Final Review
Brussels, December 12th, 2008

Achievements and Perspectives :

Control for Embedded Systems

Cluster leader : Karl-Erik Årzén

Lund University

Outline

- Structure
  - Partners and Activities
- Objectives
  - High-Level Objectives
  - Objectives and Current status per Activity
- Overall Assessment
  - Publications, Events, Research Projects
- The Future
- Scientific Highlights
  - TrueTime
  - Feedback-Based Resource Reservation
  - Event-Based Control (if time allows)

Cluster Partners

Core partners:

- Lund University – Karl-Erik Årzén
- KTH – Martin Törngren & Karl Henrik Johansson
- UPVLC – Alfons Crespo & Pedro Albertos
- CTU – Zdenek Hanzalek





Affiliated international partners:

- Lui Sha – Univ of Illinois
- Tarek Abdelzaher – Univ of Illinois


Cluster Partners

Affiliated industrial partners:

- Ericsson (Johan Eker)
- ABB Automation Technology Products (Alf Isaksson / Ulf Hagberg)
- Volvo Car Corporation (Jakob Axelsson)
- Volvo Technology (Magnus Hellring)
- Honeywell Prague Laboratory (Vladimir Havlena)
- Maquet Critical Care (Klas Engwall)
- dSpace (Joachim Stroop)

Activities

Cluster Integration Activities:

- Control for Real-Time Computing – Karl-Erik Årzén
- RT Techniques in Control System Implementation – Alfons Crespo

Network Integration Activity:

- Adaptive RT, HRT and Control – Karl-Erik Årzén

Platform Activity:

- Design Tools for Embedded Control – Martin Törngren

Long-Term Scientific Objectives

Development of methods, tools and theory that allow faster and more efficient development of ***networked embedded control*** *systems that are* ***safer****, more* ***flexible****, more* ***predictable****, have higher degree of* ***resource*** *utilization, and better* ***performance*** *than what is possible today*

Advance the state of the art in applying ***control methods*** *for providing* ***flexibility*** *and* ***robustness*** *and manage* ***uncertainty*** *in* ***embedded computing and communication systems****.*

Design Tools for Embedded Control

- **Objectives:**
  - Long-Term: A platform of tools for tasks in the development process for resource-constrained embedded control systems
- **Focus in Year 4**
  - Individual tool development, mainly Torsche (CTU) and TrueTime (Lund)
  - Development of a new middleware framework for dynamically configurable systems within the context of DySCAS.
    - architecture design, development tools, verification, validation and a demonstration built on the Saint truck
  - Continued efforts for cross-cluster discussions on model and tool integration
  - Further work on model and tool integation in the context of the EAST-ADL architecture description language and its integration with domain tools for control design (Matlab/Simulink) and safety analysis (HIP-HOPs). Within the context of ATESST 2.

Control for Real-Time Computing

- **Objectives**:
  - Advance the state of the art in applying control methods for uncertainty handling and as a way to provide flexibility and improved performance in embedded computing and communication systems.
- **Focus in Year 4**:
  - Technical work involving one or several partners:
    - Control of server systems (Lund, KTH, UIUC)
    - Feedback-Based Resource Management in Cellular Devices (Ericsson, LUND)
    - Control and Optimization of Networked Systems (KTH, Ericsson, ABB, LUND)
    - Dynamically Configurable Automotive Embedded Systems (KTH, Volvo)
    - Dynamic Memory Management (UPVLC)

Real-Time Tech. in Control System Impl.

- **Objectives**:
  - Advance the state of the art in applying real-time system methodology for embedded control system implementation
- **Focus in Year 4**:
  - Common framework activities have proceeded
  - Event-based control (Lund, KTH) (effects of delay, jitter and noise, limit cycle analysis, network scheduling, event-based PI control, state estimation)
  - Time delay and jitter compensation (UPVLC, Lund, KTH)
  - OS and language support for embedded control systems (UPVLC)
  - Scheduling and control co-design techniques (UPVLC)
  - Wireless Embedded Control and Automation (KTH, ABB, LUND, CTU)
  - Scheduling of control and signal processing calculations on FPGAs (CTU)

