Model Based ECU Development
An Integrated MiL, SiL, HiL Approach

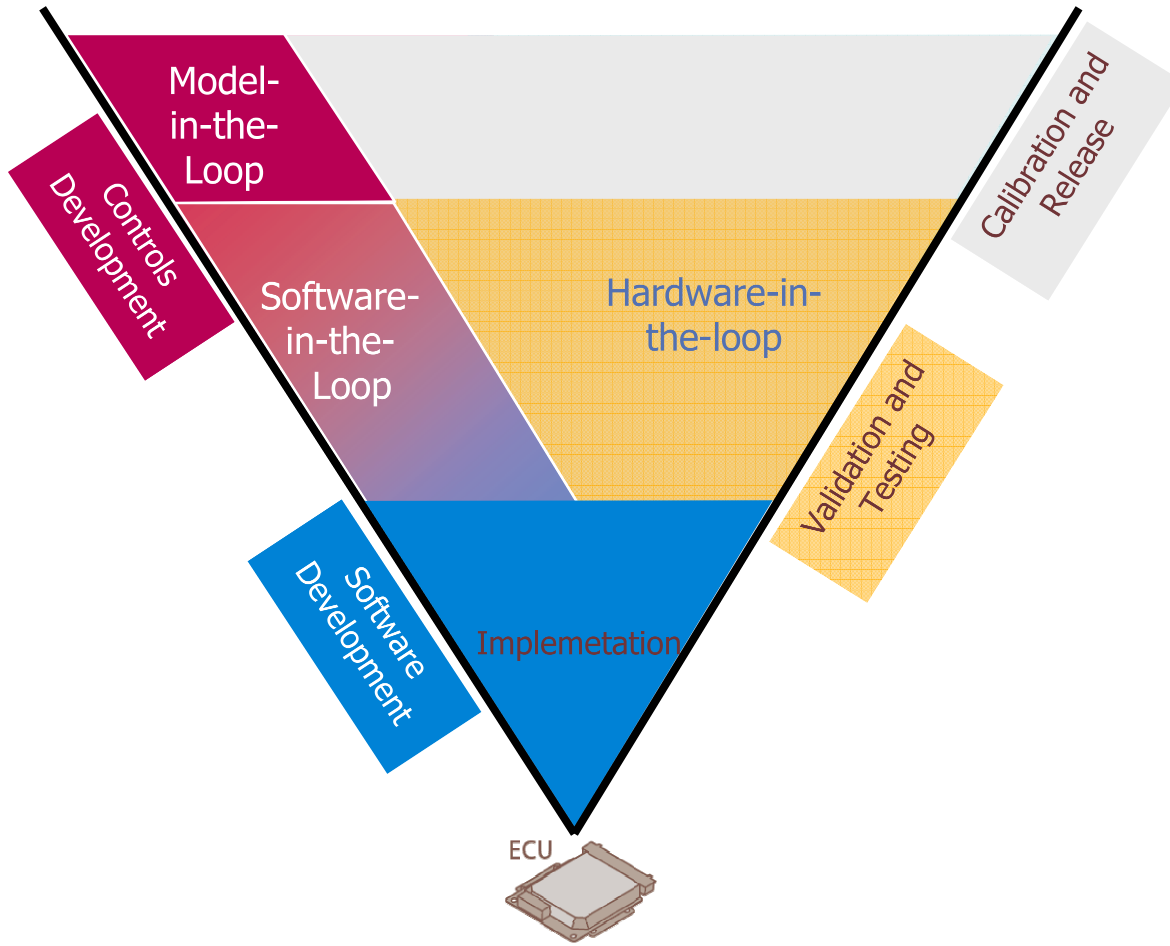
Agenda

- Model-Based ECU Development – Today
  - Model-in-the-Loop (MiL) Development
  - Software-in-the-Loop (SiL) Development
  - Hardware-in-the-Loop (HiL) Development
- Challenges of the Traditional Process
- Requirements of an Integrated MiL/SiL/HiL Aproach
- An ETAS Solutions
- Conclusions

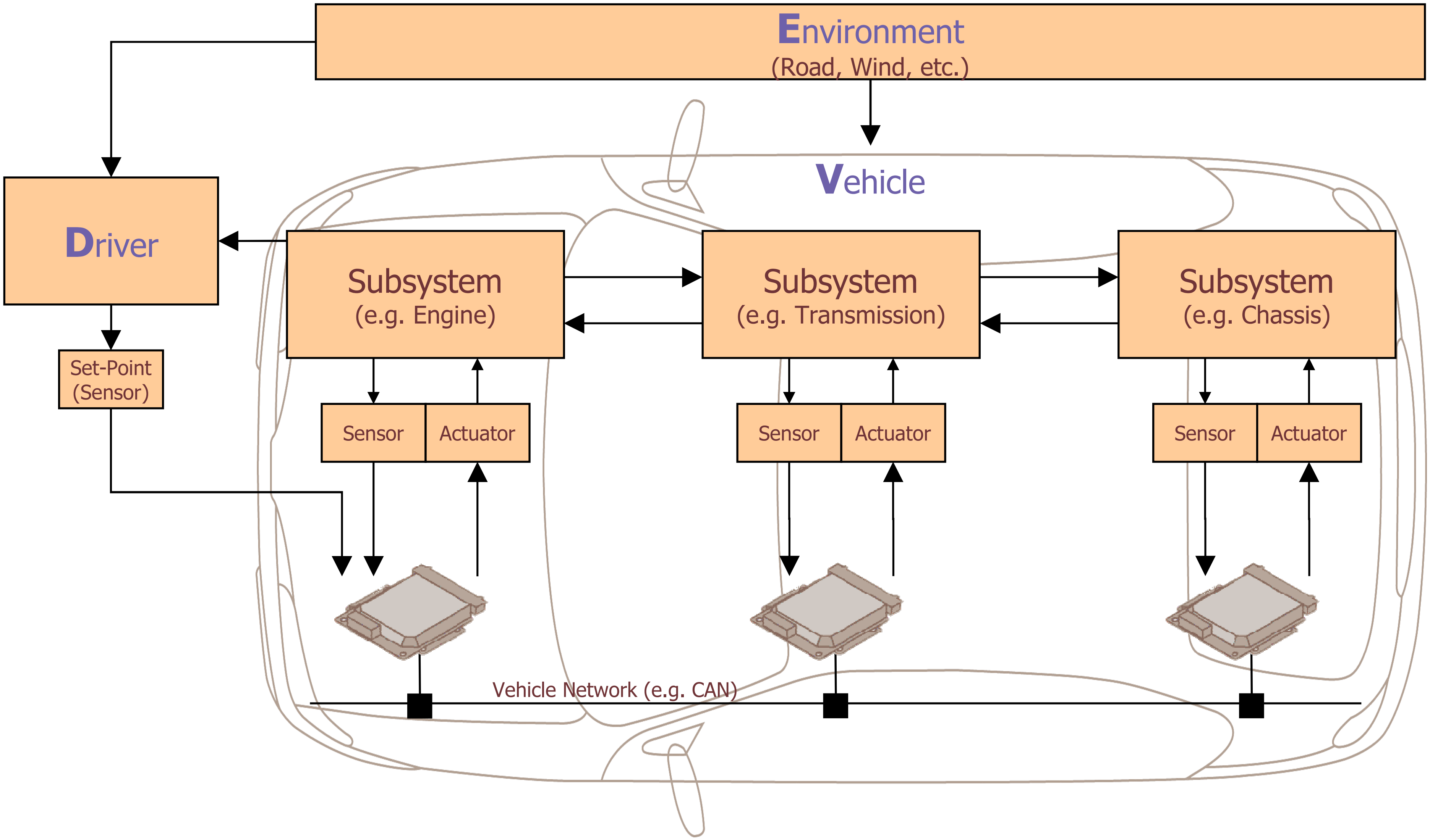
Model-Based ECU Development -Today
Process Steps

- <u>Goal</u>:
  - Rapid development, test and validation of new control strategies

