Portable Real-Time Code from PTIDES Models

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UC Berkeley

Invited Talk

Workshop on Time Analysis and Model-Based Design, from Functional Models to Distributed Deployments (TiMoBD)

ESWeek

Taipei, Taiwan, Oct. 9, 2011

The Problem we are addressing

For cyber-physical systems, *programs* do not adequately specify *behavior*.

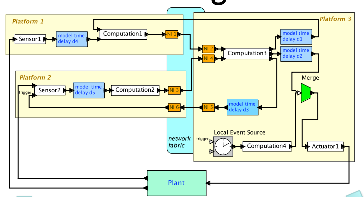
When interactions with physical processes are central, the temporal dynamics of software is a critical part of its behavior.

Today, temporal dynamics emerges from an implementation of the system, rather than being part of the model and/or program(s) specifying the system.

As a consequence, systems are *brittle* and *non-portable*.

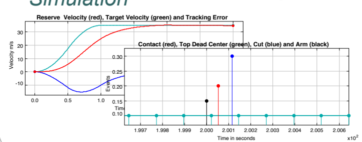
Our Goal: Determinate timing at sensors and actuators

Platform independent model of functional and timing behavior



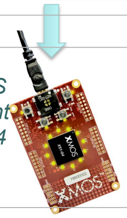
Code Generation to multiple target platforms

Simulation



Same I/O behavior w.r.t. value and timing

e.g.: XMOS development board with 4 XCores.



e.g.: Renesas 7216 Demonstration Kit

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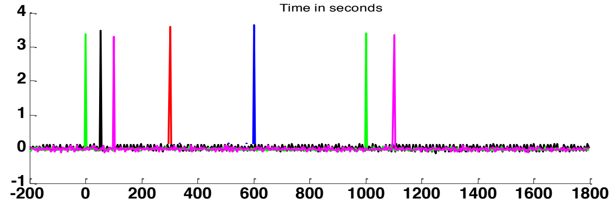
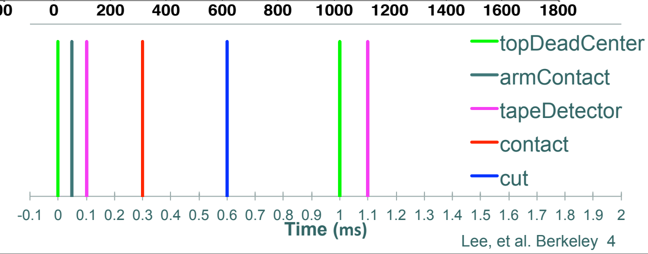
Success on a test case: Flying Paster

Timing given by simulation of the model

Timing measured by oscilloscope on a Renesas board.



Timing measured by software instrumentation on an XMOS board.



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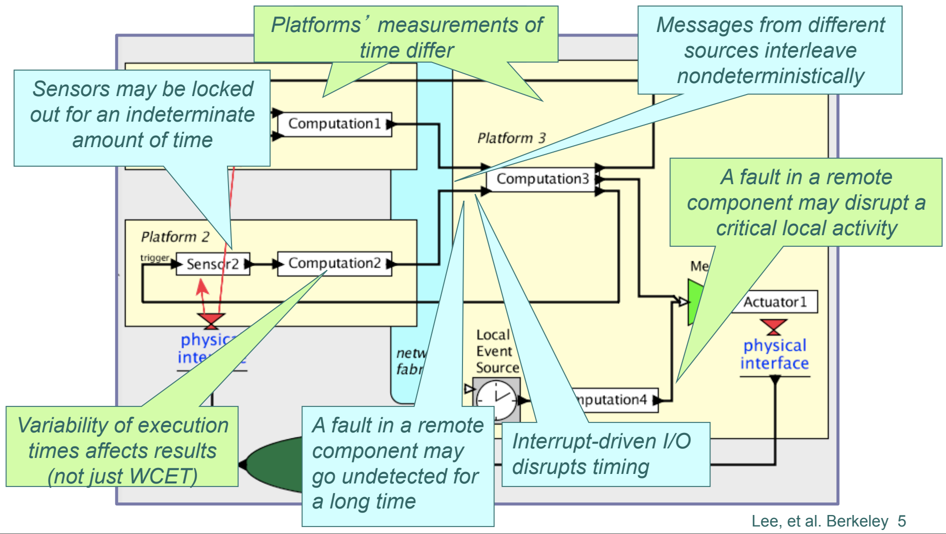
Etc…

Structure of a Cyber-Physical System

Problems that complicate analysis of *system* behavior:



