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A Concept for a Digital Thread based on the Connection of System Models and Specific Models

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TU Graz
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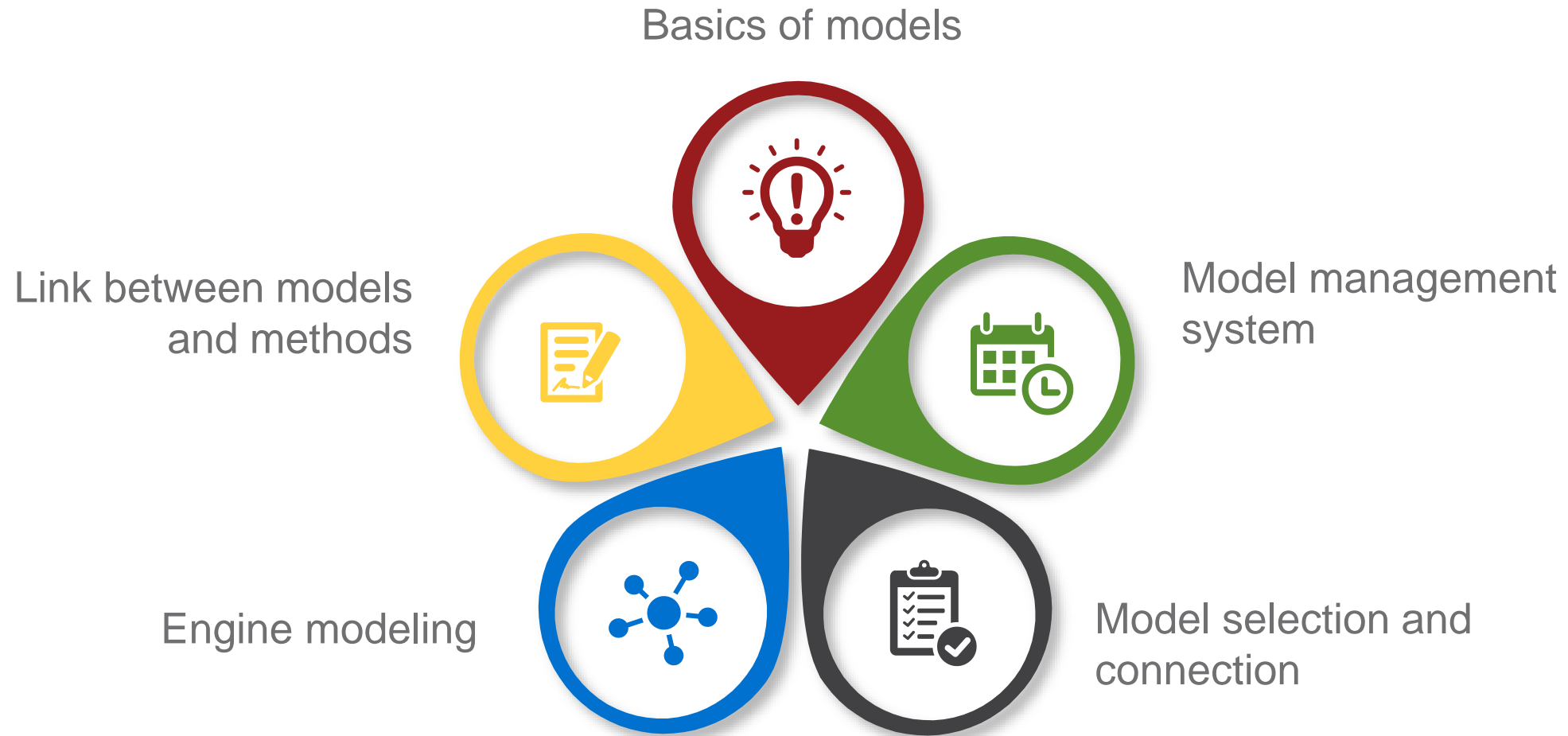## Matthias Bajzek
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- **Professional (current)**
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  - Master: Mechanical Engineering
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  - *Research and thesis: Systems Engineering and function/functional modeling*

Related publications

- Faustmann, C., Bajzek, M., Hick, H., Edtmayer, J., & Walch, S. (2020). **System models and model classification in tribological system development**. *Systems Engineering*, *23*(6), 783-794. https://doi.org/10.1002/sys.21562

- Hick, H., Bajzek, M., & Faustmann, C. (2019). **Definition of a system model for model-based development**. *SN Applied Sciences*, *1*(9). https://link.springer.com/article/10.1007%2Fs42452-019-1069-0

- Hick, H., Küpper, K., Sorger, H. (2021). **Systems Engineering for Automotive Powertrain Development** (Powertrain). Springer Nature Switzerland AG

  - Bajzek, M., Fritz, J., & Hick, H. (2020). **Systems Engineering Processes**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* (Powertrain). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_9-1

  - Bajzek, M., Fritz, J., & Hick, H. (2020). **Systems Engineering Principles**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_7-1

  - Fischer, R., Vorbach, S., Hick, H., & Bajzek, M. (2020). **Systems Engineering Organizational Constraints and Responsibilities**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* (Powertrain). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_11-1

  - Maletz, M., Bajzek, M., & Hick, H. (2020). **Systems Engineering Methods for Automotive Powertrain Development**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_31-1

  - Bajzek, M., Fritz, J., Hick, H., Maletz, M., Faustmann, C., & Stieglbauer, G. (2020). **Model Based Systems Engineering Concepts**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* (Powertrain). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_8-1

  - Faustmann, C., Kranabitl, P., Bajzek, M., Fritz, J., Hick, H., & Sorger, H. (2020). **Future of Systems Engineering**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Security Symposium for Automotive Powertrain Development: Systems Security Symposium, SSS 2020 - Conference Proceedings* [9174203] (Powertrain). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_32-1

  - Grebe, U. D., Hick, H., Rothbart, M., von Helmolt, R., Armengaud, E., Bajzek, M., & Kranabitl, P. (2020). **Challenges for Future Automotive Mobility**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_1-1

  - Schöffmann, W., Sorger, H., Faustmann, C., & Bajzek, M. (2020). **Case Study: Engine System Development**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_17-1

  - Kranabitl, P., Bajzek, M., Atzwanger, M., Schenk, D., & Hick, H. (2020). **Automotive Powertrain Development Process**. in H. Hick, K. K., & H. Sorger (Hrsg.), *Systems Engineering for Automotive Powertrain Development* (Powertrain). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_25-1

  - Hick, H., Angel, H-F., Kranabitl, P., & Wagner-Skacel, J. (2020). **Decision Making and the Influence of the Human Factor**. in H. Hick, K. Küpper, & H. Sorger (Hrsg.), *Systems Engineering for Powertrain Development* (Powertrain). Springer Nature Switzerland AG. https://doi.org/10.1007/978-3-319-68847-3_14-1

