The Past, Present and Future of Cyber-Physical Systems: A Focus on Models

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Outline

- Background of CPS and models
- Problems and concerns
- Solution approach
- Implementations on real projects

Background

- Cyber-physical system (CPS)
- Models
    - The thing being modeled
    - The model
    - The modeling paradigm
- Deterministic models
    - Determinism
    - Determine determinism
    - Deterministic modeling paradigms
        - ODEs
        - Synchronous digital logic
        - Single-threaded imperative computer programs

Problems

- Limitations of deterministic models
  - Hard to handle variations in the parameter values
  - Higher complexity over non-deterministic models
  - Can’t be applied to problems where unknown properties are critical
  - Though each model is deterministic, the combination of them is not
- Potential solution
  - Non-deterministic models

Abandon all deterministic models? No.

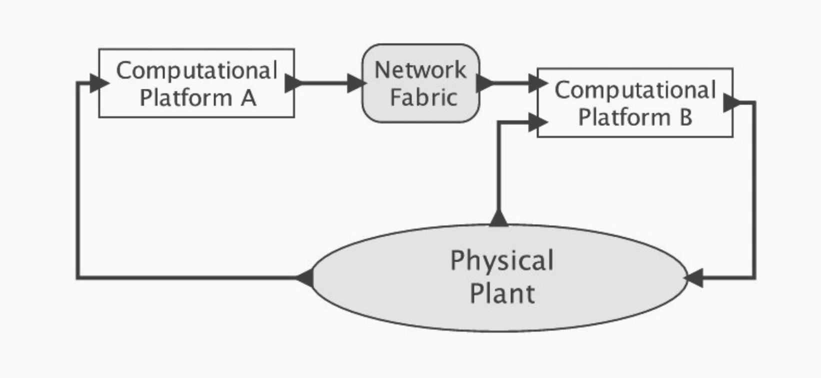
- Models != physical world
- Deterministic models have been proved to be useful in history
- There exist high fidelity implementations for deterministic models

Model Concepts : Cyber-Physical Example

A plant with sensors & actuators controlled by two systems

- The Thing being Modeled - The physical system comprising of the actual sensors and other components

- Model →



Structure of a simple cyber-physical system

- Modeling paradigm

CPS Concept

Value of a model depends on

Ease of analysis

Deterministic models

Model fidelity

Non-deterministic models

➢ Interaction between deterministic models in CPS tends to make them non-deterministic

Concerns - Model Fidelity

- ➢ Existing solutions take a deterministic approach but are not platform agnostic

- ➢ Implementation level certification => Increased Cost + Outdated hardware

Solution Approach

Bridge the gap between model and the thing being modeled

Improve time determinism

- ➢ Temporal semantics for the model : PRET
- ➢ Distributed time systems for the physical implementation : Ptides

Solution 1- PRET

CPS models require coarse timing requirements, but these systems are very time and resource expensive. Hard and soft deadlines pose similar restrictions on deterministic models.

PRET model- developed in Berkeley in 2007

Focuses on precision, predictability, and repeatability

Elements of PRET

Thread interleaved pipeline

DRAM parallelism for interleaved access

Software memory hierarchy management

Temporally isolated interrupt driven I/O

An extended ISA with instructions that explicitly control timing

Does require some sort of synchronized clock or a dependance of all elements of the model on the same clock

Benefits of PRET

Enables repeatable timing, ensuring similar behavior in controlled tests and the real world

Improves testability

Provides explicit timing requirements

Reduces system and energy costs

Solution 2- Distributed Time Systems

Clock synchronization

GPS

Networks

IEEE 1588- network based clock synchronization protocol

Opens up concerns of hacks on global synchronization networks

Requirements of Time Models

1. The precision with which time is represented should be finite and should be the same for all observers in a model. Infinite precision (as provided by real numbers) is not practically realizable in computers, and if precisions differ for different observers, then the different observers will not agree on which events are simultaneous.
2. The precision with which time is represented should be independent of the absolute magnitude of the time. In other words, the time origin (the choice for the meaning of time zero) should not affect the precision.
3. The addition of time should be associative.
4. Monotonicity: any observer of time in a model that is a sequential process (a sequence of state changes) should observe non-decreasing values of time.

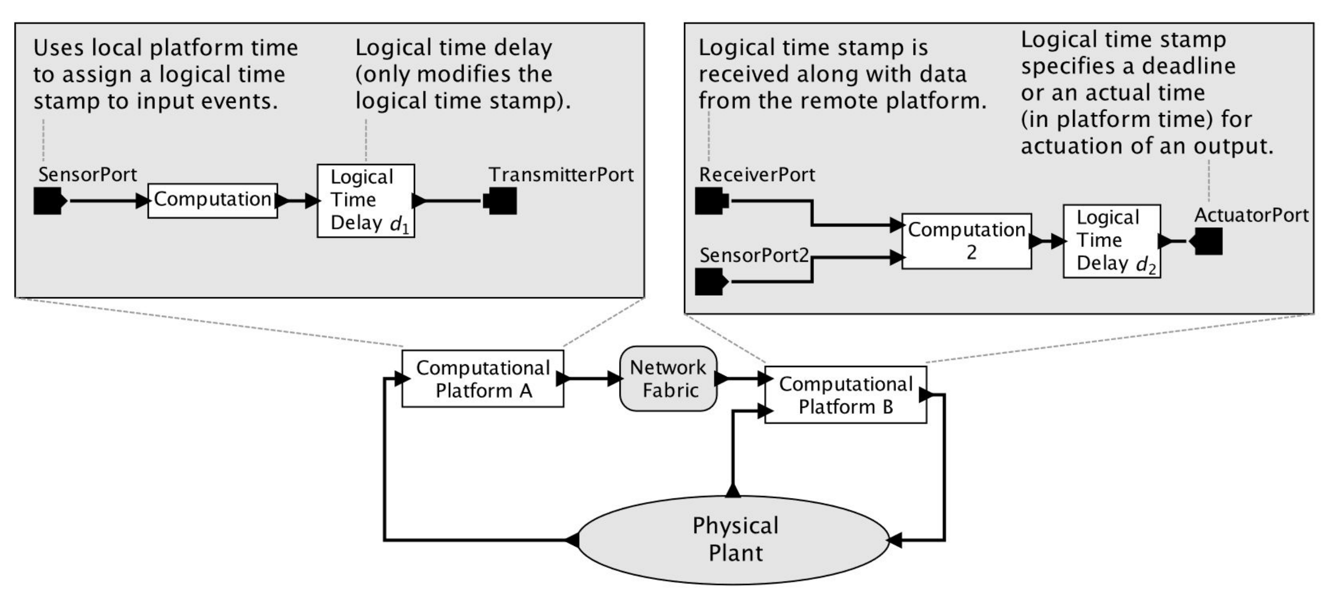
Ptides

Programming temporally-integrated distributed embedded systems

3 assumptions

1. Clocks are synchronized with a known bound on the synchronization error.
2. Every communication channel has a known bound on its latency.
3. The time taken by any computation that may affect the physical world has a known bound.

Ptides Structure



Conclusion

Cyber physical systems can be modeled through traditional models, but models such as PRET and Ptides work much better and are often more cost efficient, especially for mission-critical applications.

Key deterministic models include differential equations, synchronous digital logic, single-threaded imperative programs and instruction set architectures, and by using these specialized models, we can further CPS development and the next technology revolution

Some tailored solutions, like Ptides, can even be more robust than real time systems because changes in cyber events will not affect physical output.

Future work can include providing examples of real-life applications of these models and their results

Questions?