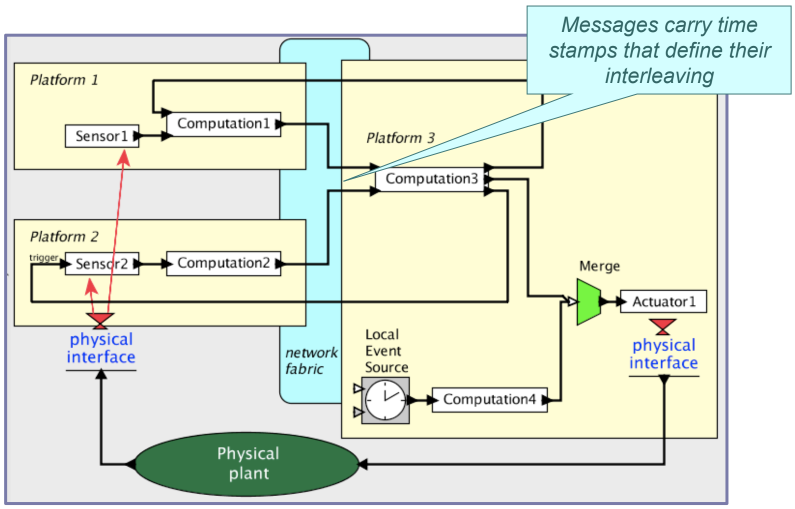
Our Programming Model

PTIDES:

Programming Temporally Integrated Distributed Embedded Systems

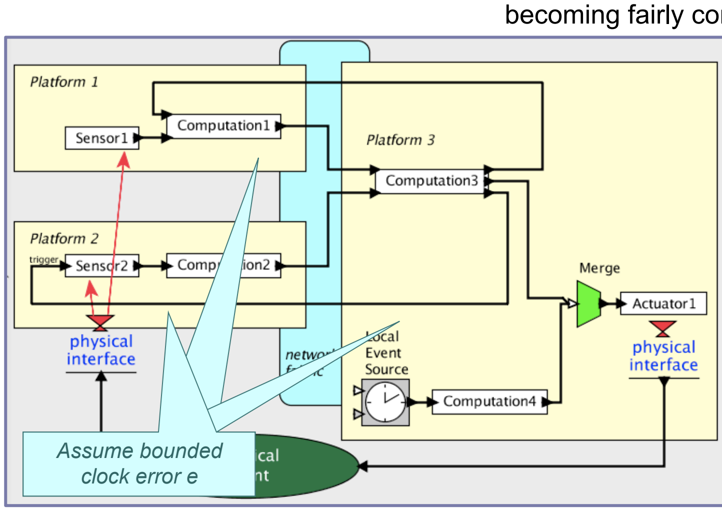
Based on a determinate discrete-event (DE) model of computation (MoC), originally developed for simulation.

Ptides: First step:
Time-stamped messages.

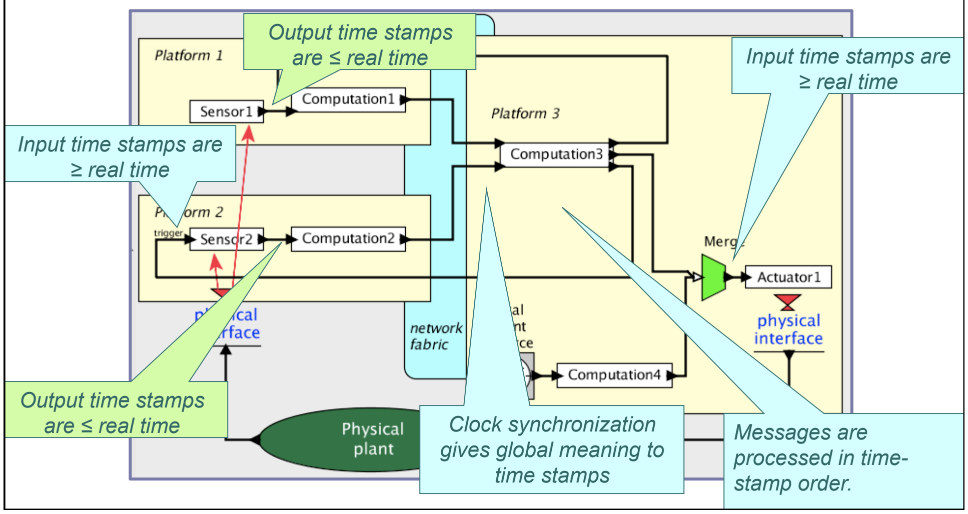


Ptides: Second step:
Network time synchronization

GPS, NTP, IEEE 1588, time-triggered busses, etc., all provide some form of common time base. These are becoming fairly common.

