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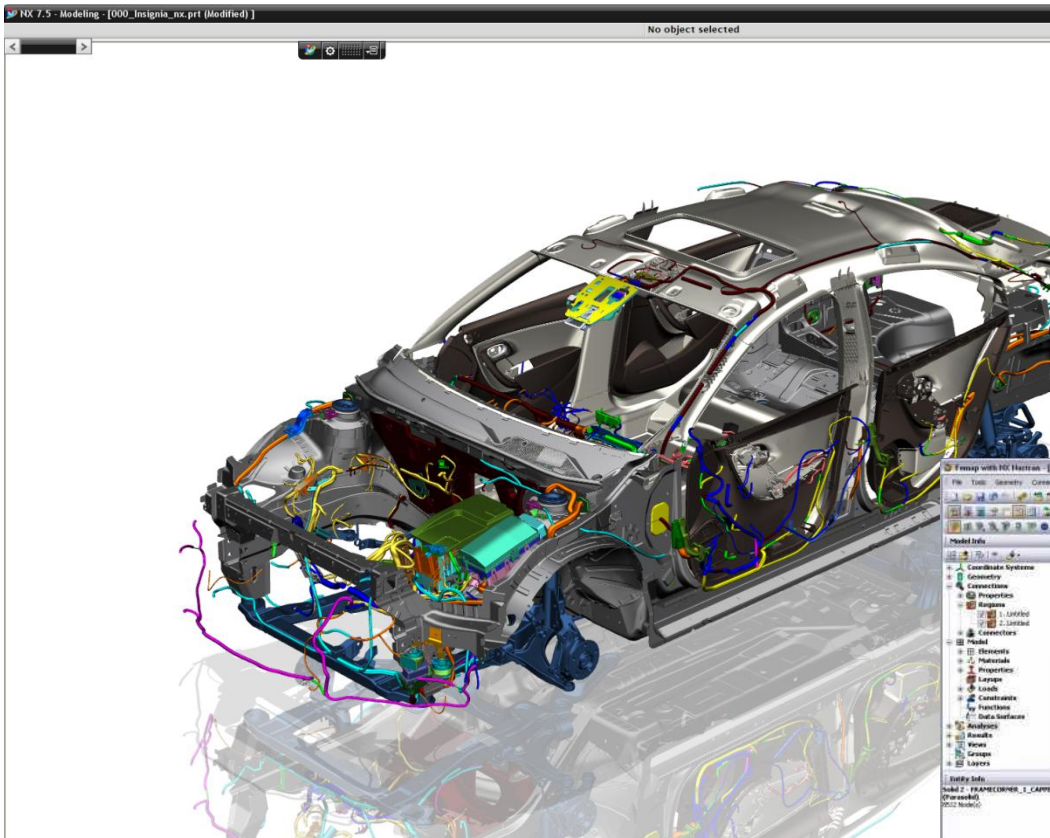
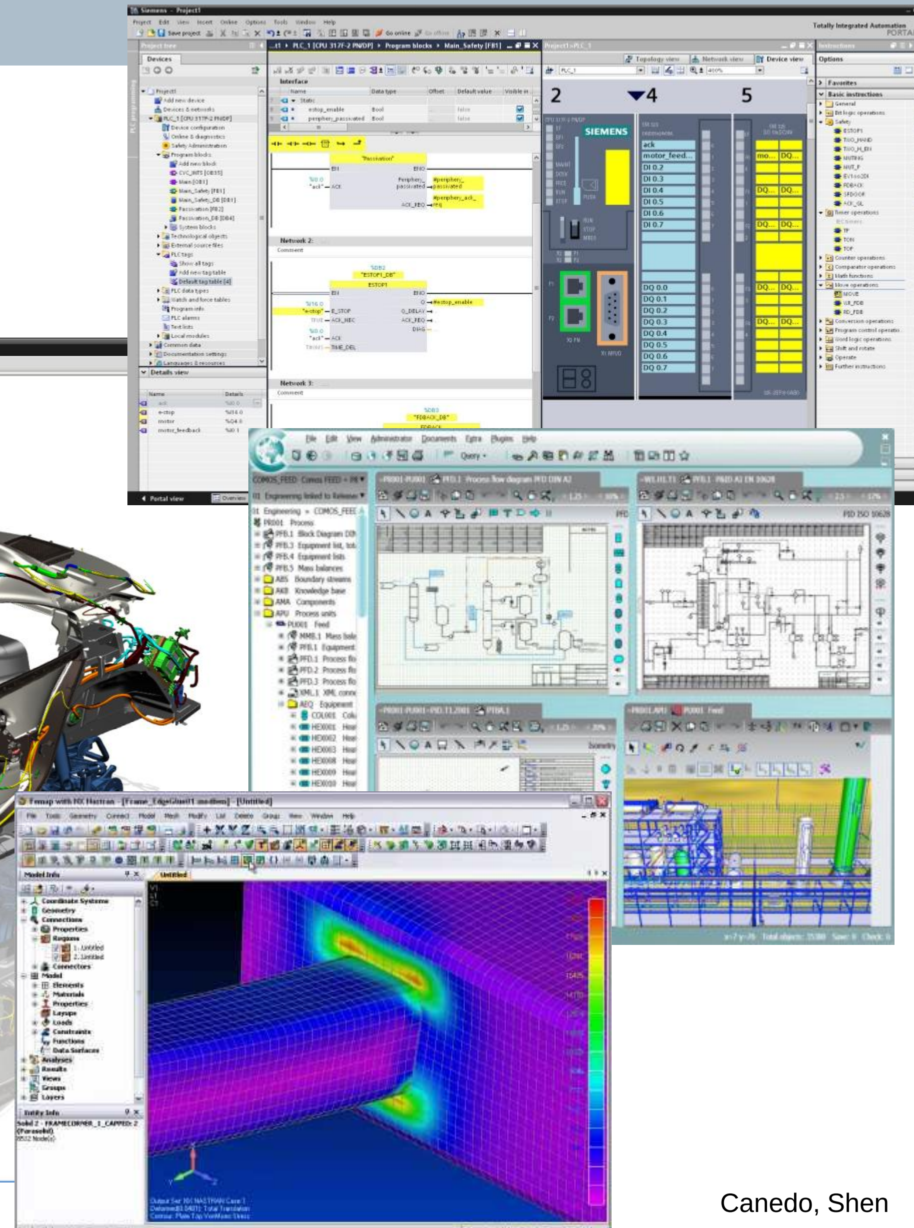
Functional Debugging of Equation-based Languages