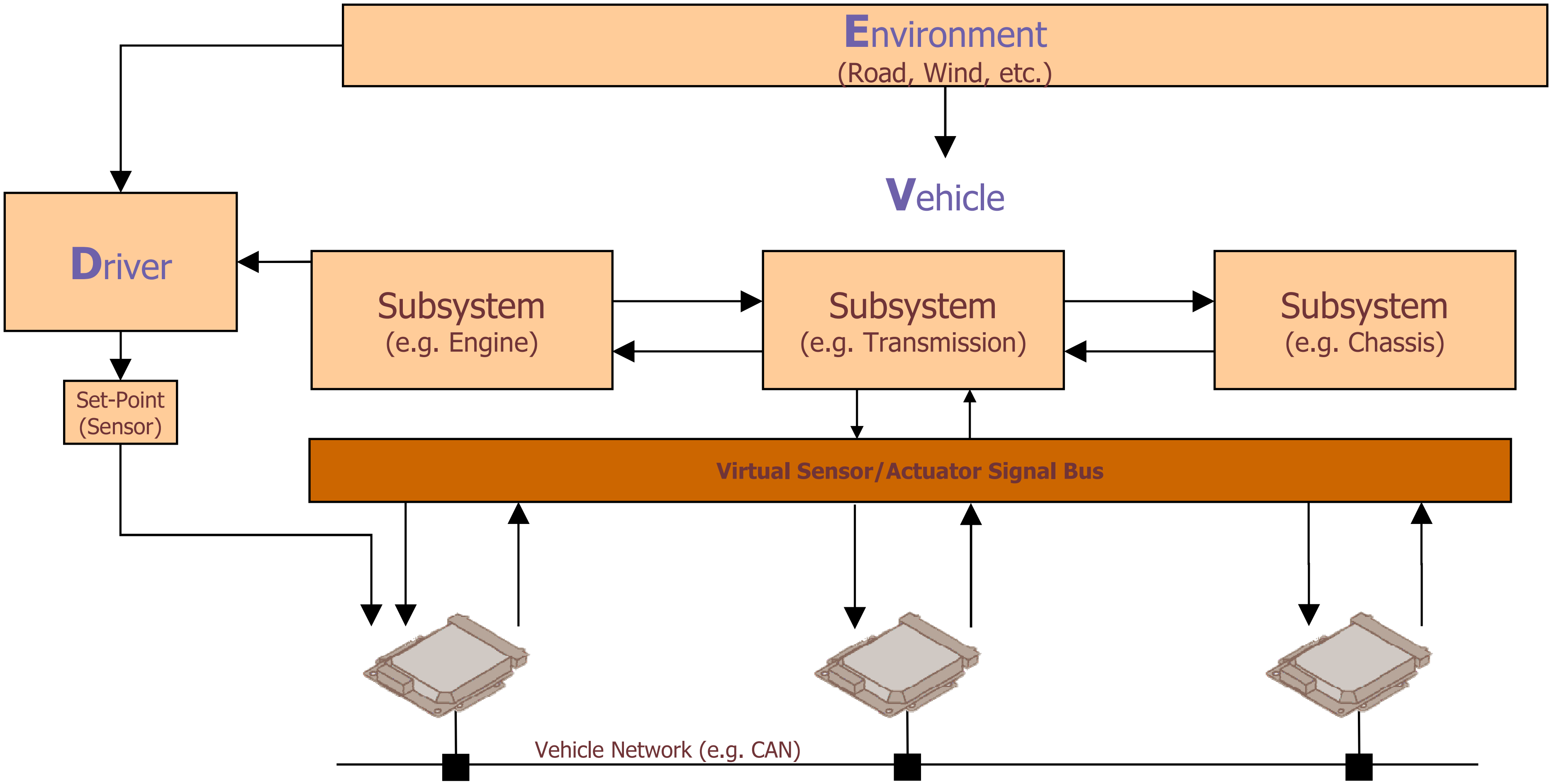
- <u>Methodologies:</u>
  - Modeling
  - Model-in-the-loop
  - Software-in-the-loop
  - Hardware-in-the-loop



