Is Science in System Integration?

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Context of Our Collaboration

- CPS consolidates as a valid scientific direction by 2010. Universities led the charge with strong involvement of computer and systems scientists and with strong industry support

- In 2010 NSF starts the CPS program in the Computer and Information Science and Engineering (CISE) directorate, establishes the CPS Virtual Organization (CPS-VO.org) at Vanderbilt, starts Annual CPS PI Meetings . First ICCPS is in 2010 Stockholm

- Between 2012-2015 industrial consortiums are created (Industrial Internet Consortium (2014), OpenFog Consortium (2015), IoT, Industry 4.0 (Germany) and the "new Gold Rush" kicks off.

Science of Integration for CPS 2010-2015
NSF CPS-Large Project: VU, UND, UMD, GMR

- **System integration**: implemented components are connected and system-level properties are verified/tested
  - High risk – many fundamental problems surface during system integration
  - Ad-hoc – ‘making it work somehow’ attitude
  - *Fundamental problem – limited composability and compositionality in heterogeneous systems lead to lack of constructivity in system design*

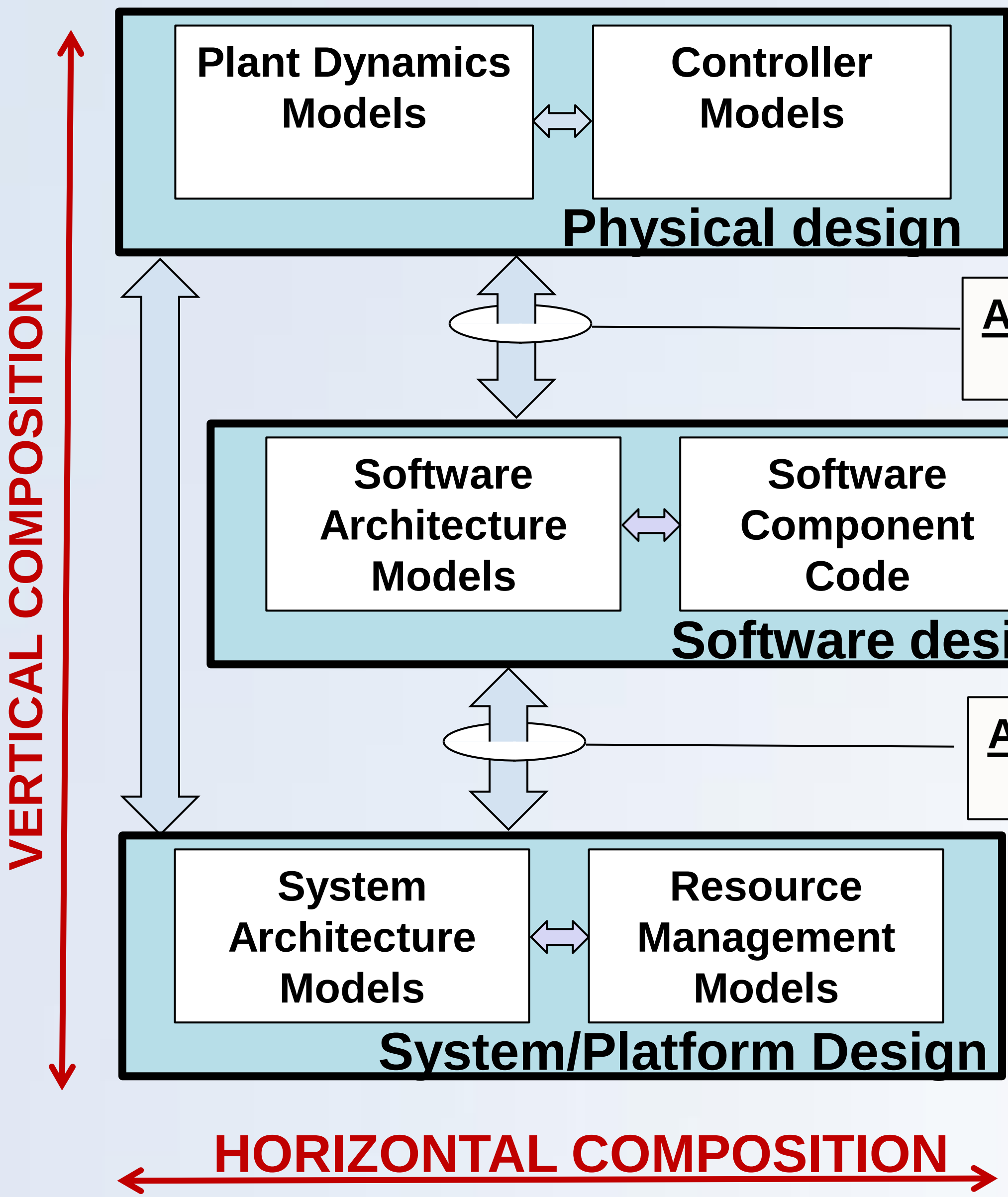
Scientific Challenge: Foundations for Correct-by-Construction Design

- **Goal: extend the limits of "correct-by-construction" design:**
  - **in *broad sense*: model- based design process that leads to manufacturable CPS products with desired properties**
  - in *narrow sense*: use architectures (design invariants) that guarantee certain properties

SoI Project Goals

1. Investigate **composition and compositionality of heterogeneous systems** to achieve constructivity and predictability in CPS integration
2. Construct **tool chains for CPS design** based on semantically rigorous methods to define and compose of heterogeneous modeling languages.
3. Experimental validation of the ideas in **automotive and other applications.**
4. **Education methods and reusable material**.

Integration Across Abstraction Layers: Much Unsolved Problems



Controller dynamics is developed without considering implementation uncertainties (e.g. word length, clock accuracy) optimizing performance.

Assumption: Effects of digital implementation can be neglected X

Software architecture models are developed without explicitly considering systems platform characteristics, even though key behavioral properties depend on it.

Assumption: Effects of platform properties can be neglected X

System-level architecture defines implementation platform configuration. Scheduling, network uncertainties introduce time varying delays that may require re-verification of key properties on all levels.

Key Results

- **Foundations**: Developed theory and has shown experimentally the compositionality of distributed safety controllers on vehicles with guaranteed stability and has **employed passivity to decouple control design from implementation uncertainties**.
- **Tools and tool architectures**: Has demonstrated the practicality and semantic soundness of horizontal integration platforms in a complex CPS tool chain
- **Education**: Introduced integrated CPS design tools in courses, undergraduate design studio and internship programs including high-school students