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Requirements Determination from Vehicle to System Level of Mechatronics – A Tier-1 Approach to Model Based Development

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Schaeffler in facts – strong starting point

Strong customer base with approx. **11,800** customers

Approximately EUR **14.4 bn** Sales in 2019

Almost **2,400** patents filed in 2019

1.1 m tons of processed steel p.a.

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75 plants
20 R&D centers

More than 170 locations in **50** countries

8.1% EBIT margin in 2019[1]

Around **84,200** employees worldwide[2]

Far more than **10,000** different products

[1] Before one-off effects | [2] As at June 30, 2020

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Three divisions – automotive OEM, Automotive Aftermarket and Industrial

Automotive OEM | Systems

Engine Systems

Transmission Systems

Chassis Systems

Hybrid and Electrical Drive Systems

Automotive Aftermarket | Segments

Passenger Cars

Light Commercial Vehicles

Heavy Commercial Vehicles

Tractors & Agricultural Vehicles

Services

Industrial | Sector Clusters

Wind

Raw Materials

Aerospace

Railway

Offroad

Two Wheelers

Power Transmission

Industrial Automation

Mechatronic Chassis Systems from Schaeffler – Active Roll Control System (iARC)

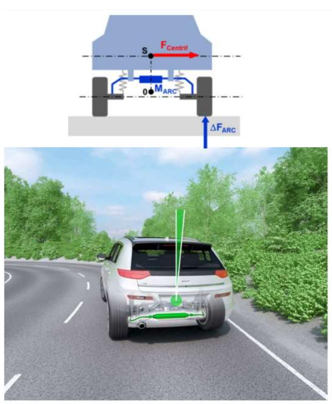
Active roll control actuator

Improve vehicle dynamics:

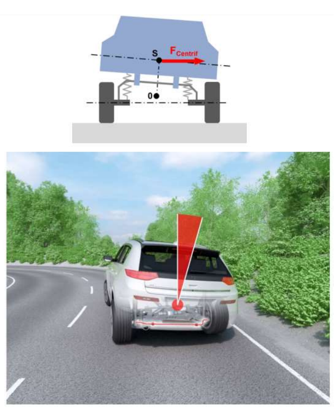
- Increase agility
- Enable selectable driving modes

Enhance comfort:

- Reduce effect from road bumps
- Increase roll damping



WITH ACTIVE ROLL CONTROL



NO ACTIVE ROLL CONTROL

ROAD DISTURBANCE

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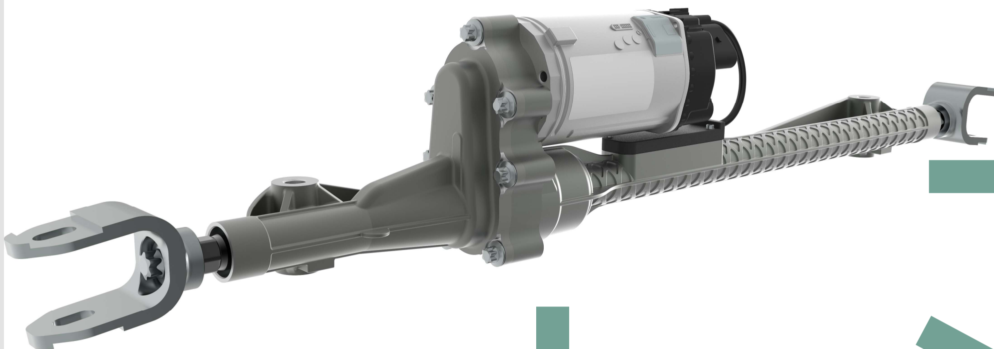
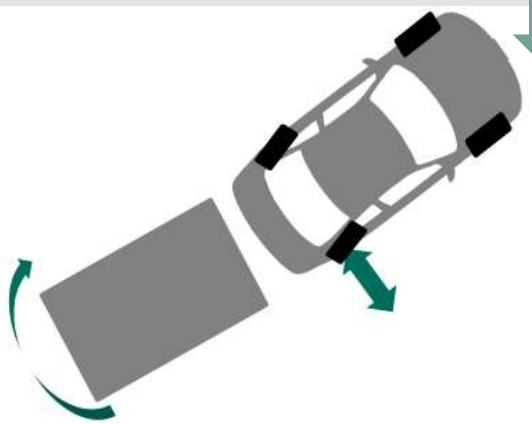
Mechatronic Chassis Systems from Schaeffler – Rear Wheel Steering (iRWS)

