

Multi-Paradigm Modeling and Simulation, a Systems Engineering perspective

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BLUF: MPM or MBSE? Both!

(Let's start with the conclusion)

Model-based systems engineering (MBSE) is the *“formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases.”* (INCOSE 2007)

“Multi-Paradigm Modeling (MPM) offers a foundational framework for gluing the several disciplines together in a consistent way. [...] MPM offers processes and tools that can combine, couple, and integrate each of the views that compose a system.” [MPM4CPS CfP]

Two theses

- *Claim#1: one cannot do MBSE without MPM*
- *Claim#2: one should not do MPM without MBSE*

Outline

1. Context
2. About AADL
3. *Claim#1: one cannot do MBSE without MPM*
4. *Claim#2: one should not apply MPM without MBSE*

Overarching objectives – or what I am striving for

But is it MBSE or MPM ?

[....] assists engineers (mainly software, but also CPS and systems engineers) with models to

Concepts

Organize stakeholders needs and elicit requirements

Capture system elements – design, reverse engineering or COTS

- Interfaces, components internals (static and behavioral), and
- a system architecture built from those: deployment, (re-)configuration

Apply analytical frameworks to assess model's “compliance to some objectives”

- Syntactic, conformance to guidelines, patterns “well-formedness”
- Quality of system, w.r.t. performance, safety, security, behavior metrics
- Behavioral correctness, e.g. model checking, simulation, proofs

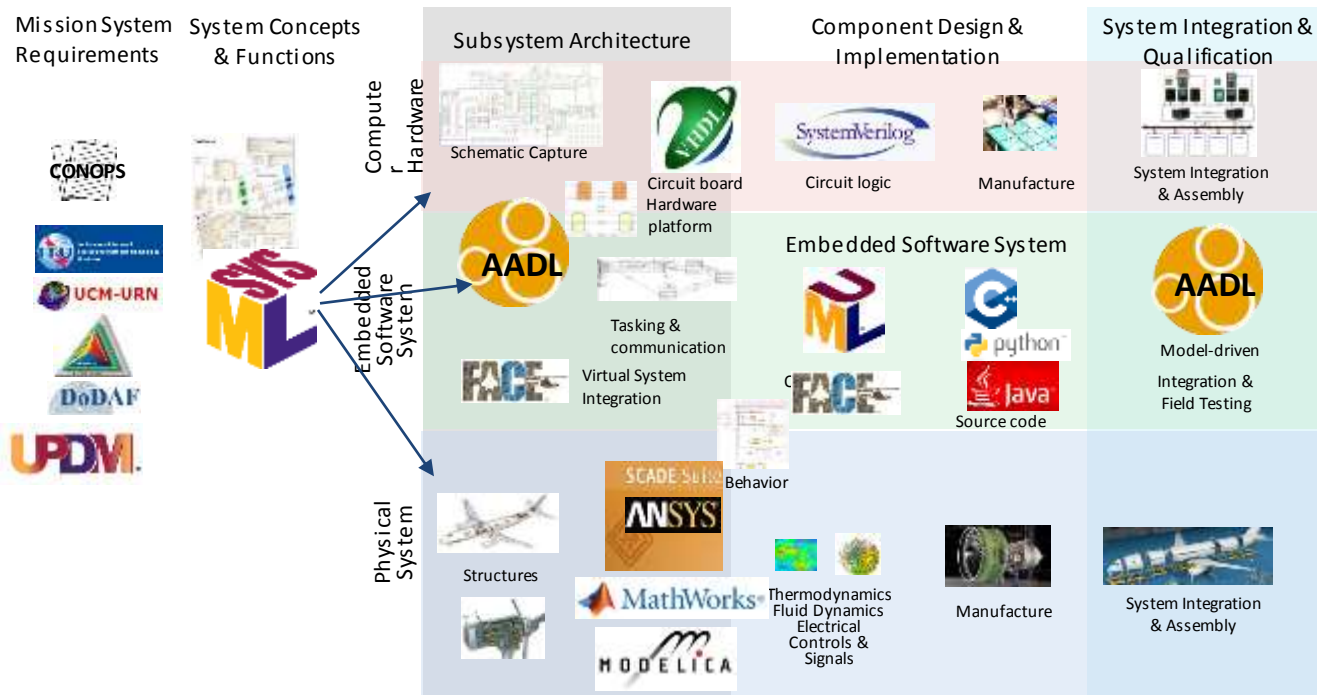
Models as processable artifacts to guide the software engineering process