Adaptive RT, HRT and Control

- **Objectives**:
  - The union of the objectives for the cluster activities, but on a network-wide level involving the ART and RTC clusters
- **Focus in Year 4**:
  - Joint research projects between the Control, ART and RTC cluster
    - Lund/SSSA, Lund/Linköping, UPVLC/York, UPC/SSSA/Aveiro, CTU/Porto, PARADES/INRIA/Trento/VERIMAG, KTH/PARADES
    - FRESCOR project (CTU, UPVLC, UCantabria, SSSA, York, TUKL, Enea, Evidence, Thales,
      Rapita, Visual Tools)
    - ACTORS project (Ericsson, Lund, TUKL, SSSA, EPFL, Akatech, Evidence)
    - Model-Based development: Models and Tools Integration (KTH/CEA/Volvo)
  - Jointly organized CDC session (INRIA/Lund)
  - Jointly organized workshop on ”Dataflow models in embedded systems”

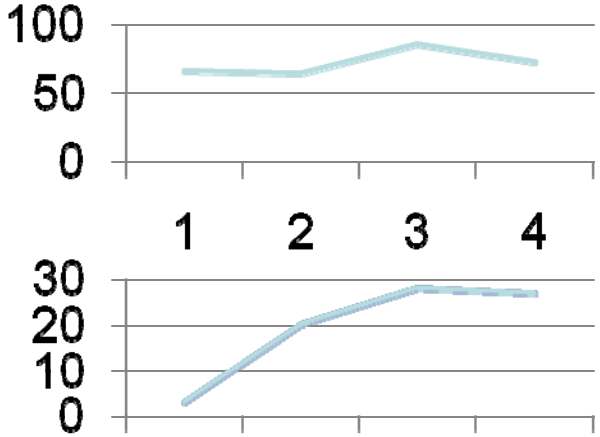
Additional Comments for Year 4

- Artist2 Embedded Control Graduate School
  - KTH, 26-30 May 2008
- Industrial collaboration continues to increase
  - Volvo, Ericsson, ABB, Siemens, Dassault Systems, Modelon,
- The Bridgit embedded control benchmark repository expanded
- Joint textbook development between KTH, Lund and Chalmers continued

State of the Integration in Europe

- A strong European research network on control for embedded systems
- The partners are well connected:
  - All partners are well established in the mainstream control community
  - All partners are well established in the embedded/real-time community
  - KTH and Lund are well established in the hybrid control community
  - KTH is well established in the wireless sensor network community
  - Lund and KTH have strong connections to the US control and embedded system communities ("*cyber-physical*")
    - Caltech, UIUC, UC Berkeley, …

Overall Assessment at the end of the NoE



- Overall assessment: Very Good
  - ~270 individual publications over four years
  - ~75 joint publications over four years
  - 2 roadmaps, 1 scientific research agenda, 1 tool survey
  - Large number of events (co-)organized, e.g.,
    - Two int. workshops on control for embedded systems (05,07)
    - Graduate course on embedded control systems (05,06,07,08)
    - Special sessions or workshops at CDC-ECC (05), IFAC World Congress (05,08), CDC (08), CACSD (07), DATE (07), CAV (07)
    - Workshops on Control in AUTOSAR and Dataflow Modeling for Embedded Systems
  - Large number of internal cluster meetings (~4 / year)

Overall Assessment at the end of the NoE

- Strong connections to other Artist clusters (e.g., ART and RTC)
  - Strong participation at Artist Summer School (Autrans)
- Large number of European and national projects :
  - ArtistDesign
    - KTH and Lund (core partners), UPVLC and CTU (affiliated partners)
  - EU FP6 STREPs and IPs
    - FRESCOR, SOCRADES, DySCAS, ATESST, SENSE
  - EU FP7 STREPs
    - ACTORS, VIKING, WIDE, FeedNetBack, Euro-NF (NoE), ATESST2, CHAT, AEOLUS
  - ARTEMESIA
    - CESAR (KTH)
  - ITEA 2
    - EUROSYSLIB

Overall Assessment at the end of the NoE

- National projects (some examples):
  - Large Swedish Linneaus grants (7.5 M€ / 10 years) to KTH (ACCESS (06)) and LUND (LCCC (08))
  - ICES KTH Embedded Systems Centre (KTH, Ericsson, ABB, Scania, Volvo)
  - EASE Industrial Excellence Centre for Embedded Applications Software Engineering (LUND, Ericsson, Sony Ericsson, ABB)
  - ENGROSS, FISS2 (LUND)
  - NECS, Promos, RAMCOORAN, reSENSE, SERAN (KTH)
  - Centre for Applied Cybernetics (CTU)
  - SIDIRELI and RT-MODEL (UPVLC)

