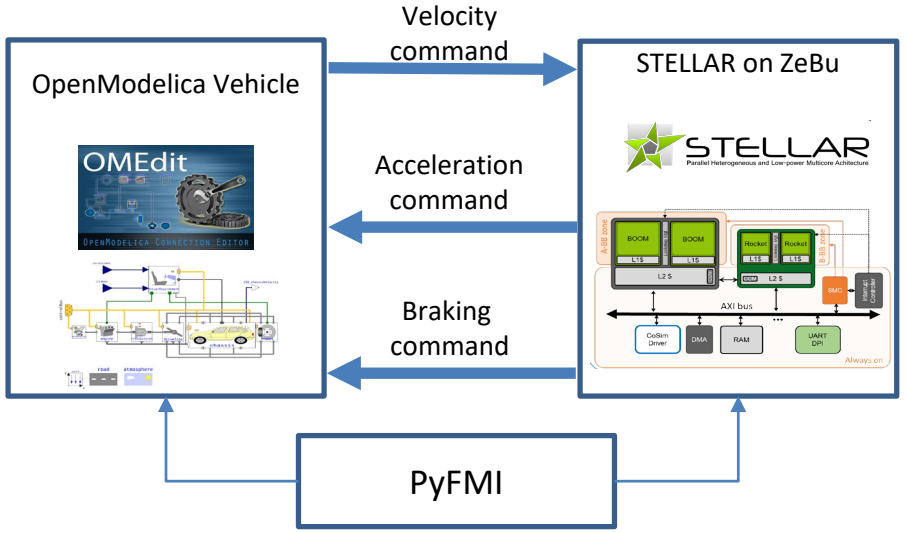
Model description example

```
<fmiModelDescription variableNamingConvention="flat" modelName="zFMU"
generationDateAndTime="2018-11-30T13:49:27.249948" description="FMU ZeBu" numberOfEventIndicators="0"
fmiVersion="2.0" guid="737a13def6464e0191e5704890233ad1" generationTool="zFmiCsvParserToXml.py">
  <CoSimulation canHandleVariableCommunicationStepSize="true" canSerializeFMUstate="false"
canGetAndSetFMUstate="false" canInterpolateInputs="false" maxOutputDerivativeOrder="0"
providesDirectionalDerivative="false" canNotUseMemoryManagementFunctions="true" canRunAsynchronuously="true"
canBeInstantiatedOnlyOncePerProcess="true" modelIdentifier="zFMU" needsExecutionTool="false"/>
  <ModelVariables>
    <ScalarVariable name="velocity" valueReference="1" description="Vehicle Chassis Velocity" causality="input"
variability="discrete" initial="approx">
      <Real start="0"/>
    </ScalarVariable>
    <ScalarVariable name="brake" valueReference="2" description="Vehicle Brake" causality="output"
variability="discrete" initial="approx">
      <Real start="0"/>
    </ScalarVariable>
    <ScalarVariable name="accelerate" valueReference="3" description="Vehicle Acceleration" causality="output"
variability="discrete" initial="approx">
      <Real start="0"/>
    </ScalarVariable>
  </ModelVariables>
  <ModelStructure>
    <Outputs>
      <Unknown index="2" dependencies=""/>
      <Unknown index="3" dependencies=""/>
    </Outputs>
  </ModelStructure>
</fmiModelDescription>
```

