Multiparadigm modeling – A Mechatronics and Embedded Control Systems perspective

Martin Törngren
Embedded Control Systems group
Mechatronics, Department of Machine Design
School of Industrial Engineering and Management
KTH - Royal Institute of Technology, Stockholm, Sweden

Outline

- Mechatronics
  - Opportunities and complexity
  - Human in the loop – who decides?
  - Embedded control systems
  - Codesign and Architecture design
  - Automotive embedded systems as an example
  - Dealing with complexity, approaches and trends
  - Industrial challenges
- Model based development in Mechatronics
  - Needs and challenges
- Research topics and challenges

Embedded Control System group

www.md.kth.se/RTC

Embedded control systems science and engineering

Research themes:

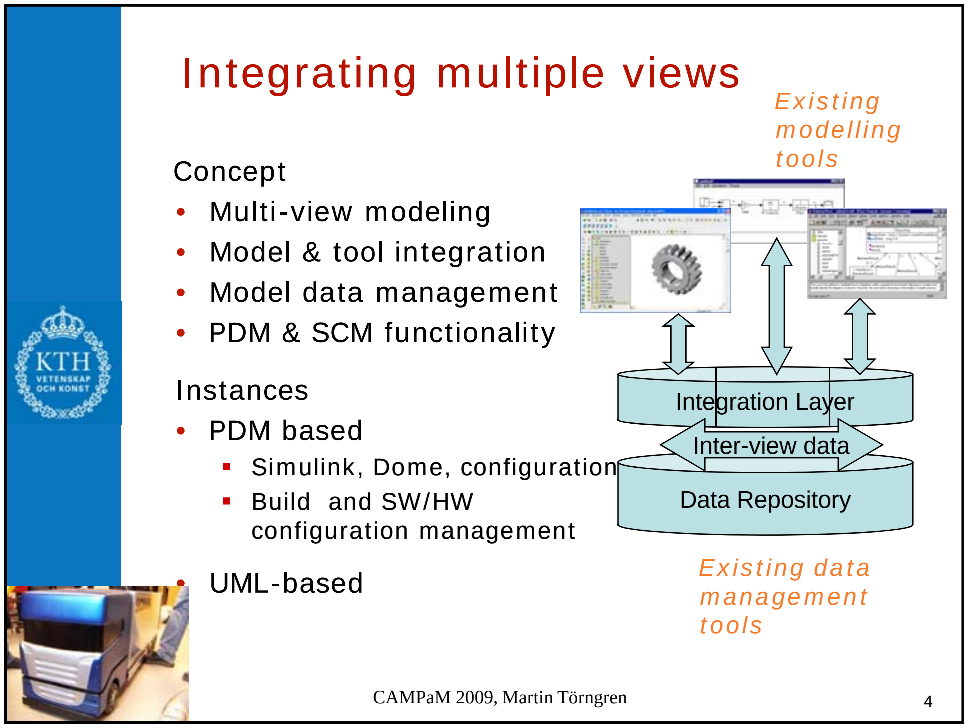
- Control and computer system co-design
- Architectural design, trade-off analysis
- Model and component based development
- Methodology
  - Cost-efficient systematic design and verification