Agenda

Basics of models

Link between models and methods

Model management system

Engine modeling

Model selection and connection
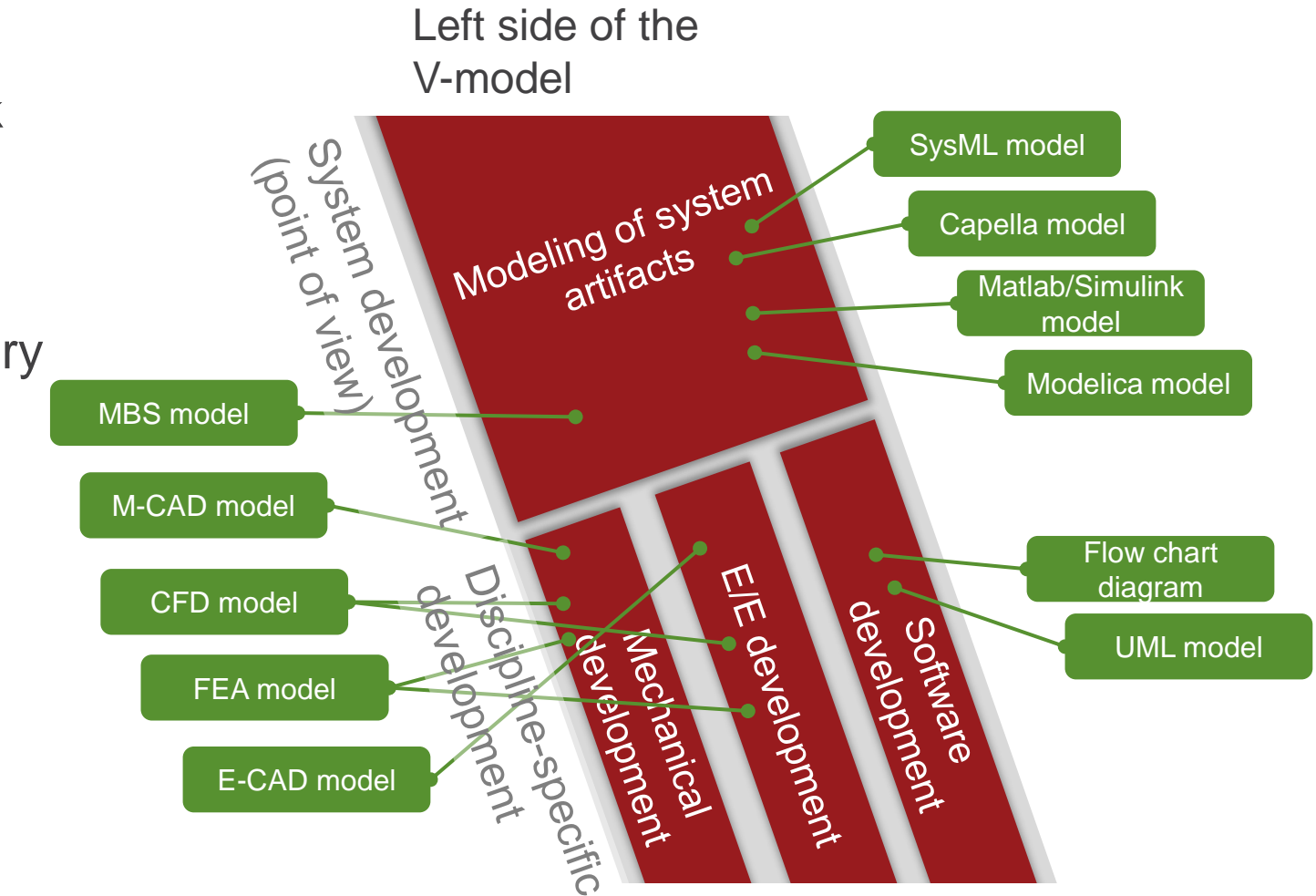
Challenges in development

- Shift to E/E and software in mechatronic or cyber-physical system
- Reduce development time and frontloading
- Reduce development and production cost
- Deliver a reliable, durable and safe system

- Use of models
- Link models
  - On same level
  - Between several levels
  - System models and (discipline) specific models
- Posit right models at right time
- Verify and validate models
- Build up the digital thread

Solution

Models

- Models, according to Stachowiak
  - Mapping property
  - Reduction property
  - Pragmatism property
- Interpretation of the model theory
  - A sketch is a model
  - An RC car is a model
  - A PowerPoint diagram is a model
- Models in context of MBSE
  - Degree of formalism
  - Digitizable
  - Connectable
  - Machine-processable

Left side of the
V-model

System development
(point of view)

