Truetime for Simulation of Networked Embedded Control Systems

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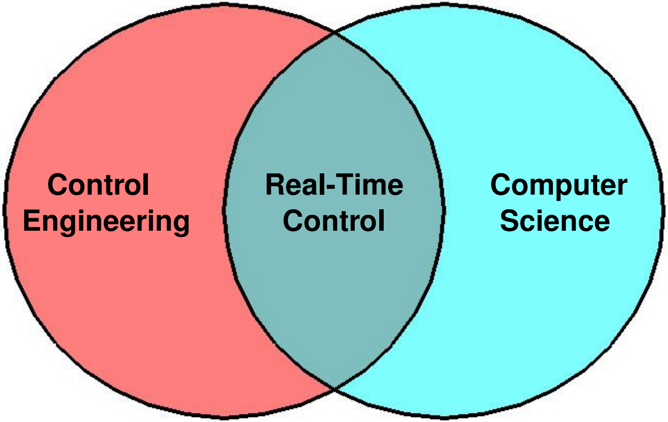
Positioning of TrueTime



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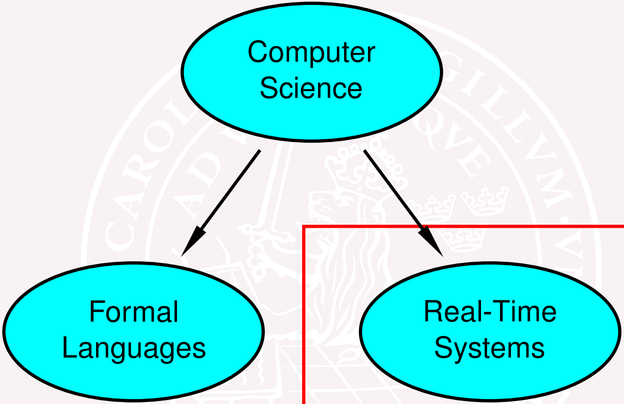

State Machines
Petri Nets
Timed Automata

RT Operating Systems
RT Scheduling Algorithms
Network Protocols

TrueTime Main Idea

Co-simulation of control task execution,
network communication, and plant dynamics.

- Simulink blocks that model real-time kernels and communication networks
- The kernels execute user code (tasks and interrupt handlers) written in C++ or MATLAB code
- The simulated application is programmed in much the same way as a real application

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Why Co-Simulation?

- Networked embedded systems are very complex systems
- Temporal nondeterminism
  - preemption by higher-priority tasks, blocking, varying computation times, kernel overhead, . . .
  - network interface delays, queuing delays, (re)transmission delays, lost packets, . . .

A Very Brief History

- 1999 – first release
- 2005 – version 1.3
  - Wireless networks
  - Battery-powered devices
  - Dynamic voltage scaling
  - Local clocks
- 2006 – version 1.4
  - User-defined pathloss function
  - AODV routing
- 2007 – version 1.5
  - Stand-alone network interface blocks

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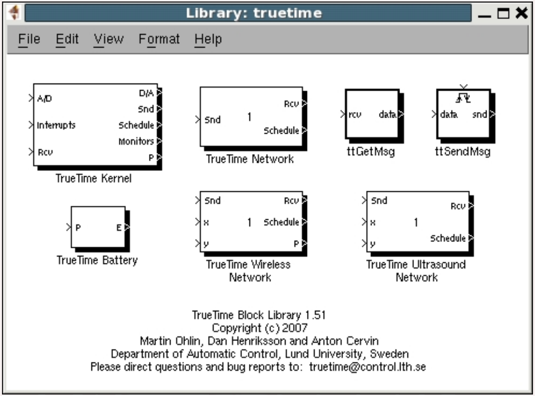
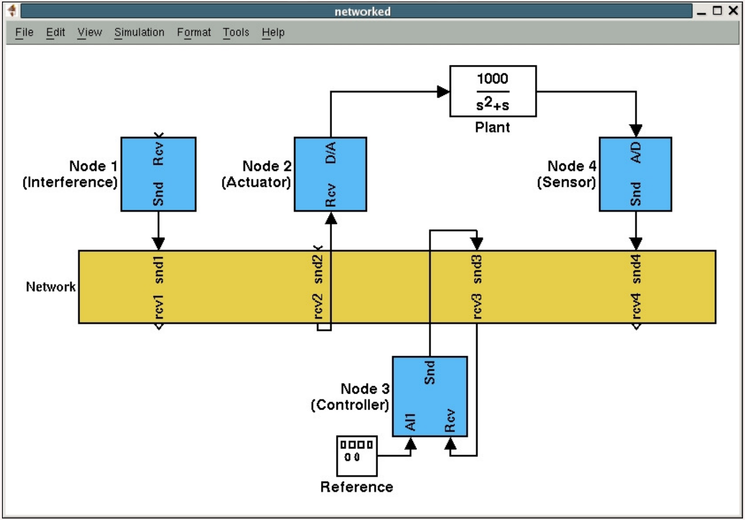
The TrueTime block library