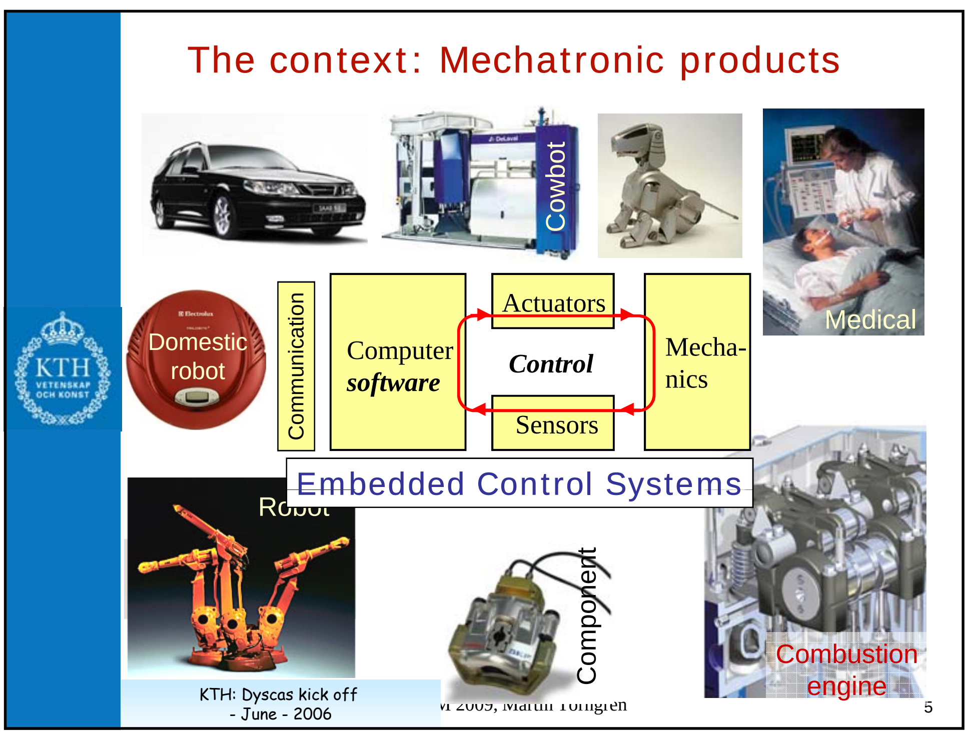
ArtistDesign, Artemis, ICES




Current topics

- Self-configuring automotive embedded systems
  - Variability, Config. management, meta-data, QoS
- State of the art and evaluations
  - Modelica, Simevents, Simulink, Sysml/UML incl. Parametrics, Ptolemy, Bond graphs, VHDL-AMS,
  - Modeling languages for embedded systems
  - Architecture trade-off analysis techniques
  - Model transf. Techniques, survey
  - Methodologies
- EAST-ADL – Architecture description language for embedded systems
- Tooling (Eclipse plug-ins)


Integrating multiple views
Concept
• Multi-view modeling
• Model & tool integration
• Model data management
• PDM & SCM functionality
Instances
• PDM based
▪ Simulink, Dome, configuration
▪ Build and SW/HW configuration management
• UML-based
Existing modelling tools
Integration Layer
Inter-view data
Data Repository
Existing data management tools
KTH VETENSKAP OCH KONST
CAMPaM 2009, Martin Törngren
4


The context: Mechatronic products
Cowbot
Medical
Domestic robot
Communication
Computer software
Actuators
Control
Sensors
Mecha-nics
Embedded Control Systems
Robot
Component
Combustion engine
KTH VETENSKAP OCH KONST
KTH: Dyscas kick off - June - 2006
5

Mechanics → Mechatronics

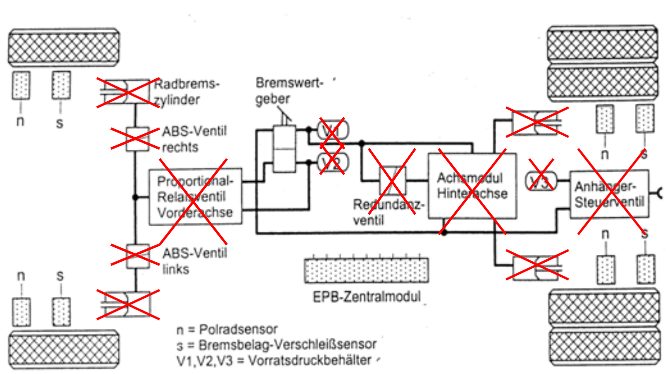
Hy-Wire från GM
Skateboard concept
(Autonomy 2)

Fuel-cell
Distributed control
Electrical actuators

CAMPaM 2009, Martin Törngren 6

Existing electronic braking system

- Distributed components for control and actuation.
  - Several interfaces between pnematics and electronics

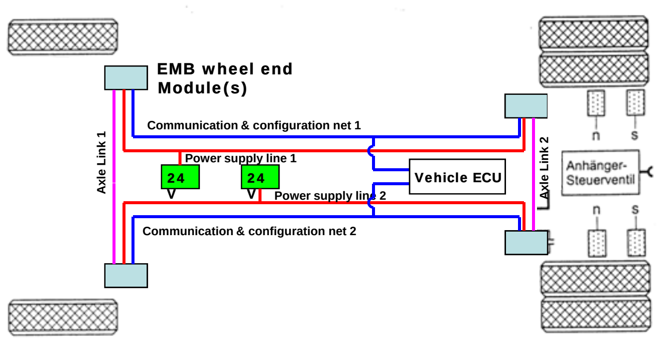


Source: Haldex

CAMPaM 2009, Martin Törngren 7

Future System (X-by wire)

- Wheel end modules with integrated control system
  - Less interfaces and system components

