Multi-Paradigm Modeling for Cyber-Physical Systems: Implications for Multidirectional Transformations and Synchronizations

Dagstuhl Seminar 18491 on Multidirectional Transformations and Synchronisations. December 2–7, 2018.

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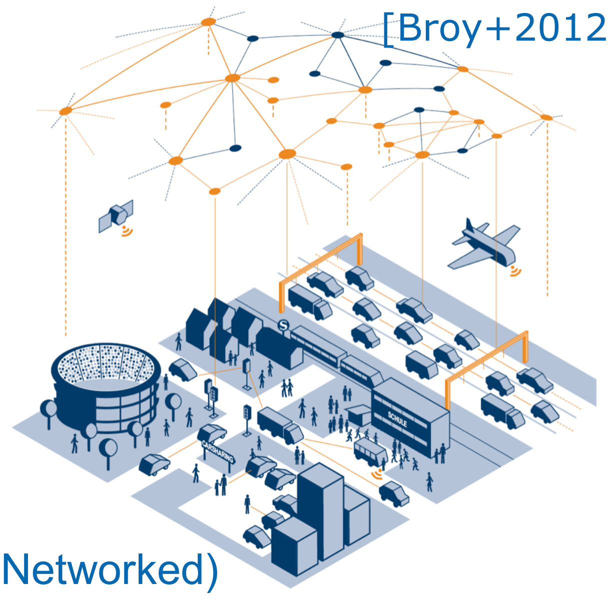
1. Cyber-Physical Systems & Integration

[Broy+2012]

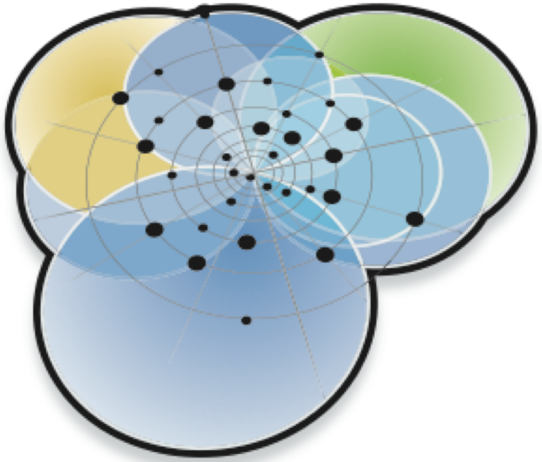


(Networked)
Cyber-Physical Systems

Internet of Things

Smart City

[Northrop+2006]



Ultra-Large-Scale Systems

http://oceanservice.noaa.gov/news/weeklynews/nov13/ioos-awards.html

Smart Home

Smart Factory -
E.g. Industry 4.0

E-Health

Smart Logistic

Micro Grids

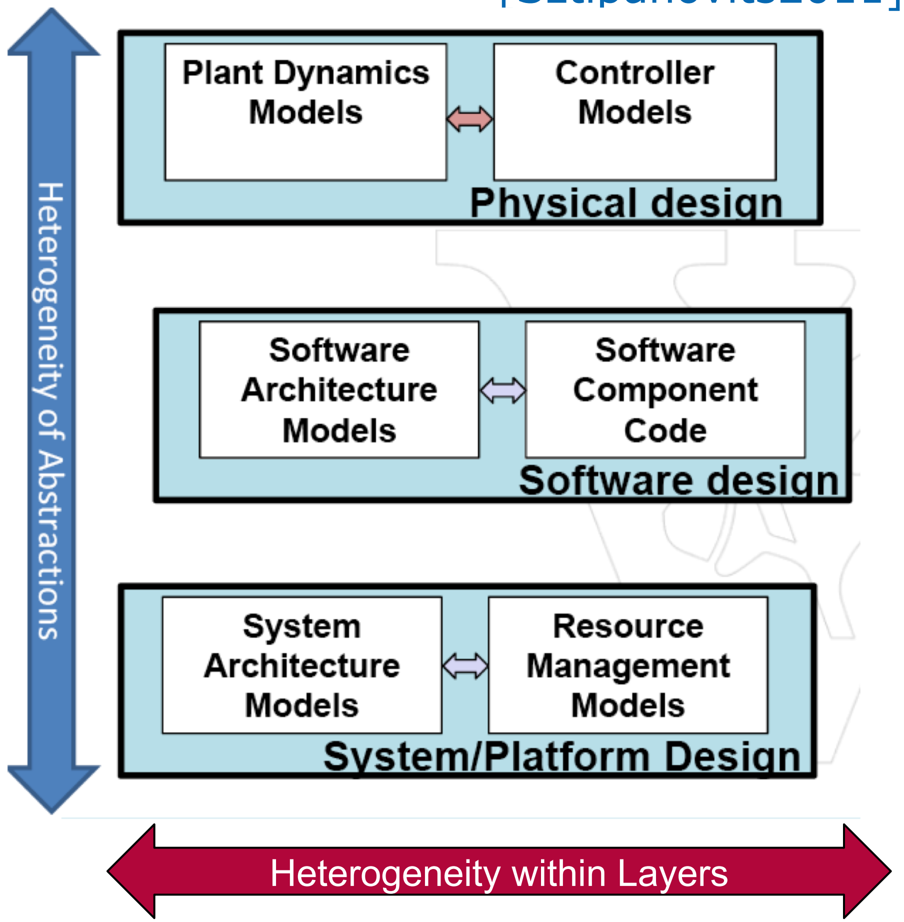
COST Action IC1404 for Multi-Paradigm Modeling for Cyber-Physical Systems (MPM4CPS)