Modeling of system artifacts

SysML model

Capella model

Matlab/Simulink model

Modelica model

MBS model

Discipline-specific development

Mechanical development

E/E development

Software development

M-CAD model

CFD model

FEA model

E-CAD model

Flow chart diagram

UML model

Cube of models

- Structure models
- Visualization of different models
- Classification of models
  - System model
  - Specific model
- The cube shows both
  - Qualitative/descriptive model
  - Quantitative model
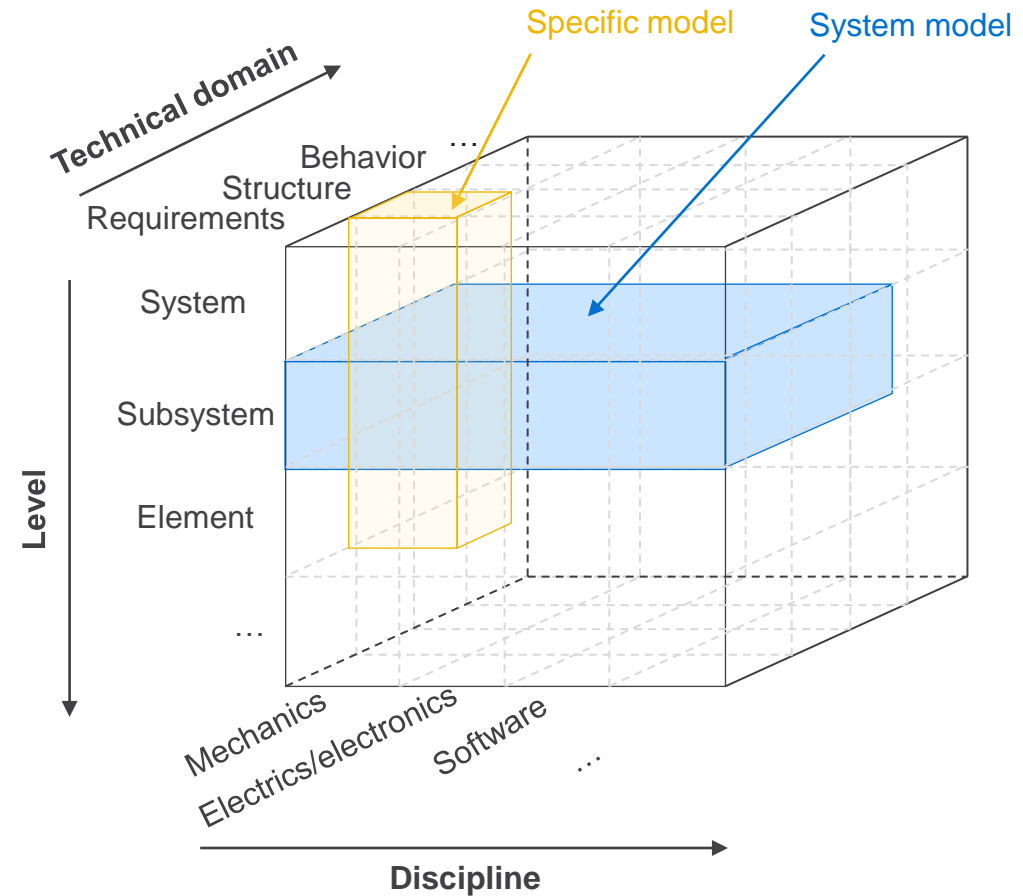
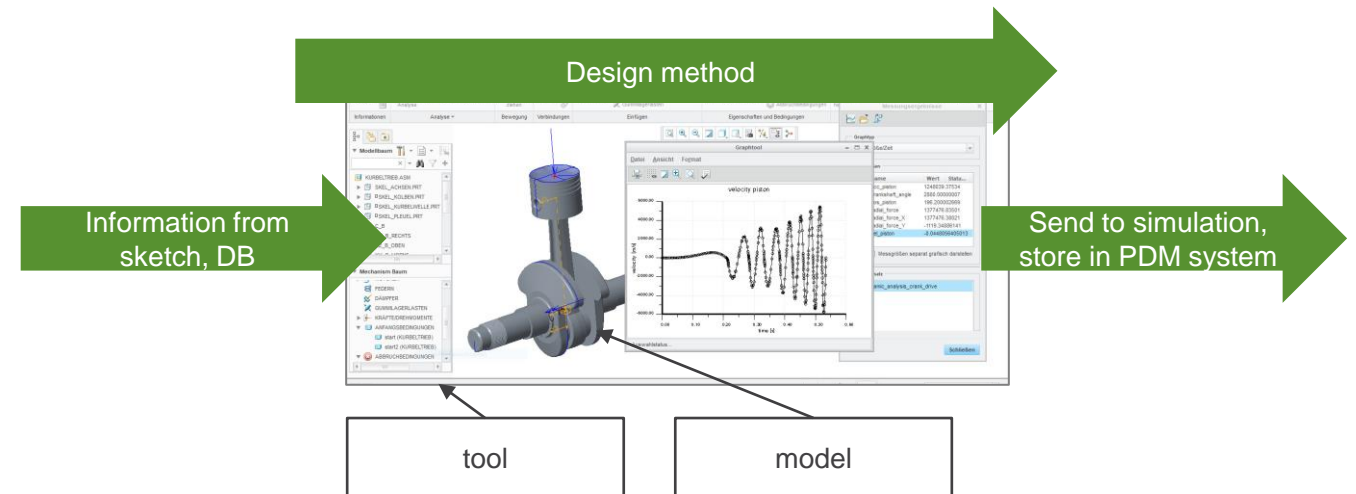Hick, H., Bajzek, M., & Faustmann, C. (2019). Definition of a system model for model-based development

Resulting questions

- How many models are required?
- When are the models required?
- **How to identify all the required models?**
- **How to select the right models?**
- How to manage the models over the product lifecycle?
- And many more
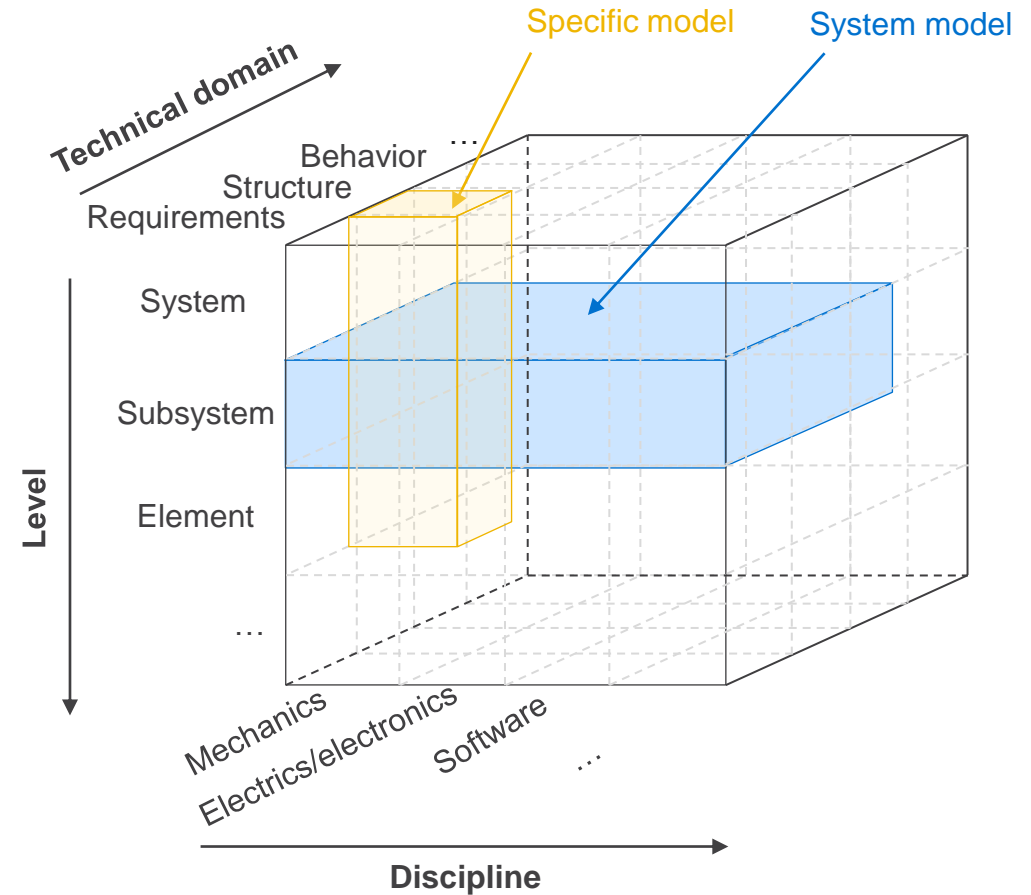
Hick, H., Bajzek, M., & Faustmann, C. (2019). Definition of a system model for model-based development