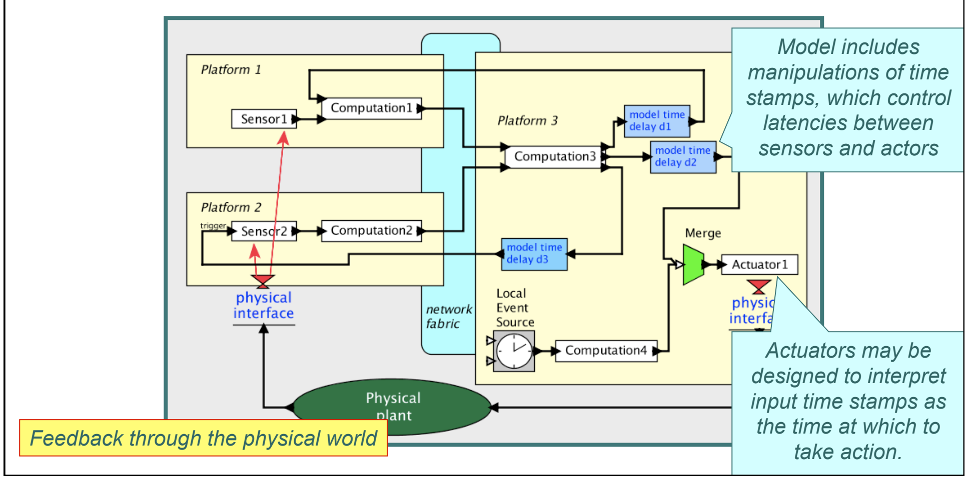


Ptides: Third step:
Bind time stamps to real time at sensors and actuators



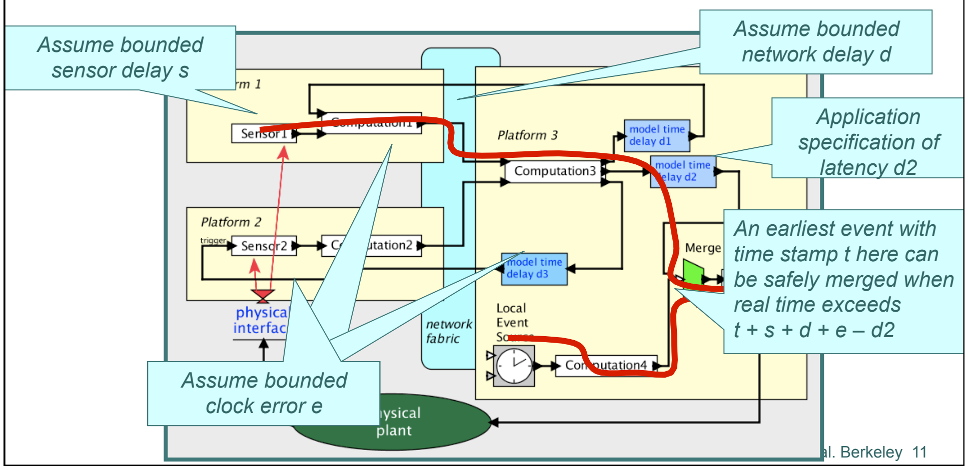
Ptides: Fourth step:
Specify latencies in the model

Global latencies between sensors and actuators become controllable, which enables analysis of system dynamics.



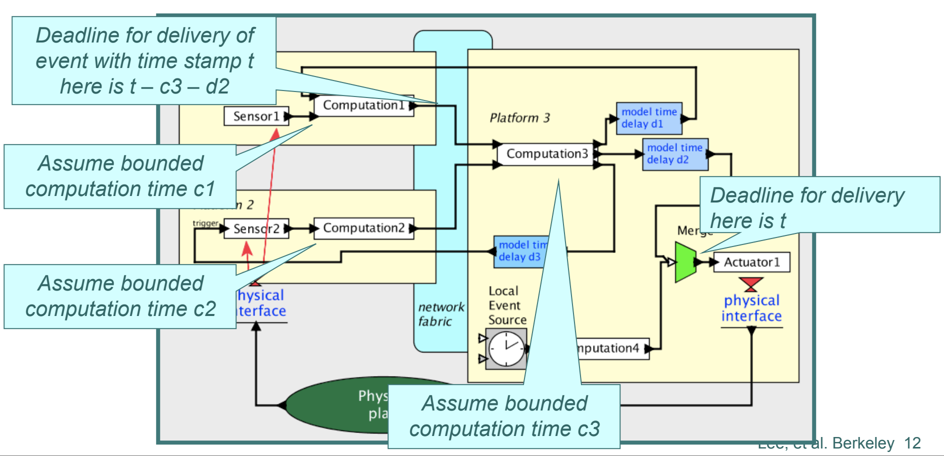
Ptides: Fifth step
Safe-to-process analysis (ensures determinacy)

Safe-to-process analysis guarantees that the generated code obeys time-stamp semantics (events are processed in time-stamp order), given some assumptions.



Ptides Schedulability Analysis
Determine whether *deadlines* can be met

Schedulability analysis incorporates computation times to determine whether we can guarantee that deadlines are met.



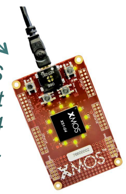
PtidyOS: A lightweight microkernel supporting Ptides semantics

An interesting property of PtidyOS is that despite being highly concurrent, preemptive, and EDF-based, it does not require threads.
A single stack is sufficient!