Status Quo

Detail Design Tools

- High complexity
- Intensive expert labor





Problems with the State-of-the-art CPS Design

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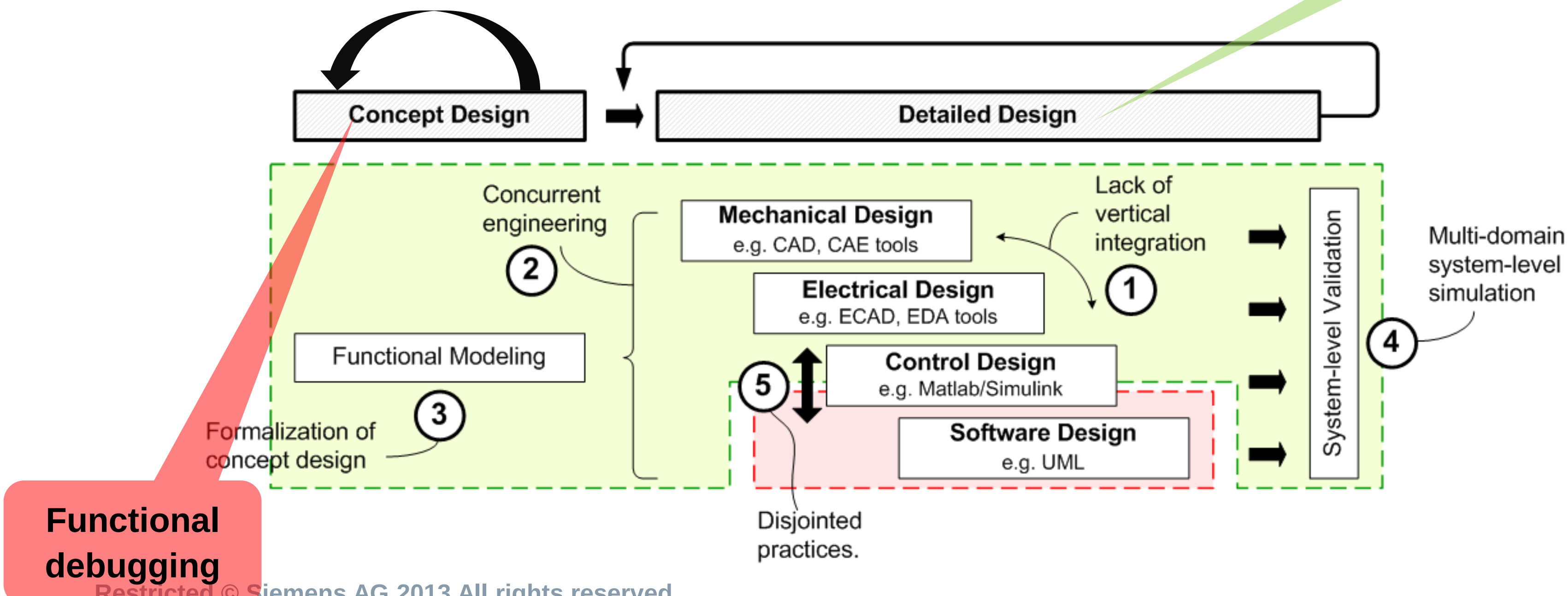
1. Lack of vertical integration
2. Serialization of the engineering practice
3. Informal concept design
4. Holistic system-level validation
5. Disjointed practices (electro-mechanical vs control)