Models and methods

A method (e.g., CAD method) is a set of several sub-methods, e.g.,

- Method to gain information
- Method to generate the model
- Method to use the information
- Method to verify and validate the model
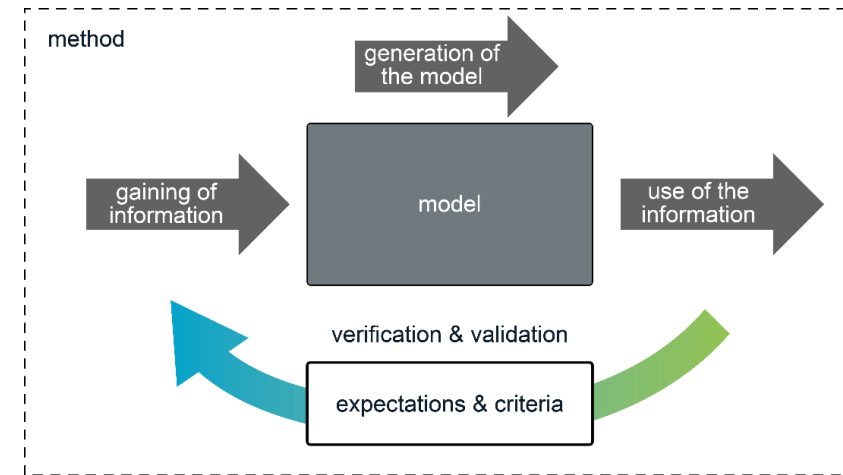
Method to identify and select models

method

generation of the model

gaining of information → model → use of the information

verification & validation

expectations & criteria

Design method

Information from sketch, DB

Send to simulation, store in PDM system

tool   model

Snapshot of models in the development process

2 Along several ways to describe the system

1 From system to discipline-specific development
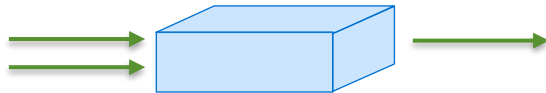
3 To the involved disciplines

Geometry Model
Multi-body dynamics model
Powertrain system model
Vehicle system model
Fluid dynamics model
Heat transfer model
Combustion model
NVH model

Technical domain

Behavior
Structure
Requirements

Vehicle
Powertrain
ICE

Level

Mechanical
Thermodynamics
Thermal
Fluid Dynamics

Discipline
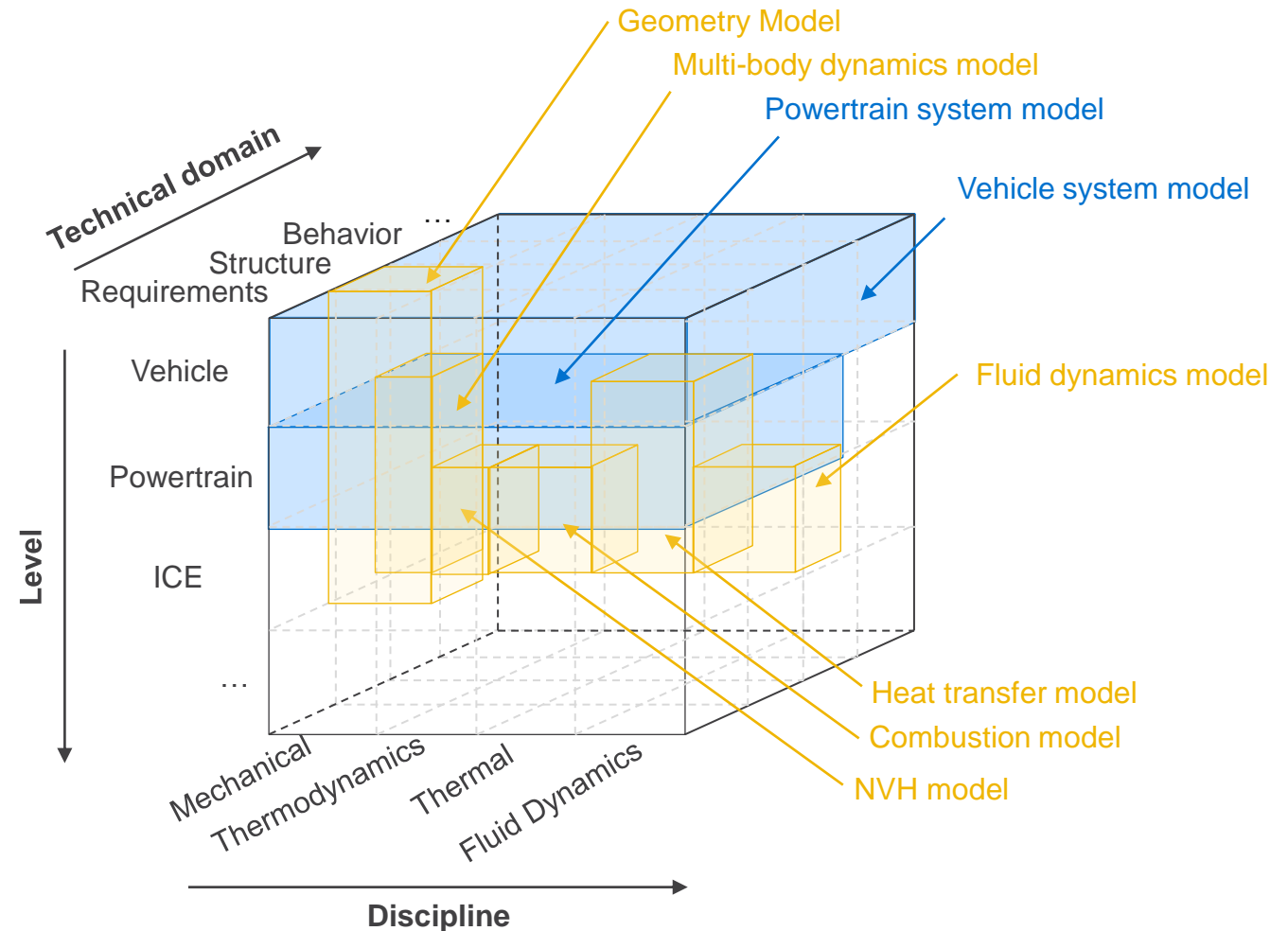
Aspects in the model landscape