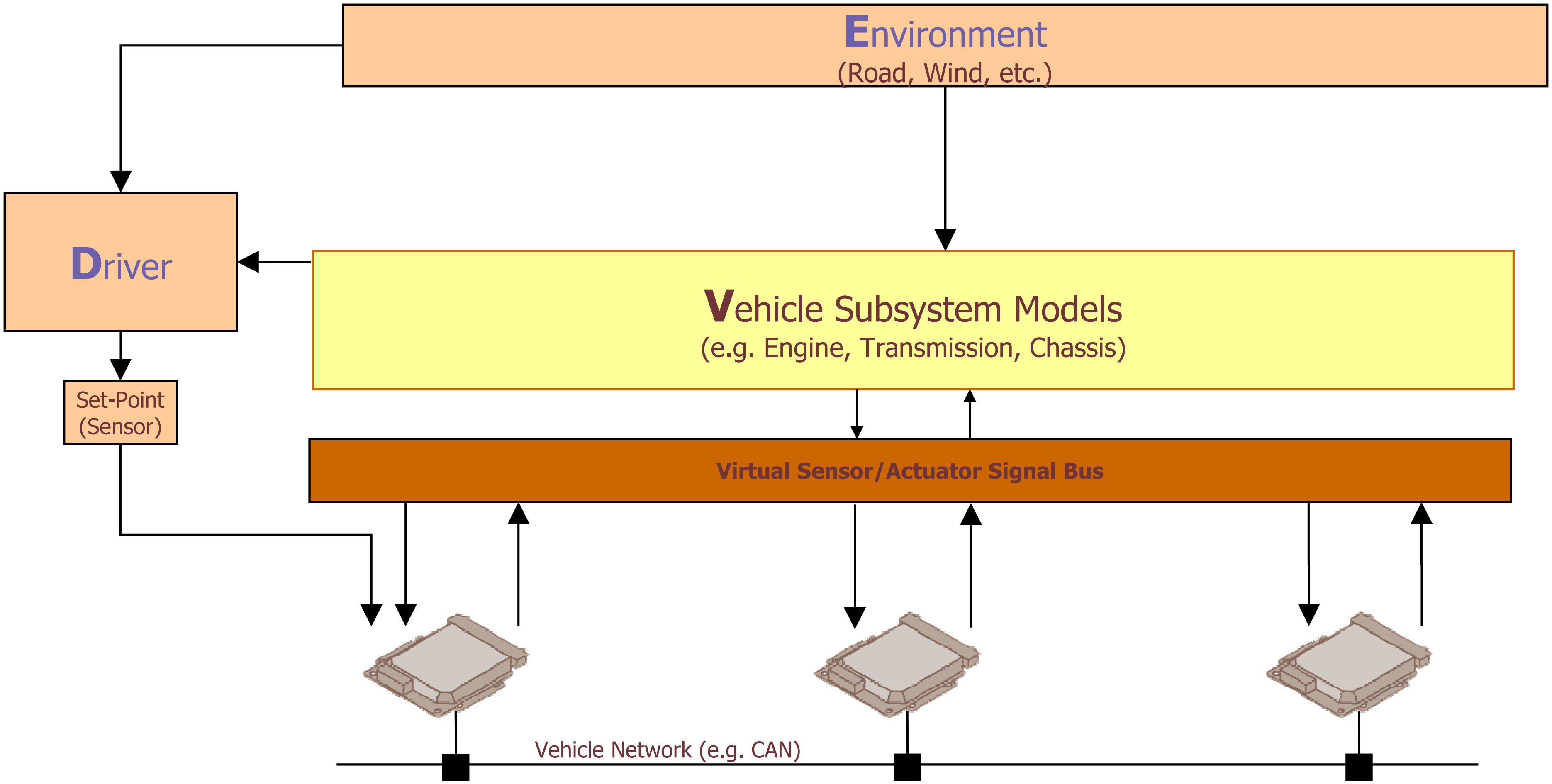
Overall System Architecture



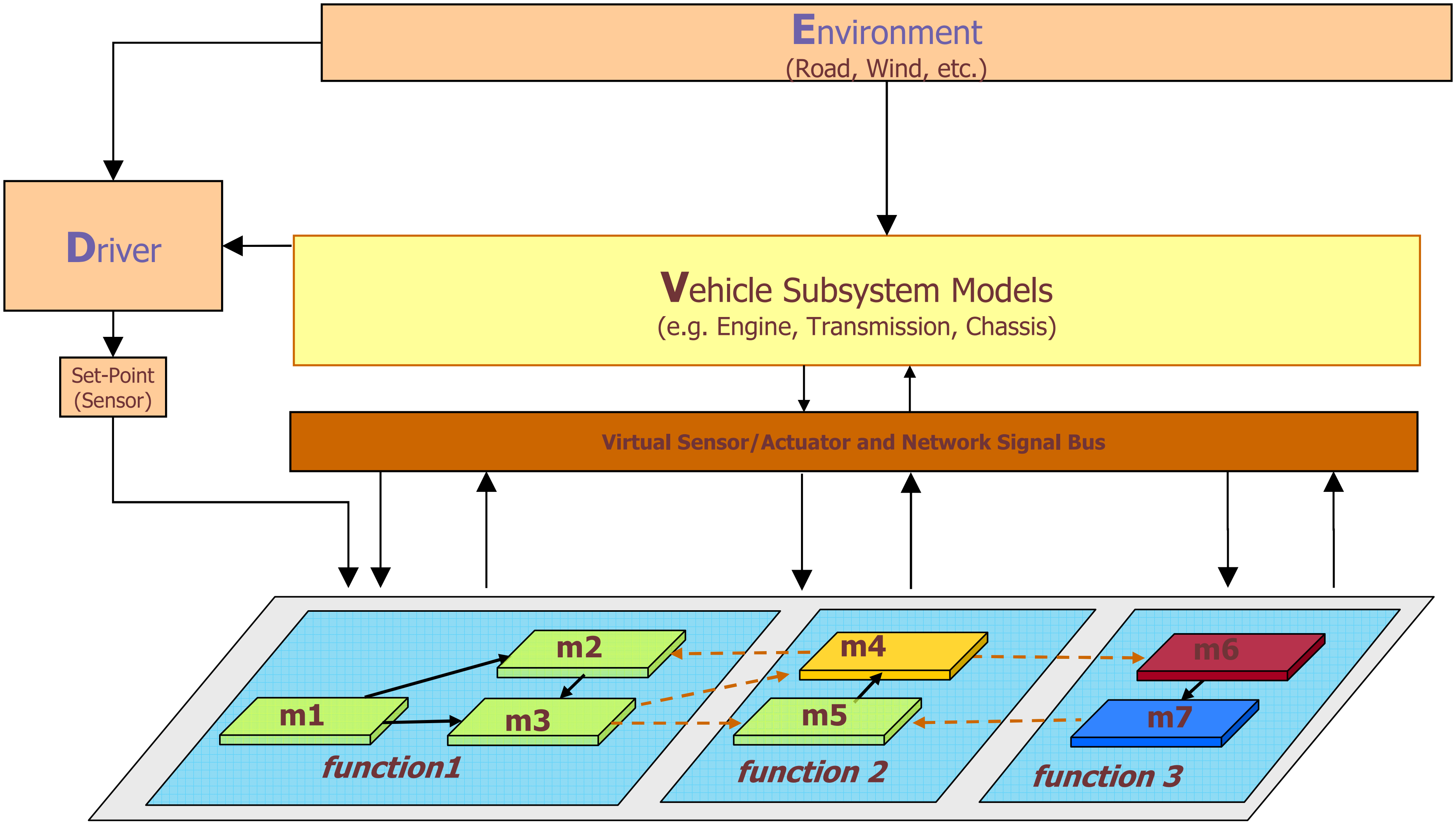
Migration to a Virtual Environment – 1/3



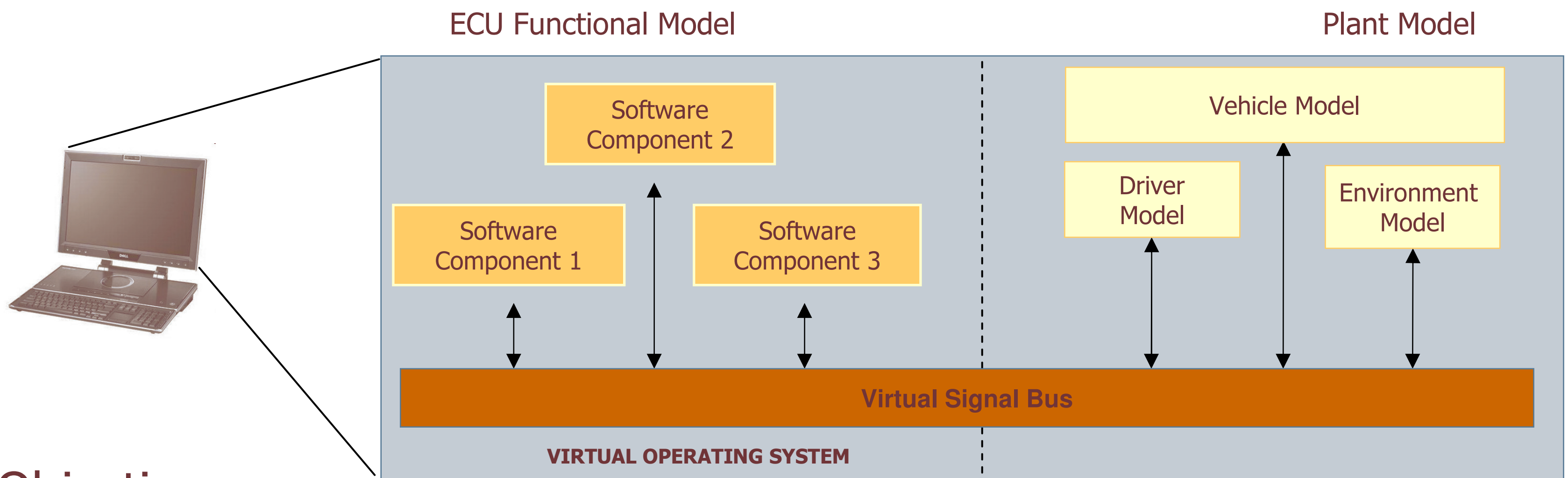
Migration to a Virtual Environment – 2/3



Migration to a Virtual Environment – 3/3



Model-in-the-Loop (MiL) Overview



- Objectives:
  - Functional validation and calibration of ECU sub-system models
  - Evaluate interactions between ECU sub-systems
  - Refinement of plant models
- Pre-requisites:
  - Plant models with adequate fidelity
  - All signal interface definitions (e.g. sensors)
  - Test scenarios for validation (e.g. test vectors, test stimuli)