State-of-the-art Debugging Techniques for Equation-based Languages

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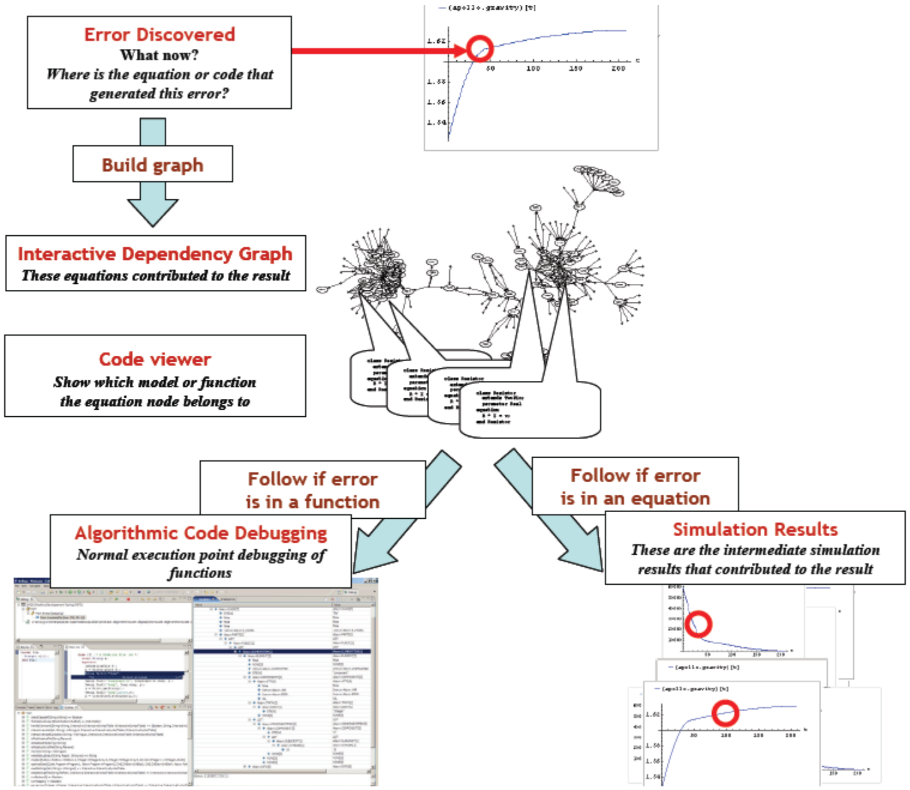
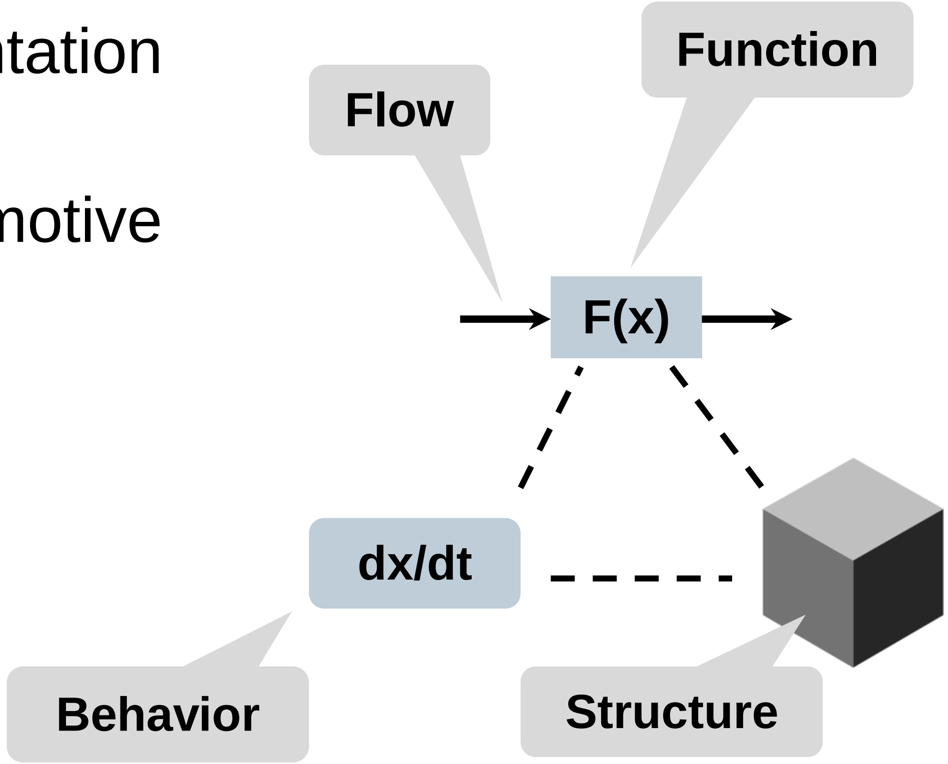
- Low-level details for detail design
- Static
  - Symbolic transformations.
- Dynamic
  - Similar to classical debugging.
- **Difficult to build a system-level context.**