PtidyOS runs on

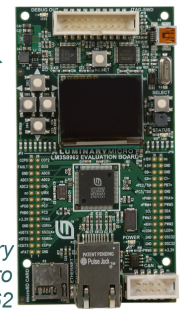
- Arm (Luminary Micro)
- Renesas
- XMOS

Occupies about 16 kbytes of memory.



XMOS development board with 4 XCores.

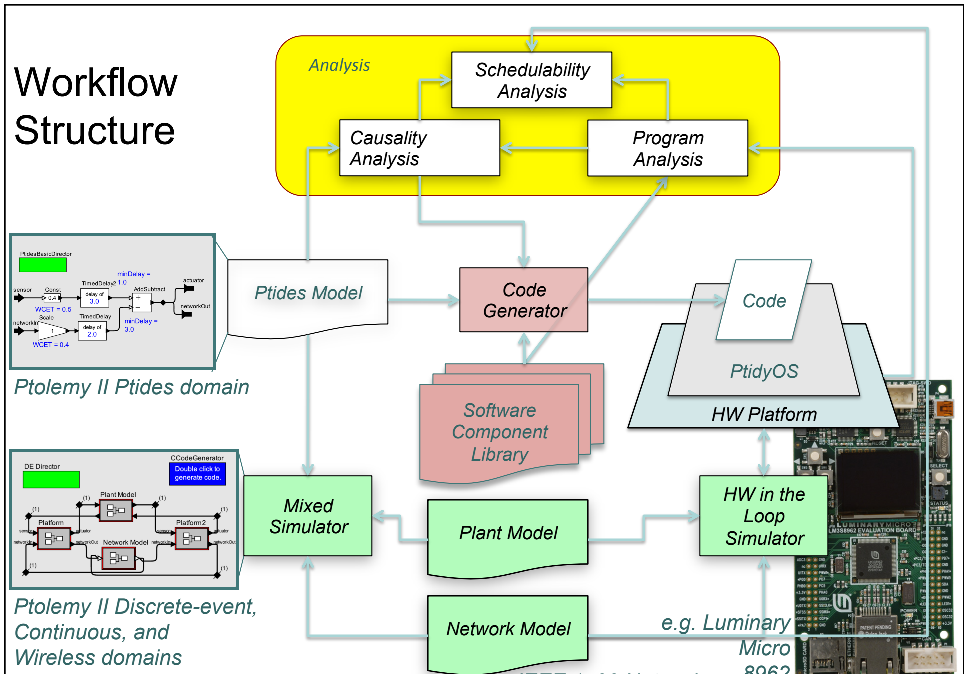
Renesas 7216 Demonstration Kit



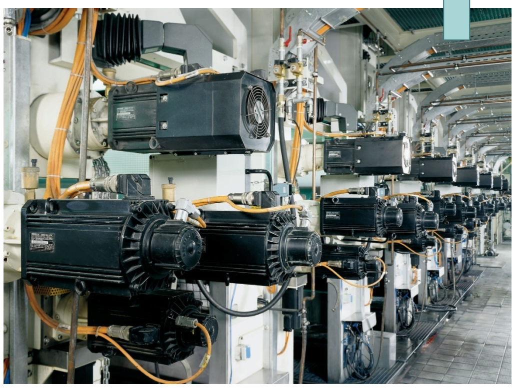
Luminary Micro 8962

The name "PtidyOS" is a bow to TinyOS, which is a similar style of runtime kernel.

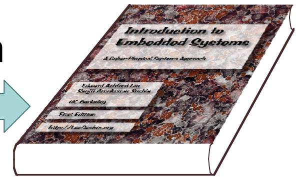
Workflow Structure



A Typical Cyber-Physical System
Printing Press



Bosch-Rexroth



- Application aspects
  - local (control)
  - distributed (coordination)
  - global (modes)
- Ethernet network
  - Synchronous, Time-Triggered
  - IEEE 1588 time-sync protocol
- High-speed, high precision
  - Speed: 1 inch/ms (~100km/hr)
  - Precision: 0.01 inch
    -> Time accuracy: 10us