Rear wheel steering actuator



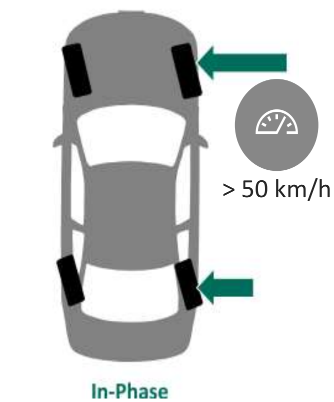
Benefits of Out-of-Phase-Steering:

- Maneuverability
- Driving Comfort
- Smaller turning circle
- Driving Agility



Benefits for driving with trailer:

- Reduce Hitch Angle
- Trailer Sway Mitigation
- Increased Towing Capacity
- Limp aside



Benefits of In-Phase-Steering:

- Vehicle Control
- Driver Comfort
- Passenger Comfort
- Driving Stability

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A Simulation Based (Reversed) March through the V-Model

Requirements:
- → Special interest from a Tier-1 perspective
- → Virtual methods to drive requirements engineering from the vehicle level are very helpful!
  - → Improved requirements quality
  - → Increased understanding of customer‘s needs
- → **We will show two examples from the variety of our methodical approaches on the following slides.**

Virtual and Real Test Driving:
- → Well established
- → State-of-the-art

Component Level Design:
- → State-of-the-art
- → Huge amount of virtual methods in every domain available

XiL-Scenarios:
- → Well established already
- → Getting more and more sophisticated
- → Several mixed scenarios (d.u.t. and its environment) possible and subject to development and permanent improvement

Vehicle Simulation for Requirements Engineering is the topic here!

