Crosscutting CPS Needs in Industry

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Outline

- A crosscutting CPS need in industry: System Integration
- Nature and scope of challenges
- Elements of a Science of System Integration

Trends in Vehicles…

<table>
<tr><th>Sectors</th><th colspan="2">Goals</th></tr>
<tr><td>Aerospace</td><td>

Aircraft that fly faster and further on less energy.
Air traffic control systems that make more efficient use of airspace.

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<tr><td>Automotive</td><td>

Automobiles that are more capable and safer but use less energy.
Highways that are safe, higher throughput and energy efficient.

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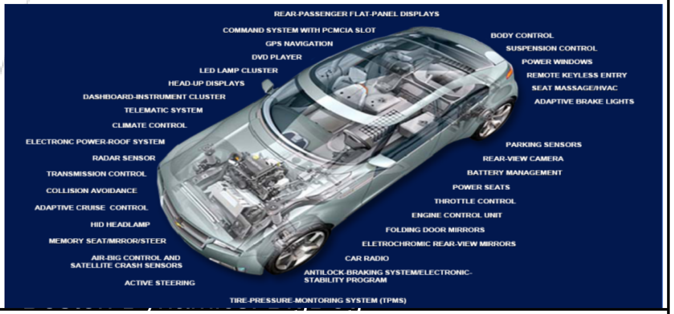

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<tr><td>Defense</td><td>

More capable defense systems
Better use of networked fleets of autonomous vehicles
Integrated, maneuverable, coordinated, energy efficient
Resilient to cyber attacks

</td><td>

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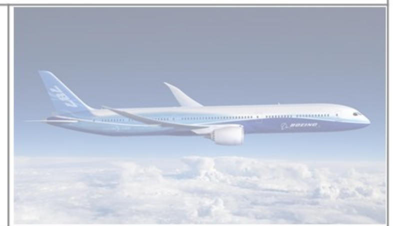
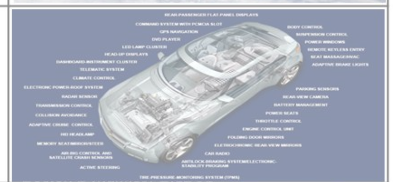
...or in a Broader Sense

Sectors	Goals	
Aerospace	• Aircraft that fly faster and further on **less energy**. • Air traffic control systems that make more efficient use of airspace.	
Automotive	• Automobiles that are more capable and safer but use less energy. • Highways that are safe, higher throughput and **energy efficient**.	
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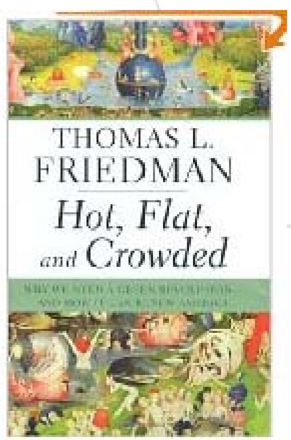

Energy Internet: When IT Meets ET

Key Enablers

- Networking and Information Technology (NIT) have been increasingly used as ***universal system integrator*** in human – scale and societal – scale systems
- Functionality and salient system characteristics emerge through the interaction of ***networked physical and computational objects***

Engineered systems turn into
Cyber-Physical Systems (CPS)

Why Integration?

NIT delivers unique precision and flexibility in **interaction** and **coordination**

Cyber

- Rich time models
- Precise interactions across highly extended spatial/temporal dimension
- Flexible, dynamic communication mechanisms
- Precise time-variant, nonlinear behavior
- Introspection, learning, reasoning

Integrated CPS

- Elaborate coordination of physical processes
- Hugely increased system size with controllable, stable behavior
- Dynamic, adaptive architectures
- Adaptive, autonomic systems
- Self monitoring, self-healing system architectures and better safety/security guarantees.

Is the Integration Role Crosscutting?

- The share of value of embedded computing/networking components in different industries:

	2003	2009
Automotive	52%	56%
Avionics/Aerospace	52%	54%
Health/Medical equipment	50%	52%
Industrial automation	43%	48%
Telecommunications	56%	58%
Consumer electronics and Intelligent Homes	60%	62%

The shift from federated to integrated architectures is a shared trend.