Ambient
Assisted Living

Challenge: Integrate Models of Computation

- Problem to integrate models within one layer as different **models of computation** are employed
- Leaky abstractions are caused by lack of composability across system layers. Consequences:
  - intractable interactions
  - unpredictable system level behavior
  - full-system verification does not scale

[Sztipanovits2011]



Integration has to cover multiple layers and their **paradigms**

2. Multiple Models and ...
(1) Multiple Models ...

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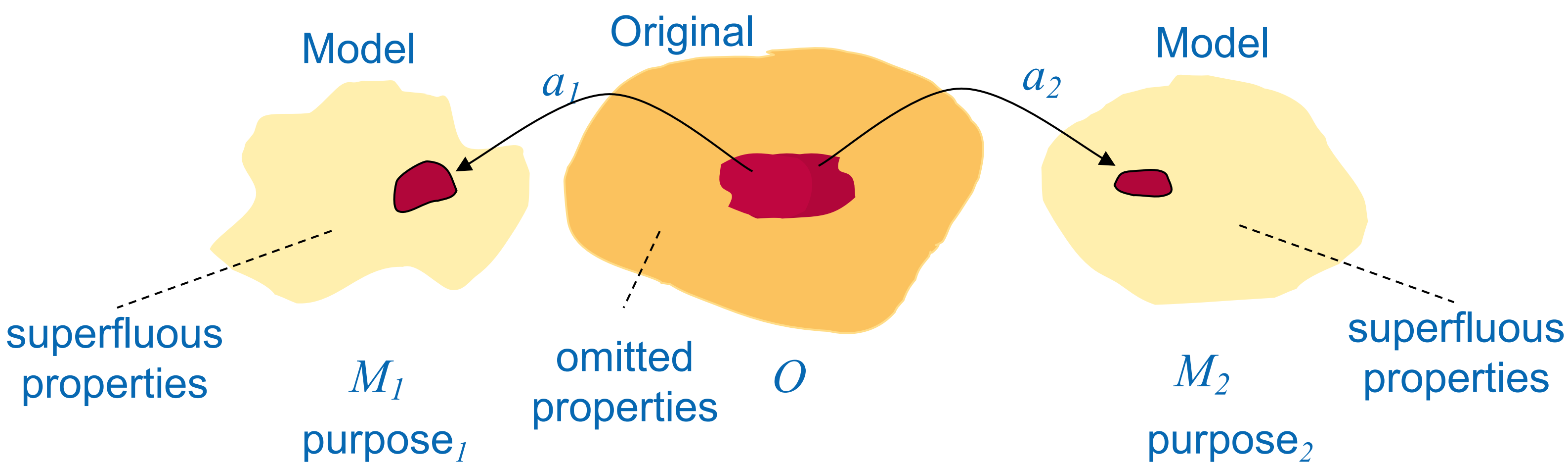
Each **model** M_j is an abstract representations of of a part or multiple parts of an existing or envisioned original used for a specific purpose.