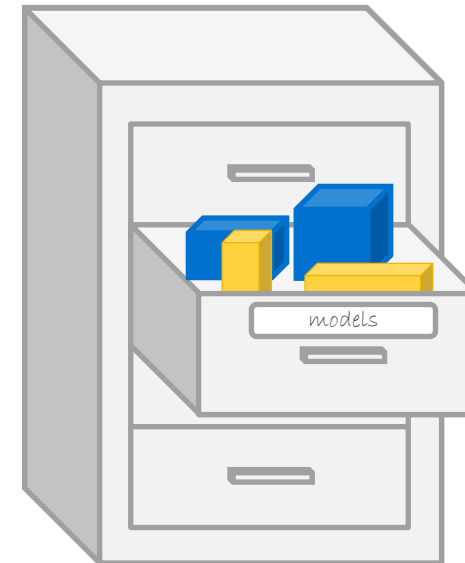- Overlapping of models
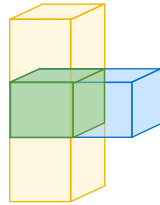
- Inputs and outputs of models
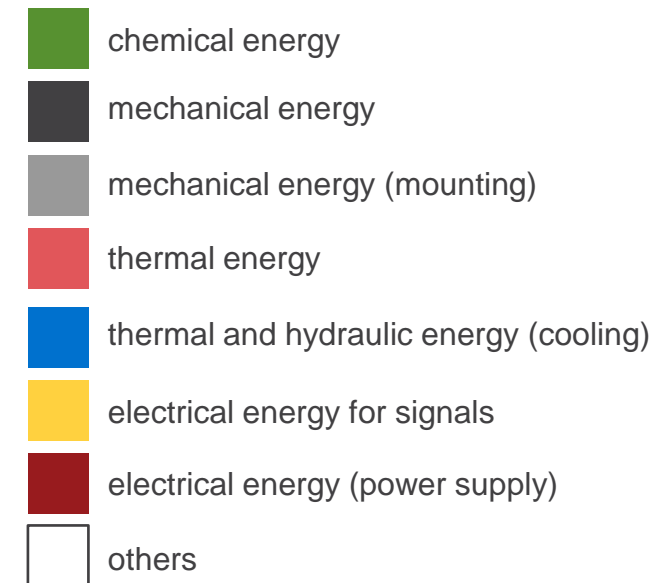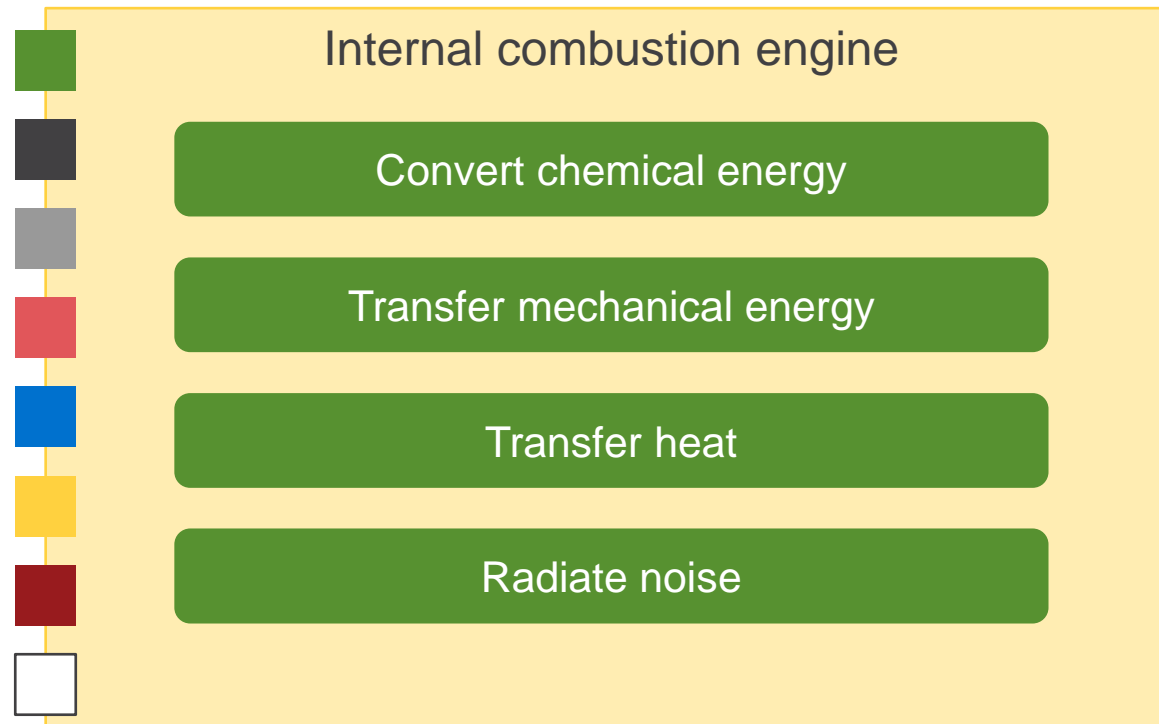
- Connection of models
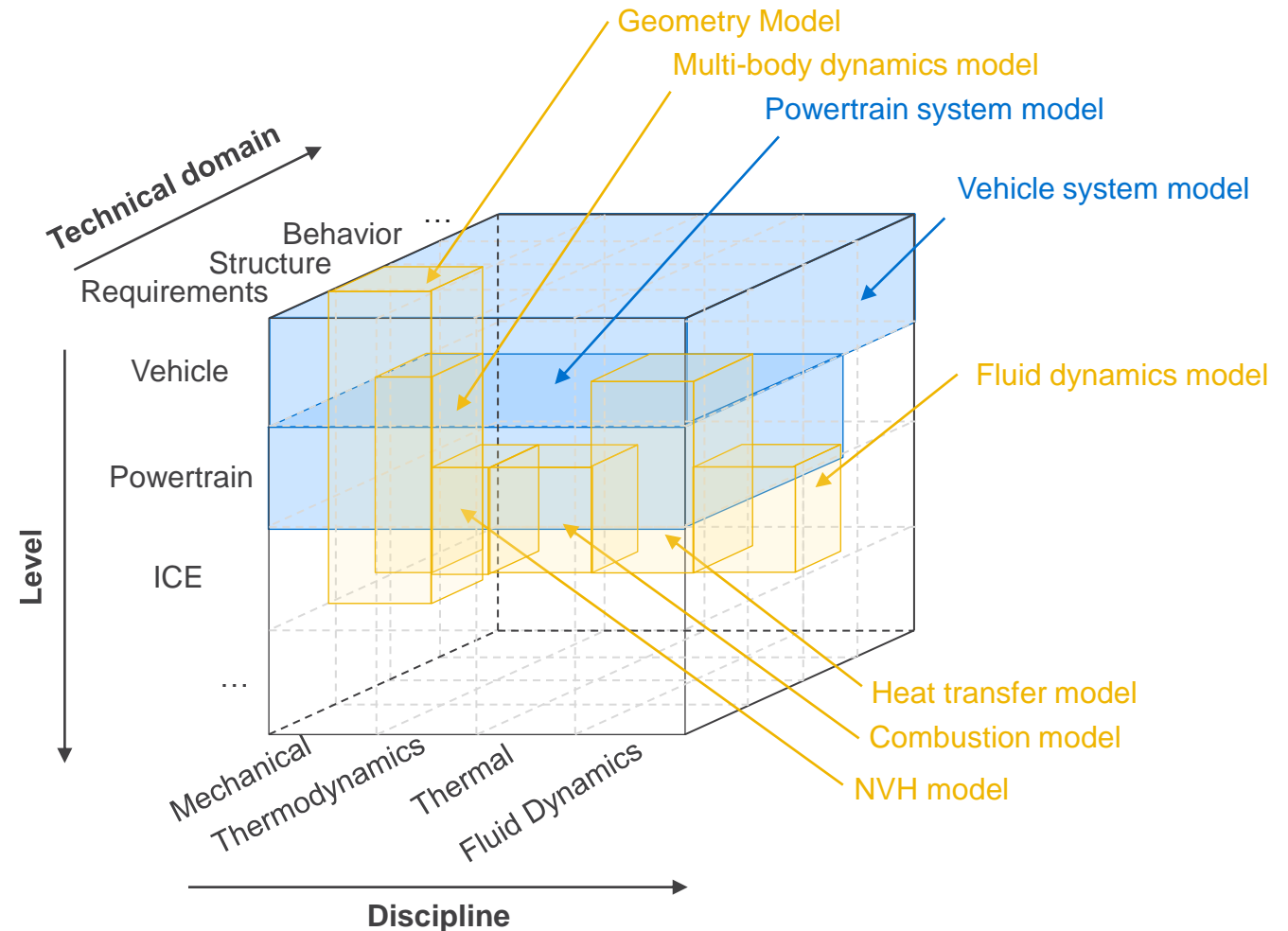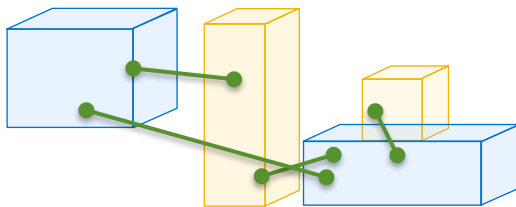
Model selection – technical part