System

- “Modeling is the new programming”

Provide more insights than CAD or code-only solution through relevant abstractions and automation

MPM landscape – science removed for the faint of heart



ISO15288 – Processes for Systems Engineering

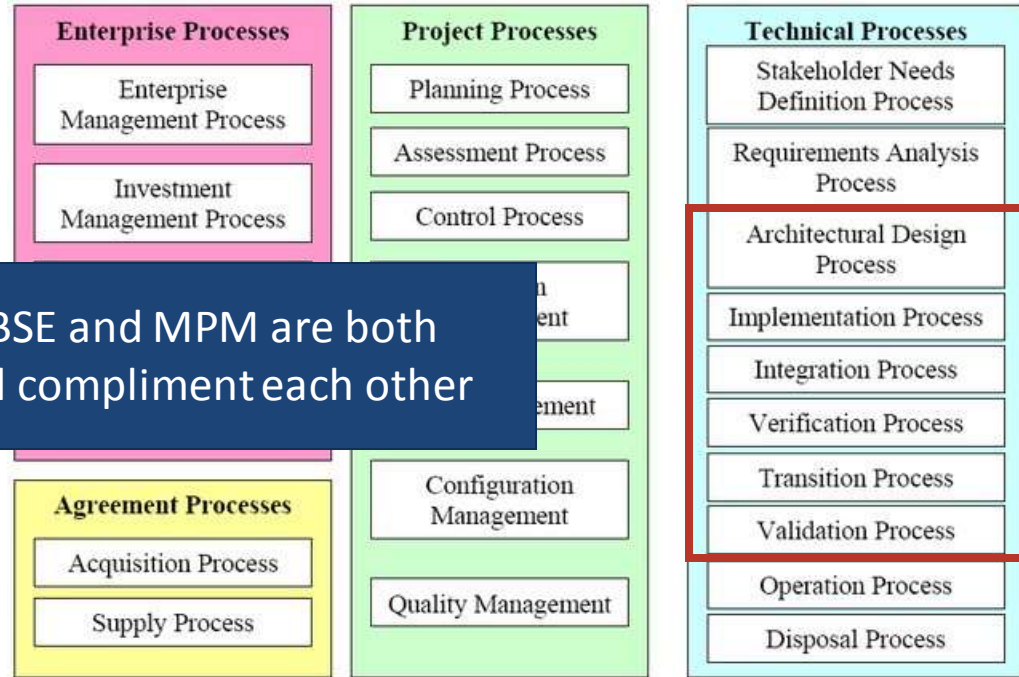
A process is a set of interrelated or interacting activities which transforms inputs into outputs (ISO 9000:2005)

- Process are organized so that they contribute to a specific goal. They are structured by an *argument* that justifies the existence

Hence, MBSE and MPM are both relevant and compliment each other

MPM provides solutions only for a subset .. But interconnected with all other process

MBSE covers all, but lack many advanced V&V or simulation support



The system life cycle processes Source: ISO/IEC 15288, Figure D.8

ISO 15288 has **23+ processes** which have **123 outcomes** derived from **403 activities**.

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The Safety-Critical Embedded Software System Challenge

Problem:

- Software increasingly dominates safety and mission-critical system development
- Issues discovered long after they are created

Goal:

Early discovery of system-level issues through virtual integration and incremental analytical assurance

Solution:

- **Language** standardized via SAE International & matured into practice through pilot projects & industry initiatives
- **Tooling** available under open source license continually enhances analysis, verification, and generation capabilities
- **Expertise** in Modeling Safety-Critical Embedded Systems



A critical task: Reducing safety and security risks through early analytical assurance

Model-Based Engineering for Cyber-Physical Systems @SEI



Create the best design that holds up over time as the system evolves.



Test the design without having to write any code.



Build a single model to assess hardware and embedded software before the system is built.

SAE AADL / ACVIP

- Standardized language and process for the engineering safety-critical systems.