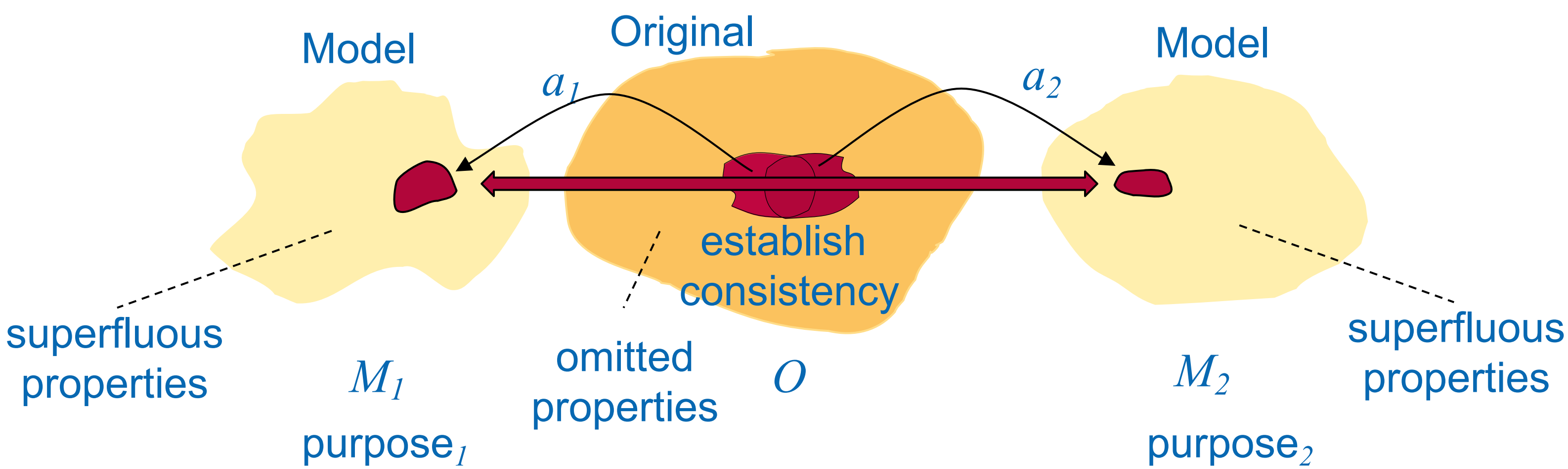


Benefit: For purpose$_j$ we replace the original O by a suitable model M_j that does not contain any irrelevant information (**reduced complexity**!)

Drawback: Does an original O consistent with both models M_1 and M_2 really exist (**consistency**)? – simple existence is often not enough!

How to Handle Multiple Models?

Try for each purposes to find a model M_j that replace the original O, does not contain any irrelevant information (reduced complexity!), and **integrate** the models systematically to establish consistency.



Key questions:

- How many models are helpful (tradeoff benefits vs. integration effort)?
- When and how is integration happen for these models?

