PDE (Partial Differential Equations) for Systems (PES)

Project Idea and Strategic Options

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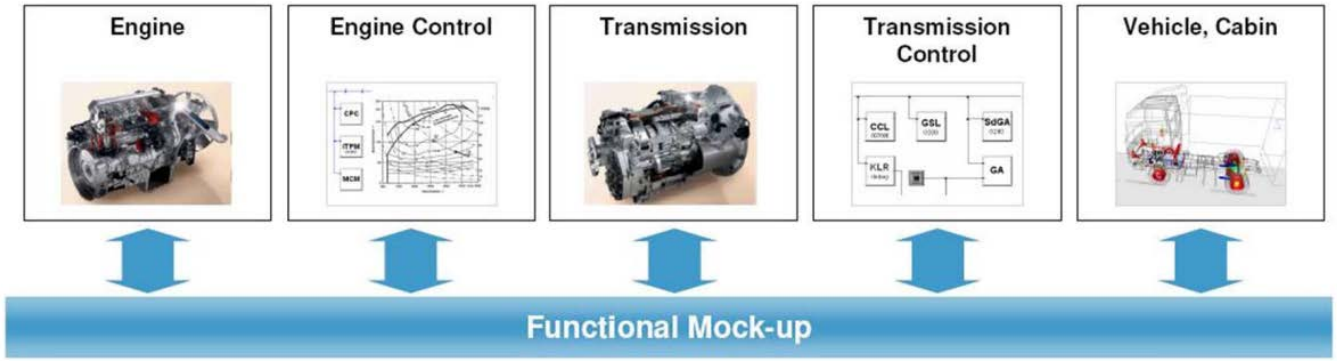
Background

- **The FMI success story**
  - Standardized interface for model based development of systems
  - 2008: Kick-off of project MODELISAR
    - Strong industrial (e.g. automotive OEMs) and tool-vendor participation, e.g. DAIMLER, VOLVO, LMS, DASSAULT SYSTEMES, ITI
  - 2018: Currently nearly 108 tool-vendors support FMI
  - Still ongoing development
    - Modelica Association Project FMI
    - Emphysis (Embedded systems with physical models in the production code soft.) by e.g. BOSCH, SIEMENS, RENAULT, dSPACE, VOLVO



+ Model-exchange

Cosimulation of the behavioral models and the embedded controller software

Background

- **Cyber-Physical Systems**
  - Rely on existence of digital twins
  - Integrate data and physical system description
    - Living digital simulation models
  - Application fields are numerous, potentially unlimited, e.g.
    - Engineer, prototype and validate systems, optimize operation, monitor conditions and health, organize maintenance, …
    - Concerns the complete product life cycle
  - Innovate value chains
- **System components with relevant distributed properties (PDEs)**
  - Represented by e.g. **Finite Elements/Volumes/Differences, CFD, ..**
  - Available exchange formats are
    - Proprietary, only (e.g. *.mnf, *.fbi, *.cdb, *.sub, *.op2, ….)
    - Limited to mechanical domain
    - Limited functionality
    - Not stable (frequent changes of specification)

Motivation

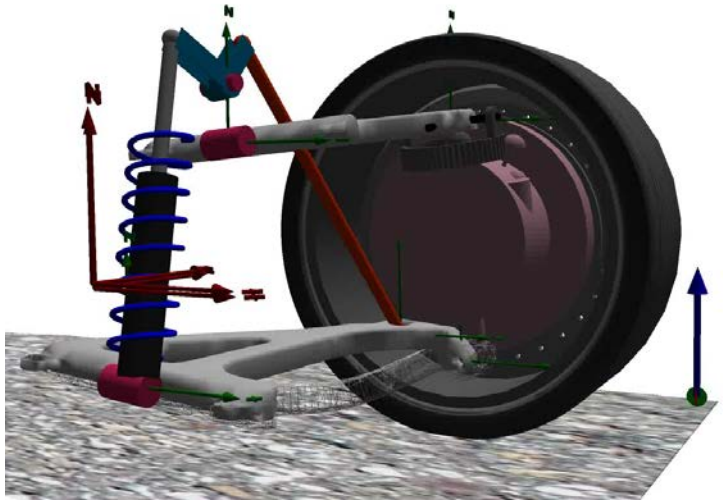
- **Resources of PDE tools are to be unlocked for digitalization.**
  - Strong industrial requests for usage of (order reduced) PDE models in systems simulation and digital twins as demanded by Industry 4.0.
  - Features research on appropriate model reduction techniques.

- **Multidisciplinary context offers bilateral R&D advantages.**
  - More collaborative work through coupling of interests.
  - Exploit Big Data from real life to improve future products

Examples

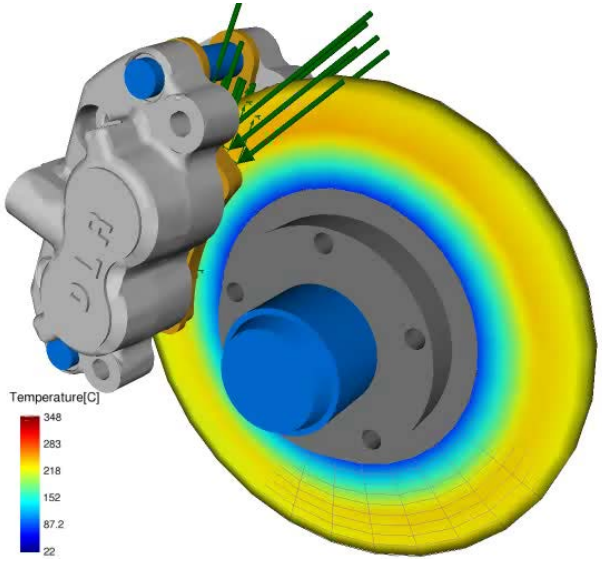
➢ Automotive suspension (mechanics)

- Monitor dynamic load accumulation of e.g. lower A-arm in operation
- Predict fatigue online with real life data in Electronic Control Unit (ECU)



➢ Brake (heat transfer domain)

- Estimate disc, pad and e.g. hydraulic fluid temperature online in ECU
- control cooperative operation with redundant actuators, e.g. electric drives, magnet track brake, … accordingly (brake blending)



PDE for Systems

- **Ideas**
  - Standardized format for the export / exchange of semi-discretized PDE models
    - Exploit FMI experiences and network
    - PDE -FMUs for co-simulation and/or model exchange
    - Option to introduce spatially distributed loads
    - Option to protect know-how by providing only DLL, no data
  - Generic interface with respect to physical domain
    Mechanics, heat transfer, electro-magnetics, fluid-mechanics, Fluid-Structure-Int., …
  - Real time capability is an important aspect, but not mandatory in general
  - Development driven by collection of use cases
  - Consortium supposed to include industrial users, PDE tool vendors (FEM, FD, CFD, ..), system simulation tool vendors and University/research organizations
  - Specification to be published under same open source license as FMI (CC-BY-SA)

  - Current understanding: 3D to 3D coupling is out-of-focus.

PDE for Systems (cont'd)

- **Initial work flow**

  - F… Model with $x \cdot 10^6$ Degrees of Freedom (DoF)
  - F… Model Reduction

  F... Tool

  ⇩ FE output filter

  - F… Reduced Model with $x \cdot 10^3$ DoF (Superelement Matrices)
  - F.. Geometry Data
  - Retained DoF

  Minimum data set

  ⇩ (Extended) FMI input specification

  - System of Differential Equations
  - Physical interfaces (e.g. frames, heat ports …for nodes)

  FMI

  – Future extensions of the minimum data set are intended.