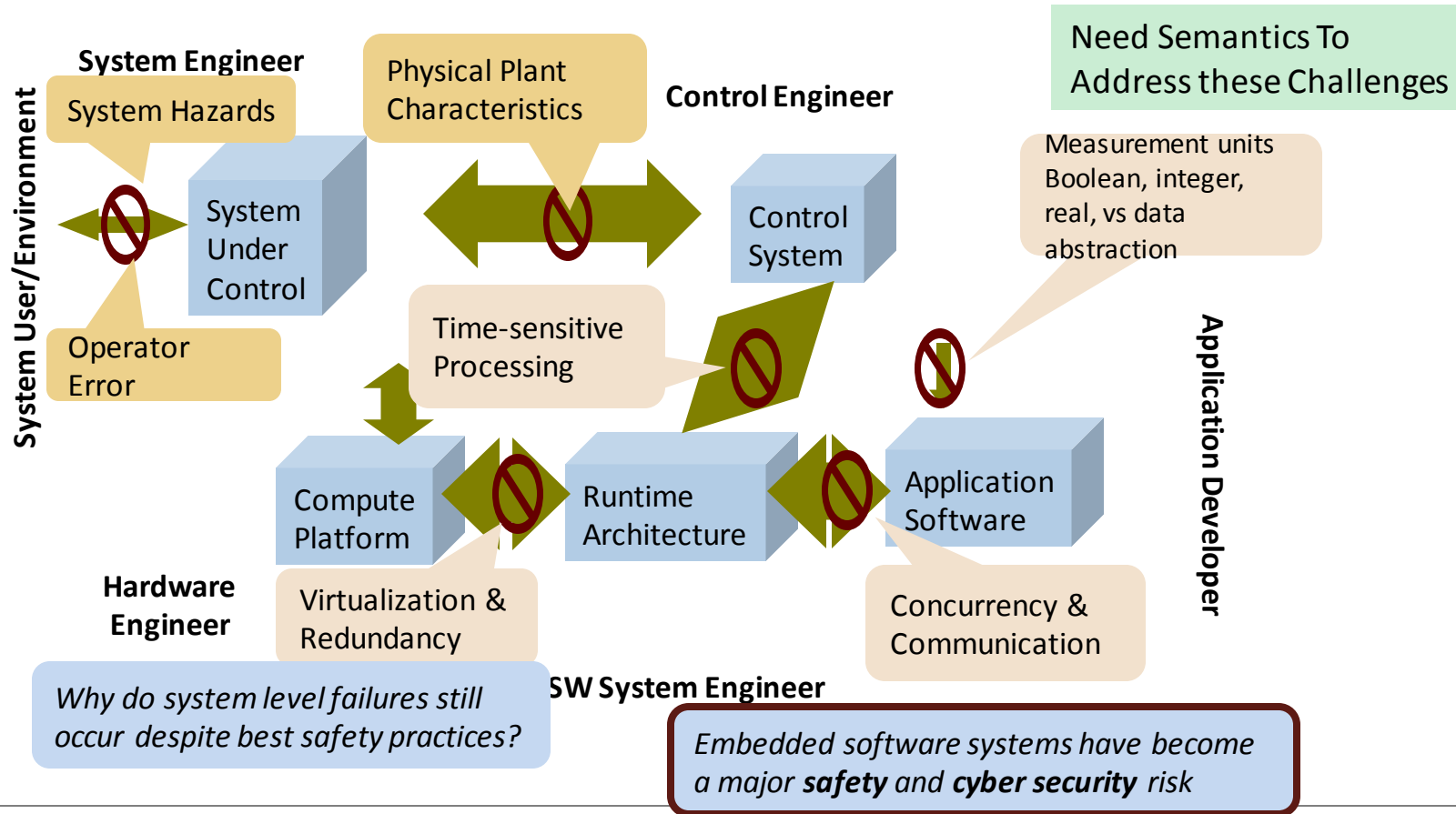
OSATE

- Open Source AADL toolset for performing verification and validation (V&V).