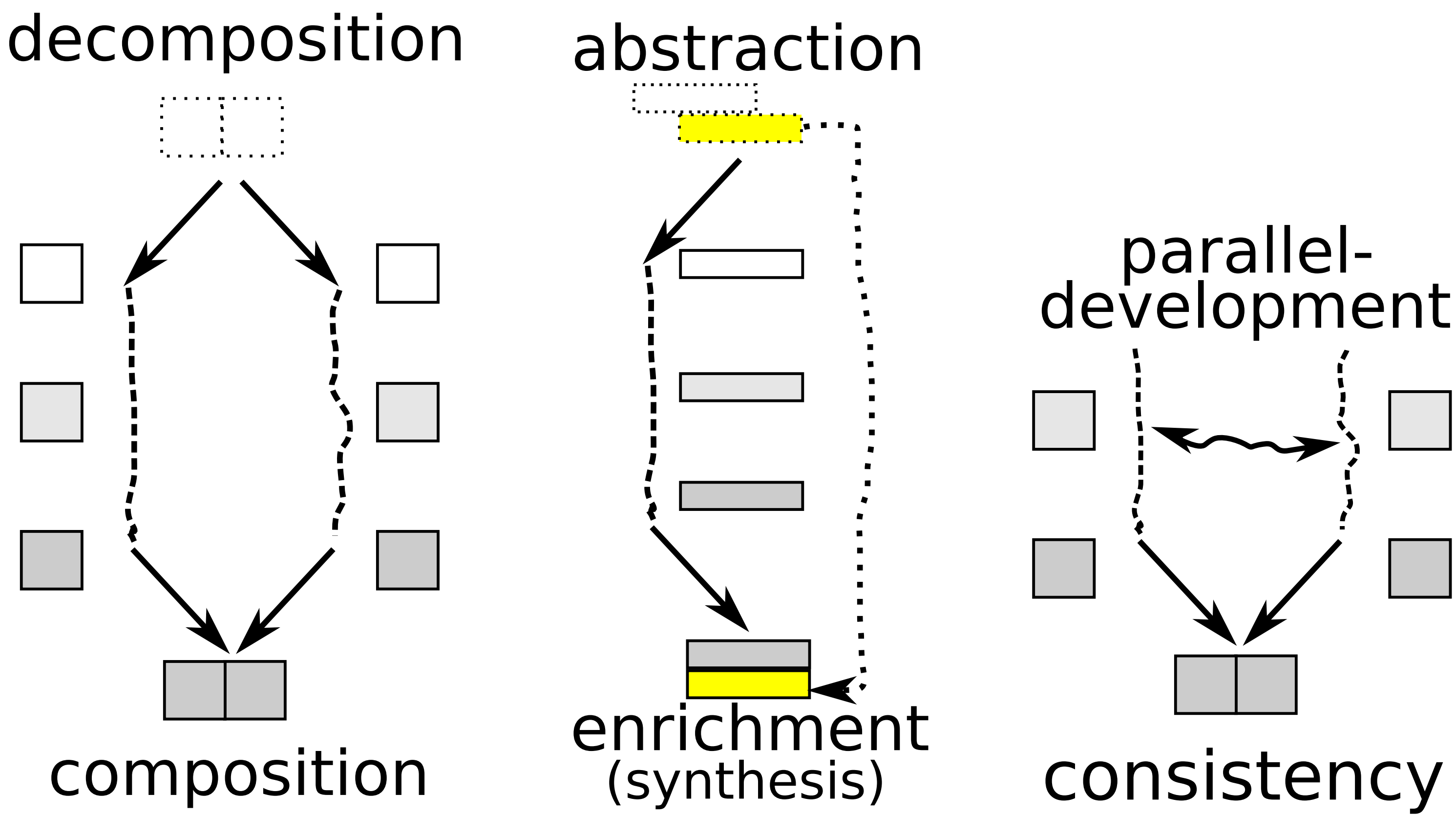
(2) Integration: When & How

Warning: We use a less restricted notion of integration than many others ...

6

Fundamental Techniques for Integration:

[Giese+2011]



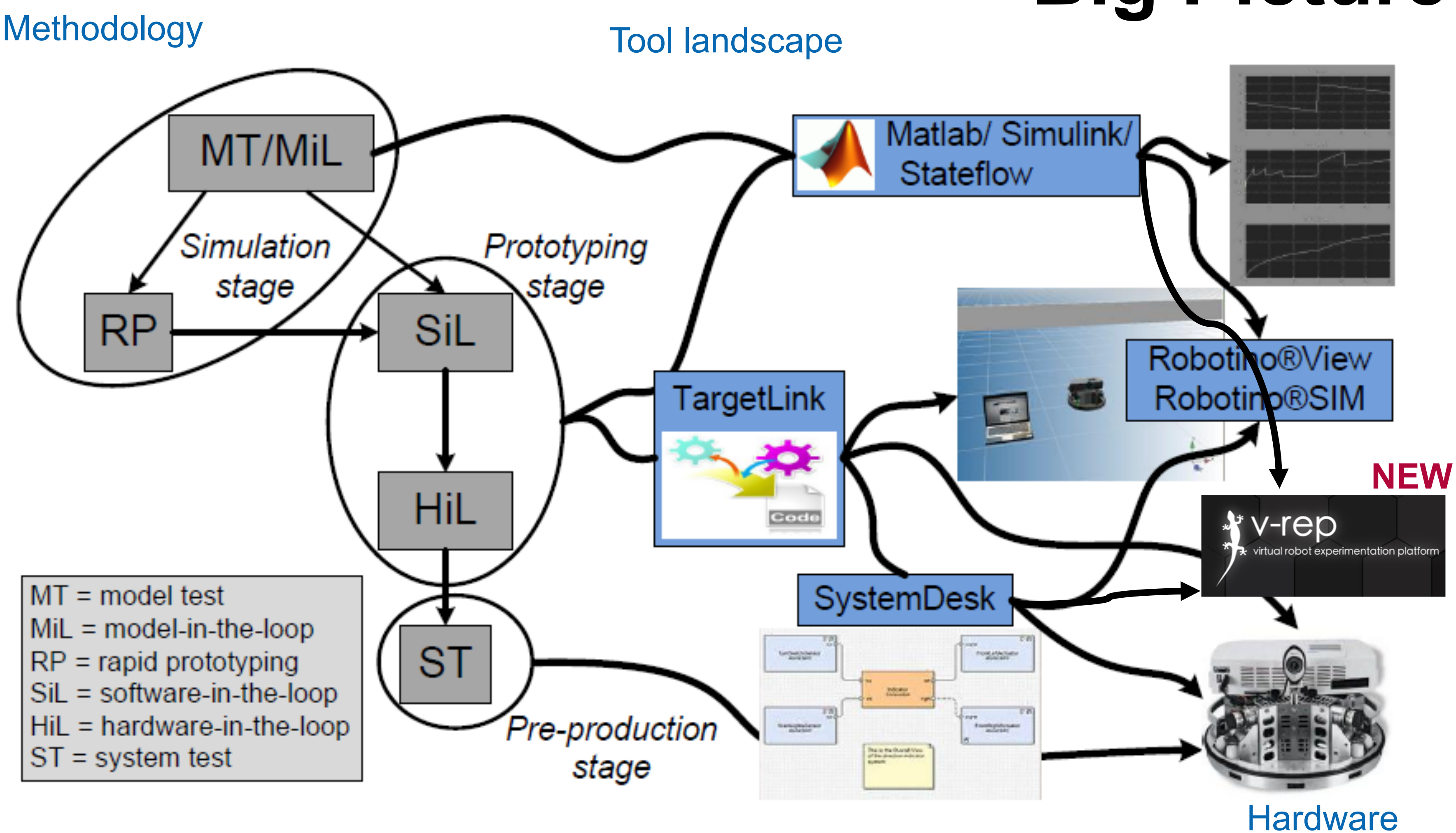
(a) composition (b) abstraction (c) consistency