Source: Adrian Pop, Martin Sjölund, Adeel Asghar, Peter Fritzson, Francesco Casella, Static and Dynamic Debugging of Modelica Models, 9th International Modelica Conference, 2012

Functional Modeling

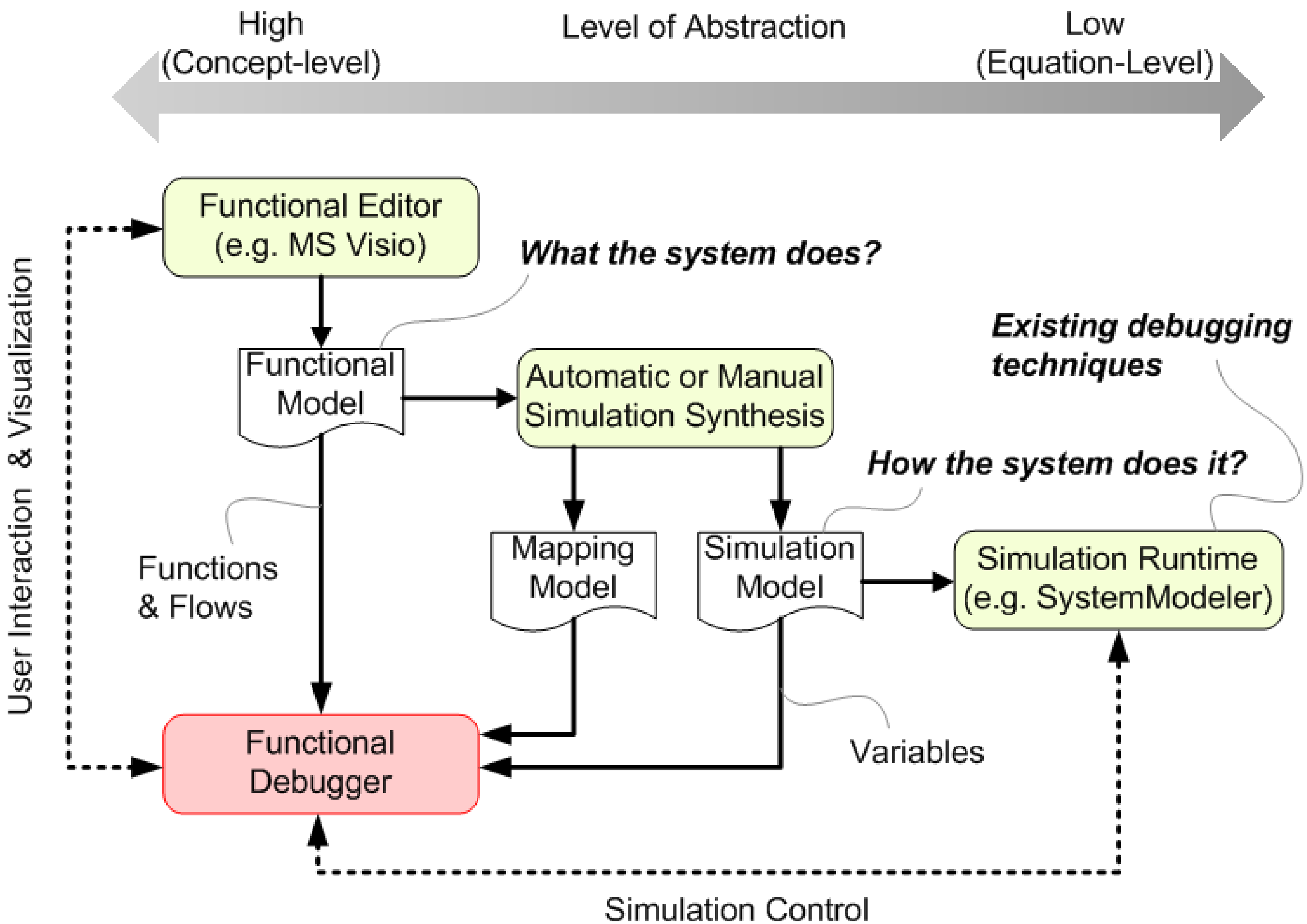
- ***What*** the system does
- Natural language
- Inter-disciplinary communication
- Visual syntax and well defined semantics
- Multi-disciplinary representation
- Functions and flows
- Standard practice in automotive