Events organized during Y4

- The Fourth Graduate School on Embedded Control Systems, Stockholm, May 2008
- Workshop on “Embedded Control Systems: From Design to Implementation”, IFAC World Congress, Seoul, Korea, 6 July, 2008
- Participated in the “HYCON” workshop “Complex Embedded and Networked Control Systems” IFAC World Congress, Seoul, Korea, 5-6 July, 2008
- Workshop on “DataFlow Modeling for Embedded Systems” with the ART cluster and ACTORS, Pisa, 5 May, 2008
- Invited session on networked embedded control for CDC 2008 organized together with Albert Benveniste from RTC
- KTH and Lund co-organized the EU-US’08 workshop on Networked Information and Control Systems Stockholm, 16 June 2008.
- Zdenek Hanzalek General Chair for the 20th Euromicro Conference on Real-Time Systems (ECRTS 08), Prague, July 2-4, 2008
- Two workshops on model-based development coorganized with ATESST
- Industrial seminar at KTH

The Future

- Within ArtistDesign
  - Thematic cluster: “OS and Networks”
    - Lund (core partner), UPVLC and CTU (affiliated partners)
  - Transversal activity “Design for Adaptivity” led by Lund
  - Thematic cluster: Modeling & Validation
    - KTH (core)
  - The Graduate Course on Embedded Control will continue
    - Preliminarily in Pisa 2009
- Within other European Projects
  - ACTORS, FRESCOR, ……
  - ….

The Future

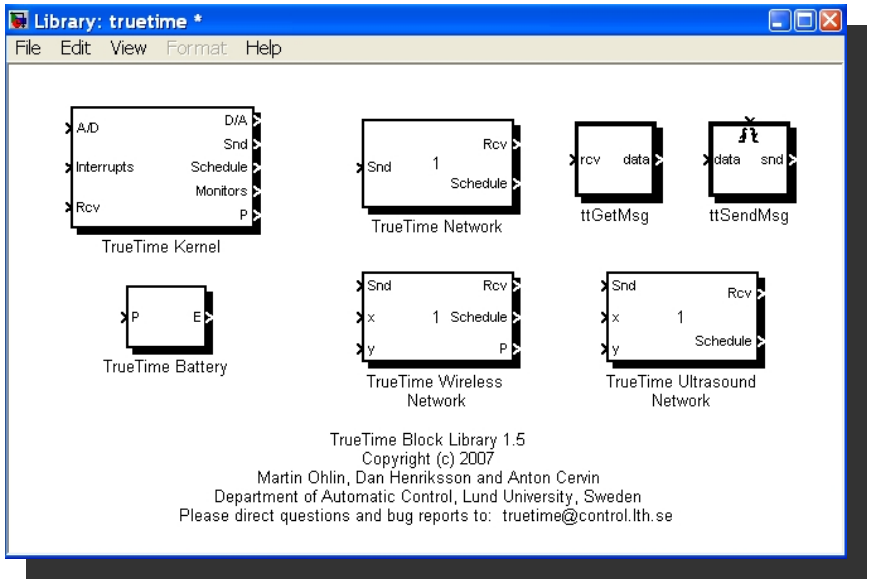
- Other initiatives, e.g.
  - Årzén is co-chairing FeBID 2009
  - KTH and Lund have taken the initiative for a Swedish bid for organizing Cyber-Physical Week in Stockholm, April 2010
  - Joint session for ADHS 09 being organized
  - ….