Source: “Study of Worldwide Trends and R&D Programm*es* in Embedded Systems in View of Maximising the Impact of a Technology Platform in the Area” EU Commission, 2005

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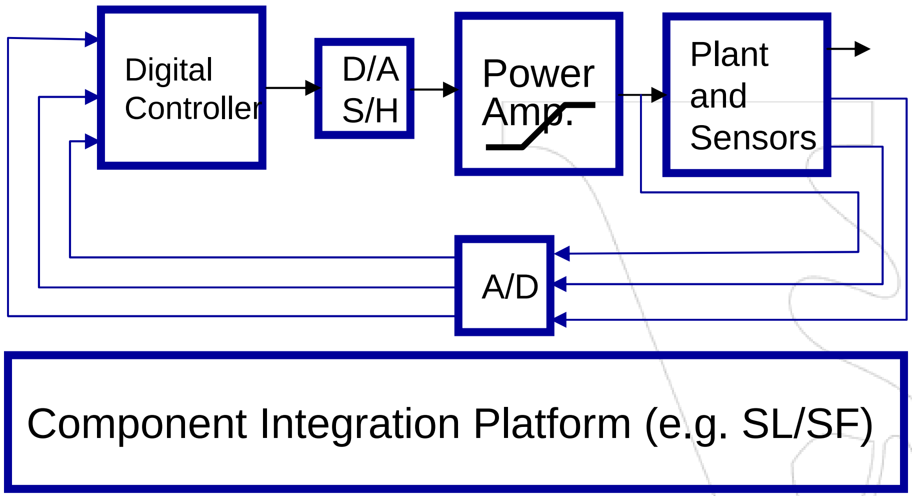
Dimensions of CPS Integration

Across each design concerns (functional, safety/security, physical platform):

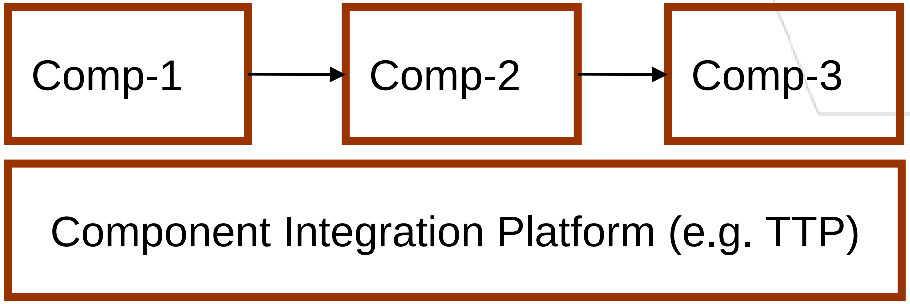
- Components
- Layers
- System of Systems

Component Integration

Functional: E.g.: Dynamics



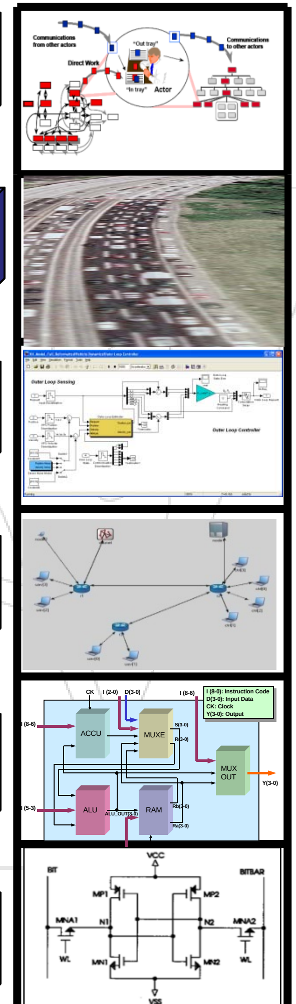
Software: E.g. Timing



- Composability and compositionality are key concepts
- Defined for carefully selected properties (dynamics, latency, power,..)
- Decomposed into *structure*, *interaction* and *behavior*
- *Challenges*:
  - composition frameworks that guarantee essential properties
  - Heterogeneous composition

Multi-Layer System Integration

Roles	Layers
Cognitive processes Social interaction Command and control	Human Organization
Coordination Data distribution	System Operation Layer
Component interactions Component behaviors Architecture	SW/Component Layer
Resource management Scheduling Separation	OS/Network Layer
Timing/performance Fault management Power management	HW/Systems Layer
Heat dissipation Crossover Radiation effects	Materials & Devices