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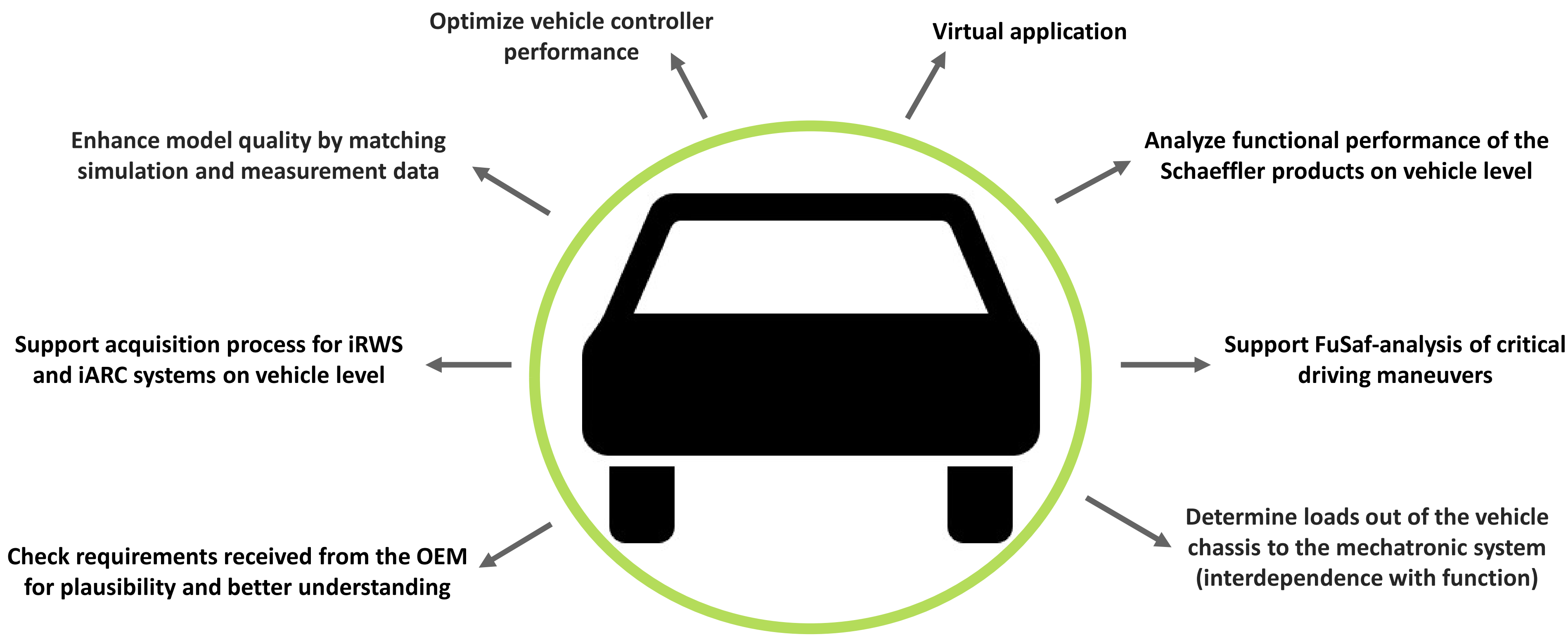
Virtual Vehicle to Support Mechatronic Development (Overview)



Maximum Impact: Vehicle Requirements Interact with (almost) every Development Step.

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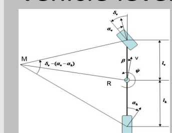
Vehicle Model Build-up with Schaeffler iRWS- and iARC-System Models

Matlab /Simulink

Vehicle level



Schaeffler Chassis Controller

Product level

Rear wheel steering

Active roll control system

- Information from CarMaker to Matlab
  - Front steering wheel angle
  - Vehicle velocity
  - Chassis tie rod forces (left right)
  - Roll angle

- Information from Matlab to CarMaker
  - Rear wheel steering angle
  - iRWS travel and torque
  - iARC torque

IPG - CarMaker

- Following vehicle information integrated:
  - K&C Data
  - Tire model
  - Vehicle, road, driver model
  - Damper curves
  - Validation of different driving maneuver

validated vehicle model

Integration Platform for our Products in Vehicle Context

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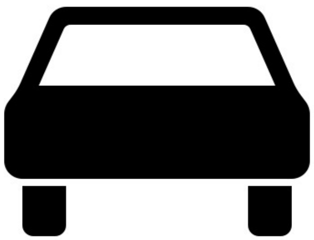
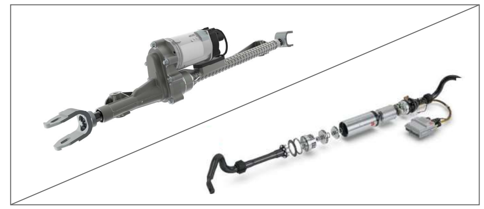
Requirements Analysis Procedure Using Vehicle Simulation

Business Requirements Document



Requirements for Schaeffler chassis products



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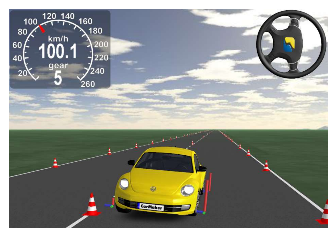
- Are the requirements realistic?
- What does the requirements mean on vehicle level?
- What does this mean w.r.t. functional safety?