Functional Debugging

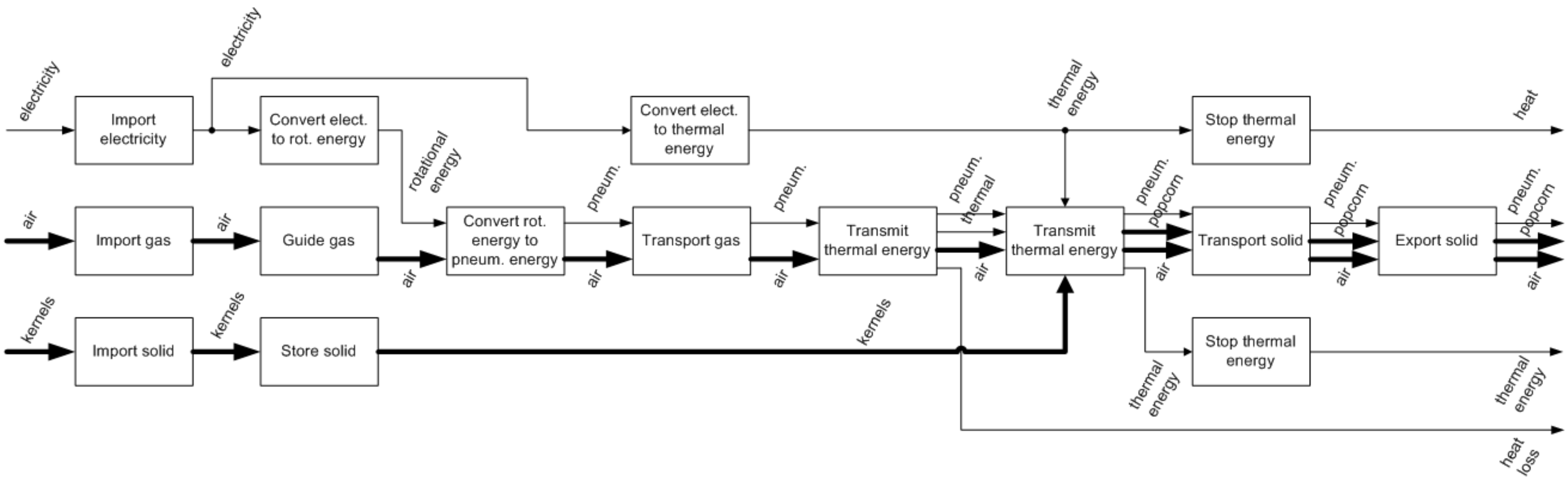
- The mechanism by which the variables of a running simulation are visualized through a high-level functional model to create an **implementation independent understanding** of the system.
- Coupling of behaviors to functions.
- High-level behavioral simulation.
  - **“What” not “how”**
- System-level integration problems.
- Design space exploration.
- Visualization of system flows.

Functional Debugger



Functional Basis

- Well defined vocabulary by NIST
- Three flow categories
  - Material, energy, signal → 18 flow types
- Eight function categories
  - 32 elementary functions
- Execution flows from left-to-right



Mapping between Functional and Behavioral Models

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Currently implemented

Functional Modeling		Equation-based Languages		
Flow Class	Flow Type	Conjugate Vars. (Effort/Flow)	System-Level Lang.	Domain Specific Lang.
Energy	Electrical	Electromotive Force / Current	MSL, Simscape	Spice, VHDL-AMS
	Mechanical (Rotational)	Torque / Angular Velocity	MSL, Simscape	NX Motion, Adams
	Mechanical (Translational)	Force / Linear Velocity	MSL, Simscape	NX Motion, Adams
	Mechanical (Vibrational)	Amplitude / Frequency		NASTRAN, Adams
	Hydraulic	Pressure / Volumetric Flow	Modelon, Simscape	SIMIT
	Pneumatic	Pressure / Mass Flow	MSL	
	Thermal	Temperature / Heat Flow	MSL, Simscape	Nastran
	Electromagnetic	Intensity / Velocity		
	Magnetic	Mag. Force / Mag. Flux Rate	MSL	
	Chemical	Affinity / Reaction Rate	BioChem	
	Biological	Pressure / Volumetric Flow	BioChem, Wolfram	
	Human	Force / Motion		
	Acoustic	Pressure / Particle Velocity	SoundDuctFlow	Actran
	Radioactive	Intensity / Decay Rate		
Signal	Status		StateGraph, Simulink	dSPACE, LabView, UML
	Control		StateGraph, Simulink	dSPACE, LabView, UML
Material	Human			Technomatix , Queueing
	Gas			Technomatix , NASTRAN
	Liquid			Technomatix , NASTRAN
	Solid			Technomatix , Queueing