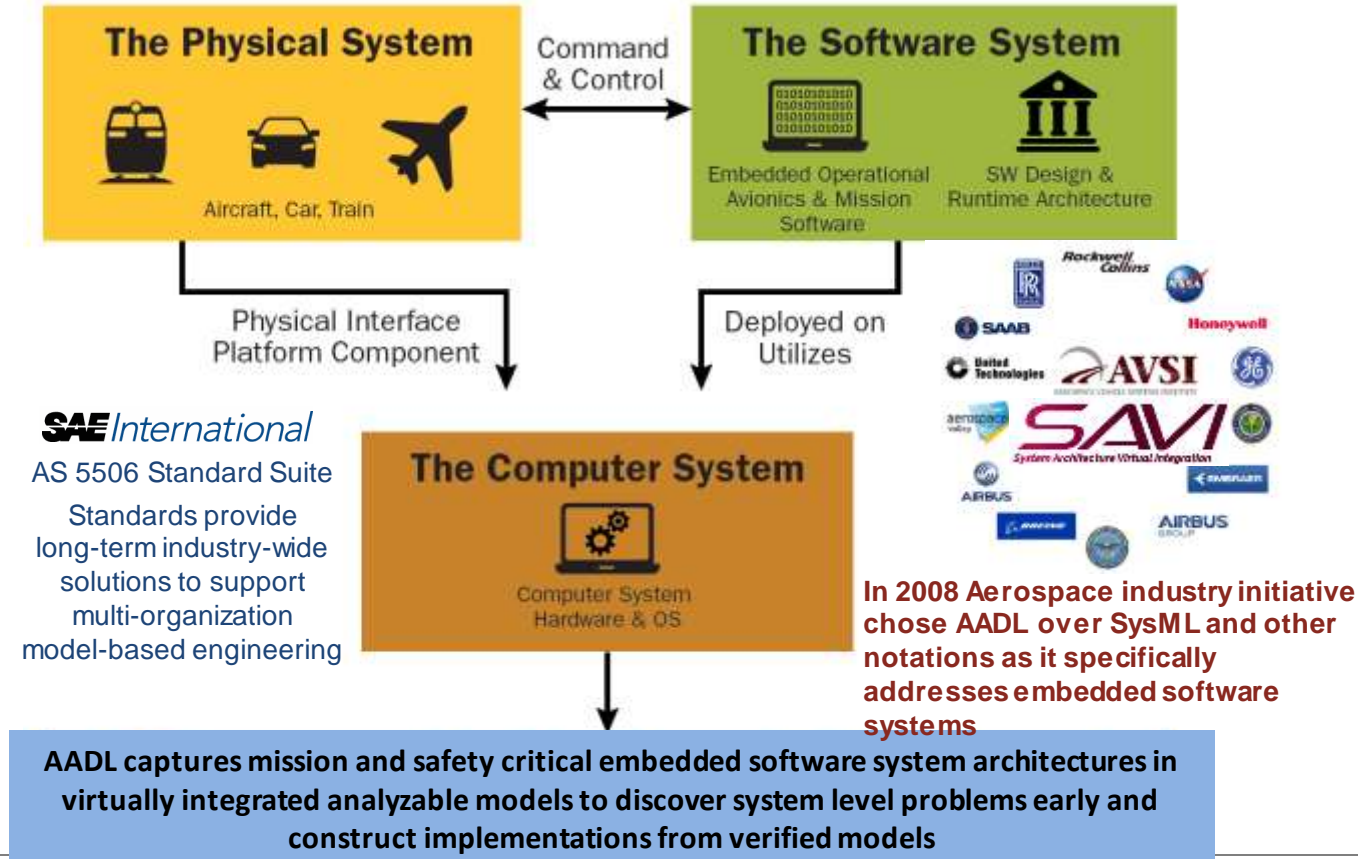
DoD Transitioning

- Maturity increased through pilot projects and trainings.