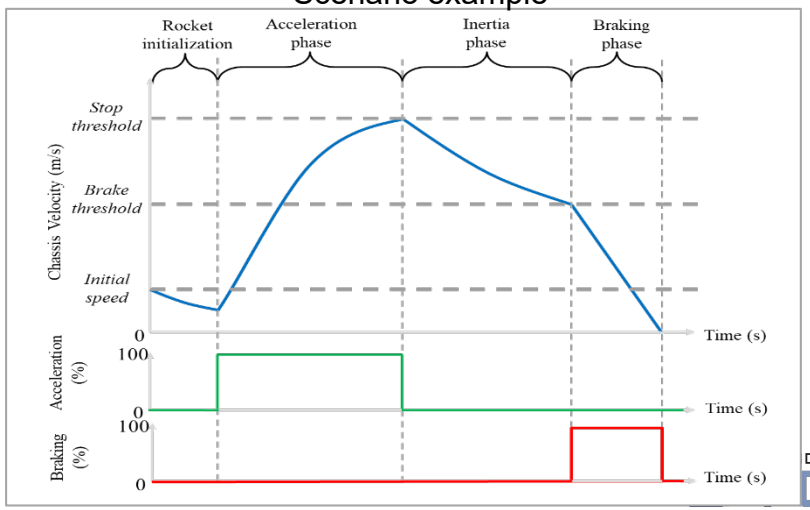
EXPERIMENTS

Overview

- Evaluation based on a multi-physics environment
  - a FMU vehicle model in OpenModelica
  - a multi-core processor based on RISC-V rocket core emulated on ZeBu (ZeBu FMU)
- Data exchange and the synchronization between the two FMUs controlled by PyFMI master
- Experiment's goal
  - To control the vehicle speed of the FMU vehicle with one rocket core