R F L B P

Mapping Model

- Data structure that maintains the mapping between the functional model and the simulation model.
- Specifies the debugging actions to be taken in the functional debugger GUI.

UID	Type	Func/Flow	Simulation Component	Debugging Action
f11	Flow	RME	Drivetrain.Engine.engineSpeed	if ($var > 4000) f11.ChangeColor(Red)
f15	Flow	Signal	Drivetrain.driver1.brakeSignal	if ($var > 0.05) f15.setInvisible();
f92	Function	Convert RME to TME	Drivetrain.body.flange_a.f	if ($var > 60) f11.ChangeColor(Red)

- Proposal: describe what functions are realized by the components in the MSL

Our Implementation

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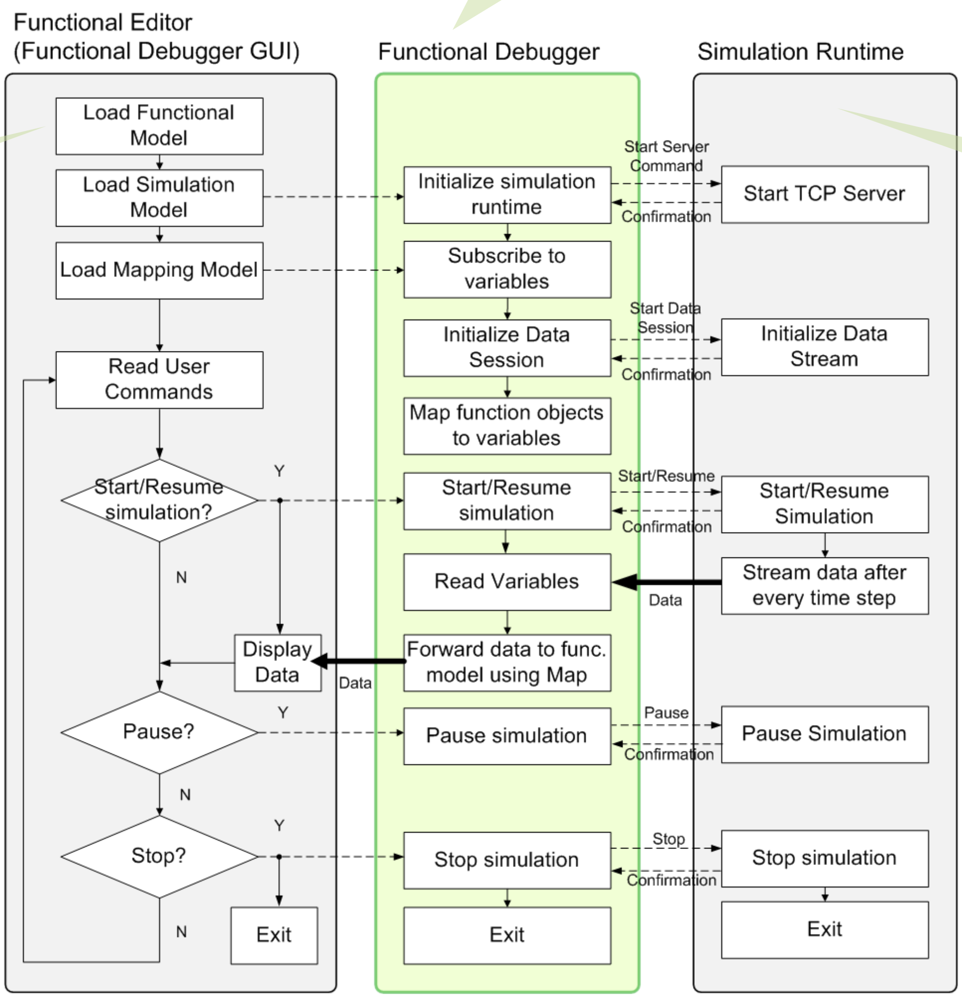
Communication (e.g. FMI)