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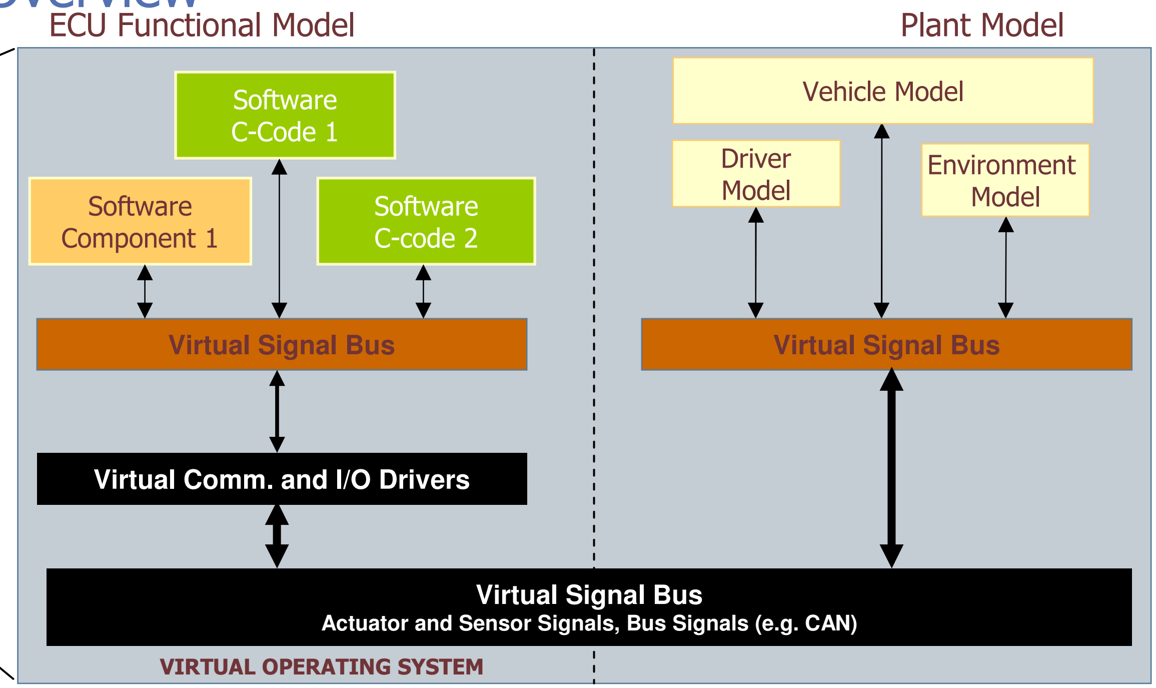
Software-in-the-Loop (SiL) Overview



- Objectives:
  - Functional validation of ECU software architecture
    → e.g. CAN bus configuration and load
  - Verification of ECU software implementation against model
- Pre-requisites:
  - ECU software modules (C-code)
  - ECU communication architecture (e.g. CAN network)
  - Test scenarios from MiL (e.g. test vectors, test stimuli)

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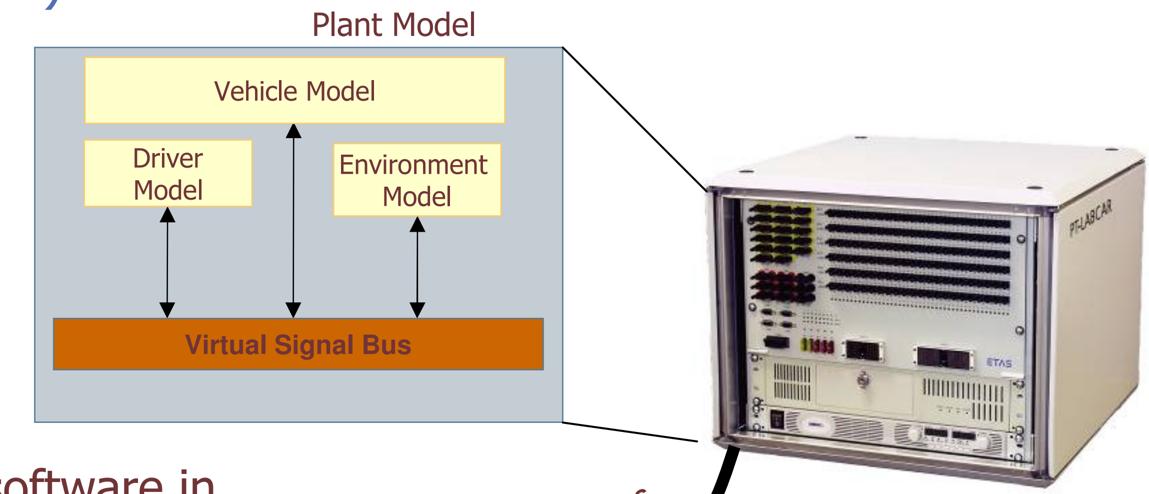
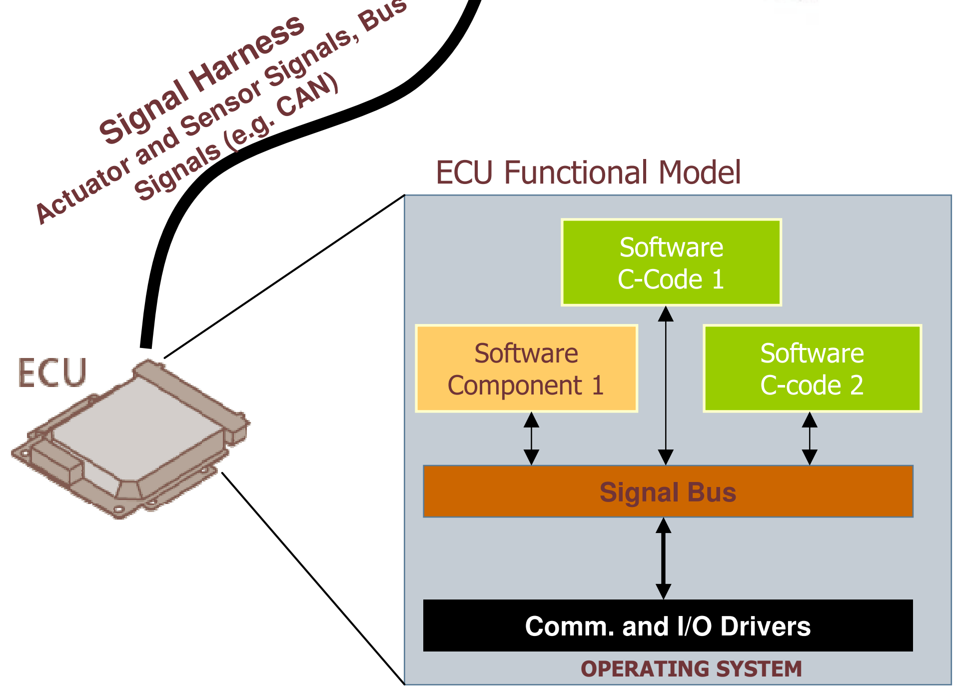
Hardware-in-the-Loop (HiL) Overview



- Objectives:
  - Validation of ECU software in real-time with actual sensor and actuator signals
  - Better calibration values
- Prerequisites:
  - Plant model should run in real-time
  - Emulation of all electrical interfaces of the ECU
  - All control models converted to ECU code



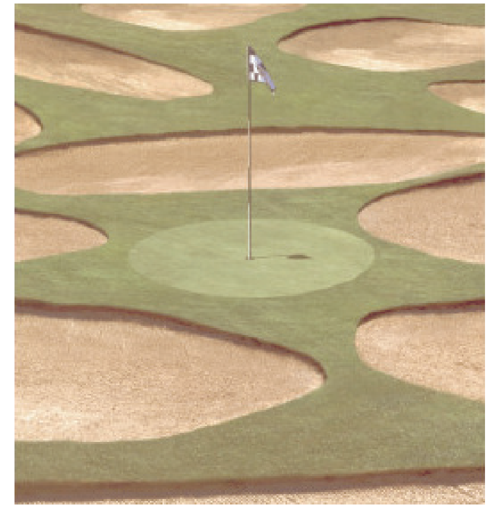
Challenges of the Traditional Process - 1/3

- Increasing complexity of plant models
  - Controls development needs domain specific models
    → slow to execute on the PC (e.g. transmission hydraulics, fuel-cell stacks)

- Function oriented ECU development
  - Models are built in different environments or different versions of the same environment
  - Model data and interfaces are difficult to merge

- Distribution of electronic features over multiple ECUs
  - Higher system integration and validation complexity

Challenges of the Traditional Process - 2/3



- System and sub-system testing
  - Test cases for MiL cannot be reused in HiL
    → Due to tool and configuration inconsistencies
  - Tests scripts have to be adapted when HiL hardware is switched

- Handling of C-code for SiL
  - Large number of legacy C-code modules are needed
    → Current solutions are not modular and scalable
  - Limited access to C-code parameters for measurement and calibration
  - Production standards (ASAP, MSR, OSEK etc.) are not compatible