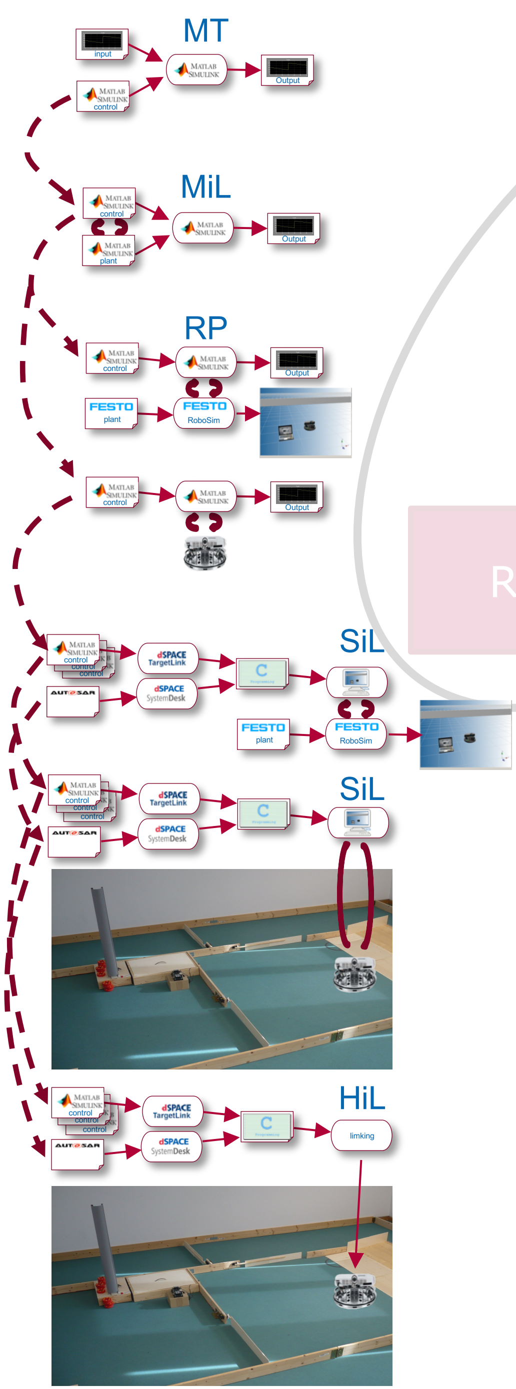
Level of Integration

- **Representation-level**: integration efforts only guarantee that a joint representation is reached
- **Syntax-level**: integration efforts lead to correct syntax
- **Semantics-level**: integration efforts lead to compatibility at the level of the semantics