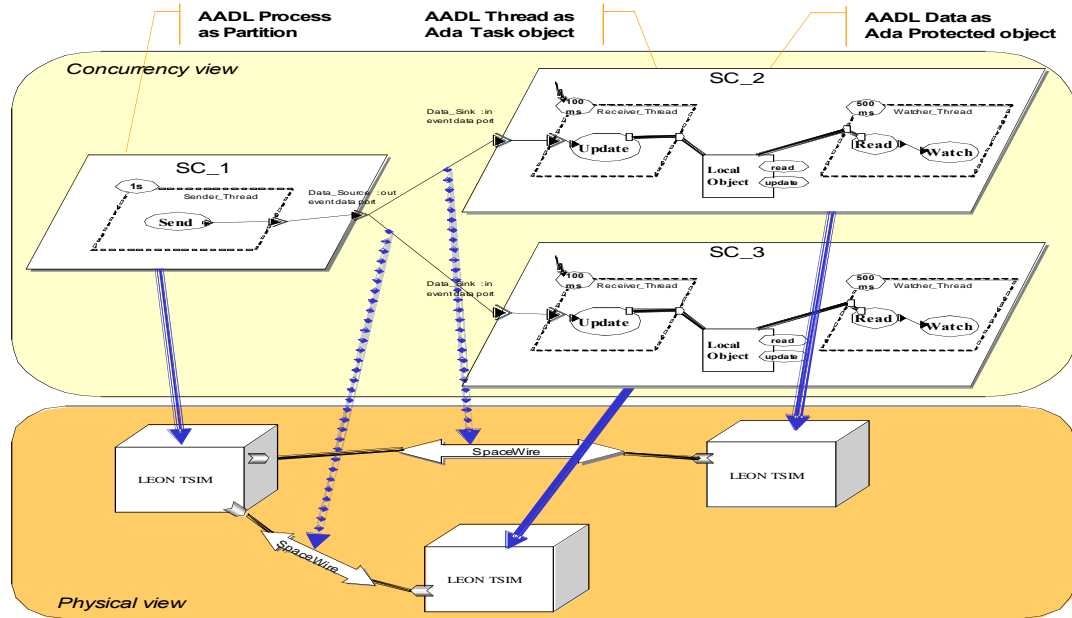
Interleaved problems – why we need MPM-like techniques



Architecture Analysis & Design Language (AADL) Standard Targets Embedded Software Systems



AADL



General AADL tool: OSATE

Requirements verifications: ALISA

**Middleware synthesis : Ada, C
(POSIX, ARINC653), RTOS: Ocarina**

**Scheduling: Gateways to Cheddar,
MAST**

Error modeling, FTA, FMEA: OSATE

**Model checking: Petri Nets (Time
and CPN), LNT**

Security Analysis, CI/CD, [...]

AADL goal is to provide “ground truth” for describing safety-critical systems

SAE International AADL Standard Suite (AS-5506 series)

Core AADL language standard [V1 2004, V2 2012, V2.2 2017, V2.3 2022]

- Focused on *embedded software system modeling, analysis, and generation*

Standardized AADL Annex Extensions

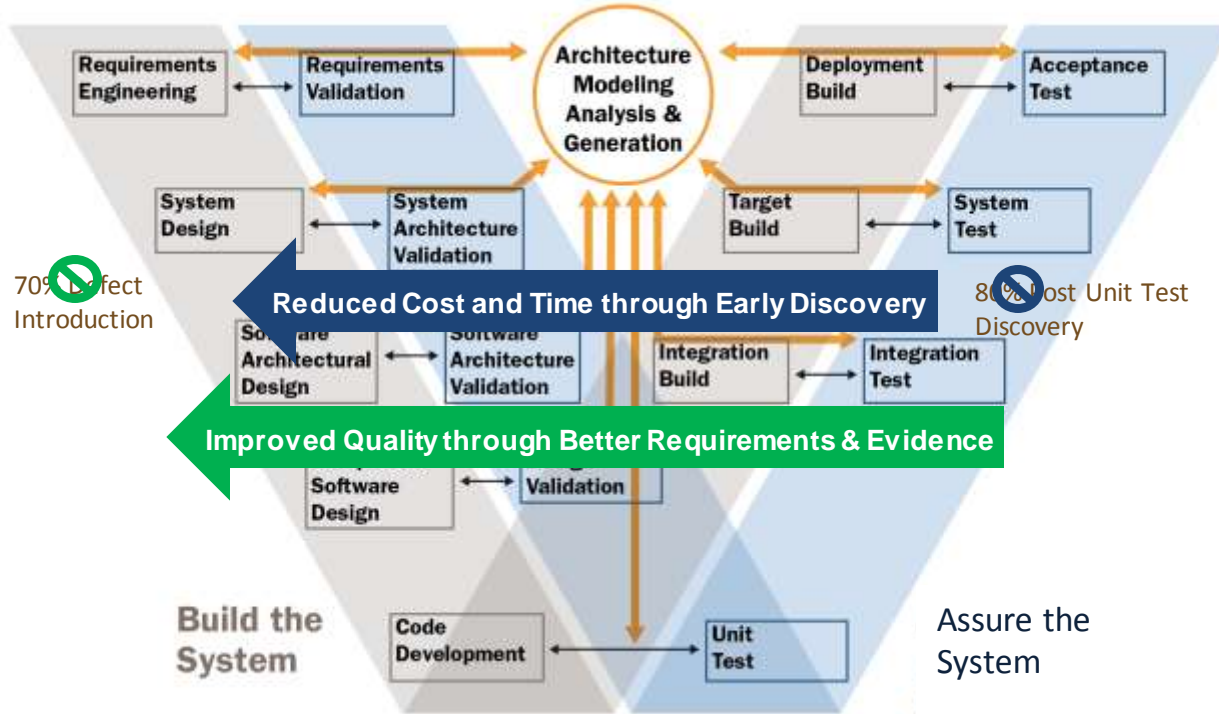
- Error Model language for safety, reliability, security analysis [2006, 2015]
- ARINC653 extension for partitioned architectures [2011, 2015]
- Behavior Specification Language for modes and interaction behavior [2011, 2017]
- Data Modeling extension for interfacing with data models (UML, ASN.1, ...) [2011]
- AADL Runtime System & Code Generation [2006, 2015]
- FACE Annex [2019]