Challenges of the Traditional Process - 3/3

- Control over model execution in MiL and SiL
  - Execution may not adapt to PC compute power
  - Speed-up or slow-down not possible

- Relative timing behavior of control modules in MiL and SiL
  - No provision to schedule control modules to run according to production OS requirements (e.g. OSEK)

- User Interfaces and Data Exchange between MiL/SiL and HiL
  - Different tools require creation and maintenance of separate calibration and measurement profiles
  - Often, datasets cannot be easily exchanged

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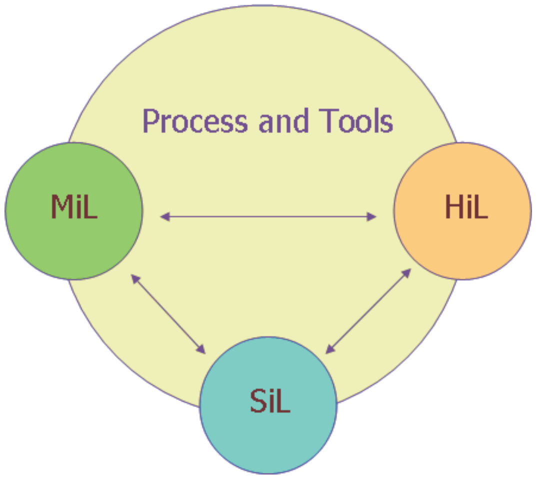
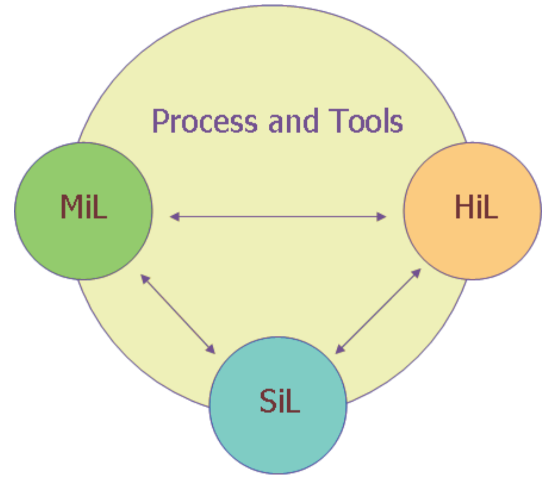
An Integrated MiL/SiL/HiL Approach
Requirements - 1/4



Plant Models:

- Flexibility in coupling with plant models of different origins, platforms and interfaces
- Support for both homogeneous (single executable) and heterogeneous (co-simulation) modes on the PC
- Ability to control the run-time behavior on the PC
  → speed-up, slow-down as needed (available compute power)
- Re-use of the same plant model across MiL, SiL and HiL
- Re-use of stimuli sets (e.g. driver inputs, closed-loop drive profiles etc.) from MiL to SiL to HiL

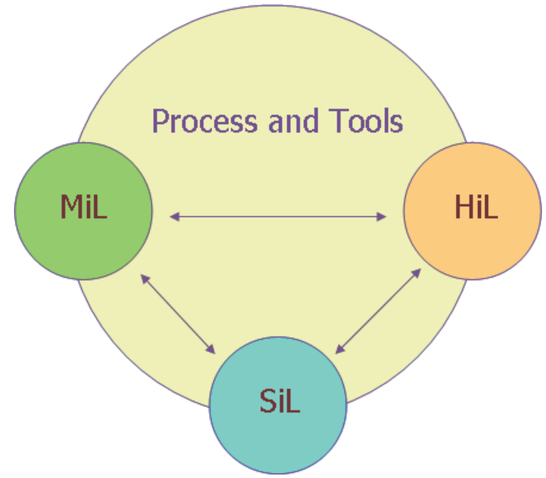
An Integrated MiL/SiL/HiL Approach
Requirements - 2/4



Control System Models:

- Maintain the modularity of function oriented ECU development
  → i.e. integrate models from different modeling tools, versions and organizations into one system
- Ease of connecting control model signals with plant model signals
  → i.e. creating the Virtual Signal Bus
- Support for upcoming standards
  → e.g. AUTOSAR interface description files
- Ability to schedule various sub-systems to run under timer or event driven tasks on the PC
- Fast turnaround times for MiL and SiL
  → i.e. incrementally build and compile model changes

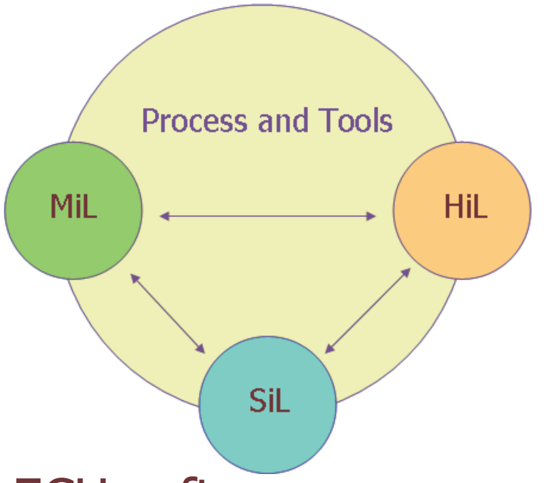
An Integrated MiL/SiL/HiL Approach
Requirements - 3/4



C-code integration:

- Ability to integrate C-code with models at different levels
  → e.g. source code, object code, .dll files, .lib files
- Measure and calibrate C-code parameters in SiL
  → e.g. re-use available ASAM-MCD-2MC description files
- Validate models and C-code while utilizing “platform services” on the desktop PC
  → e.g., RTOS settings, timer and event based tasks etc.
- Maintain modular C-code architecture of the ECU in SiL

An Integrated MiL/SiL/HiL Approach Requirements - 4/4



Process:

- Identical user interface for control of plant and ECU software models
  → especially important as one moves from PC (MiL/SiL) to HiL

- Ability to re-use MiL/SiL artifacts in HiL
  - Test-scripts
  - ECU model calibrations
  - Plant models
  - Data sets (e.g. stimuli, test data)

An Integrated MiL/SiL/HiL Approach
ETAS Solution

INTECRIO

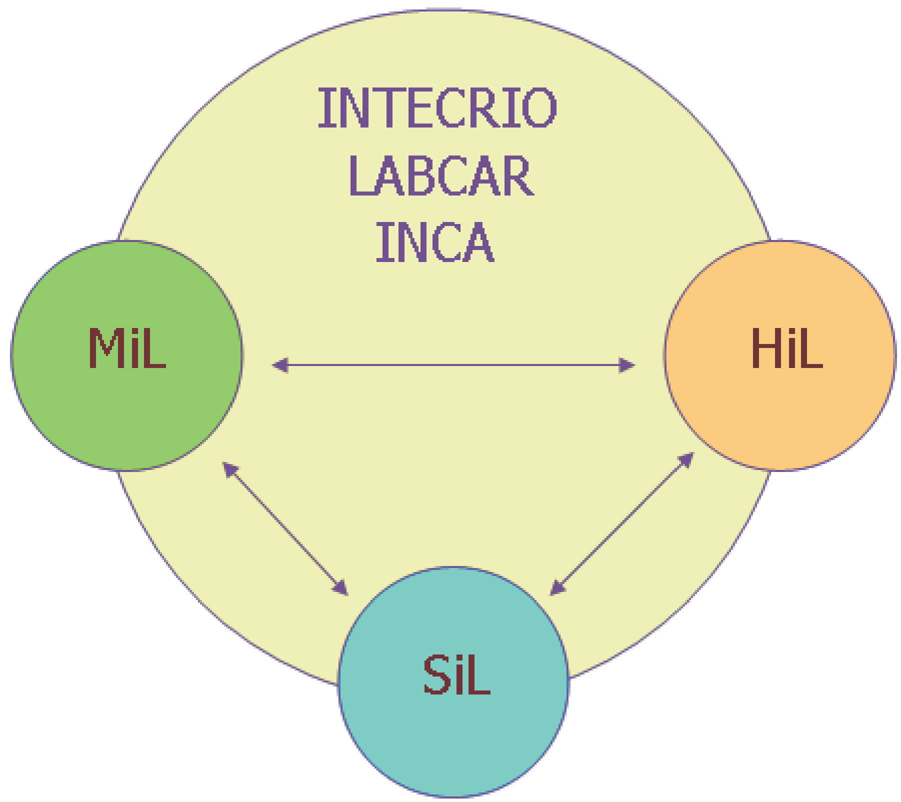
- A comprehensive PC based integration platform for MiL and SiL