- **System related identifiers**
  - **Required statements**
  - **Availability of input information**
  - **Level of system hierarchy**
  - **Required disciplines**
  - **…**
- Project related identifiers
  - Phase in the development process
  - Required system maturity
  - Available time to edit
  - Model fidelity
  - …

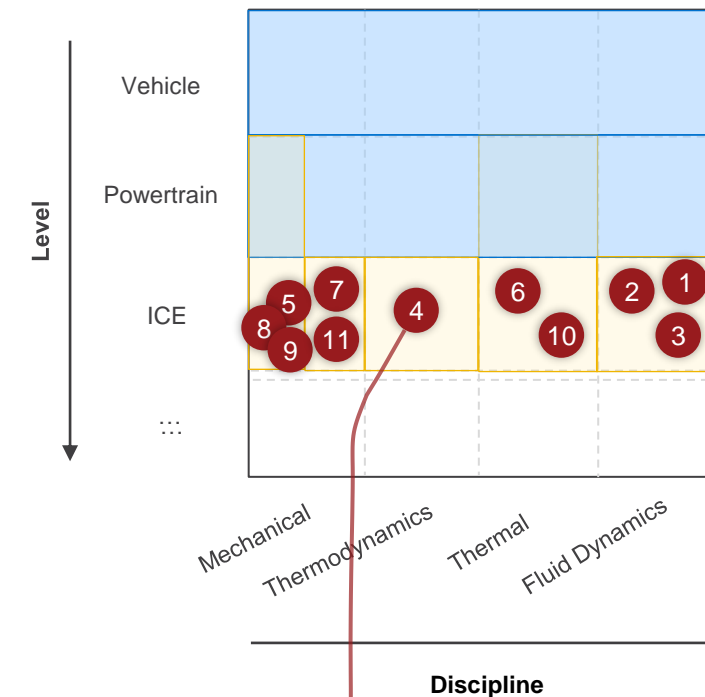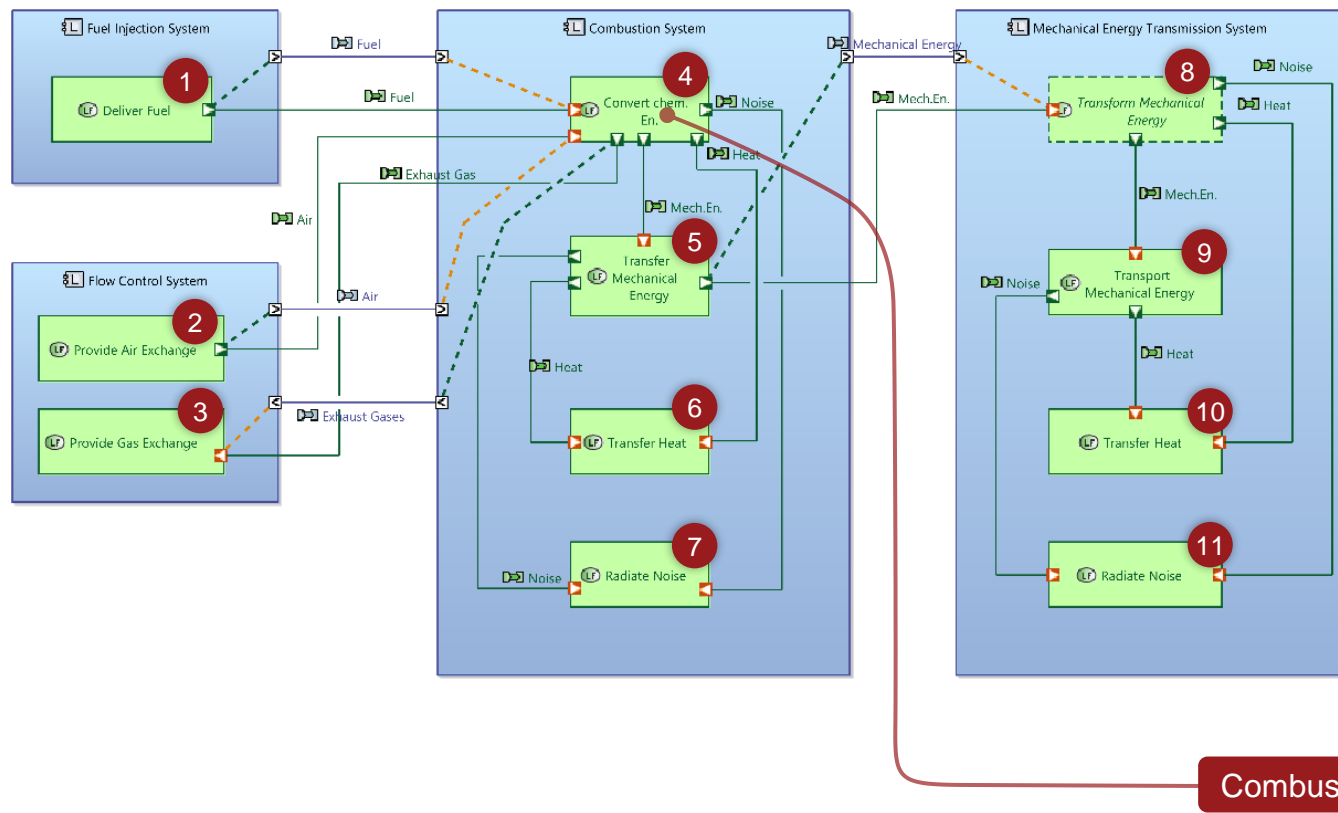# A view on engine development

Internal combustion engine

- Convert chemical energy
- Transfer mechanical energy
- Transfer heat
- Radiate noise

Legend:

- 🟩 chemical energy
- ⬛ mechanical energy
- ⬜ mechanical energy (mounting)
- 🟥 thermal energy
- 🟦 thermal and hydraulic energy (cooling)
- 🟨 electrical energy for signals
- 🟫 electrical energy (power supply)
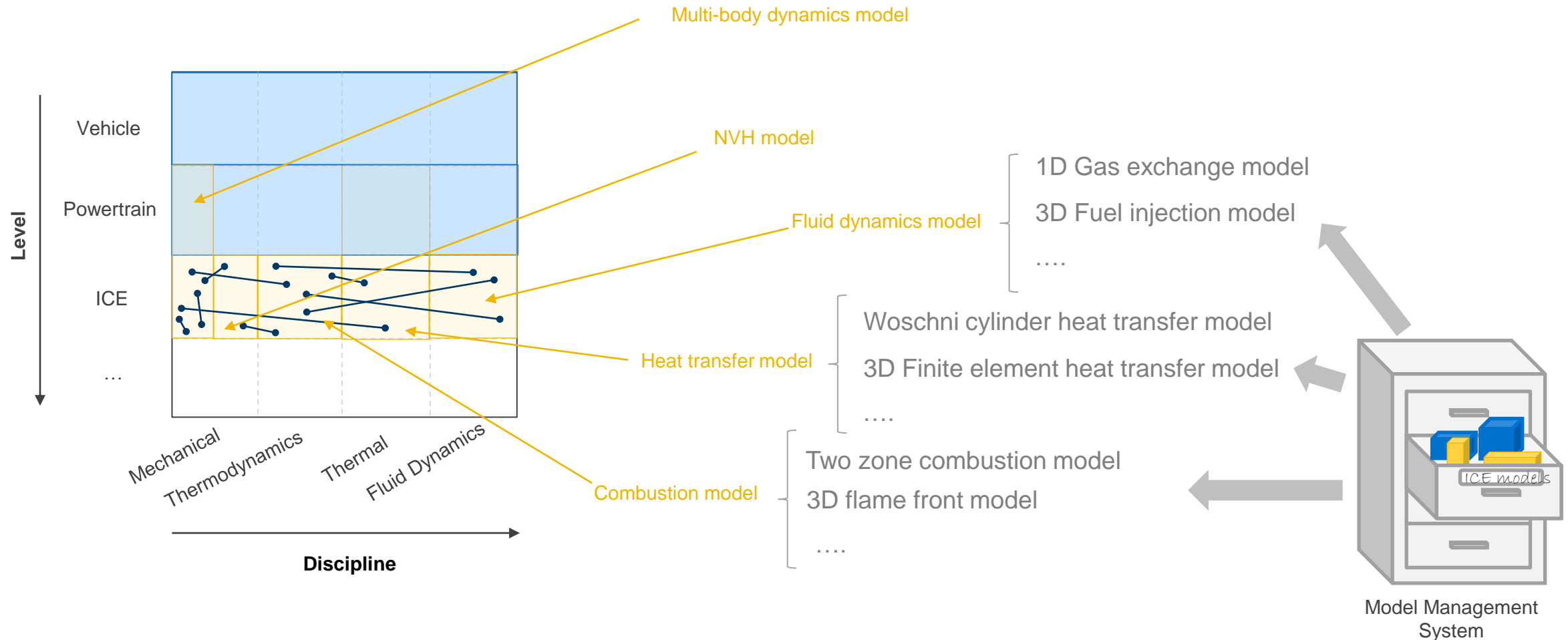- ⬜ others

Descriptive engine modeling (simplified and conceptual)