3. CPSLab & Integration:

Big Picture

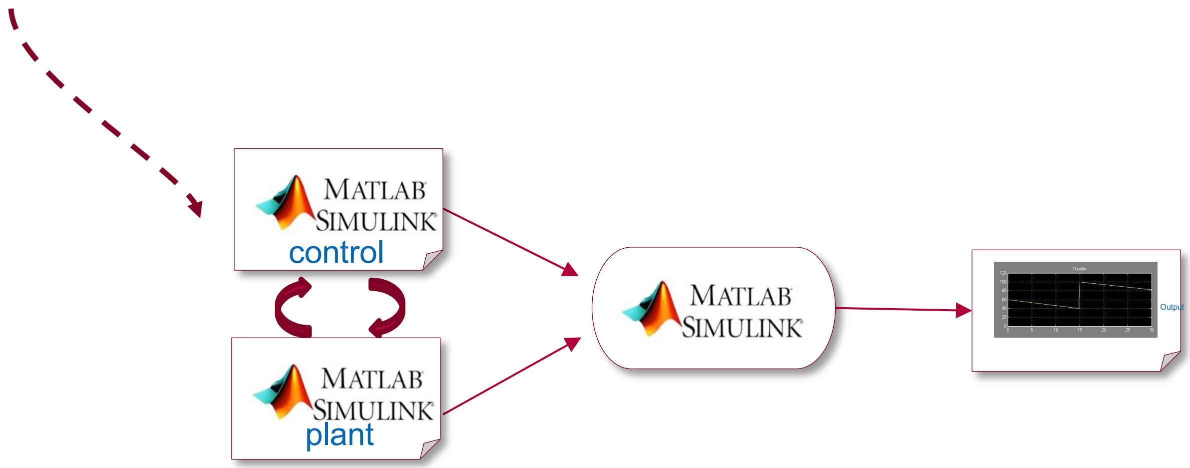


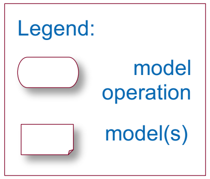


Legend:
- tool
- model

- Vertical **enrichment** of functional models (consistency manually)
- Horizontal **integration** of functional and plant models
- Horizontal **integration** of multiple functional models, an architecture model, and a plant model
- Vertical **enrichment** of multiple functional models, an architecture model, and a plant model (to realize functions while meeting resource constraints)

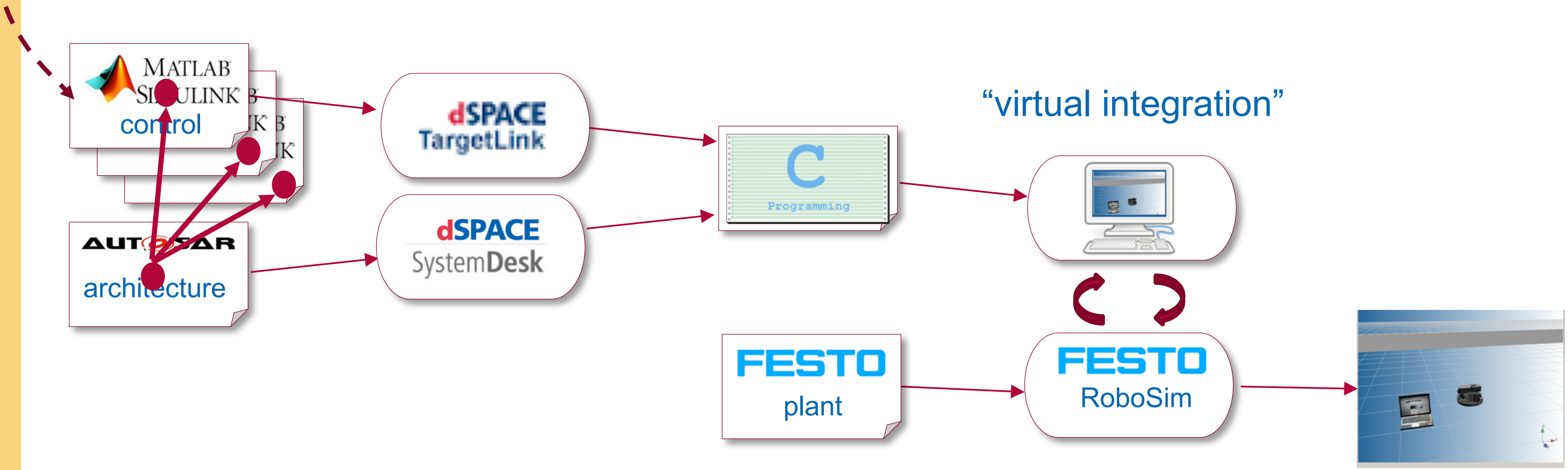
Model in the Loop (MiL)