Front-end (e.g. SysML)

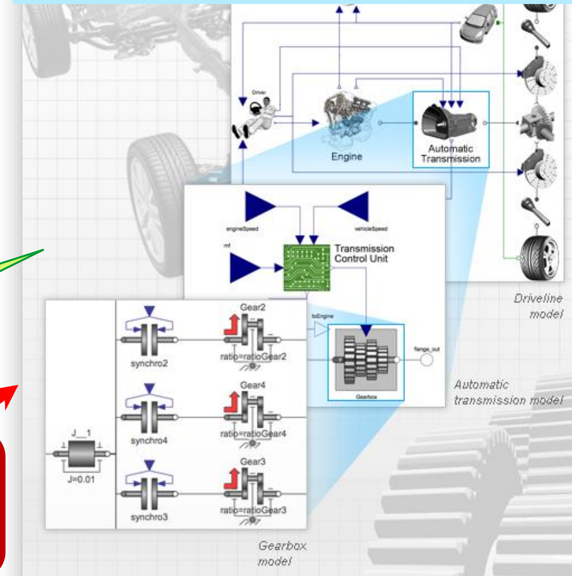
Runtime (e.g. OpenModelica)



Automotive Example

- Drivetrain of an internal combustion engine car.

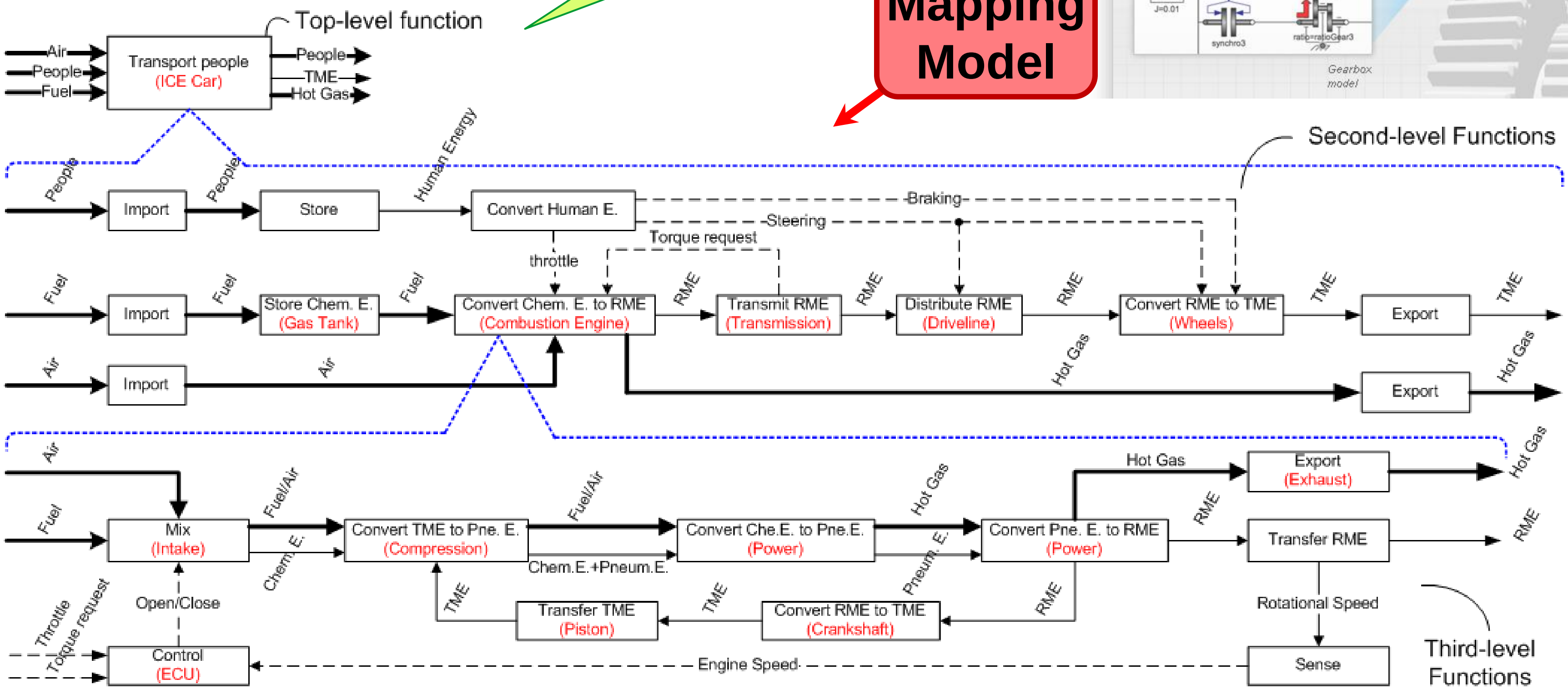
Source: Wolfram Research – System Modeler