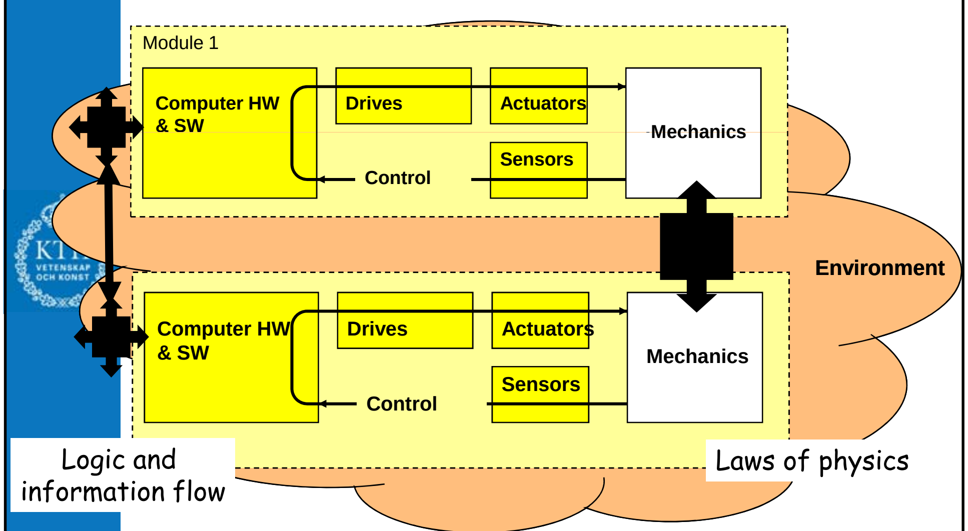


Source: Haldex

CAMPaM 2009, Martin Törngren 8

Mechanics vs. Mechatronics;

adding flexible information processing and flow



CAMPaM 2009, Martin Törngren 9

”Purely” mechanical vehicle

	Susp.C	Brake	Steer	Wheel	Diff	Trans	Clutch	Eng	Driver
Susp				X					X
Brake				X					X
Steer				X					X
Wheel	X	X	X		X				
Diff				X		X			
Trans					X		X		
Clutch						X		X	X
Eng							X		
Driver	X	X	X				X		