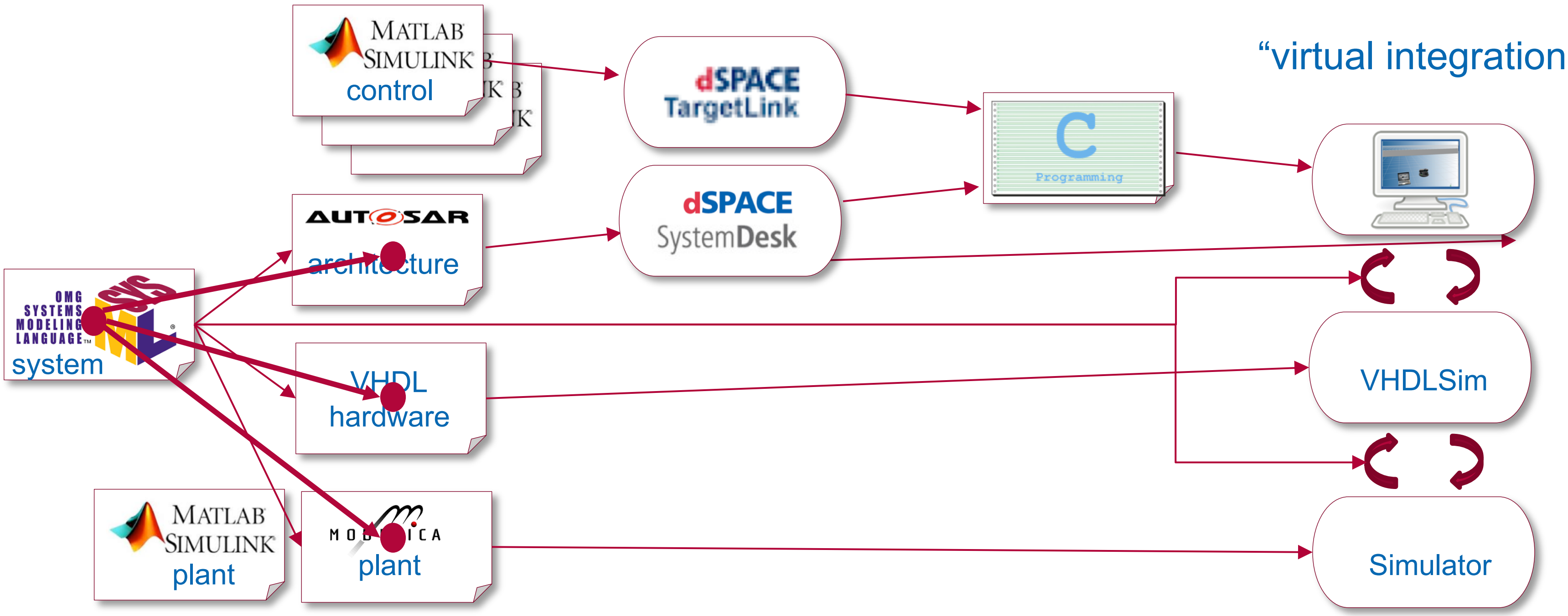
- Layer: Abstract Control Algorithm + Idealized Plant
- Domain: Control/Software + Physics
- Multi-Paradigm: Yes, if control is discrete
- Cyber-Physical system: Yes, as control is cyber world and plant is from the physical world
- Integration: Decomposition & Composition + parallel development; semantics-level