- Evidence produced as a result of automated tool-supported analysis
 - Performance analysis: worst-case response time, schedulability of the system
 - Safety analysis: computing fault trees, probability of reaching an unsafe state
 - Automated model review: conformance to modeling guidelines
 - Code generation: generating “correct-by-construction” software

TQL-5, i.e. verification tools.
Output :- evidence, part of some argument

TQL-1 tools, i.e. output is part of final system

Improved Cost, Time and Quality



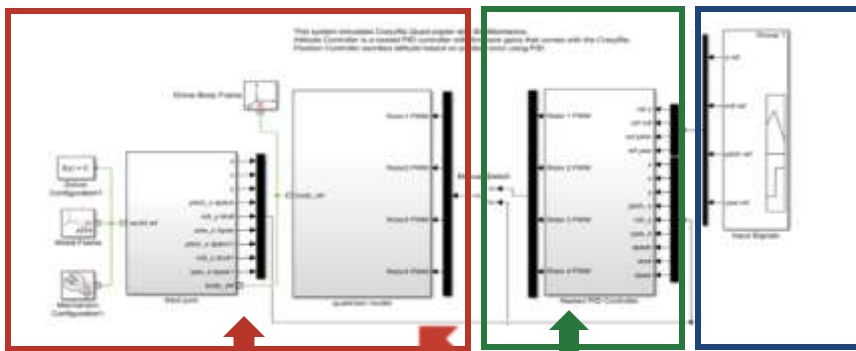
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TwinOps problem space: CPS Integration and Testing

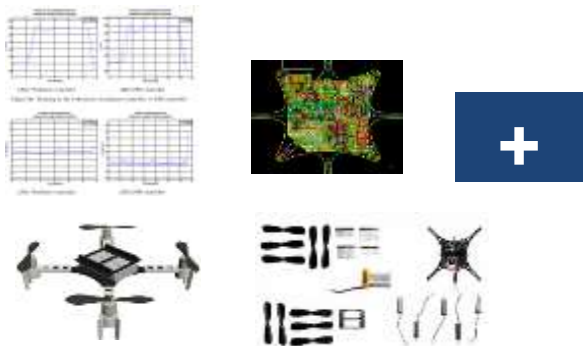
See [MPM4CPS'20] for details

High-Level Architecture

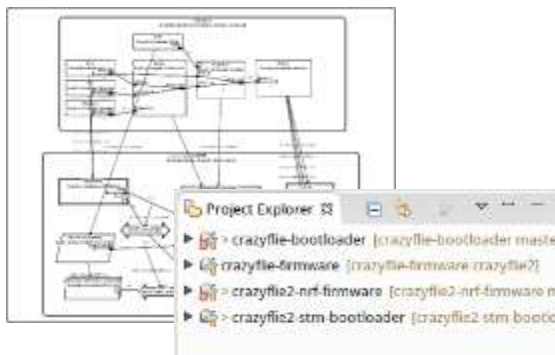


TwinOps: leverage other source of truth (e.g., CAD, Physics)
 ⇒ Use precise models instead of (naïve) abstractions for improved SW V&V
 ⇒ Combine domains, including SysEng