- Requirements from the OEM
- Vehicle Regulation (StvZO)
- Vehicle Norms (DIN)
- VDA Driving Maneuvers

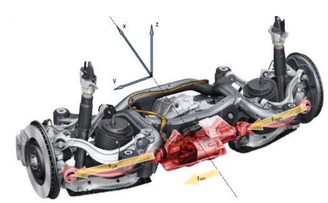
Feedback regarding product requirements



Vehicle Simulation

System simulation input

Vehicle simulation output



System Simulation

Model- and Simulation-Driven Requirements Development in Close Collaboration

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Virtual Calibration of Vehicle Requirements Based on Vehicle Roll Characteristic

iARC-requirement rolling behaviour from OEM for different driving modes:

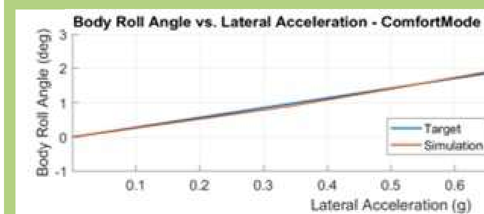
Driving mode	Roll angle vs. lateral acceleration
Comfort mode	2.80 °/g
Dynamic mode	1.00 °/g

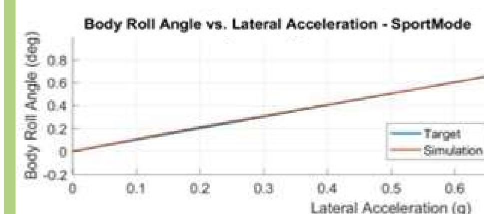
Driving maneuver for calibration:

Driving a circle with slowly increasing steering angle (1deg/s)
Constant velocity: 100 km/h

Parameter studies to optimize the parameter of iARC function

Result of virtual calibration





- **Benefits of virtual calibration:**
  - Saving of time with simultaneous engineering
  - Simple and fast parameter optimization and studies are possible
  - Safe commissioning of function in the vehicle
  - Digital Twin of real democar

Virtual Calibration Improves Development Maturity at an Early Stage

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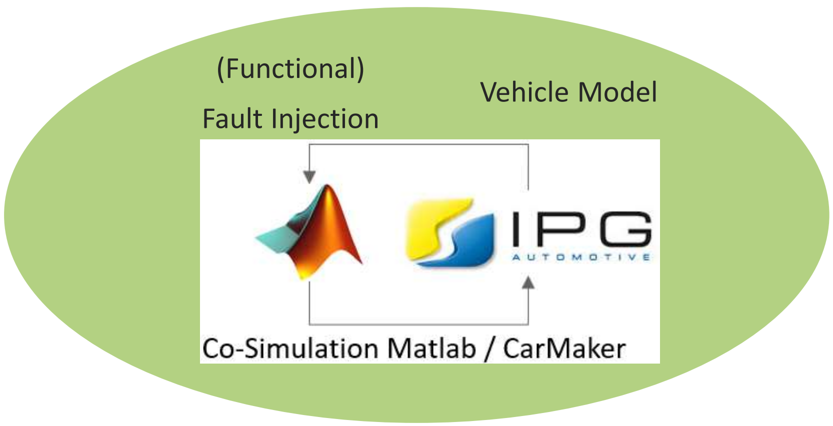
Functional Error Simulation for Democar Vehicle Clearance

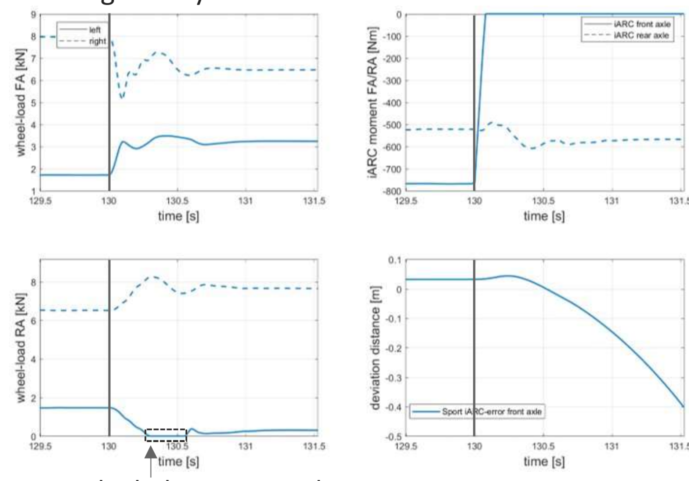
Simulation:

FuSaf-Simulation to analyse the vehicle behaviour in different driving maneuvers

- Driving maneuvers (open and closed loop)
  - Fishhook-Maneuver
  - Steady-State Circle
  - Step Steer Test
  - Etc.



Example for iARC error @ Democar during Steady-State Circular Test:



- Vehicle loses ground contact ----
- Front axle error injection @ t=130s → iARC torque = 0 Nm —

Results:

- Democar clearance (e.g. tip over hazard)
- Understanding of critical driving maneuvers

Functional Safety Analysis for Safe Mechatronic Systems according to ASIL Specifications

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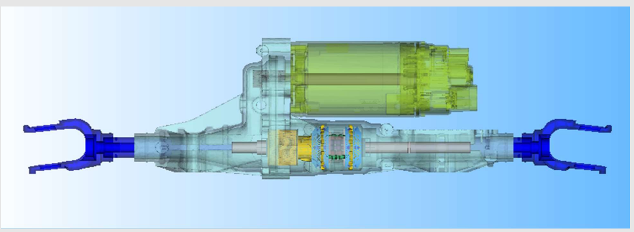
Finding Model Architecture when Combining Model Classes

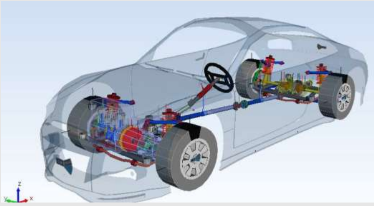
- **Simulation of mechanical loads at axle level using virtual K&C test rig**

Schaeffler Chassis Component



- Steering actuator as MBS in Simpack
- Need for load spectra for strength/fatigue calculation for mechanical design
  - Tie-rod forces and torques

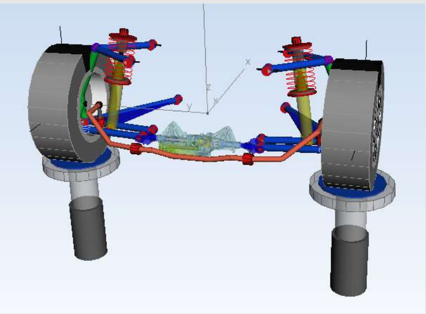
Integration in Vehicle Model in Simpack



- Integration of chassis component
- Simulation of the test run
- Provide load spectra for strength/fatigue calculation
- Requires the hole vehicle data (Stiffness, 3D geometries)

Model reduction

Integration in Axle test rig in Simpack



- The whole vehicle model is reduced to an axle model in Simpack
- Integration of chassis component (steering)
- Provide load spectra for strength/Fatigue calculation on axle level
- Requires a virtual test rig to initiate wheel body contact forces
- The input forces will be generated from CarMaker simulation

Model Boundaries and Simulation Interfaces Chosen Carefully Considering Effort and Costs

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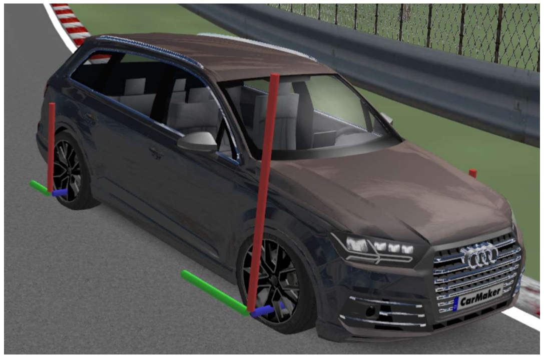
Mechanical Loads from Virtual Test Drive