LABCAR

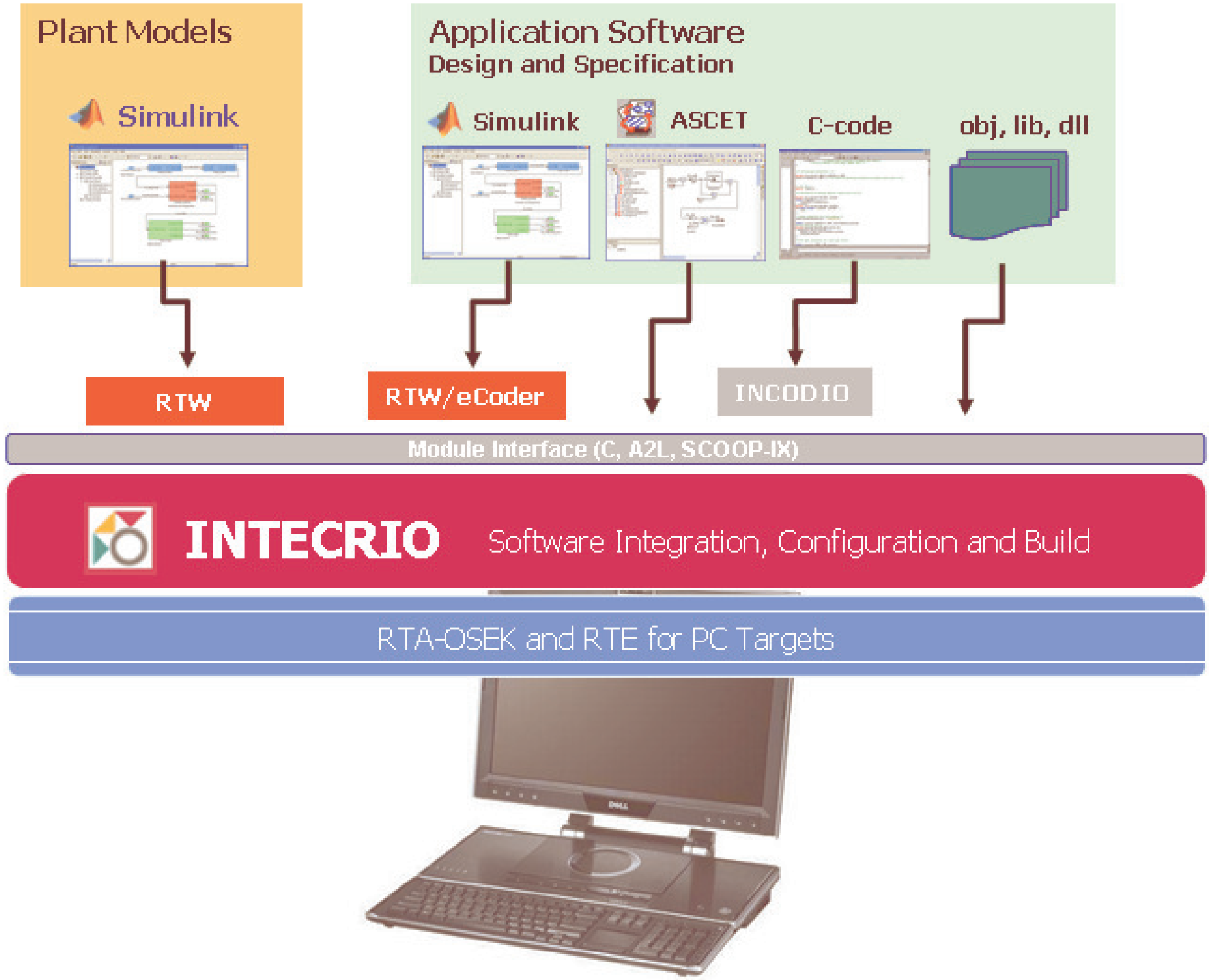
- A HiL system with scalable hardware and open software architecture