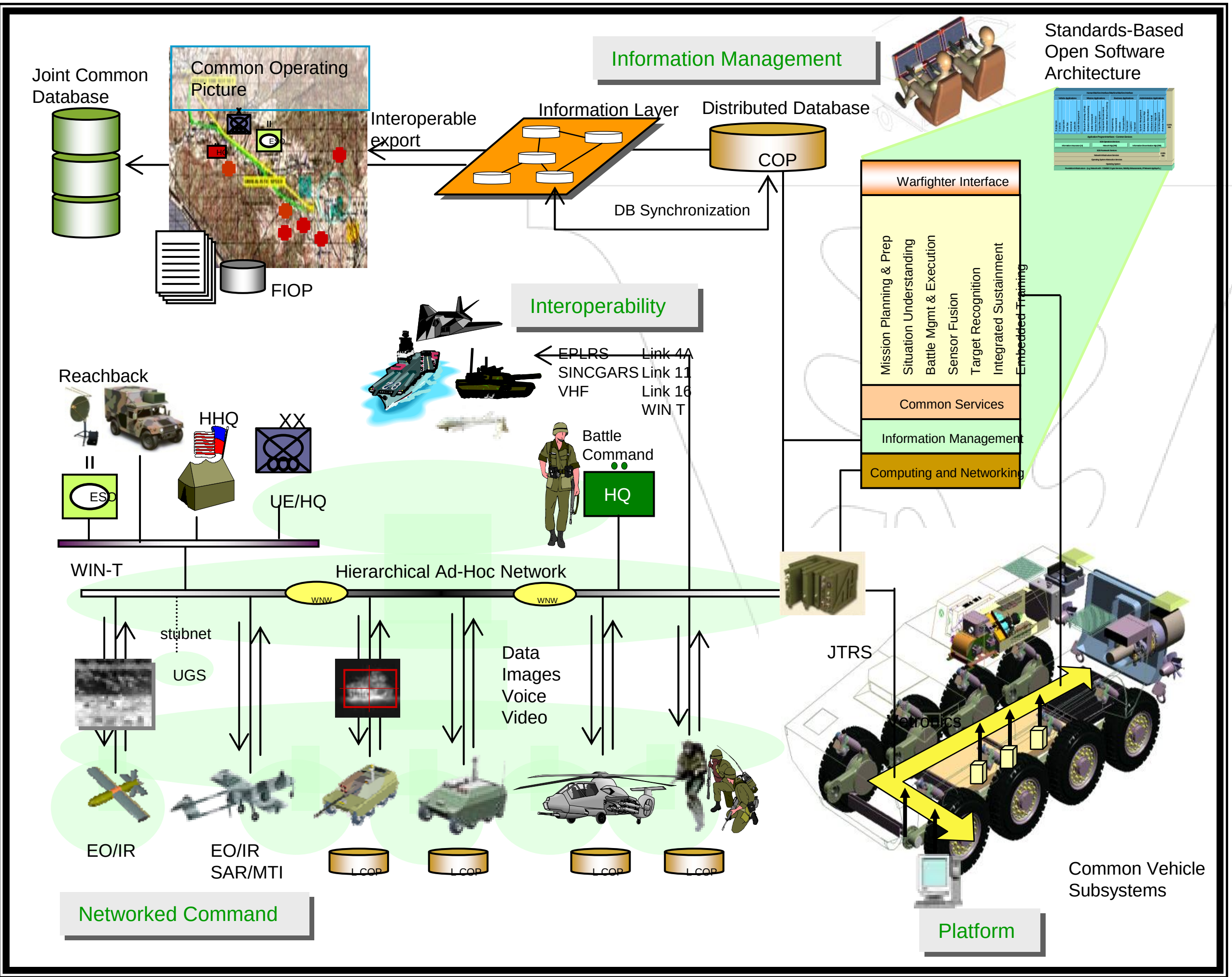


Characteristics

- Inter-layer interactions
- Effects propagate across the layers
- Efficiency and optimization drives toward intractability
- Inter-layer relationship:
  - mapping
  - refinement
  - synthesis
- *Challenges*:
  - modeling,
  - constraining
  - composing

System of System Integration

Future Military Systems in the Field



- Heterogeneous CPS
- Open Dynamic Architecture
  - heterogeneous networking
  - heterogeneous components
- Very high level concurrency with complex interactions
- *Challenges*:
  - understanding and
  - predicting behavior

Real-Life CPS Development

- All integration dimensions are present
- Systems are evolving along “spiral-outs”
- New technical challenges are emerging and potential solutions need to be rapidly explored
- All layers of the system are subject to modifications, there are no well defined synchronization points in the development process
- Integration is inherently incremental; deployed systems need to be integrated with components on different level of maturity: prototypical and with simulated systems/components.