- A Kernel block, three Network blocks, and a Battery block
  - Simulink S-functions written in C++
  - Event-based execution using zero-crossing functions
  - Portable to other simulation environments

Example – Networked Control Loop



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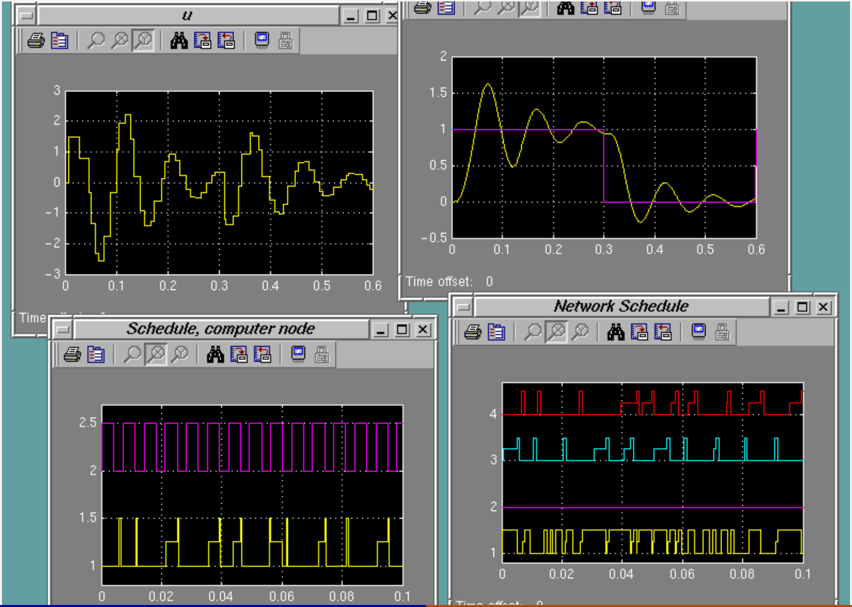
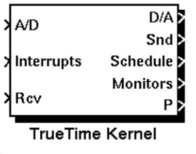


The Kernel Block

- Simulates a generic real-time kernel with A/D-D/A and network interfaces
- Executes user-defined tasks and interrupt handlers
- Supports various scheduling policies
- Supports all common real-time primitives (sleepUntil, setPriority, wait/notify, . . .)
- More features: context switch overheads, overrun handlers, data logging, . . .



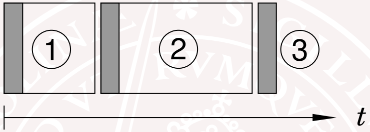
Example of Kernel Initialization Script

```
nbrInputs = 3;
nbrOutputs = 3;
ttInitKernel(nbrInputs, nbrOutputs, 'prioFP');
periods = [0.01 0.02 0.04];
code = 'my_ctrl';
for k = 1:3
   data.u = 0;
   taskname = ['Task ' num2str(k)];
   offset = 0;
   period = periods(k);
   prio = k;
   ttCreatePeriodicTask(taskname,offset,period,prio,code,data);
end
```

Code Functions

- Each task or interrupt handler in the user application must be implemented in a code function
- The code function is called repeatedly by the kernel during the simulation
- The simulated execution time of the code is returned by the code function
- Three options for the implementation:
  - C++ code (fast)
  - MATLAB code (medium)
  - Simulink block diagram (slow)

Code Segments



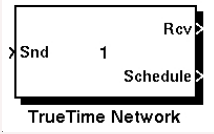
- The code is divided into one or several segments
- The code in each segment is executed nonpreemptively
- Multiple segments are used to simulate
  - input-output delays
  - self-suspensions
  - waiting (for events, semaphores, monitors, or mailboxes)
  - loops or branches