Scientific Highlights

- Several highlights over the four years:
  - Control Kernel
  - Event-based control
  - Tool development (TrueTime, Jitterbug, TORSCHE, AIDA, …)
  - Robot control in Java
  - Model-based development: model and tool integration
  - Sensor network and MANET simulation
  - FPGA scheduling
  - Co-design of scheduling and control
  - Control of server systems
  - Feedback-based resource management
- A biased selection
  - No demos this year

Highlights: TrueTime

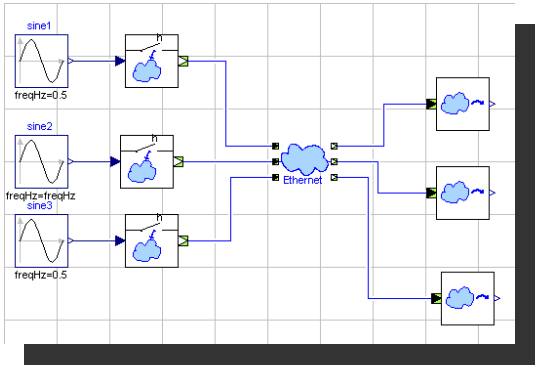
- During the course of Artist2 the TrueTime toolbox from Lund has been developed substantially
- Simulation of
  - Real-time kernels
  - Wired and wireless networks
  - Batteries
- Event-based models embedded in Matlab/Simulink



- A useful tool for R&D in networked and/or embedded control, mobile robotics, and sensor & actuator networks
  - ~1.000 downloads for each new version

TrueTime Examples

- ACTORS STREP
  - Simulation of multicore platforms and Improved support for reservation-based bandwidth scheduling incl. Linux (Lund, SSSA)
- CHAT STREP
  - Support for simulation of PROFINET fieldbus (Lund, Siemens)
- EUROSYSLIB (ITEA 2)
  - Network simulation part ported to Modelica/Dymola (Lund)
- SOCRADES IP
  - Support for Wireless HART (ABB, USiena)
- WIDE STREP
  - TrueTime will be the basis for a design and simulation toolbox for networked control (KTH, Honeywell, USiena)
- RUNES IP
  - Sensor network simulations (recall last years review)



TrueTime Examples

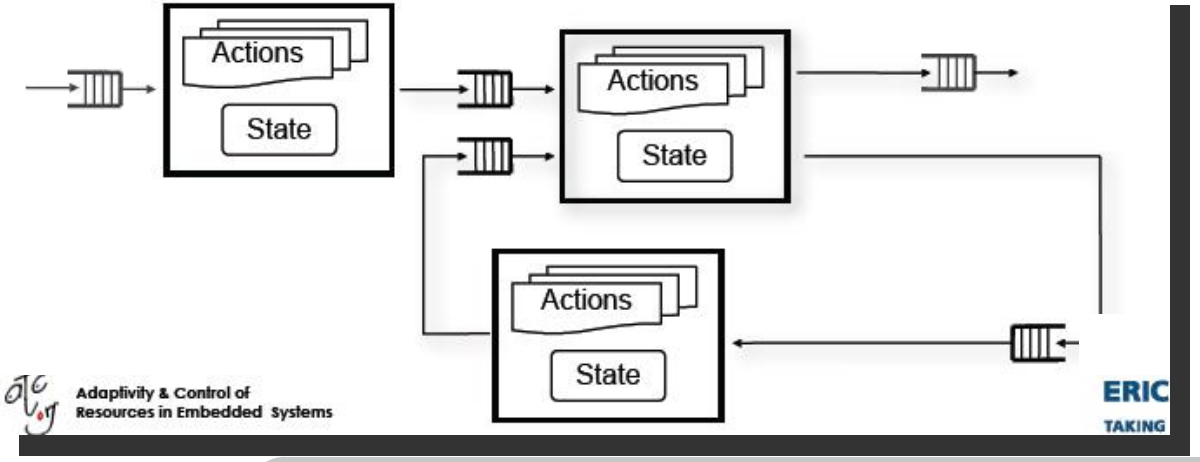
- Bosch AG
  - Implemented support for Flexray and TT-CAN
  - Several Artist2 partners are or have been using TrueTime in their research, e.g.
  - UAveiro
    - Experimental platform for research on flexible networking
  - TUKL
    - Control-based evaluation of different scheduling policies
- Currently
  - Version 2.0 soon to be released
    - GPL license

Highlights: Feedback-Based Resource Management

- The topic of FRESCOR (FP6) and ACTORS (FP7) where most of the cluster partners are active
- ACTORS – Adaptivity and Control of Resources in Embedded Systems
  - Ericsson (coord), SSSA, TUKL, Lund, EPFL, Akatech, Evidence
- Three main parts:
  - Dataflow Modeling for multimedia, control and signal processing
  - Reservation-based resource management (virtualization)
  - Feedback for providing adaptivity
- Demonstrators
  - Media streaming on cellular phones, control, high-performance video
- Platform: ARM 11 multicore with Linux 2.6.26