INCA

- ECU measurement and calibration software

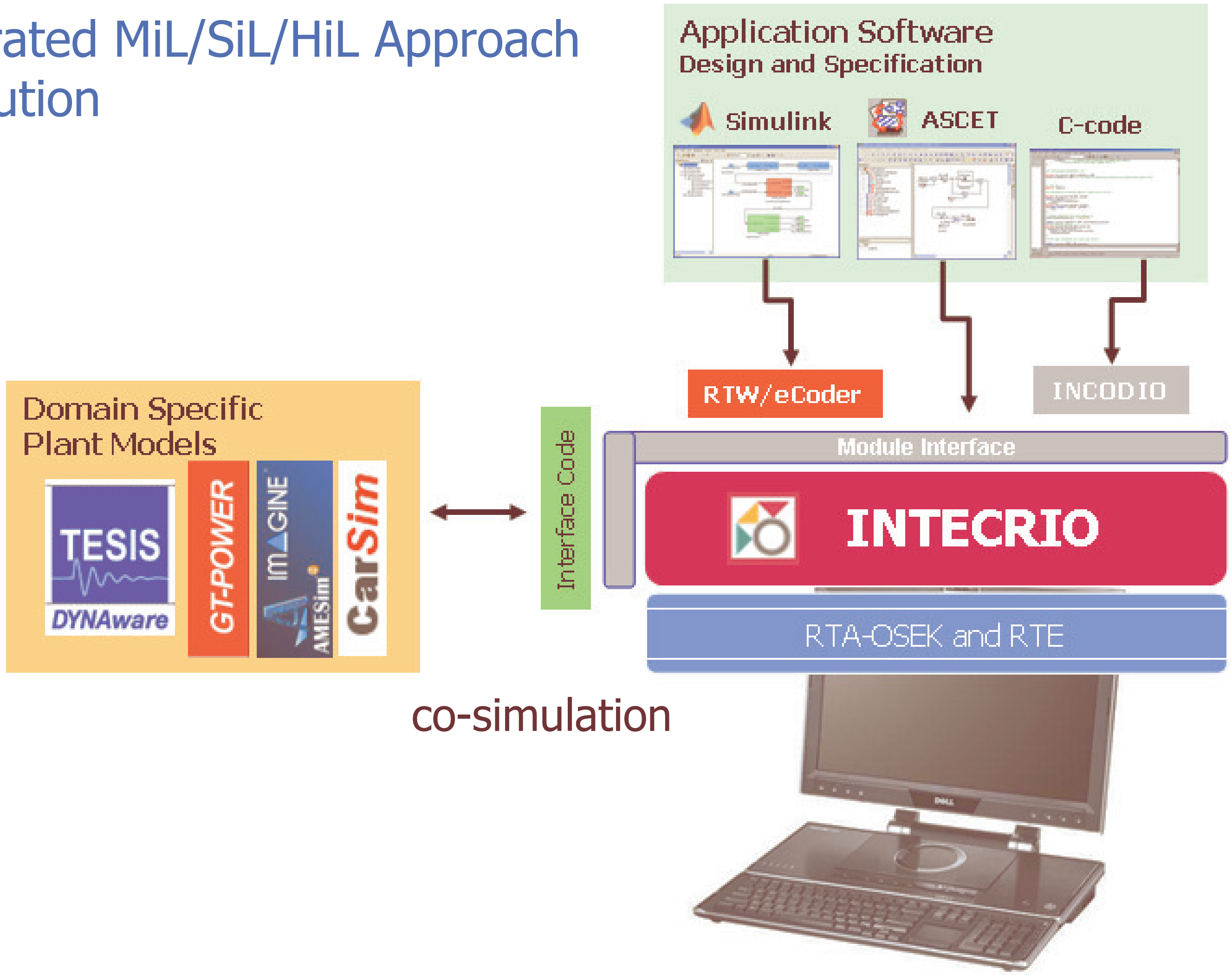


An Integrated MiL/SiL/HiL Approach
ETAS Solution



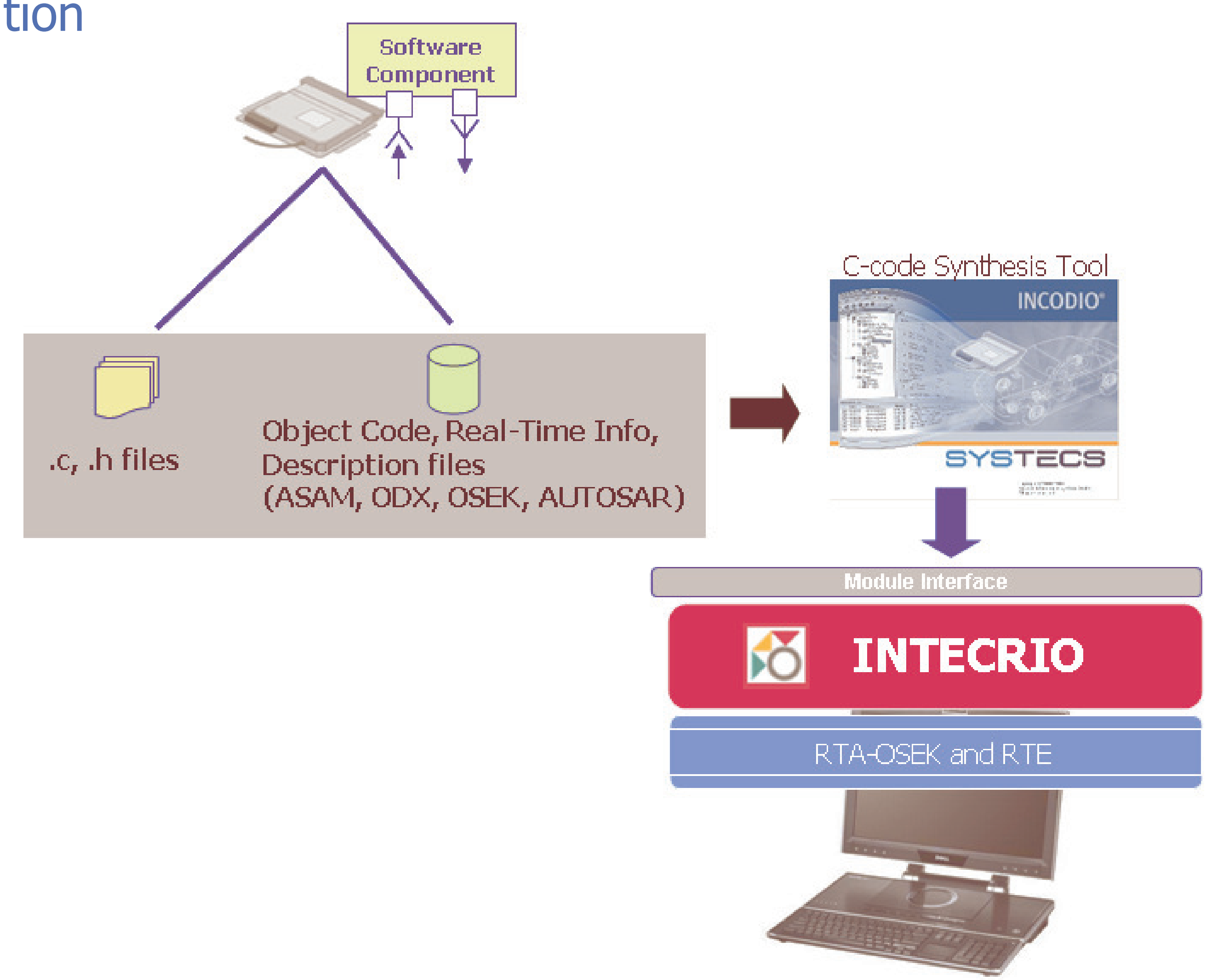
INTECRIO as a homogeneous MiL/SiL integration platform

An Integrated MiL/SiL/HiL Approach
ETAS Solution



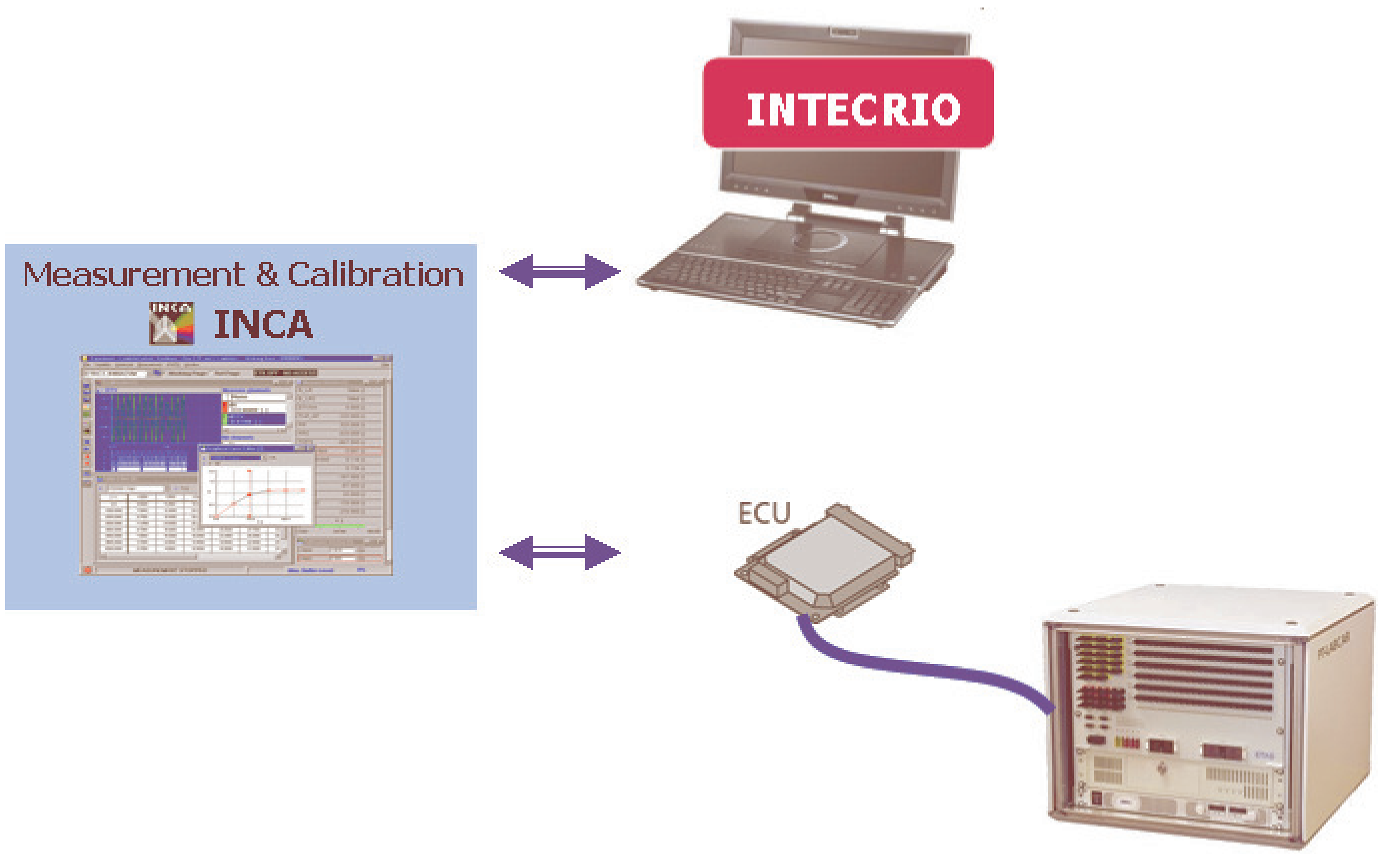
INTECRIO as a heterogeneous MiL/SiL integration platform