X – Mechanical relation

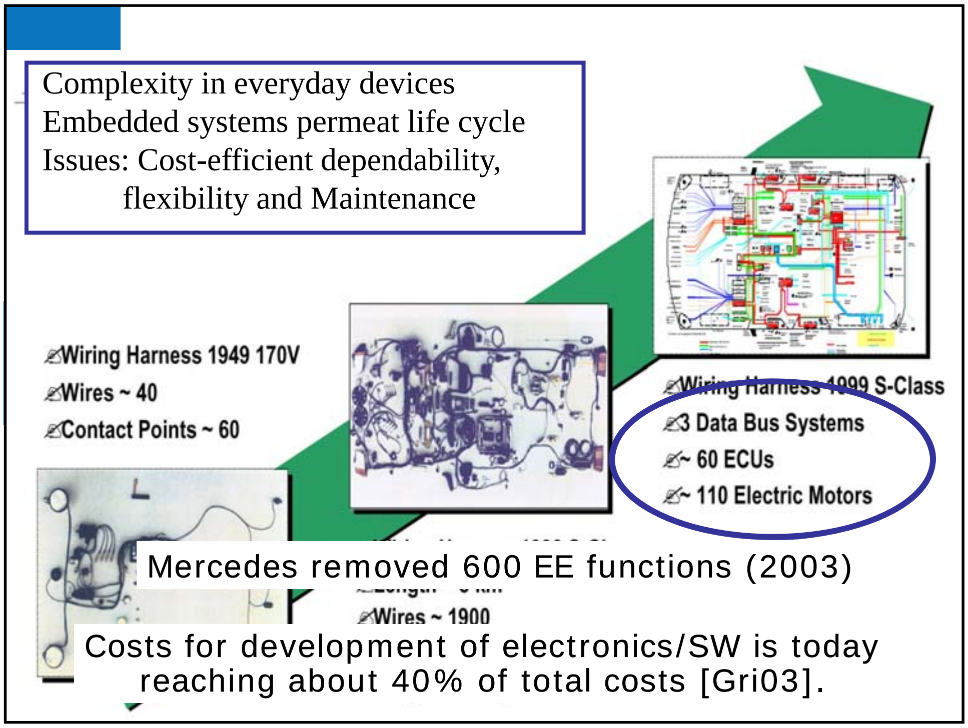
CAMPaM 2009, Martin Törngren 10

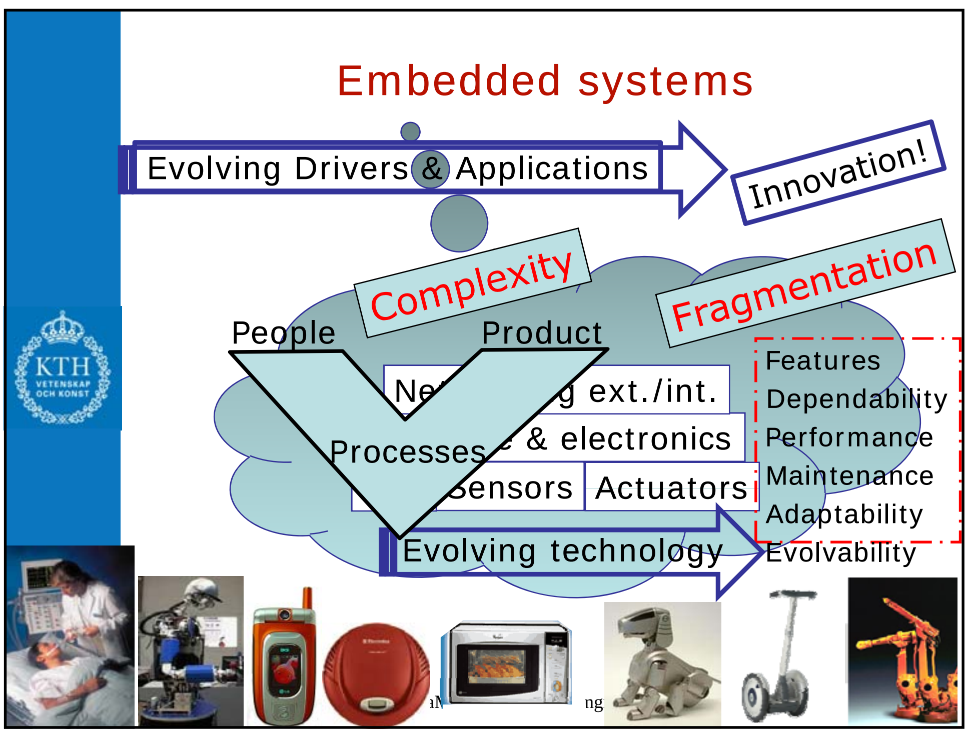
Fully programmable vehicle!

	Susp	Brake	Steer	Wheel	Diff	Trans	Clutch	Eng	Driver
Susp		P	P	X+P	P	P	P	P	X+P
Brake	P		P	X+P	P	P	P	P	X+P
Steer	P	P		X+P	P	P	P	P	X+P
Wheel	X	X	X+P		X				
Diff	P	P	P	X+P		X+P	P	P	
Trans	P	P	P	P	X+P		X+P	P	P
Clutch		P	P		P	X+P		X+P	P
Eng	P	P	P	P	P	P	X+P		P
Driver	P	X+P	X+P		P	P	X+P	P	

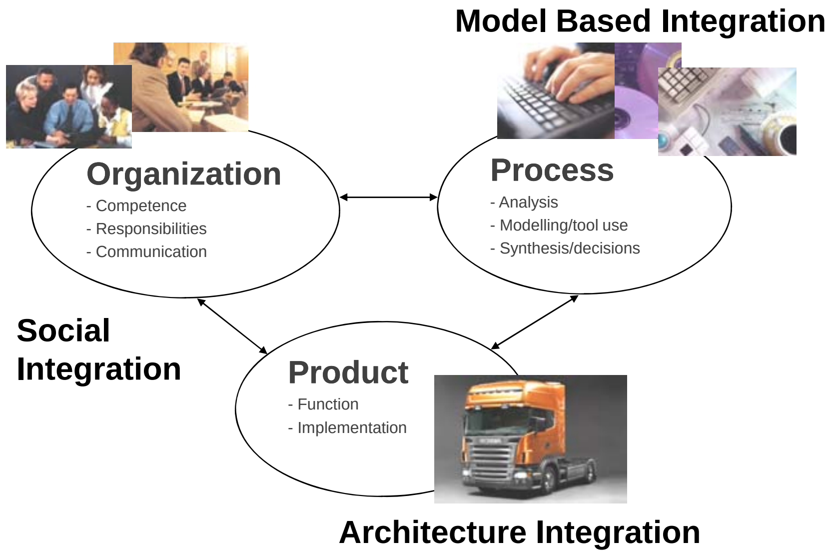
P – Programmable relation
X – Possible change

CAMPaM 2009, Martin Törngren 11


Complexity in everyday devices
Embedded systems permeat life cycle
Issues: Cost-efficient dependability, flexibility and Maintenance
Wiring Harness 1949 170V
Wires ~ 40
Contact Points ~ 60
Wiring Harness 1999 S-Class
3 Data Bus Systems
~ 60 ECUs
~ 110 Electric Motors
Mercedes removed 600 EE functions (2003)
Wires ~ 1900
Costs for development of electronics/SW is today reaching about 40% of total costs [Gri03].


Embedded systems
Evolving Drivers & Applications
Innovation!
Complexity
Fragmentation
People
Product
ext./int.
Processes
& electronics
Sensors
Actuators
Evolving technology
Features
Dependability
Performance
Maintenance
Adaptability
Evolvability