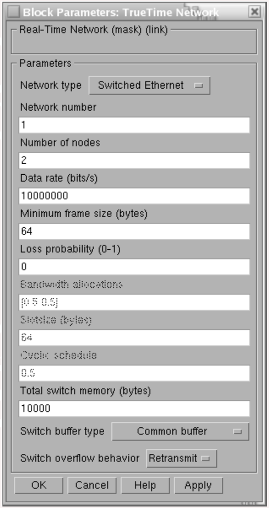
Example of a MATLAB Code Function

```
function [exectime,data] = my_ctrl(segment,data)
switch segment,
  case 1,
     data.y = ttAnalogIn(1);
     data.u = calculate_output(data.x,data.y);
     exectime = 0.002;
  case 2,
     ttAnalogOut(1,data.u);
     data.x = update_state(data.x,data.y);
     exectime = 0.004;
   case 3,
     exectime = -1;
end
```

The Wired Network Block

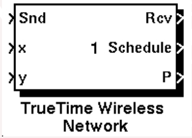
- Supports six common MAC layer policies:
  - CSMA/CD (Ethernet)
  - CSMA/AMP (CAN)
  - Round Robin (Token bus)
  - FDMA
  - TDMA
  - Switched Ethernet
- Policy-dependent network parameters
- Generates a transmission schedule

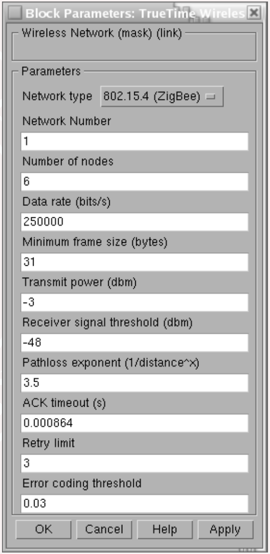




The Wireless Network Block

- Used in the same way as the wired network block
- Supports two common MAC layer policies:
  - 802.11b/g (WLAN)
  - 802.15.4 (ZigBee)
- Variable network parameters
- x and y inputs for node locations
- Generates a transmission schedule





The Wireless Network Model

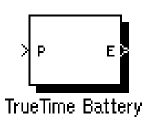
- Isotropic antennas
- Default path-loss formula:

$$\frac{1}{d^a}$$

  - d – distance between nodes $\left(= \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}\right)$
  - a – environment parameter (e.g., 2–4)
- The SIR in the receiver is calculated, and a probabilistic measure is used to determine the number of bit errors
- An error coding threshold is used to determine whether the package can be reconstructed

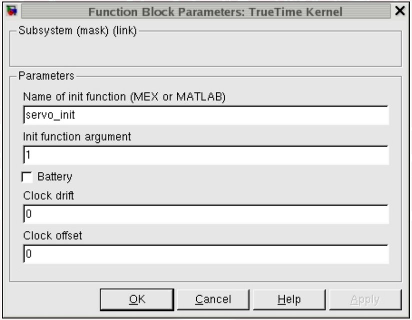
The Battery Block / Dynamic Voltage Scaling

- Simulation of battery-powered devices
- Simple integrator model
  - Discharged or charged
- Energy sinks:
  - Computations, radio transmissions, usage of sensors and actuators, ...
- Dynamic Voltage Scaling
  - The kernel CPU speed can be changed from the application to consume less power



Local Clocks with Offset and Drift

- Distributed systems with local clocks
- Sensor networks are based on cheap hardware:
  - Low manufacturing accuracy ⇒ large clock drift
- Simulate clock synchronization protocols



A Real-World Application

- Multiple processors and networks
- Based on VxWorks and IBM Rational Rose RT
- Used TrueTime to describe the timing behavior
- Has ported TrueTime to a mechatronics simulation environment

“We found TrueTime to be a great tool for describing the timing behavior in a straightforward way.”

More Real-World Applications

Bosch AG

- Extended the network block with support for TTCAN and Flexray
- Used for investigating the impact of time-triggered communication on a distributed vehicle dynamics control system

Haldex AB

- Simulation of CAN-based distributed control systems

TrueTime – Summary

Co-simulation of

- computations inside computer nodes
- wired and wireless communication between nodes
- the dynamics of the physical plant under control
- sensor and actuator dynamics
- the dynamics of mobile robots/nodes
  - position-dependent communication conditions
- the dynamics of the environment
- energy consumption in the nodes

Some Work in Progress

- Multi-threaded C++ version
  - No code segments
- Scilab/Scicos version

Download

TrueTime is freeware and can be downloaded from

`http://www.control.lth.se/truetime`