Descriptive engine modeling (simplified and conceptual)
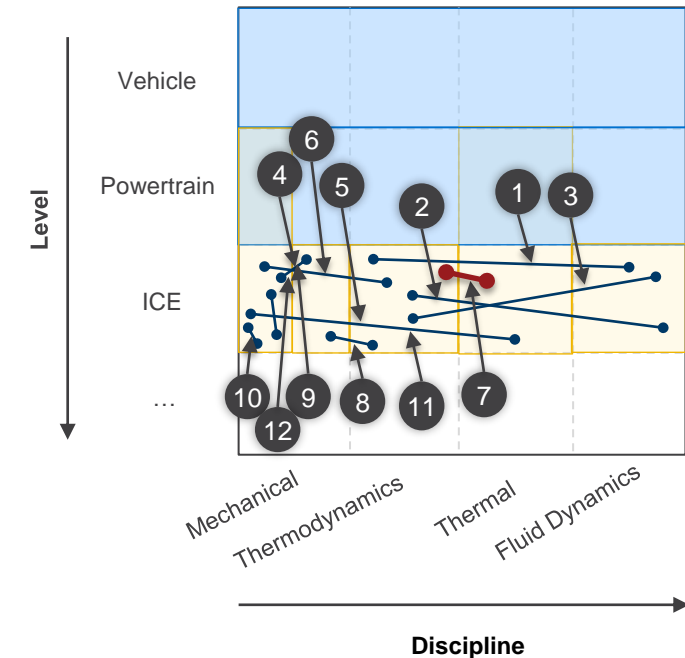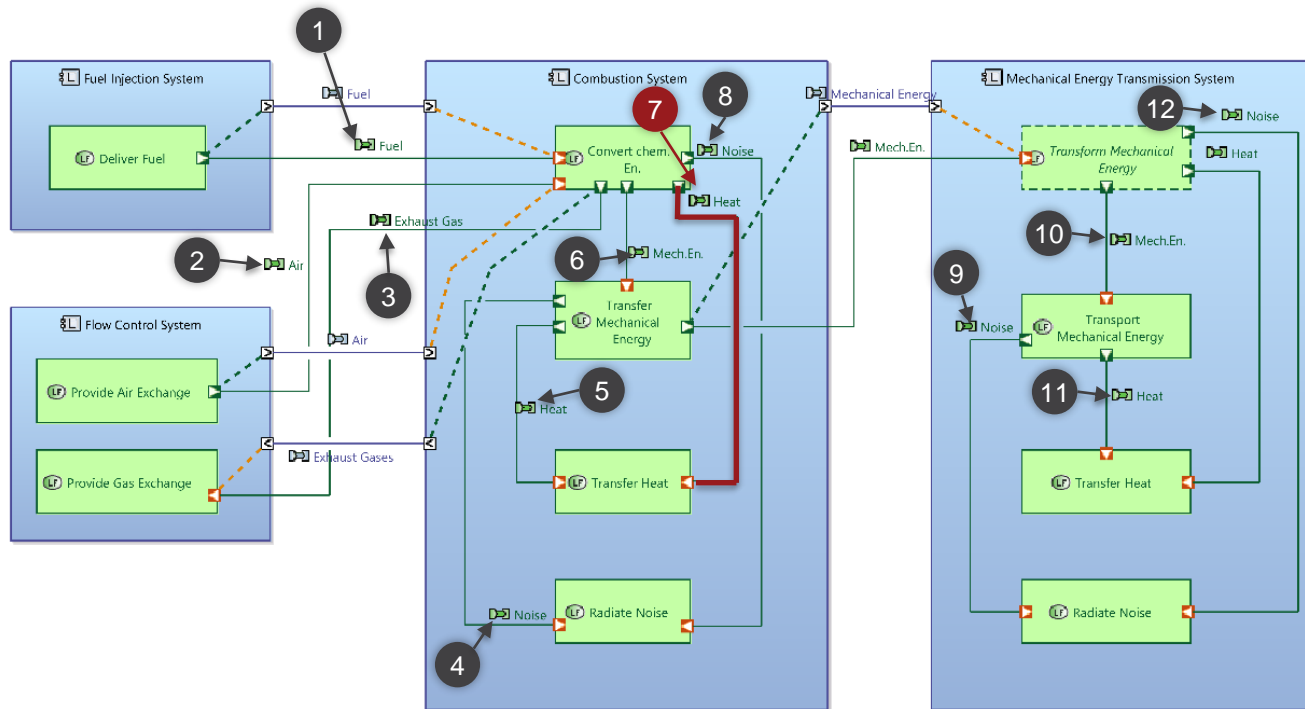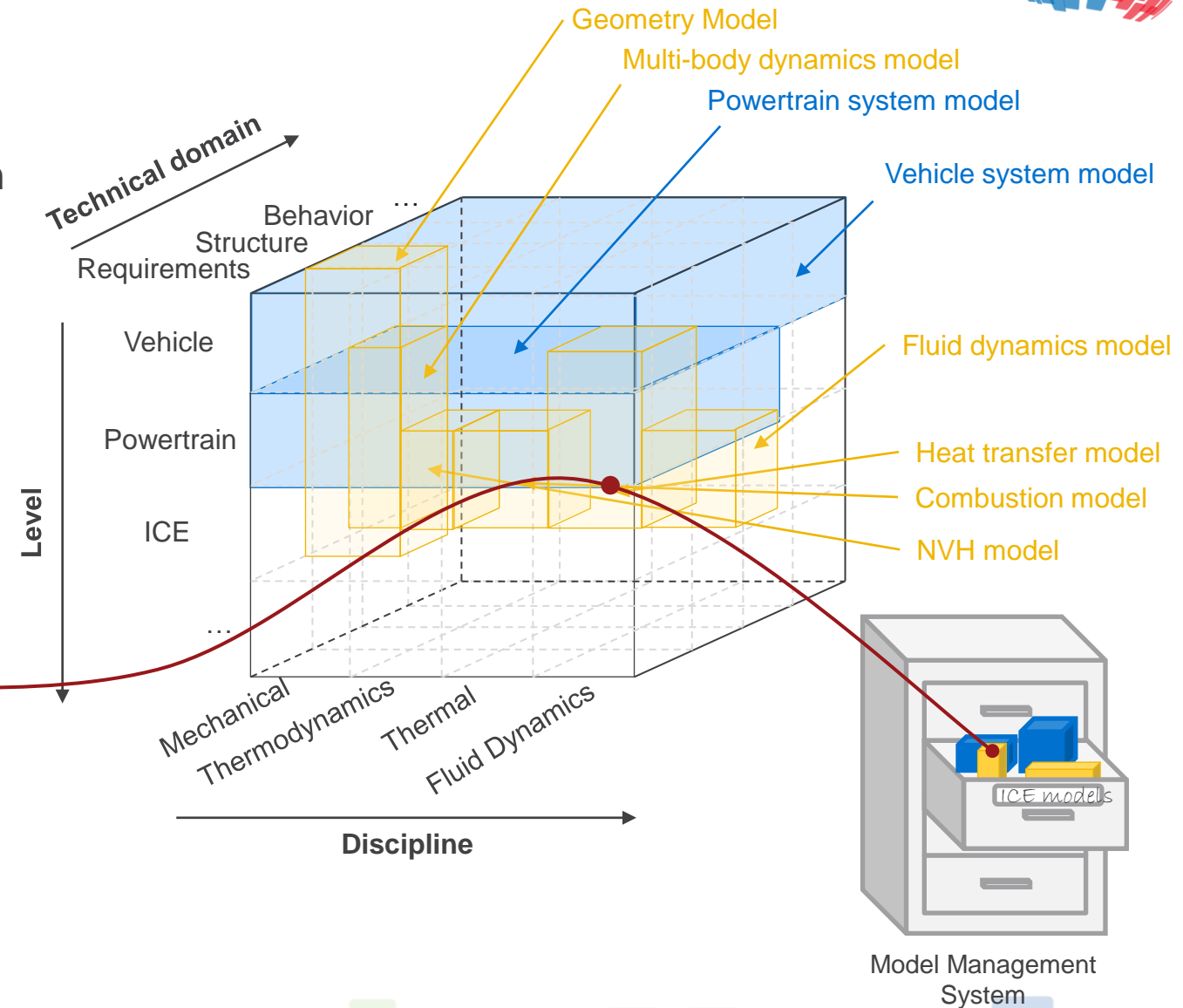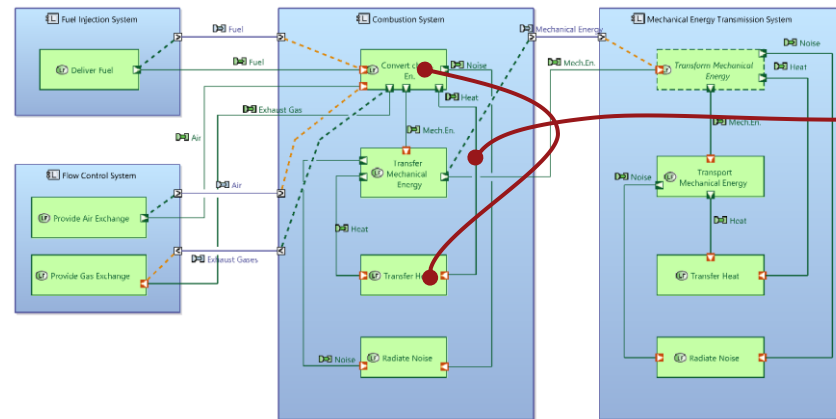
The bigger picture

Model selection – organizational part

- Availability of the model
- Status (creation, validation, released) of the model
- Skills and experience required for model application
- Allocated methods
- Responsibility for the model content
- Interfaces of the model and IT-tool/infrastructure
- …

Take aways

- Cube for model structuring and visualization
- Descriptive functional model for model identification, selection and connection
- A step towards the digital thread
- Next steps: further development of the method and practical realization

Geometry Model
Multi-body dynamics model
Powertrain system model
Vehicle system model
Fluid dynamics model
Heat transfer model
Combustion model
NVH model

Technical domain

Behavior
Structure
Requirements

Level

Vehicle

Powertrain

ICE

Mechanical
Thermodynamics
Thermal
Fluid Dynamics

Discipline

ICE models

Model Management System

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**If you have any questions,
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