Development of complex products



CAMPaM 2009, Martin Törngren 14

Automotive embedded systems and model based engineering

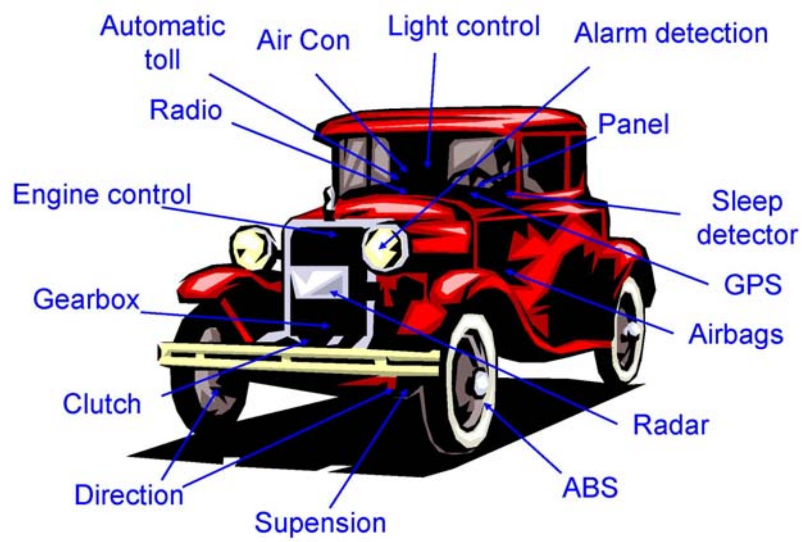
Specifics:

- Tightly coupled systems: Software, electronics, mechanics
- Hybrid behaviors, timing and criticality ”levels”
- Emergent behavior more difficult to control and understand due to
  - Information and physical interactions
  - Systems integration (uncontrolled behavior)
  - Connection with external behavior

- Multiple tools, modeling languages and standards
- Well established disciplinary/subsystem MBE
  - Control, Electronics, Mechanics
- Weak MBE for systems architecting and integration
- Weak MBE for software engineering; Autosar is pushing a change

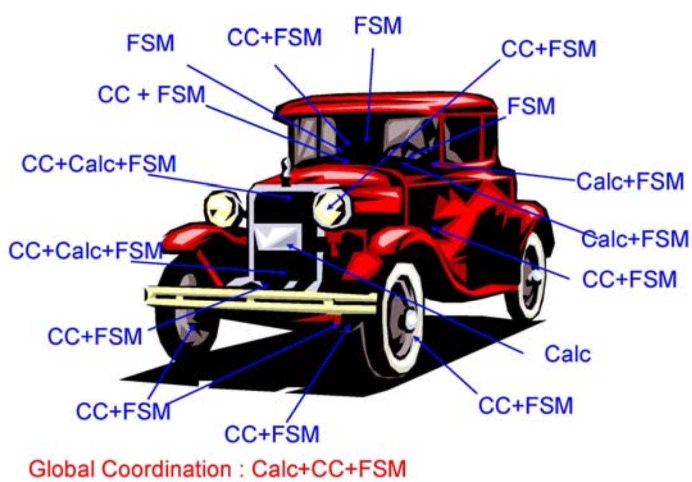
CAMPaM 2009, Martin Törngren 15

Automotivev embedded functionality



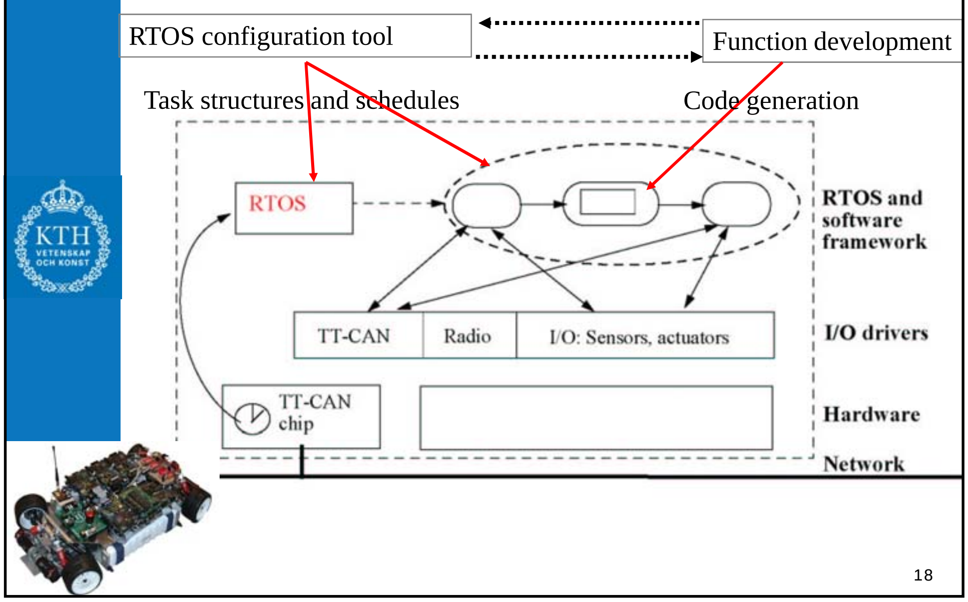
Source: Gerard Berry, Artist summer school