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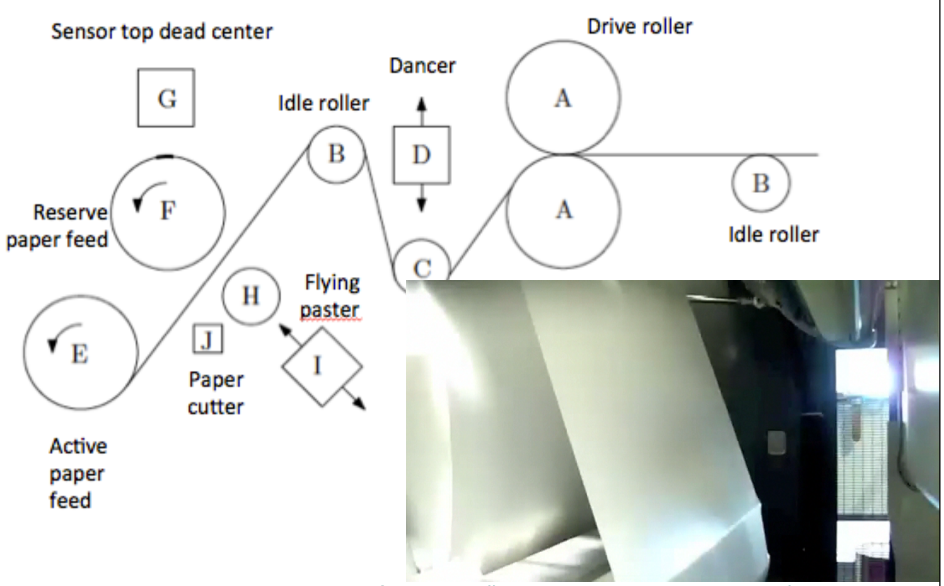
Example – Flying Paster



Source: http://offsetpressman.blogspot.com/2011/03/how-flying-paster-works.ht

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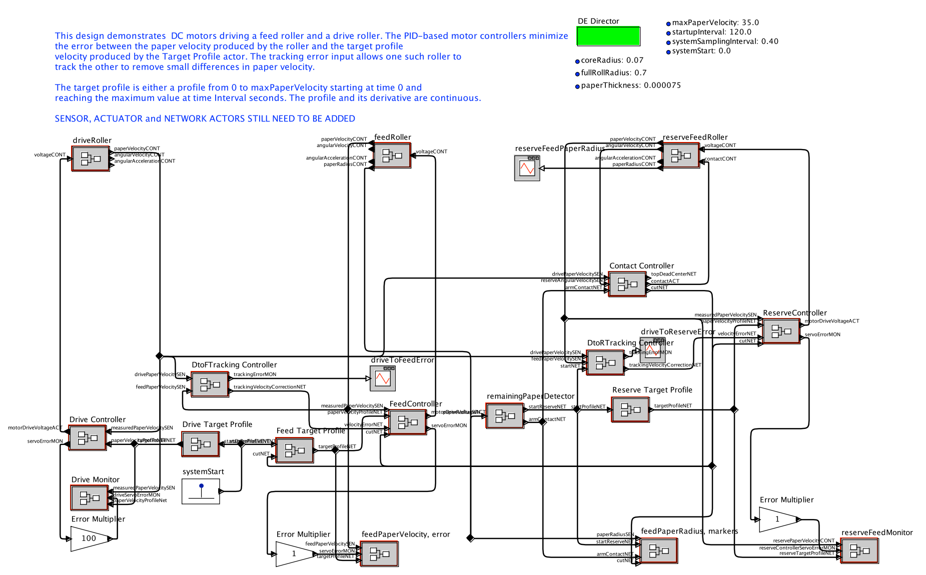
Flying Paster

Printing Press – Model in Ptolemy II

See talk Thursday by Patricia Derler at workshop on Model-Based Design with a Focus on Extra-Functional Properties



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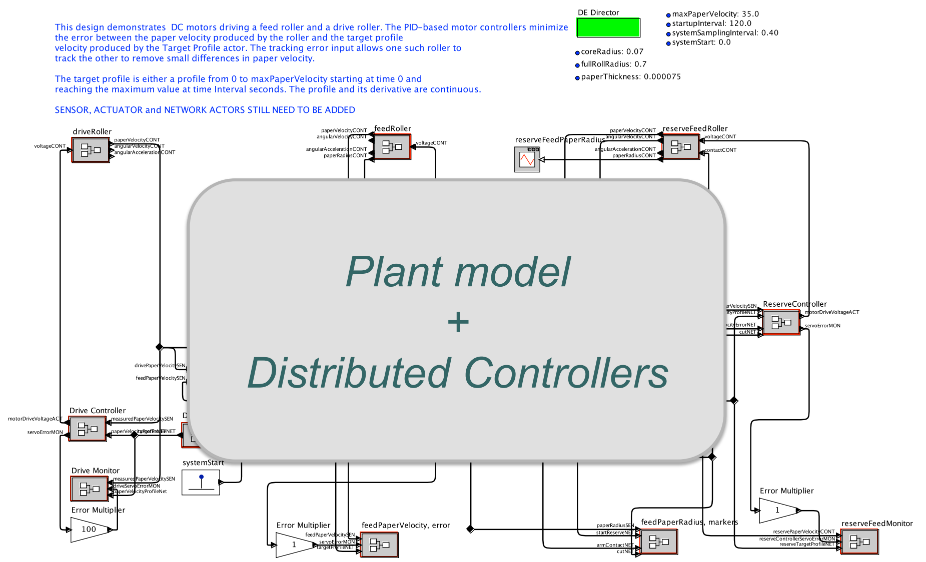