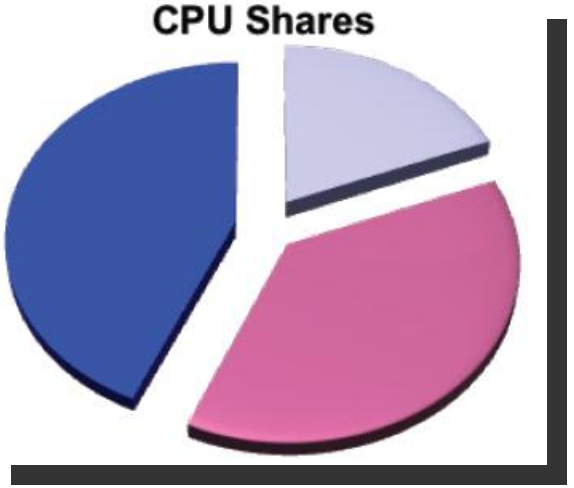
ACTORS: Dataflow Modeling

- Data flow programming with actors (Hewitt, Kahn, etc)
  - Associate resources with streams
  - Clean cut between execution specifics and algorithm design
  - Strict semantics with explicit parallelism provides foundation for analysis and model transformation
- CAL Actor Language (UC Berkeley, Xilinx) http://opendf.org
  - Part of MPEG/RVC