Types of behaviors of automotive embedded systems



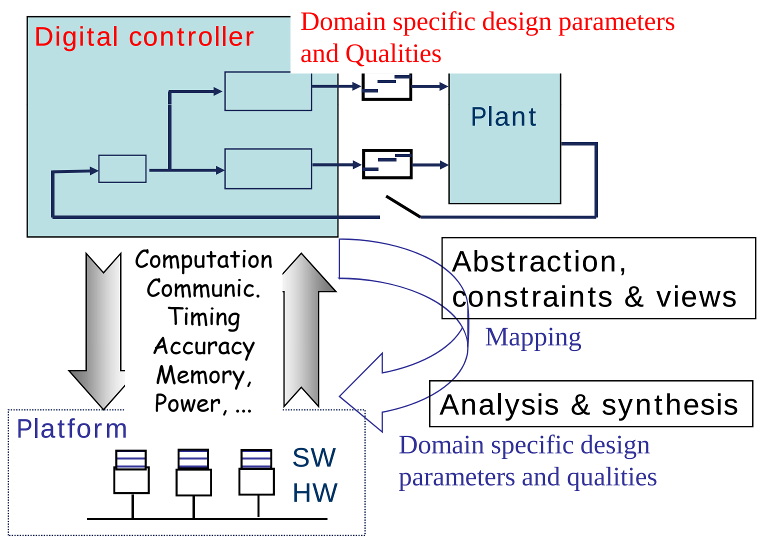
Source: Gerard Berry, Artist summer school

Example integration (Far project)



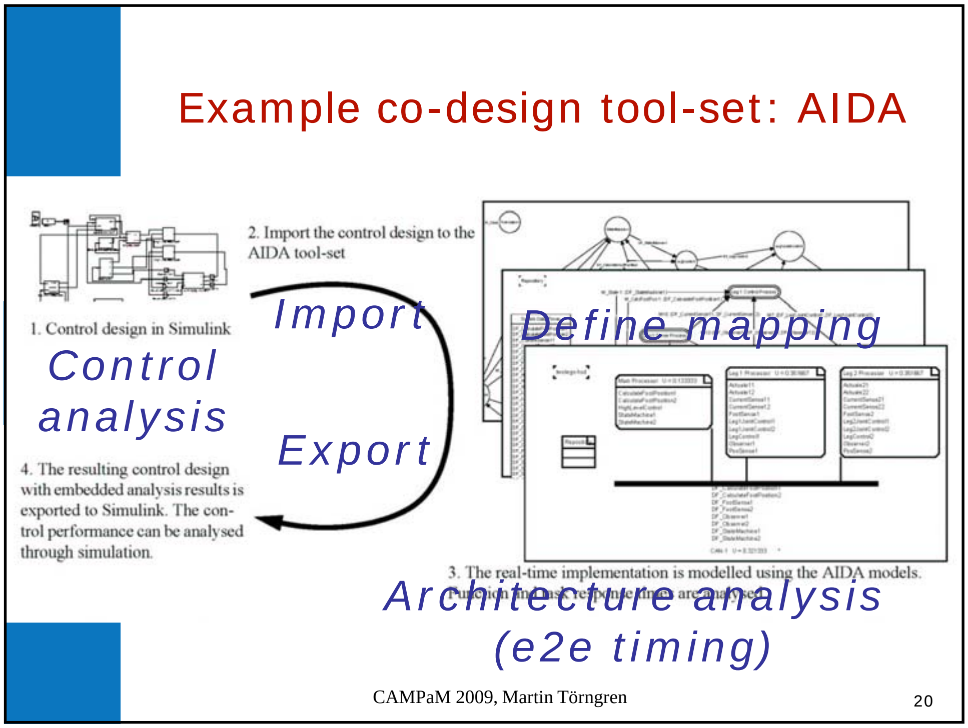
18

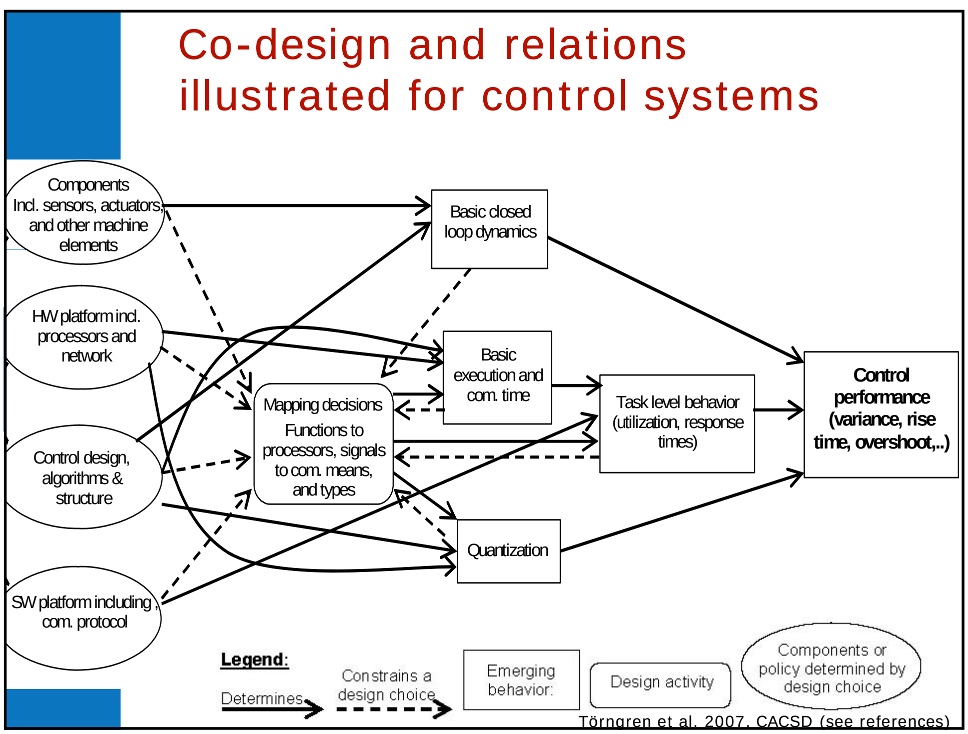
Characterizing control/embedded systems co-design