CarMaker

- **Driving Scenarios**
  - VDA, Lane change,….
  - Special maneuvers

Vx δ

- **Vehicle Modell in CarMaker**



  - Generate forces for the test rig

x (shaft)

Fx

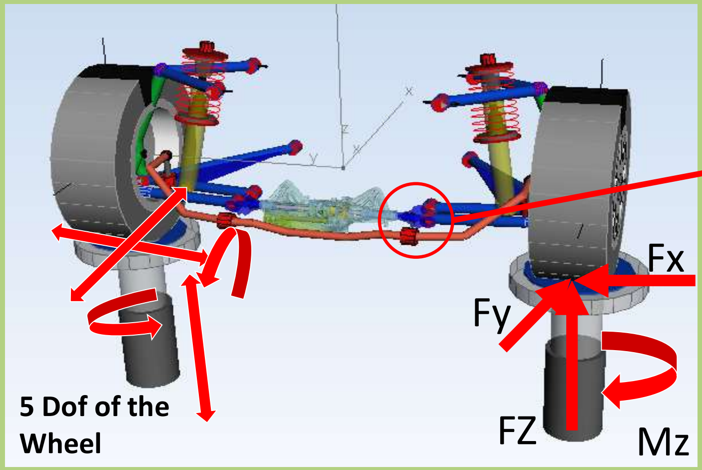
FY

FZ

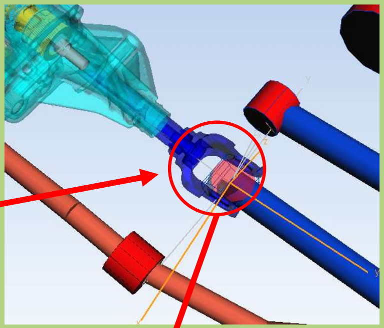
Mz

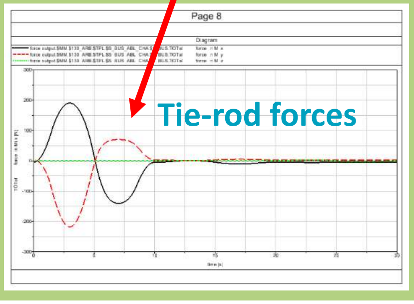
Simpack

- **Axle test rig in Simpack**



- Tie rod Acting forces





Getting the Maximum Benefit from Each Modeling Class – Synergy of Multi-Body- and System-Simulation

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Conclusion and Further Ahead

Summary:

- Two Examples from our Methodical Portfolio have been shown.
- Top Down Approach:
    - Vehicle Level (Stakeholder Requirements)
    - System Level (System Requirements)
    - Component Level (Component Requirements)

Outlook:

- ➢ Continue model and simulation based development
    - – System Architecture Development
    - – System Design
    - – Verification, Integration, Validation
- ➢ Interaction of virtual and real instances of vehicle, system and components (mechanics, SW, ECU)