5 Siemens CKI Project Review

Printing Press – Model in Ptolemy II

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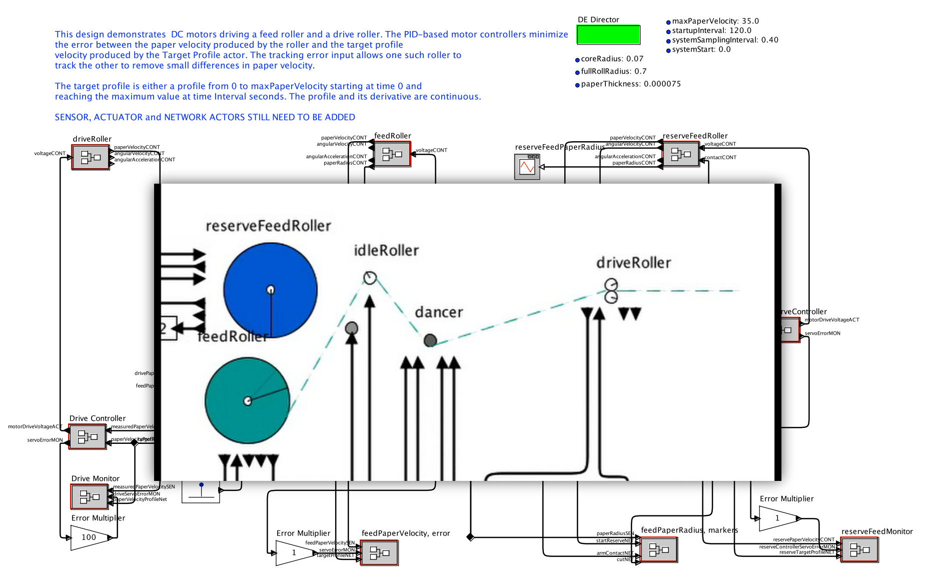

