An Architecture Approach to Heterogeneous Verification of CPS

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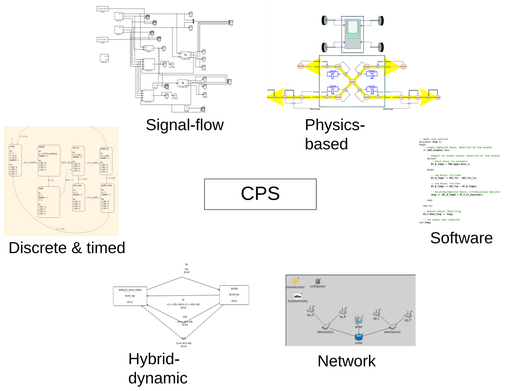
Project Goals



Multiple modeling formalisms for CPS

How do we

- **guarantee that the models represent the actual system?**
- **guarantee that the models are consistent with each other?**
- **infer system-level properties from heterogeneous analyses of these heterogeneous models?**

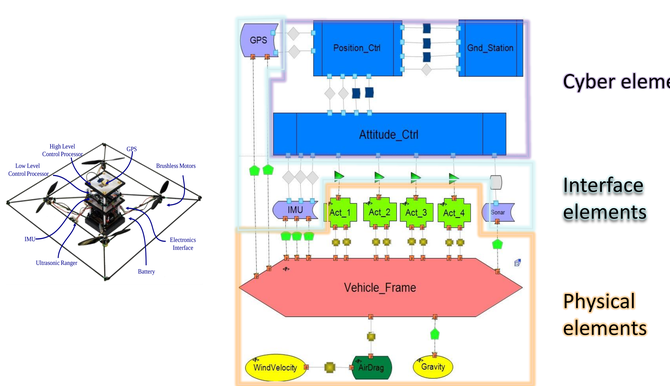
Architectural Modeling of Cyber-Physical Systems

Architectures

- **Annotated graphs of components and connectors to represent system structure**
- **Standardized notations (architectural styles) provide a vocabulary of components and connectors as well as certain classes of properties**

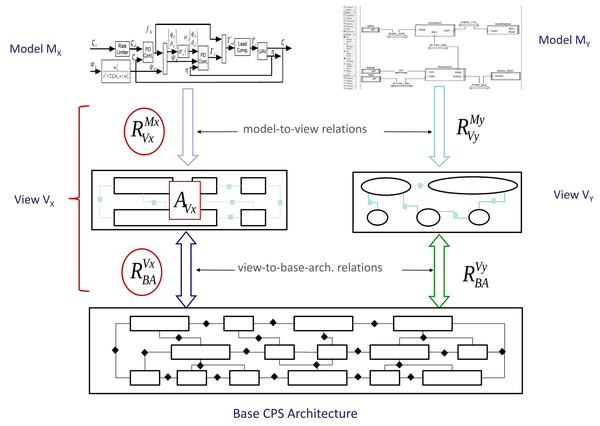
Proposed CPS Architectural Style [1]

- **Cyber elements based on principal computational elements and pathways in the system, e.g., controller, estimator components, point-to-point, publish-subscribe connectors**
- **Physical elements based on effort-flow modeling, e.g., source and storage components, equal effort or power-flow connectors**
- **Interface elements, e.g., C2P and P2C transducers**

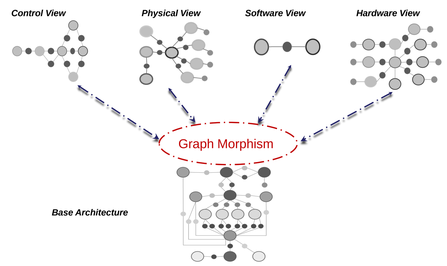


STARMAC quadrotor and its CPS architecture [2]