CAMPaM 2009, Martin Törngren

19


Example co-design tool-set: AIDA
1. Control design in Simulink
2. Import the control design to the AIDA tool-set
Import
Define mapping
Control analysis
Export
4. The resulting control design with embedded analysis results is exported to Simulink. The control performance can be analysed through simulation.
3. The real-time implementation is modelled using the AIDA models. Function and task response times are analysed.
Architecture analysis (e2e timing)
CAMPaM 2009, Martin Törngren
20


Co-design and relations illustrated for control systems
Components Incl. sensors, actuators, and other machine elements
HW platform incl. processors and network
Control design, algorithms & structure
SW platform including com. protocol
Basic closed loop dynamics
Basic execution and com. time
Mapping decisions Functions to processors, signals to com. means, and types
Task level behavior (utilization, response times)
Quantization
Control performance (variance, rise time, overshoot,..)
Legend:
Determines
Constrains a design choice
Emerging behavior:
Design activity
Components or policy determined by design choice
Törngren et al. 2007, CACSD (see references)

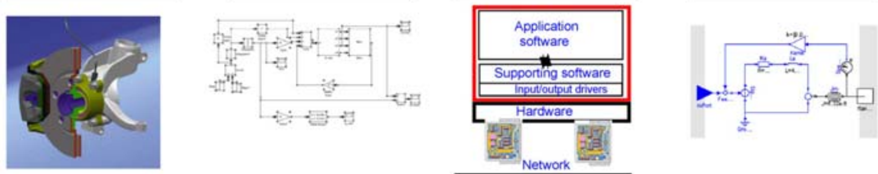
Research at the Mechatronics lab/KTH

Specifications

System design (behavior, structure)

control

Mechanics | EE | Electronics | Software



Integration

Components, tools, people and processes

CAMPaM 2009, Martin Törngren 22

Technology landscape for model based embedded systems engineering

<u>Information management</u>

- PDM/STEP-based
- OMG/MOF-based
- SCM tools
- Embedded systems specific (”non” standard)

<u>Technical process</u>

- Requirements engineering
- Behavior modeling/sim.
- Architecture design
- Safety engineering
- CAD, cabling harness
- Thermal, power, …

- Open frameworks & environments (e.g. Eclipse, GME)
- Technologies (metamodeling, formats, transformations, analysis, tools) and Standards
- Evolving area!

CAMPaM 2009, Martin Törngren 23

Automotive Embedded systems and MBE

- Limited usage of UML/SysML
  - Subsets, e.g. sequence diagrams (specs, testing), structure diagrams (architecture), software design
  - Meta-/information-modeling, for example in Autosar
- Many efforts (research and industrial) in furthering UML/SysML for Embedded systems modeling
  - Domain specific modeling languages; EAST-ADL, AADL
  - Projects, e.g. ATESST2, CESAR, Modelisar, Speeds, SysModel and Timmo
  - Safety related standards are studied to incorporate considerations for MBE (e.g. ISO26262)

CAMPaM 2009, Martin Törngren 24

EAST-ADL in a nut-shell

ATESST

A non traditional ADL in the sense that it covers much more:

- Variability
- Requirements
- Safety
- Behavior
- Environment Modelling
- Design methodology

Concrete results

- Domain model and UML2 Profile
- Prototype Tool
- Active Safety Demonstrator
- Examples and case studies

EAST-ADL has been developed in: EAST-EAA, ATESST and ATESST2.

Now being consider in CESAR.