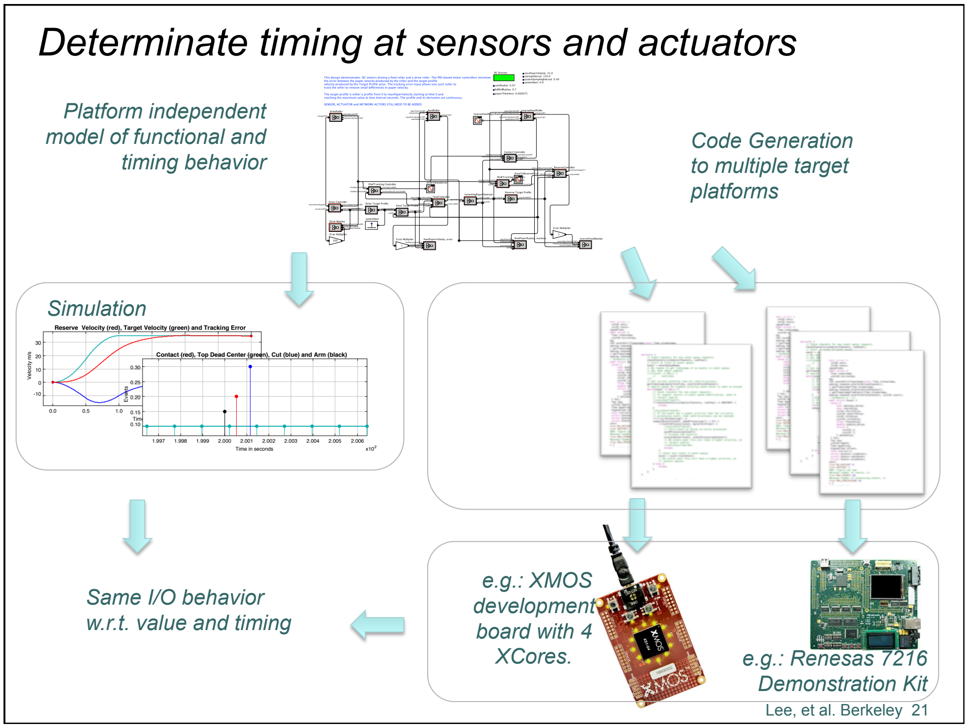
Determinate timing at sensors and actuators
Platform independent model of functional and timing behavior
Code Generation to multiple target platforms
Simulation
Same I/O behavior w.r.t. value and timing
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e.g.: Renesas 7216 Demonstration Kit
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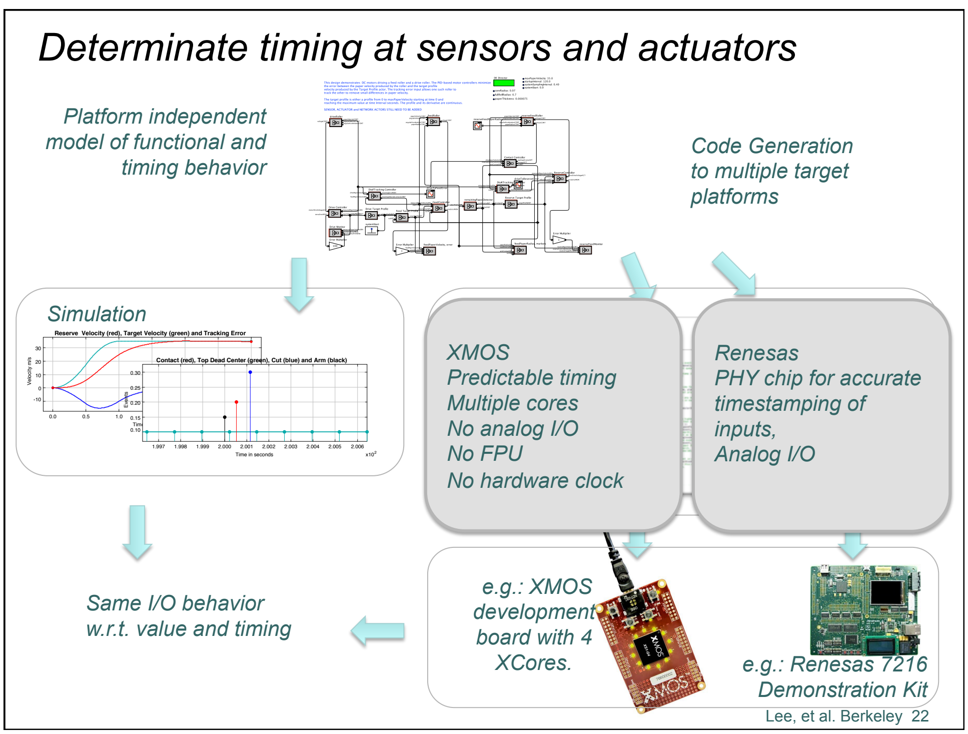
Determinate timing at sensors and actuators
Platform independent model of functional and timing behavior
Code Generation to multiple target platforms
Simulation
XMOS
Predictable timing
Multiple cores
No analog I/O
No FPU
No hardware clock
Renesas
PHY chip for accurate timestamping of inputs,
Analog I/O
Same I/O behavior w.r.t. value and timing
e.g.: XMOS development board with 4 XCores.
e.g.: Renesas 7216 Demonstration Kit
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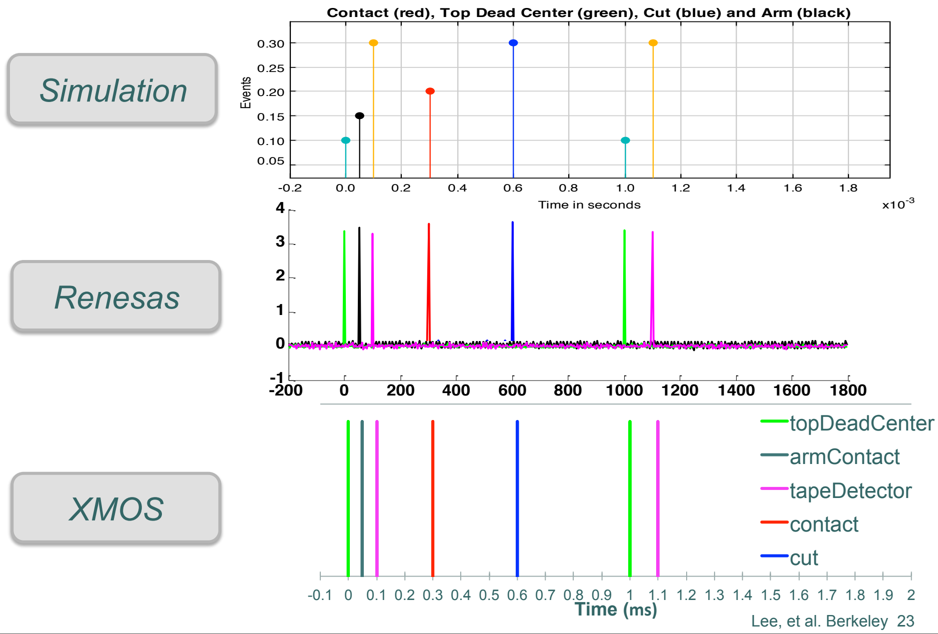
Renesas vs. XMOS: Measured I/O timing