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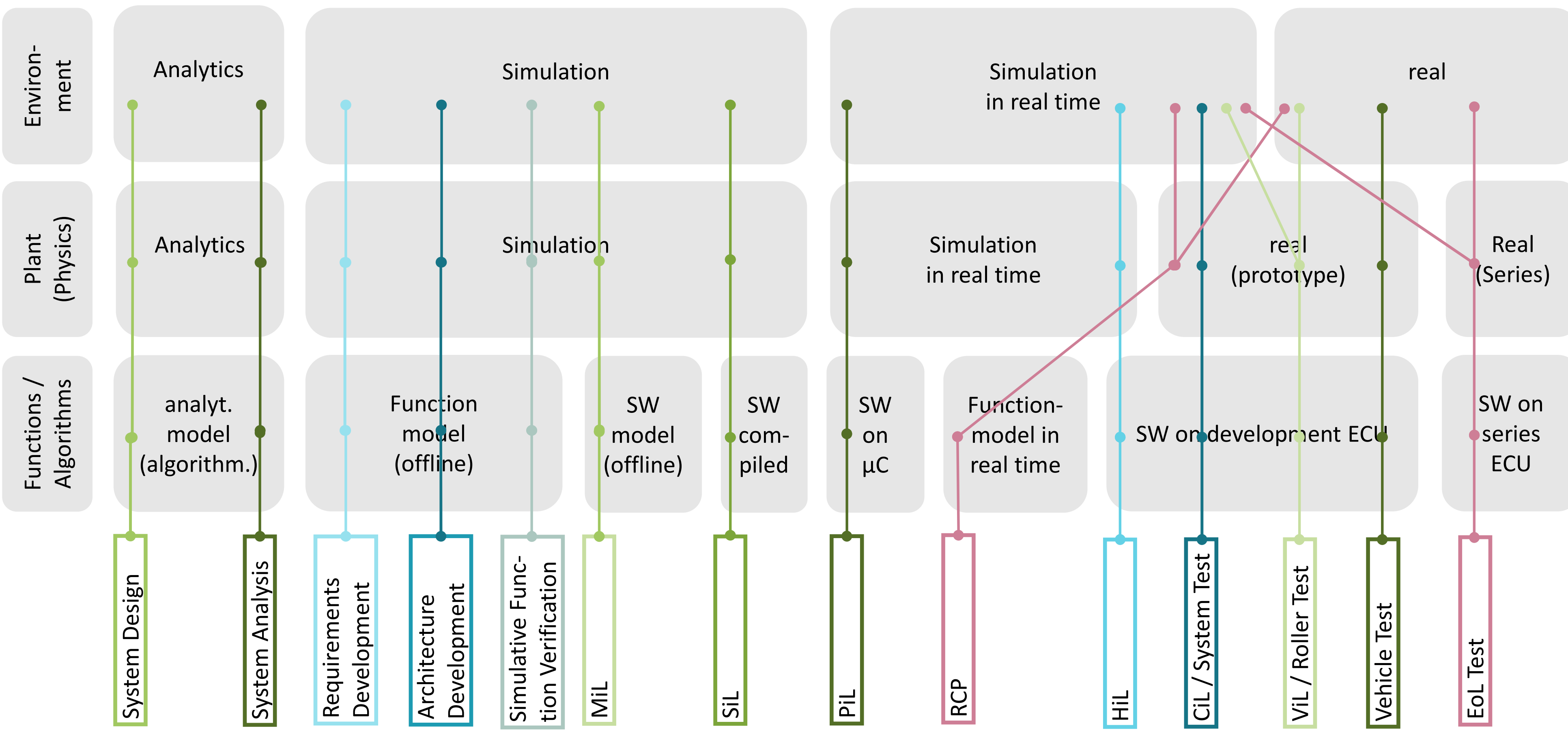
Models and real Instances of Function, Plant and Environment
→ Comprehensive View on Analytical and Simulation Models for Mechatronic Development



Models and real Instances of Function, Plant and Environment
→ Comprehensive View on Analytical and Simulation Models for Mechatronic Development

Environ-ment

Plant (Physics)

Functions / Algorithms

Real (Series)

SW on series ECU

Overall Mission

- Continuously find optimal paths through the V:
  - Provide suitable models for the right purpose
  - Ensure consistency among all models
- Permanently
  - Increase Customer Orientation
  - Deepen System Unterstanding
  - Improve Efficiency
- In this sense vehicle simulation is our top layer in mechatronic development

System Design | MiL | SiL | PiL | RCP | HiL | CiL / System | Vehicle Test | EoL Test

Thank you for your attention.

Please feel free to ask questions.