How Is It Solved Today?

- Systems are integrated when all components are delivered
  - Acquisition pushes in this direction
- Integration means: “Make it working somehow”
- System Integration Labs do not offer support for spiral development
  - Neither acquisition practices
- There is no approach to deal with incomplete specifications and components

System Integration is the highest risk,
most expensive, least predictable step in CPS design

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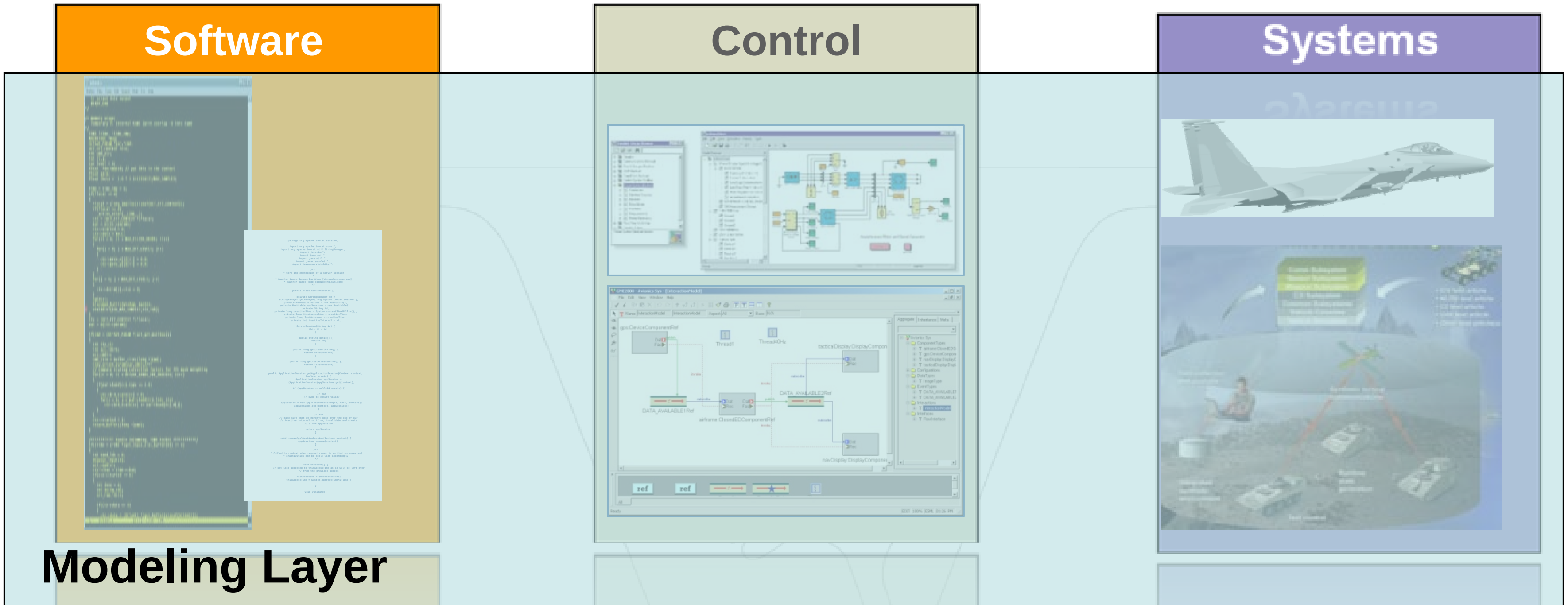
Components

- Model-based design
  - Foundation for convergence across disciplines
- Composition theories for heterogeneous systems
  - Decoupling
  - Orthogonalization
- Agile System Integration
  - Extensive use of modeling and model evolution
  - Multi-model simulation

Convergence: Model-Based Design



- **Systems Engineering**: Model-based design has been the state of practice
- **Control Engineering**: Wide acceptance due to popular tools like MathWorks Simulink/StateFlow
- **Software Engineering**: Increasing acceptance due to OMG's MDA push and wider availability of tool suites