An Integrated MiL/SiL/HiL Approach
ETAS Solution



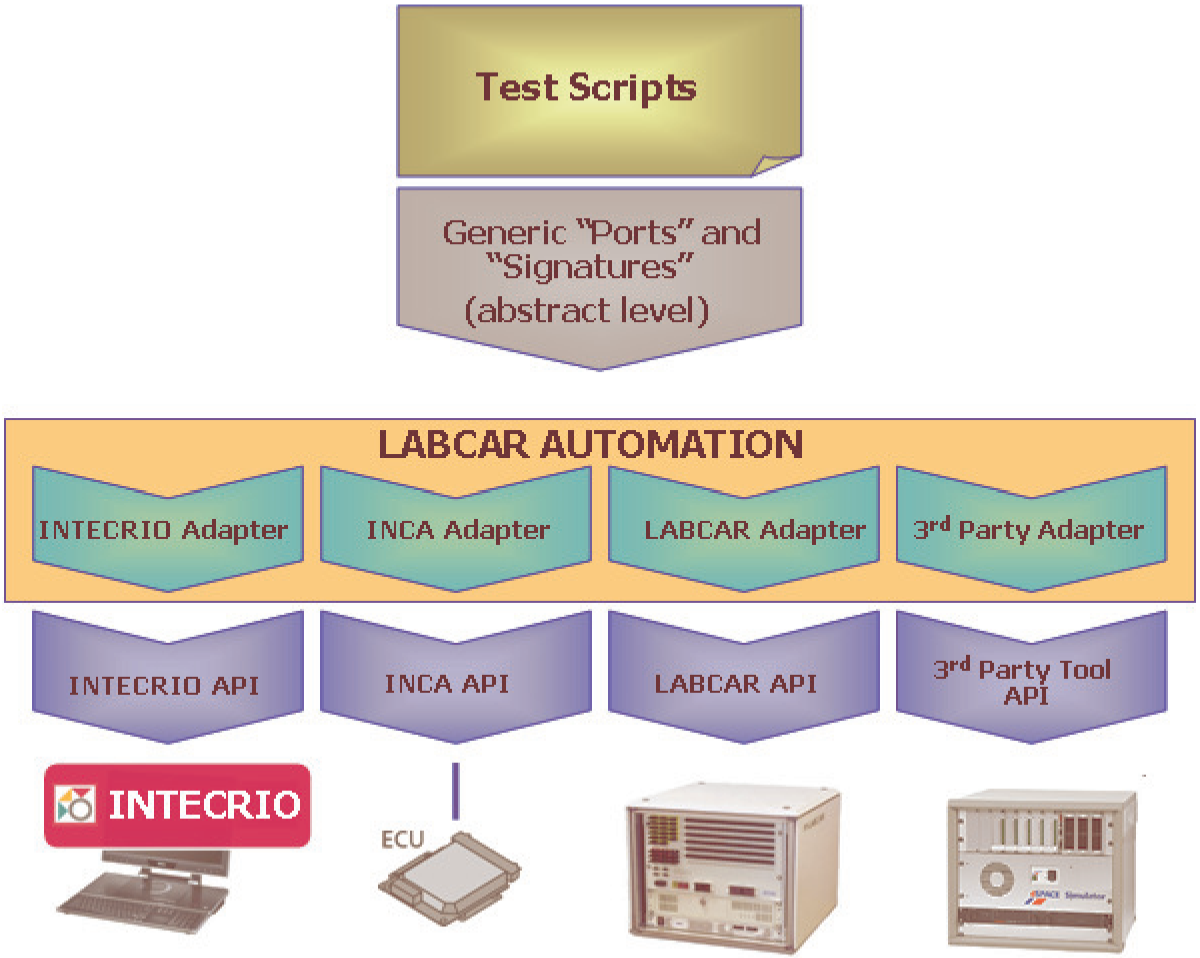
Integrating C-code in INTECRIO via INCODIO for MiL and SiL

An Integrated MiL/SiL/HiL Approach
ETAS Solution



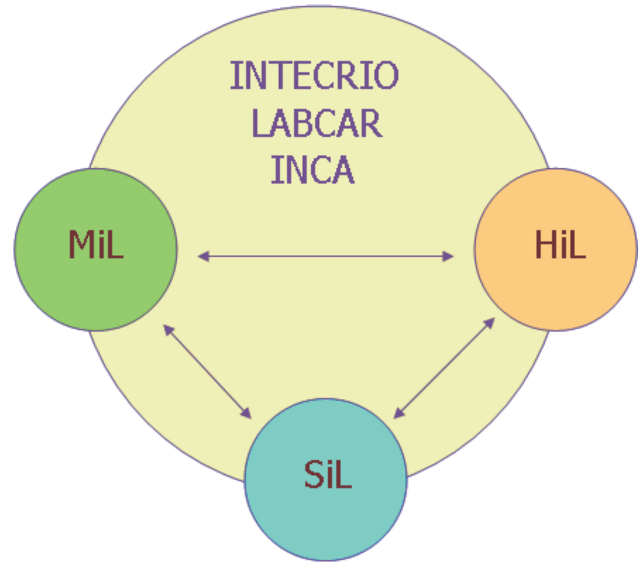
Using INCA for Calibration and Measurement in MiL, SiL and HiL

An Integrated MiL/SiL/HiL Approach
ETAS Solution



Using LABCAR-AUTOMATION for Testing in MiL, SiL and HiL

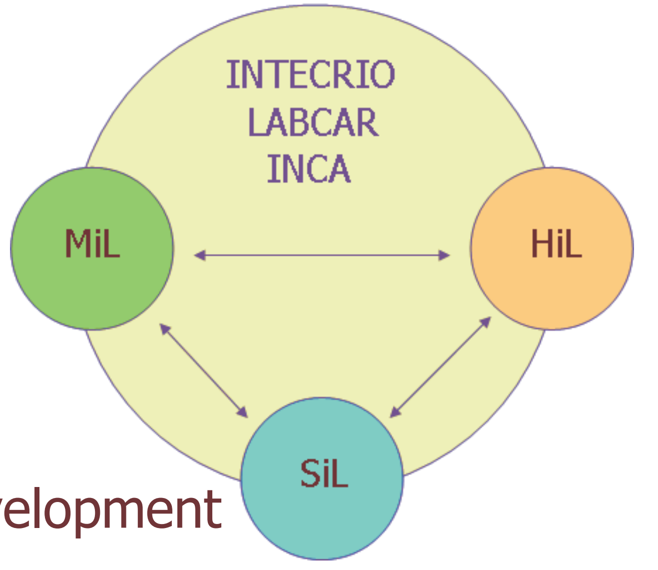
An Integrated MiL/SiL/HiL Approach
Customer Success Stories



- A major US OEM
  - Major advance in calibration development:
    → 75% in MiL, 100% in HiL
  - Most software bugs removed before going into vehicle
  - 3x improvement in turnaround times over standard process
    → i.e., controls and plant model changes in MiL
  - 7x improvement in model execution times on the PC

- A major European OEM
  - 5x improvement in model execution times on the PC
  - Sharing experiments, data, stimuli between users

An Integrated MiL/SiL/HiL Approach
Conclusions



INTECRIO, LABCAR, and INCA

- A integrated tool suite for MiL, SiL and HiL development

Key Advantages:

- Reduce non value-added steps (e.g. data conversion, adaptation of test sequences, GUIs etc.)
- Re-use test scripts, stimuli, plant models and ECU data
- Reduce costs associated with the ECU development process

  → do more in the virtual environment

  → reduce dependence on fleet and dyno testing

Model Based ECU Development
An Integrated MiL, SiL, HiL Approach

Thank you for your attention!
Your questions are welcome.