Models as Architectural Views

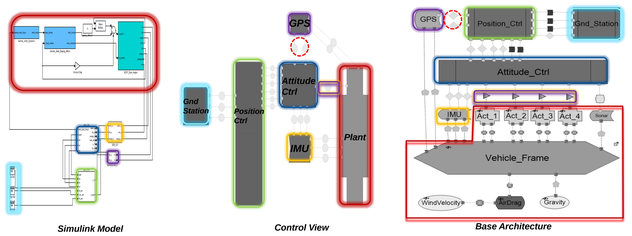


Structural Consistency using Graph Morphisms



Weak consistency (correctness)

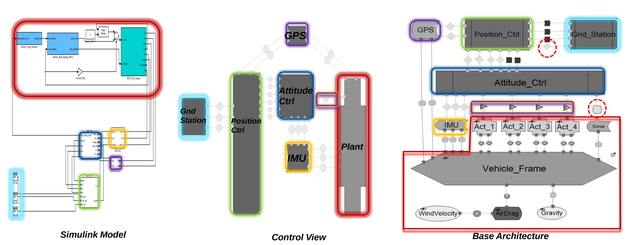
- **Each element in the view has a corresponding element in the base, i.e., graph monomorphism**



STARMAC control view incorrectness – connector mismatch [3]

Strong consistency (completeness)

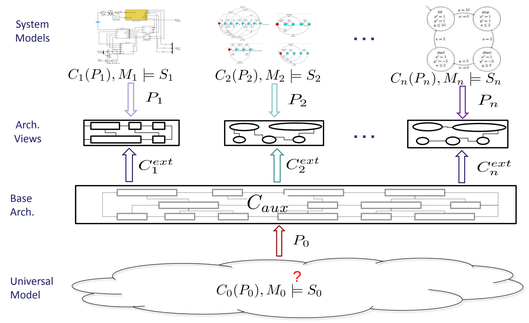
- **Each element in the base has a corresponding element in the view, i.e., graph isomorphism**



STARMAC control view incompleteness – missing connectors [3]

Parameters to support Heterogeneous Verification

- **Parameters as the first step towards adding semantics to the architectural framework**
- **Parameter constraints define the valuations of the parameters and affect the system/model behavior**
- **Auxiliary constraint captures parameter dependencies across the system and the models**



Q. Heterogeneous models with their own parameters and specifications are verified independently. Can we guarantee that the underlying system satisfies its specification (without building a universal model)?

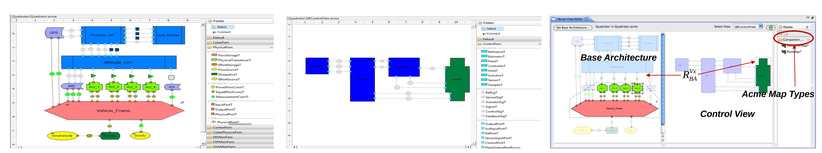
A. For safety specifications, if

1. **each model abstracts the underlying system**
2. **each verification task succeeds, i.e., $C_i(P_i), M_i \models S_i$**
3. **model-level specifications (S_i) cover the system-level specification (S_0), i.e., $\bigwedge_i S_i \Rightarrow S_0$**
4. **models are external-constraint consistent, i.e., $C_i^{ext} := (C_0 \wedge C_{aux}) \downarrow_{P_i} \Rightarrow C_i$**

then $C_0(P_0), M_0 \models S_0$. [4]

Tool Support in AcmeStudio

- **AcmeStudio is a semantically extensible framework for architectural design and analysis with built-in support for styles, system structure and constraints**
- **View consistency plugin under development. Uses maximum common sub-graph matching algorithm at back end**
- **Support for parameter constraints planned**



Base Architecture (left) and view (center) modeling in AcmeStudio. View consistency plug-in under development (right).

References

[1] Rajhans et al., An Architectural Approach to the Design and Analysis of Cyber-Physical Systems, MPM '09.
[2] Bhave et al., Augmenting Software Architectures with Physical Components, ERTS^2 '10.
[3] Bhave et al., View Consistency in Architectures for Cyber-Physical Systems, ICCPS '11.
[4] Rajhans et al., Using Parameters in Architectural Views to Support Heterogeneous Verification, CDC' 11.