Model-Based Design & Platforms

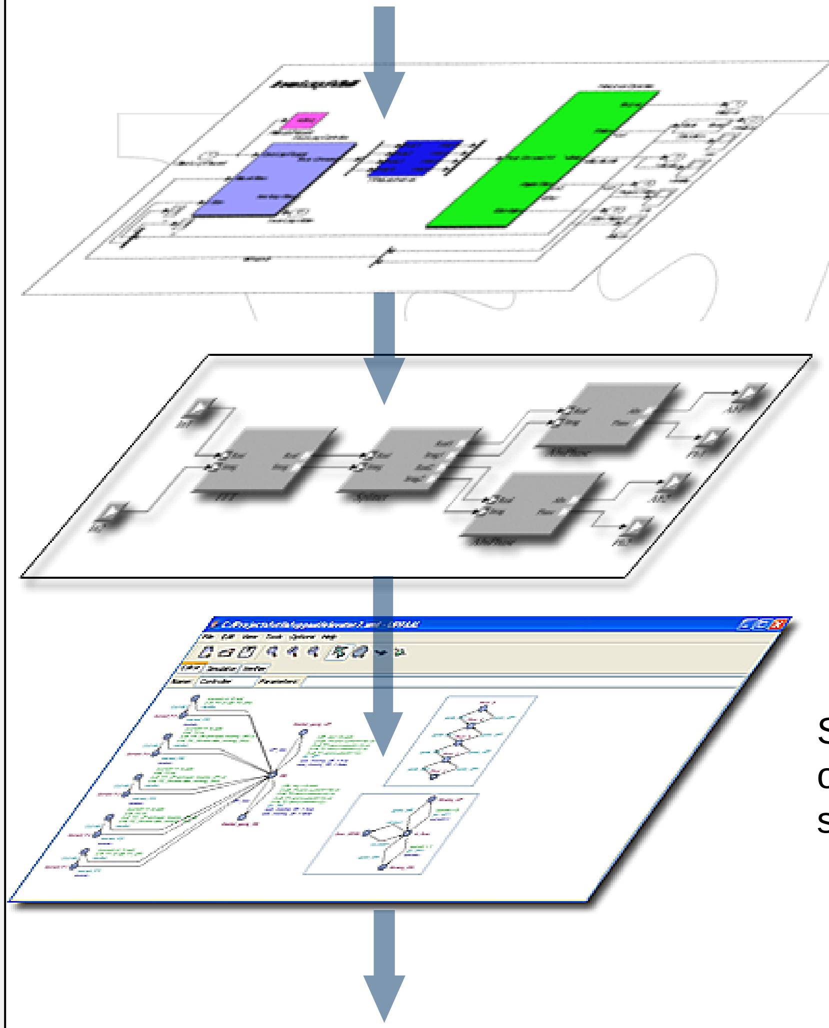
Key Idea: Manage design complexity by creating abstraction layers in the design flow.

(Platform-based design: Alberto Sangiovanni-Vincentelli)

Abstraction layers define platforms.

Abstractions are linked through mapping.

Abstraction layers allow the verification of different properties .