Implementation Space

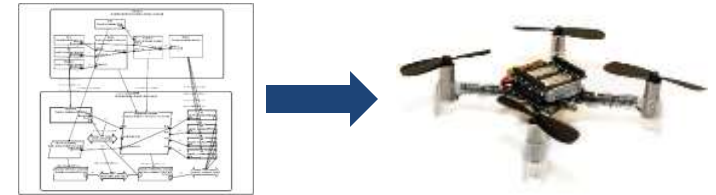


SW/HW Architecture



Technology Focus: Models and Code Generation

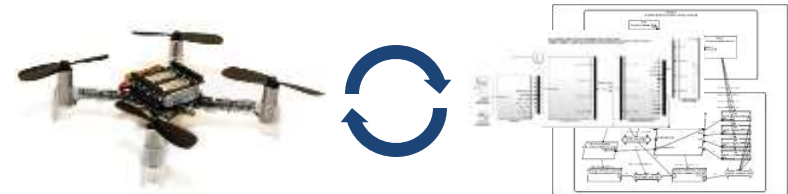
One can **generate code** from models ready to be embedded in the system (e.g., AADL to C) and get insights from the system to refine the model metrics.



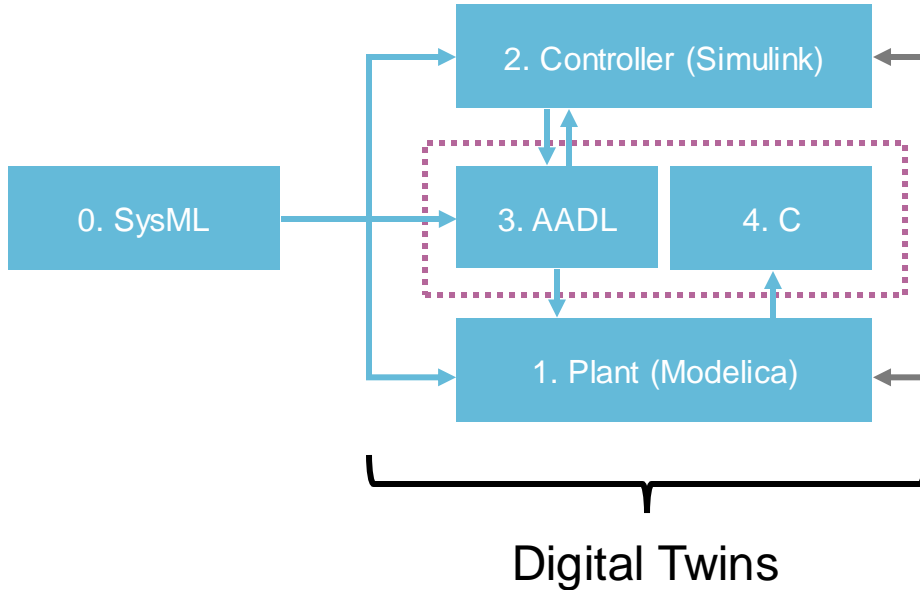
One can **simulate models** and generate simulation code as a mock-up of some system parts.



One can build **Digital Twins**, that compare actual system and its digital simulated doppelganger.