Scenario: Complex Horizontal Integration



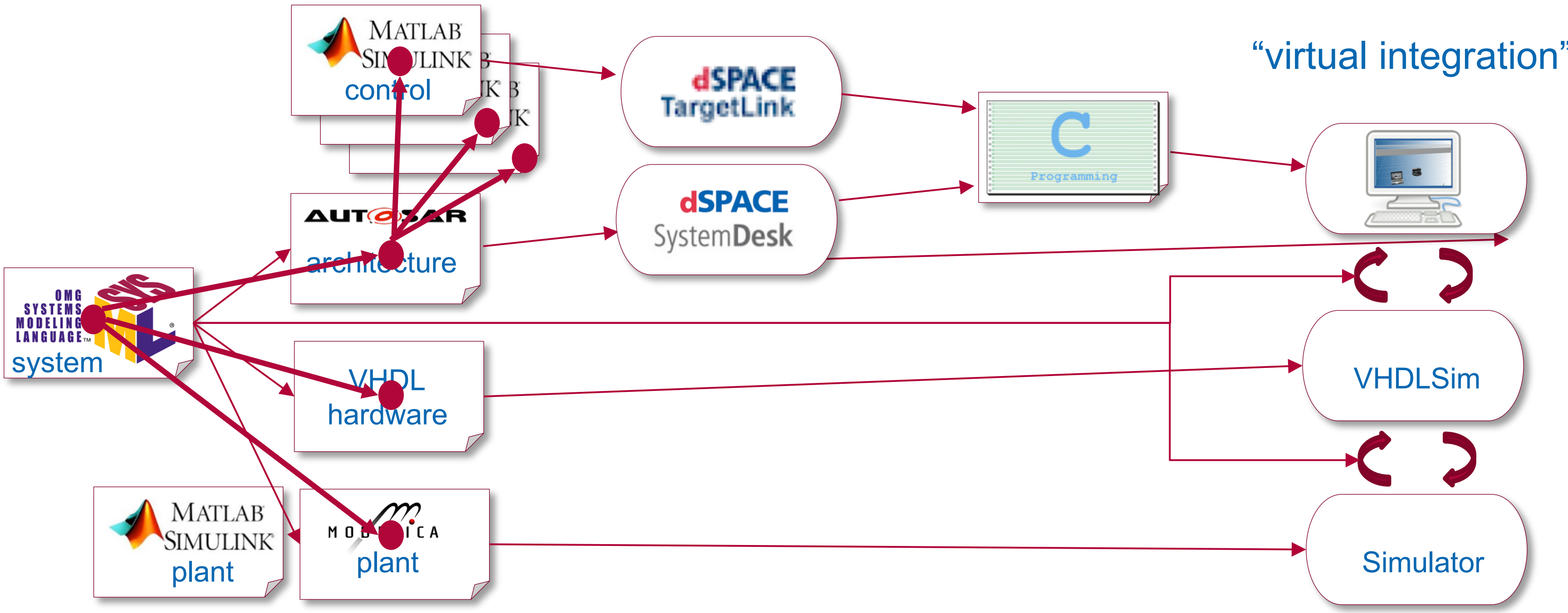
- Horizontal combination of multiple functional models by the architecture via the generated software (integration by composition for functions, integration by abstraction for OS)
- Downwards propagation can be expected, but must be managed
- Upwards propagation is usually forbidden (suppressed)
- Horizontal propagation is therefore also forbidden (suppressed)

Scenario: More Complex Horizontal Integration



- Horizontal combination of multiple specific structures (Autosar: software; VHDL: hardware, Matlab/Modelica: plant) via a generic structure (SysML)
- Downwards propagation can be expected, but must be managed
- Upwards propagation is usually forbidden (suppressed)
- Horizontal propagation is therefore also forbidden (suppressed)

Scenario: More Complex Horizontal Integration



- Vertical **decomposition** via a generic system structure (SysML) containing multiple specific structures (Matlab: control; Autosar: software; VHDL: hardware, Matlab/Modelica: plant; ...)
- Consistency between models and in the models interact, which may lead to transitive propagation/conflicts

4. Needs for Integration

Observations:

- A **horizontal composition** is often **mainly** done to establish consistency at the **semantics-level** to ensure that the different models fit together (“virtual integration”). Keep syntax-level consistency throughout the development for a **horizontal composition** of n models (a **multidirectional transformation or synchronization**) is not really an issue.

Implications:

- We can help as **semantics-level checks** for the **horizontal composition** of n models requires **syntax-level consistency** as prerequisite!

Needs for Integration

Observations:

- Often propagation between multiple models (**multidirectional transformation or synchronization**) was not wanted/permitted.

Implications:

- Need for concepts to manage permission to do only changes as permitted (interfaces?)
- To unleash the full potential of **multidirectional transformation or synchronization** we have to study the context (processes, activities, … = mega models / paradigm) and identify how processes and activities can be improved.

Needs for Integration

Observations:

- The overlapping parts are linked to not overlapping parts and therefore **conflicts** may also result w.r.t. not overlapping parts.

Implications:

- For the overlapping parts we cannot expect to achieve more than has been achieved for the **merging of multiple versions** and also related finding may be relevant to us (limits for merging, living with inconsistencies, ...). => **semantics-level** likely not feasible

5. Conclusion & Outlook

For Future MPM4CPS with self-adaptation we get:
- Runtime model sync.
- Executable Runtime Mega Models organizing the sync. and other model operations
- ...

- **Multiple models** and their **integra** developing complex systems
- In case of **cyber-physical systems** it holds:
  - models employ **different paradigms** specific for their **layer**
  - **Integration** of the models is of **paramount importance**

- **Current integration challenges:**
  - Build cost-effectively tools to integrate the models at the **semantics-level** (not only syntax-level) for a "virtual integration" to also support analysis of **emergent properties**
  - **Multidirectional transformation and synchronization** may establish **syntax-level consistency** throughout the development to enable **automated semantics-level integration checks**

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