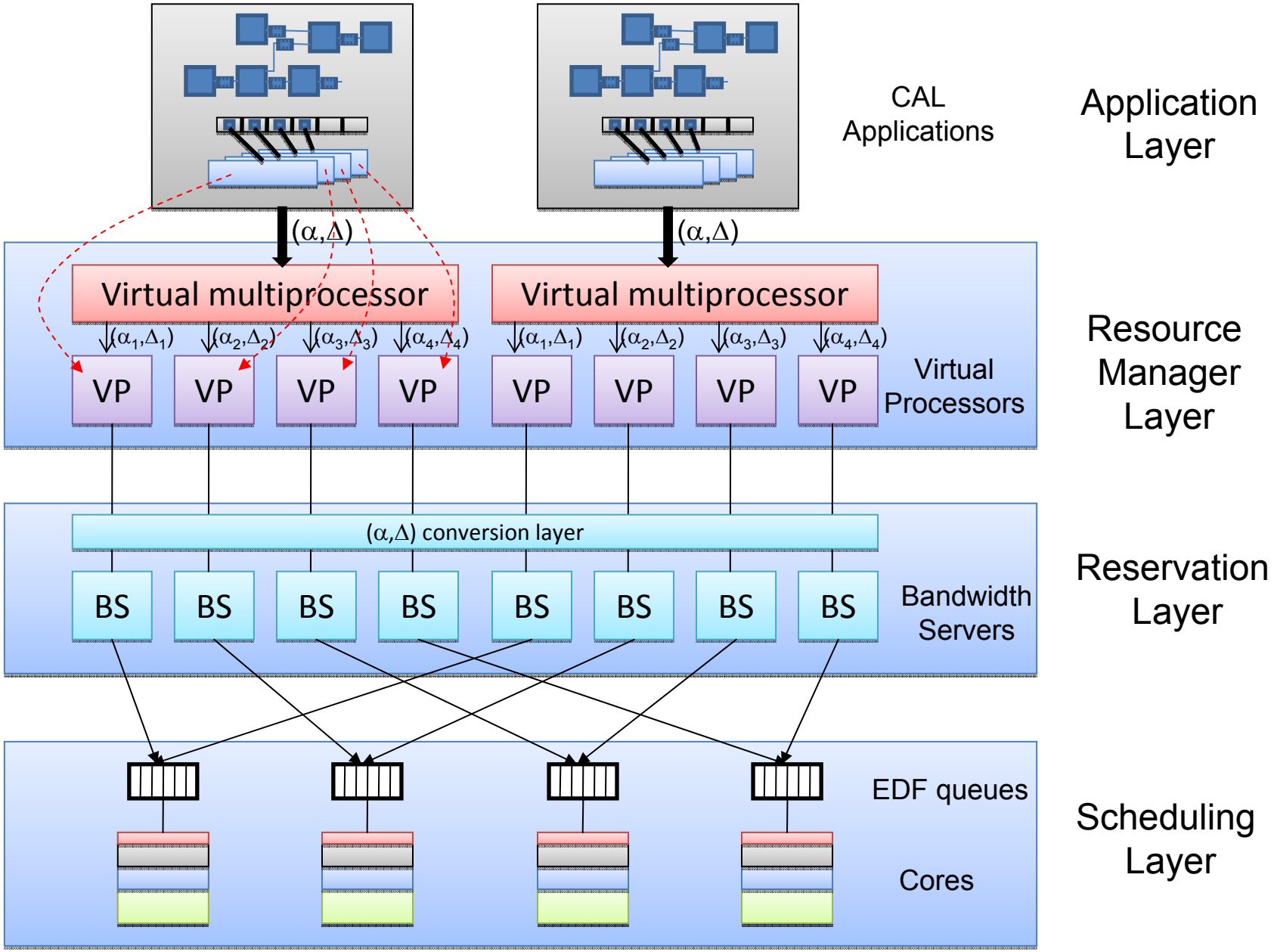
ACTORS: Resource Reservations

- Bandwidth server for resource reservations
- Virtual processors (and multiprocesors)
- Decouples the behavior of parallel activities (temporal isolation)
- Simplifies design and testing since behavior is more predictable
- Resource guarantees make component design feasible



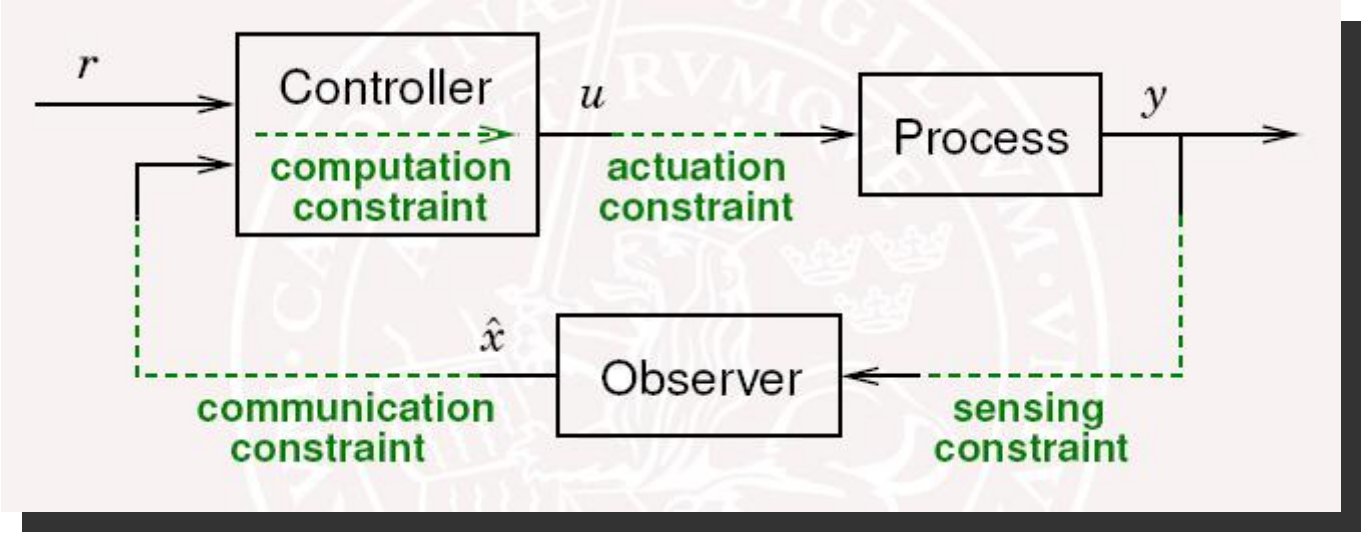
ACTORS: Feedback

- Feedback at multiple levels:
  - Feedback control to achieve system-level adaptivity
    - Control the size of the reservations
    - Global QoS management
  - Feedback control to achieve adaptive reservations
  - Feedback control within the CAL applications
  - Adjust resource consumption to allocated resources
  - Feedback-based parallelization