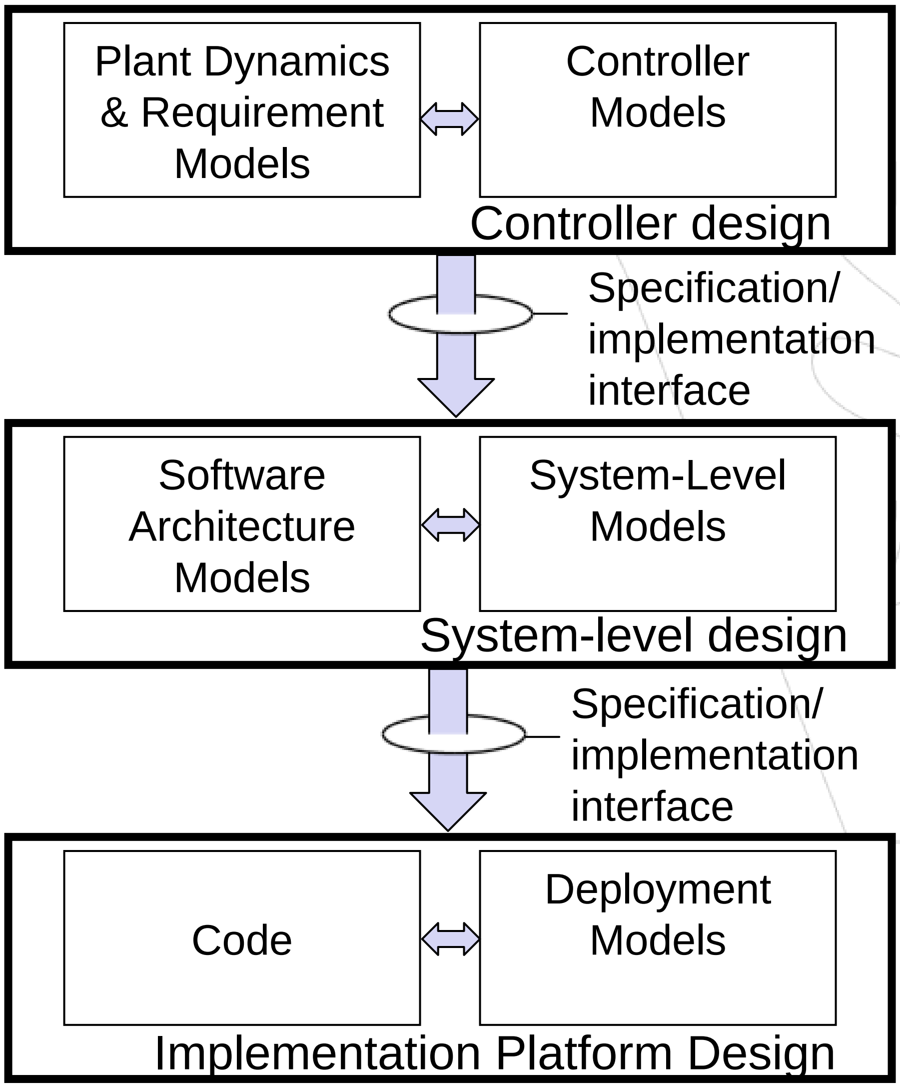
Dynamics models define the composition of functions that describe system behavior.

Software architecture model defines the software components and their interaction .

System-level architecture defines a set of concurrent functional units, where the software architecture can be deployed.

Composition in Heterogeneous Systems

How to achieve composability and compositionality?



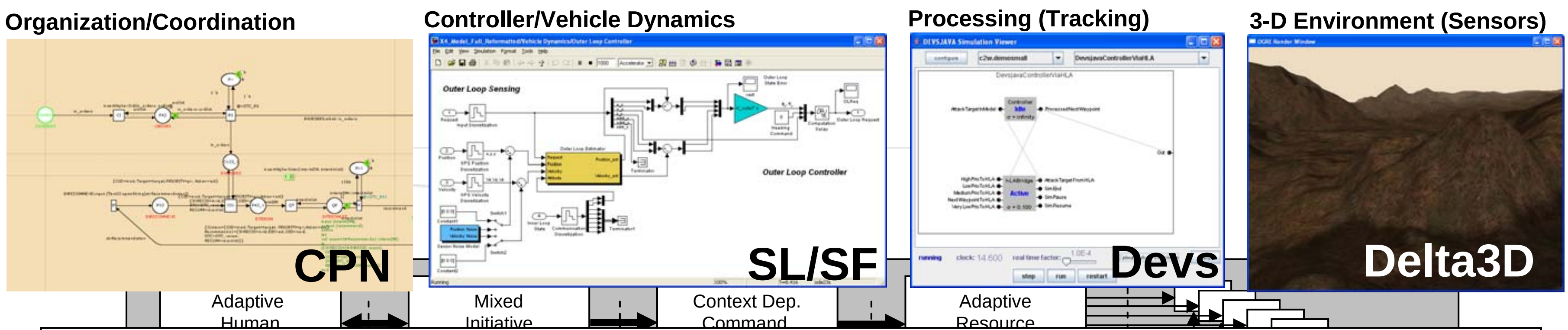
- **Orthogonality among the design layers**
  - Controller design depends on assumptions about implementation
  - Orthogonalization removes assumptions
    - E.g. Passivity
- **Decoupling across design layers**
  - E.g., Time Triggered Architecture
  - Timing specification drives execution
  - Static structure
- **Fundamental change in design flows**
  - Cross- layer abstractions
  - New specification/implementation interface
  - Redefining testing and verification

Agile System Integration...