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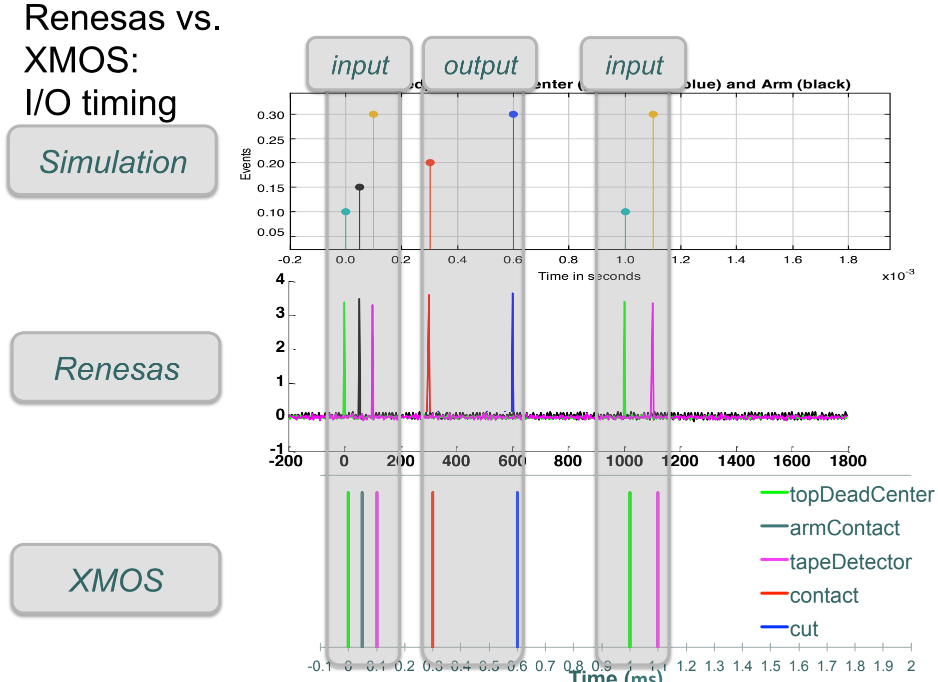
Renesas vs. XMOS: I/O timing



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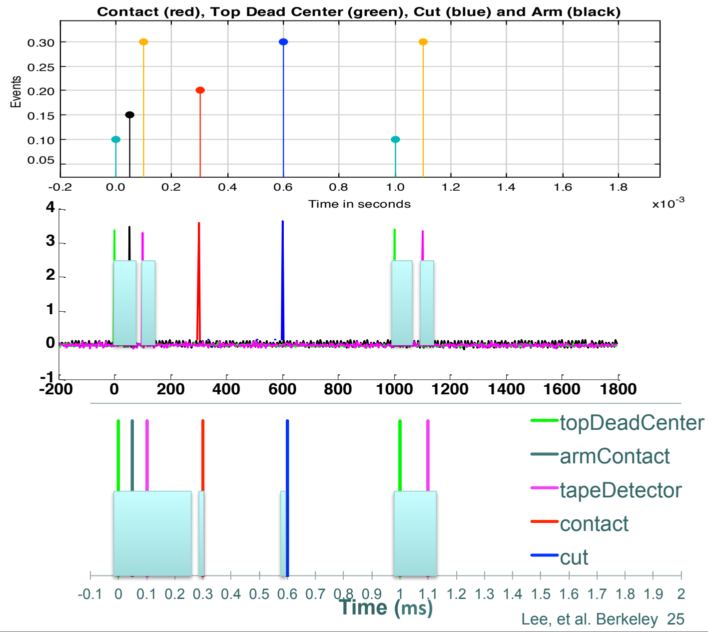
Renesas vs. XMOS: Busy vs. Idle Time

Simulation

Renesas

XMOS



Ptides Publications

http://chess.eecs.berkeley.edu/ptides/

- Y. Zhao, J. Liu, E. A. Lee, "**A Programming Model for Time-Synchronized Distributed Real-Time Systems**," RTAS 2007.
- T. H. Feng and E. A. Lee, "**Real-Time Distributed Discrete-Event Execution with Fault Tolerance**," RTAS 2008.
- P. Derler, E. A. Lee, and S. Matic, "**Simulation and implementation of the ptides programming model**," DS-RT 2008.
- J. Zou, S. Matic, E. A. Lee, T. H. Feng, and P. Derler, "**Execution strategies for Ptides, a programming model for distributed embedded systems**," RTAS 2009.
- J. Zou, J. Auerbach, D. F. Bacon, E. A. Lee, "**PTIDES on Flexible Task Graph: Real-Time Embedded System Building from Theory to Practice**," LCTES 2009.
- J. C. Eidson, E. A. Lee, S. Matic, S. A. Seshia and J. Zou, "**Time-centric Models For Designing Embedded Cyber-physical Systems**," ACES-MB 2010.
- J. C. Eidson, E. A. Lee, S. Matic, S. A. Seshia, and J. Zou, **Distributed Real-Time Software for Cyber-Physical Systems**, To appear in *Proceedings of the IEEE* special issue on CPS, December, 2011.

Conclusions

Overview References:
•Lee. **Computing needs time**. CACM, 52(5):70–79, 2009
•Derler, Lee, Sangiovanni-Vincentelli, **Modeling Cyber-Physical Systems**, To appear in Proc. of the IEEE December, 2011.

Today, timing behavior is a property only of *realizations* of software systems.

Tomorrow, timing behavior will be a semantic property of *programs* and *models*.

Raffaello Sanzio da Urbino – The Athens School