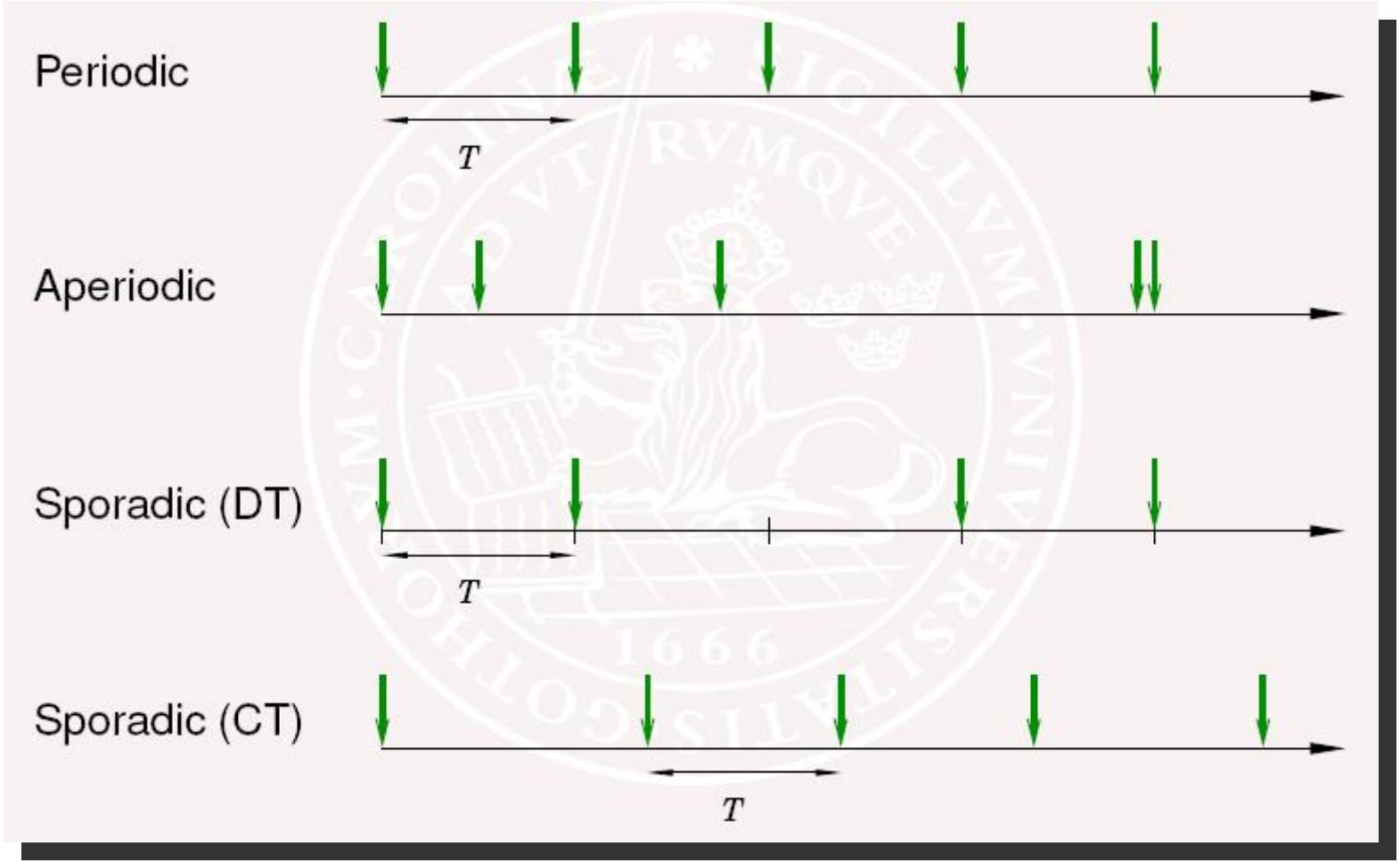

CAL Applications
Application Layer
(α,Δ)
(α,Δ)
Virtual multiprocessor
Virtual multiprocessor
(α1,Δ1)
(α2,Δ2)
(α3,Δ3)
(α4,Δ4)
(α1,Δ1)
(α2,Δ2)
(α3,Δ3)
(α4,Δ4)
VP
VP
VP
VP
VP
VP
VP
VP
Virtual Processors
Resource Manager Layer
(α,Δ) conversion layer
BS
BS
BS
BS
BS
BS
BS
BS
Bandwidth Servers
Reservation Layer
EDF queues
Cores
Scheduling Layer