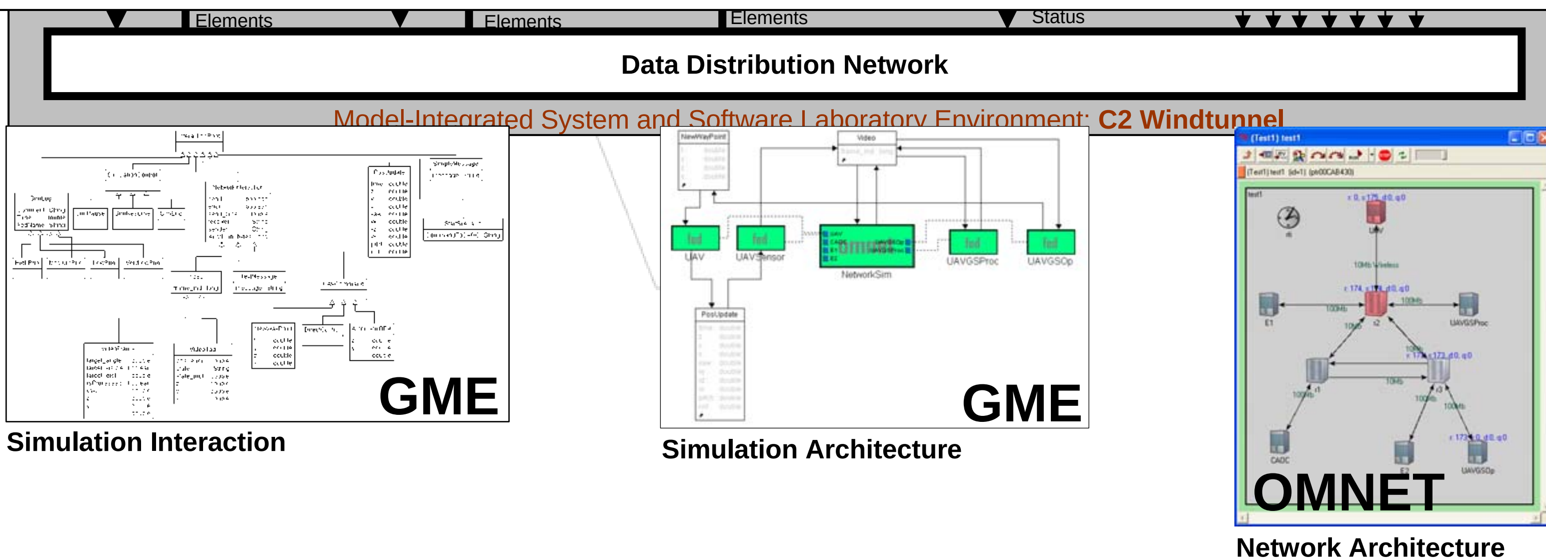
Agile tools and processes for:

- Rapid modeling of Components and Systems
- Rapid synthesis of adapters and wrappers to integrate systems and components at three levels of fidelity
  - deployed, fully qualified
  - experimental prototype
  - simulated
- Rapid configuration of experiments
  - deployment of services,
  - configuration of environment simulators,
  - config of instrumentation
- Rapid experimental runs
  - control launch, run, post run data collection
  - virtualization of experimental platforms to enable large-scale experiments
- Analysis
  - mapping results back to requirements
- Iterate

...Requires Agile Tools: Multi-Model Simulation Integration



How can we integrate the models?
How can we integrate the simulated heterogeneous system components?
How can we integrate the simulation engines?



Benefits

Challenges	Model-Based Design	Composition Theories	Agile System Integration
All integration dimensions are present	✓	✓	
The system is evolving along "spiral-outs"	✓	✓	✓
New technical challenges are emerging and potential solutions need to be rapidly explored	✓		✓
All layers of the system are subject to modifications, there are no well defined synchronization points in the development process		✓	✓
Integration is inherently incremental; deployed systems need to be integrated with components on different level of maturity: prototypical and with simulated systems/components	✓	✓	✓

Summary

- CPS-s represent the “center of gravity” in NIT applications in the future
- System Integration for CPS is a crosscutting CPS need
- An important challenge: Science of System Integration