MBSE and MPM, => MBSE perspective



1-2-3-4: “mega-modeling” V&V

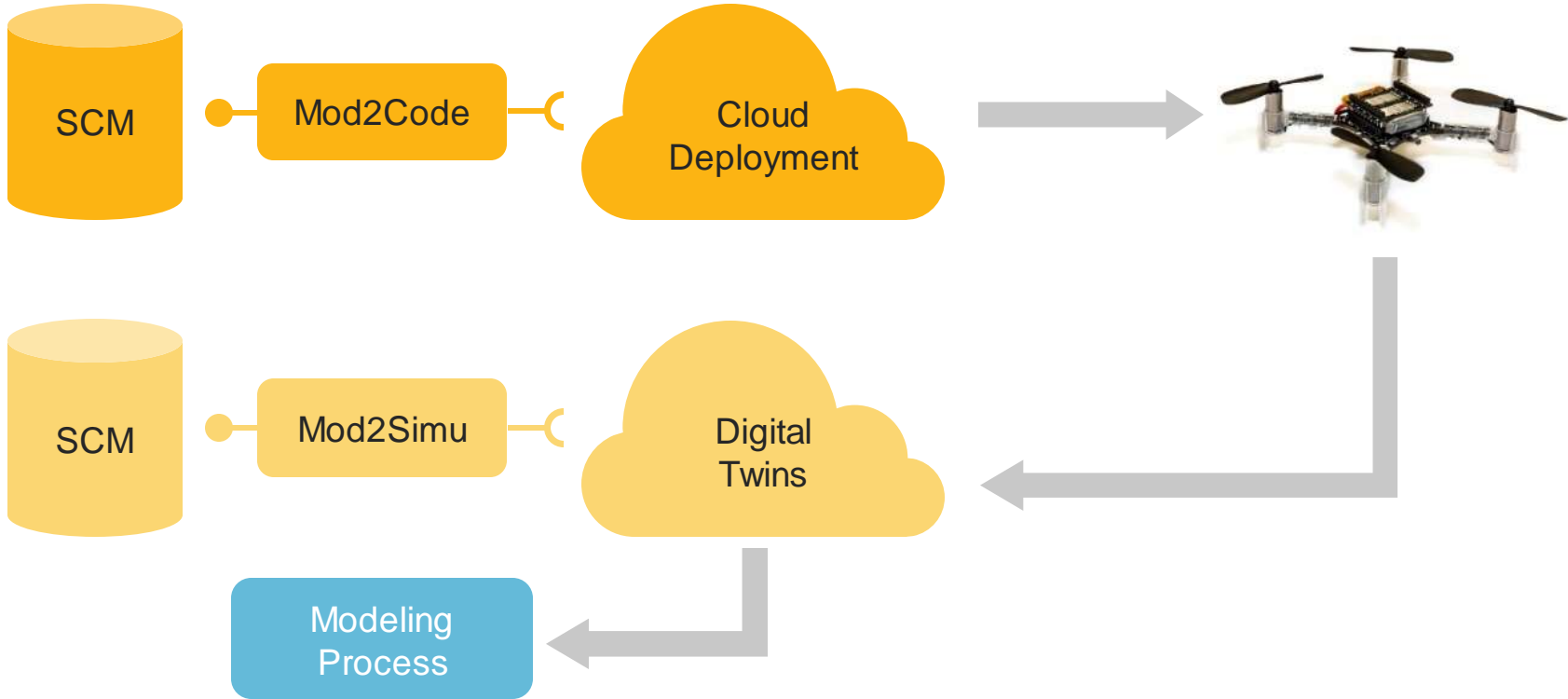
- 1-2: HLR validation
- 2-(3+4): validation of LLR
- 1+(3+4): virtual integration



Digital Twins of UAV vs. UAV flying: validation of Modelica model, efficiency of the controller (overshoot verification) and timing verification of software.



From ModDevOps to TwinOps



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MBSE and MPM, => MPM perspective

1-2-3-4: “mega-modeling” V&V

- 1-2: HLR validation
- 2-(3+4): validation of IIR



How to organize models? Matryoshka principles

- AADL extends/refines the SysML model block diagrams
- Simulink implements requirements for a controller
- Modelica implements operational context

=> notional process encoded, “model₁ + operation => model₂”

Caveat: Liskov principle: a model refining another model should preserve some properties (structural, behavioral)

MPM must build on Systems Engineering and MBSE to define

- Each process involved
- Goal of each step within a process

MBSE and MPM,

=> MPM perspective

1-2-3-4: “mega-modeling” V&V



How to “run” models?

- AADL orchestrates software execution on target
- FMI to do co-simulation AADL/Simulink/Modelica

AADL architecture acts as a master algorithm for simulation

- AADL orchestrates the execution of simulation models of devices (models of the environment) and software (e.g. SCADE, Simulink, etc)
- Underlying assumptions on clocks, sampling time dictated by the schedule constraints set by the architecture

What about system-level simulation?

- WiP: DEVS to provide semantics of AADL itself
- MPM should embrace all aspects of a CPS, need faithful characterization of the cyber component
- How to provide “science” in the way we assemble those models?

Conclusion

Just opening the box: MBSE and MPM are two fruitful research topics

“engineering” dimension: support the construction of large complex systems

- With enough confidence models are useful!
- Interoperability solved through DEVS/FMI, meta-modeling, and model transformations

“scientific” dimension TBD to achieve confidence:

- Heterogeneous models can be weaved and
- The resulting (coupled) model has a valid semantics, i.e. a valid interpretation

Conflicting issues: scalability/fidelity, i.e. finding the right abstraction for the right property