Coordinated by Volvo
Automotive, Suppliers
Tool vendors
Universities including KTH

Alignment/integration:

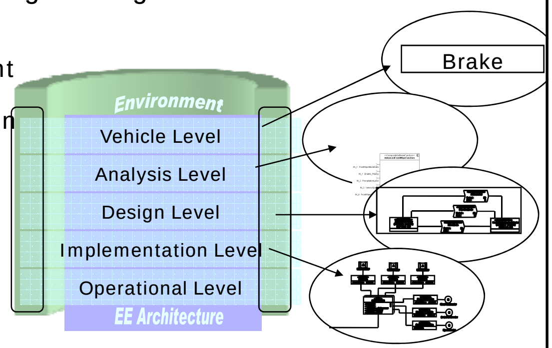
- SysML, AADL, AUTOSAR
- ISO26262
- IST/EUCAR Active Safety

www.atesst.org

CAMPaM 2009, Martin Törngren 25

Objectives

- EAST-ADL provides means to represent the embedded system in several abstraction levels
- Different kinds of engineering information
  - Requirements
  - Feature content
  - Functional content
  - Variability
  - Safety information
  - V&V Information
  - SW architecture (AUTOSAR)
- Traceability
- Analysis and synthesis
- Document generation and views



Relation to other modeling languages and approaches?

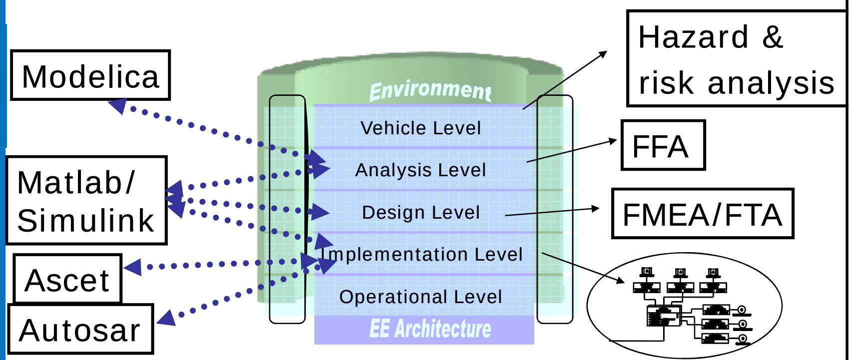
Why Not UML?
- EAST-ADL is implemented as a UML2 profile, adding properties for embedded systems.

Why not SysML?
- EAST-ADL is a specialization of applicable SysML concepts

Why not Autosar?
- EAST-ADL complements Autosar with for example functional structure and safety properties

Why not proven proprietary tools (Simulink, Statemate, Modelica, ASCET, ...)?
- ATESST integrates external tools and provides an information structure for the engineering data regardless of tool

EAST-ADL and domain specific tools - focusing on behavioral modeling



EAST-ADL and Simulink

EAST-ADL

- Information structuring
- Predefined views and levels of abstraction
- Constitutes an integration point
- Focused on structure but provides also native behavior

Simulink

- Behavior modeling and simulation
- Modeling at different levels of abstraction
- Behavior focused; many models of computation
- Logical structuring for
  - model management
  - code generation
  - SW components

Many technical issues!
Semantics in the transformation!

EAST-ADL support for safety engineering

- ***Error Modeling*** - capturing and managing potential errors and propagations at different levels of abstraction. I-FMEA
- ***Safety Analysis*** - inferring causes and consequences of errors through external tools. FTA
- ***Safety Requirements*** - specifying hazards and subsequent function and quality requirements.
- ***Safety Case Method*** - arguing that a system is acceptably safe in a particular context.

CAMPaM 2009, Martin Törngren 30

Challenges

- Still a long way to go for full model based (embedded) systems engineering
- Information and model management
  - Lack of CM on model level
  - Lack of unified way of handling sofware (SCM) and hardware (PDM)
- Lack of workable exchange formats
  - XMI/DI, AP233
  - Specific ones exist
    - Network messages (CAN, Flexray, …)
    - Debugging and calibration formats (ASAM/ASAP)
- Methodologies and training/guidelines
- CBD + MBD: Components with meta-data ; contracts defining assumptions for reuse
  - Compositionality!

CAMPaM 2009, Martin Törngren 31

Challenges

- Requirements -> Test cases
- Incorporation of "formal" analysis and verification for embedded systems
  Connecting design and analysis models
  - Simulink and Safety
  - Architecture and timing analysis
  - Nominal and error behavior
- Code generation as a synthesis problem
  - Automated decision making; Impact on actual behavior
- DSL solutions
  - Require multiple domain experts
  - Meta-modeling and transformation experts
  - Rapid prototyping environments (evolving DSL)

Suggestions for CAMPaM topics

- Formalism taxonomy / framework
  - Multitude of existing and new "formalisms" and supporting technologies!
  - Terminology
    - Behavior, structure, properties
    - Design context: LoA, qualities, analysis, tasks
    - Technology: E.g. different types of model transformations
- Model/tool integration and management
  - Mechanics, electronics, software, systems
  - Roadmap
  - Bottlenecks, research focus
  - Industrial and scientific perspectives