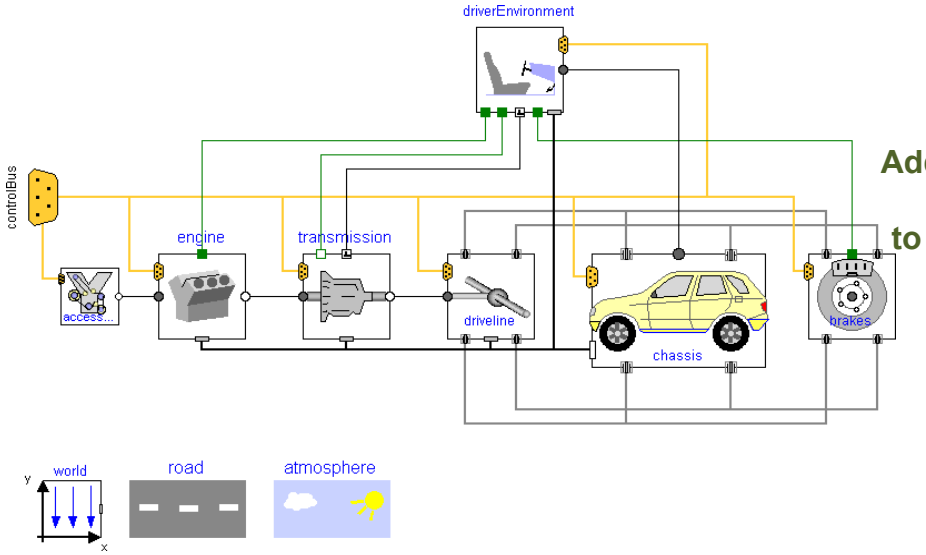


Scenario example



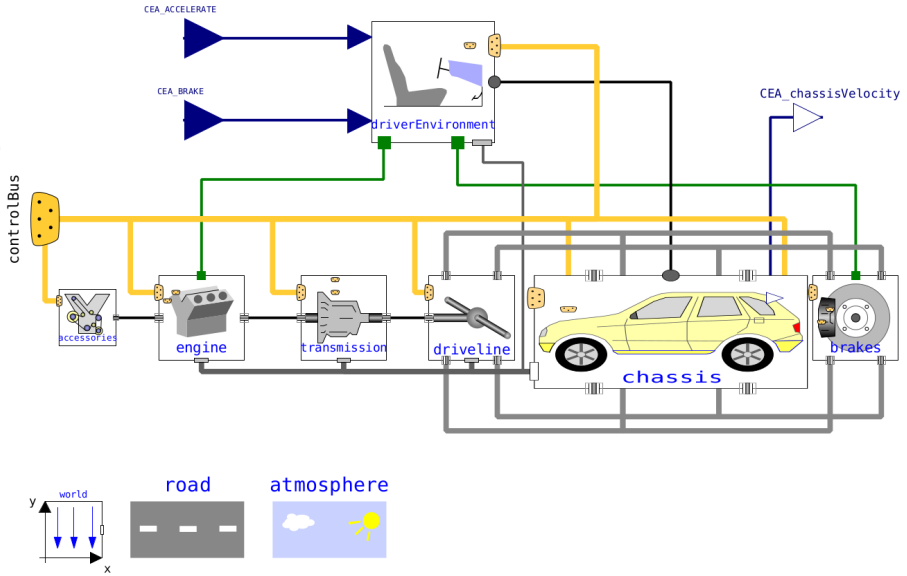
Vehicle model in OpenModelica

Initial model



Adding inputs/outputs to communicate to external components

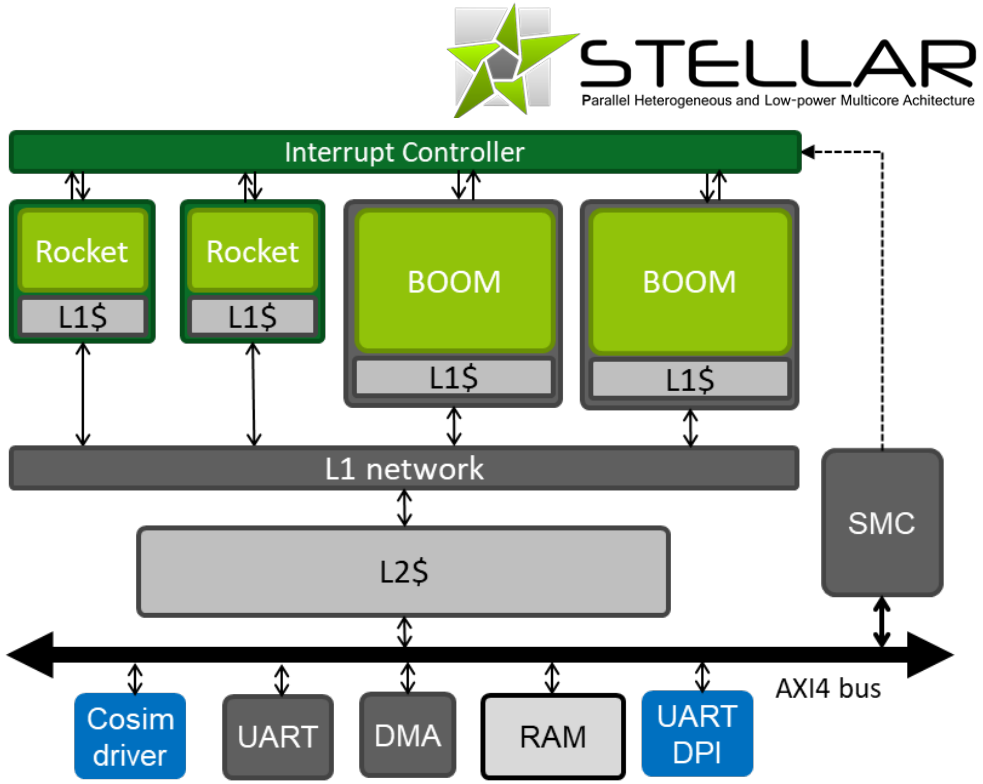
Modified model



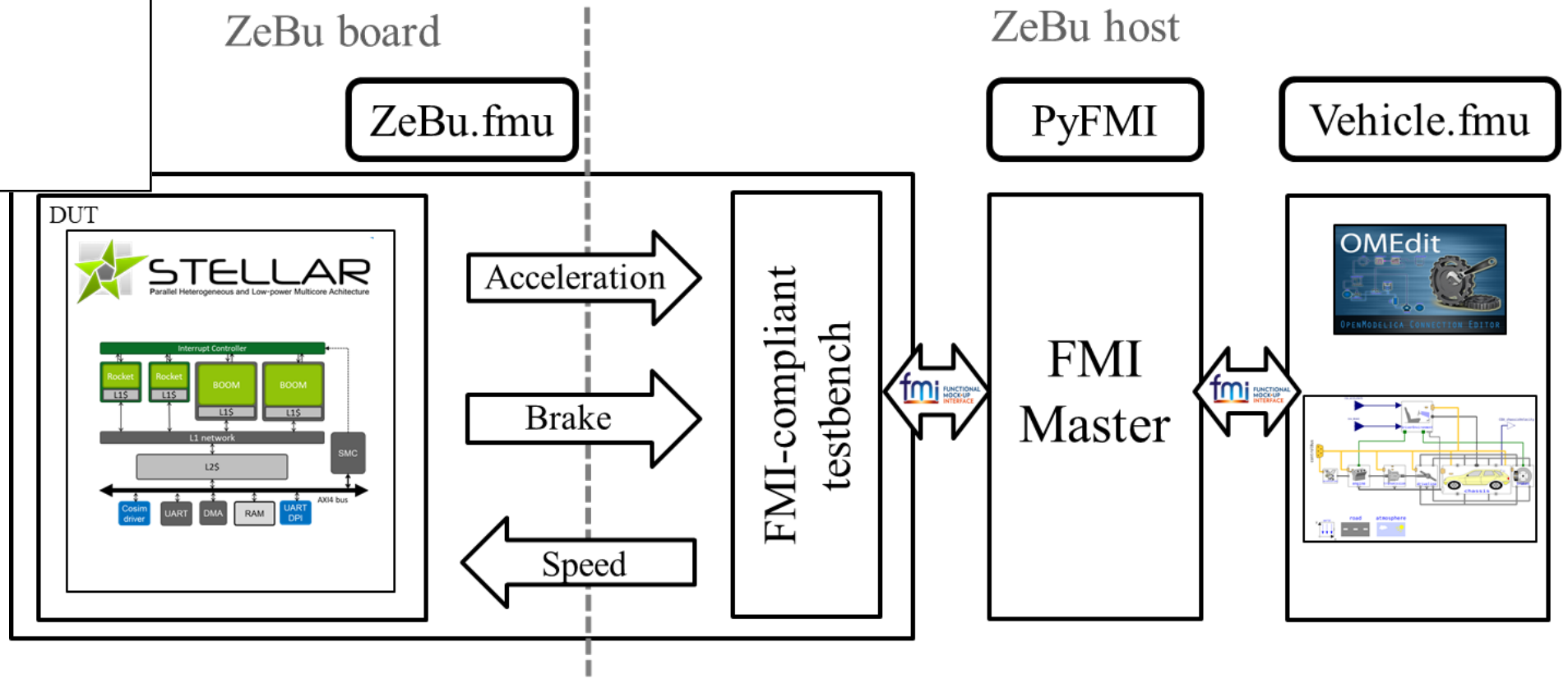
- Complexity of OpenModelica vehicle
  - 150 non-trivial equations and variables
  - Whole system consists of 10 main sub-systems
- Provides standard interface definitions for automotive subsystems and vehicle models.
- Designed to promote compatibility between the various automotive libraries and provide a flexible, powerful structure for vehicle modelling.

STELLAR: Parallel Heteregenous and Low-power Multicore Architecture

- A big.LITTLE like 64-bit heterogeneous multicore
  - Small cores
    - Rocket without FPU based
    - 8ko L1 caches
  - Big cores
    - Triple issue BOOM based
    - 32ko L1 caches
  - L1 cache coherency (MESI)
  - Instructions monitor (ROCC)
- Complete AMBA interconnection
  - Generated by Synopsys Core Assembler
  - AXI4 + AHB + APB network
  - I2C, UART and timers peripherals
- Main features
  - Smart monitoring
    - Performance, ageing, power consumption, BB zones
  - Heterogeneous management (FAMP and HW accelerators)
  - Semi-automatic MPSoC generation



Results



- Master simulation information: final simulation time = 240s and step size = 1s
  - The co-simulation duration is 5s
- Thanks to ZeBu, the hardware-based control accelerates the co-simulation (up to 100x compared to RTL simulation)

Conclusion

- Integration of ZeBu Server-3 emulator platform into a multi-physics automotive simulation environment through the use of FMI
- The proposed approach is based on creating a FMI to ZeBu adaptation functions
  - An automatic FMU generation flow is also proposed.
- Validation of the integration
  - Co-simulation between OpenModelica (modeling a vehicle) and ZeBu (implementing a RISC-V based multicore architecture) for vehicle speed control
  - The hardware-based control accelerates the co-simulation (up to 100x compared to RTL simulation)

Thank you

Any questions?