Simulation Model

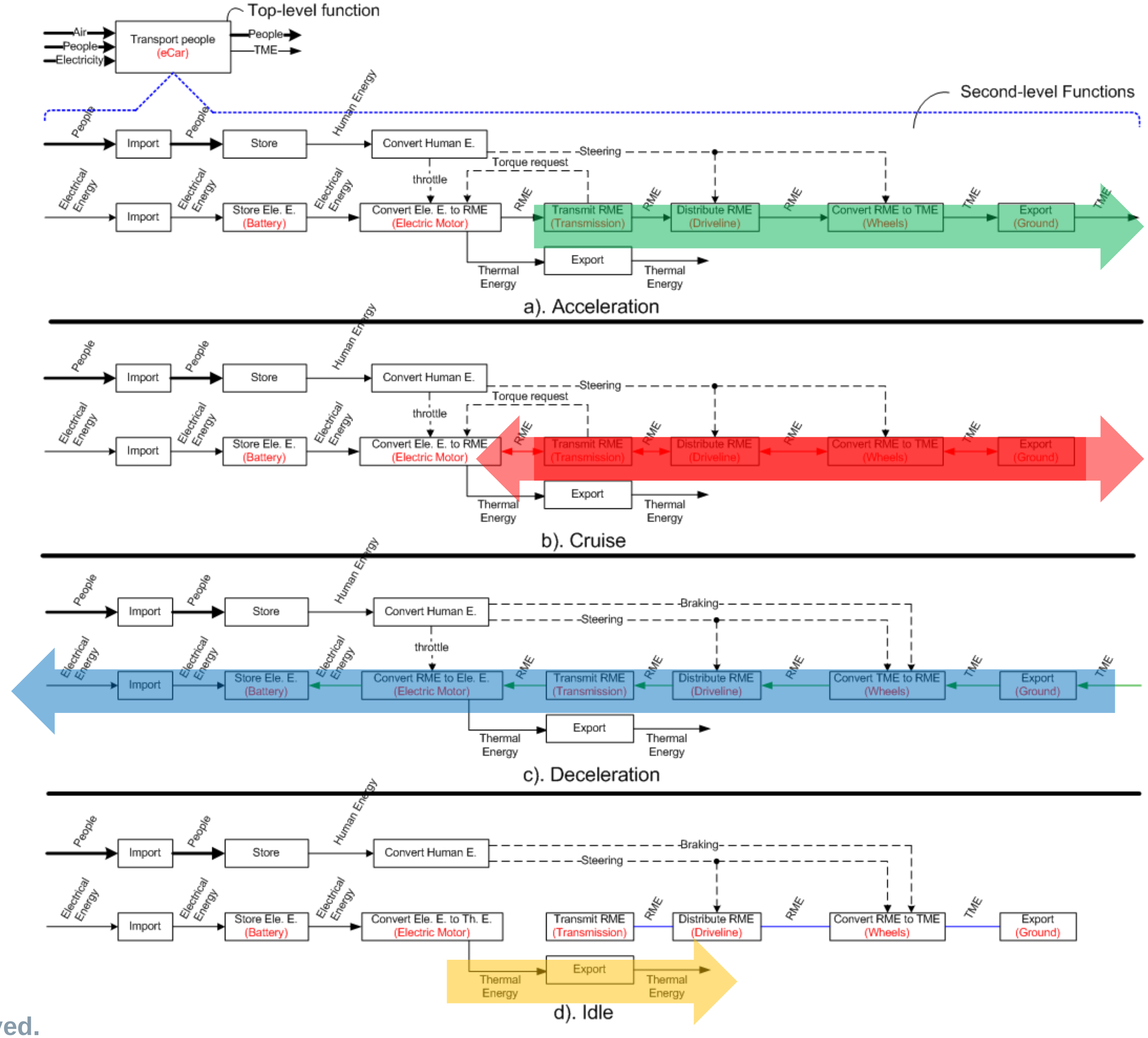
Functional Model

Mapping Model



Functional Debugging

- System configuration
  - V6, V8
- Use-cases
  - Driving cycles
- Performance targets
  - Fuel economy
  - NVH



Summary

- **Functional debugging for concept design**
  - Visualization of system flows
  - Mapping of functions to behavioral models through conjugate variables
  - Design space exploration tool
  - Orthogonal to existing debugging techniques
- **Systems Engineering tools**
  - Requirements, Functions, Logical, Physical
- **Multi-tool debugging interface**
    - e.g. Modelica, Nastran, VHDL

Thank you!

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