Highlights: Event-Based Control

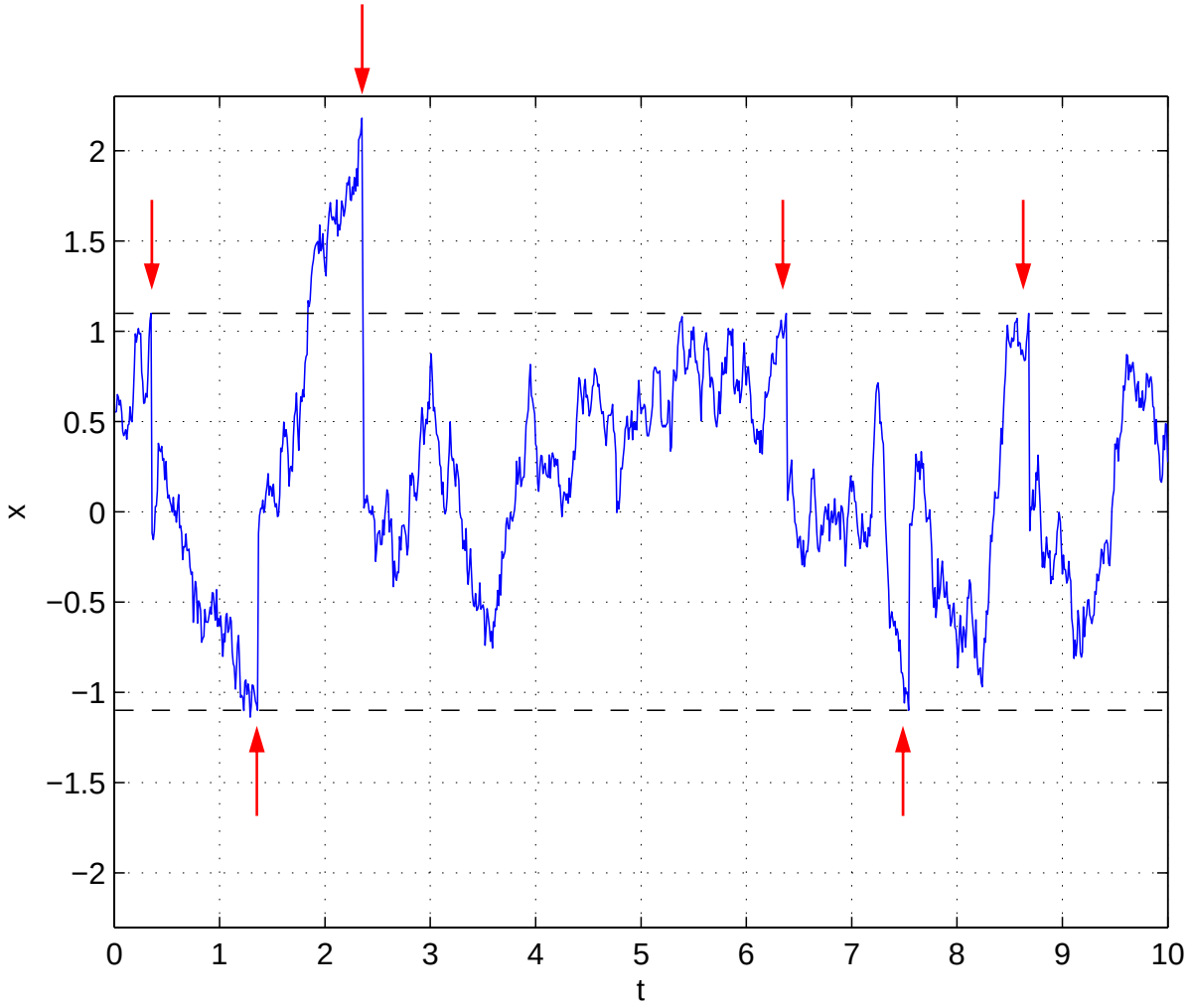
- During the course of Artist2 there has been an increased interest in event-based control in Lund and KTH
- Motivated by the resource constraints in networked embedded control



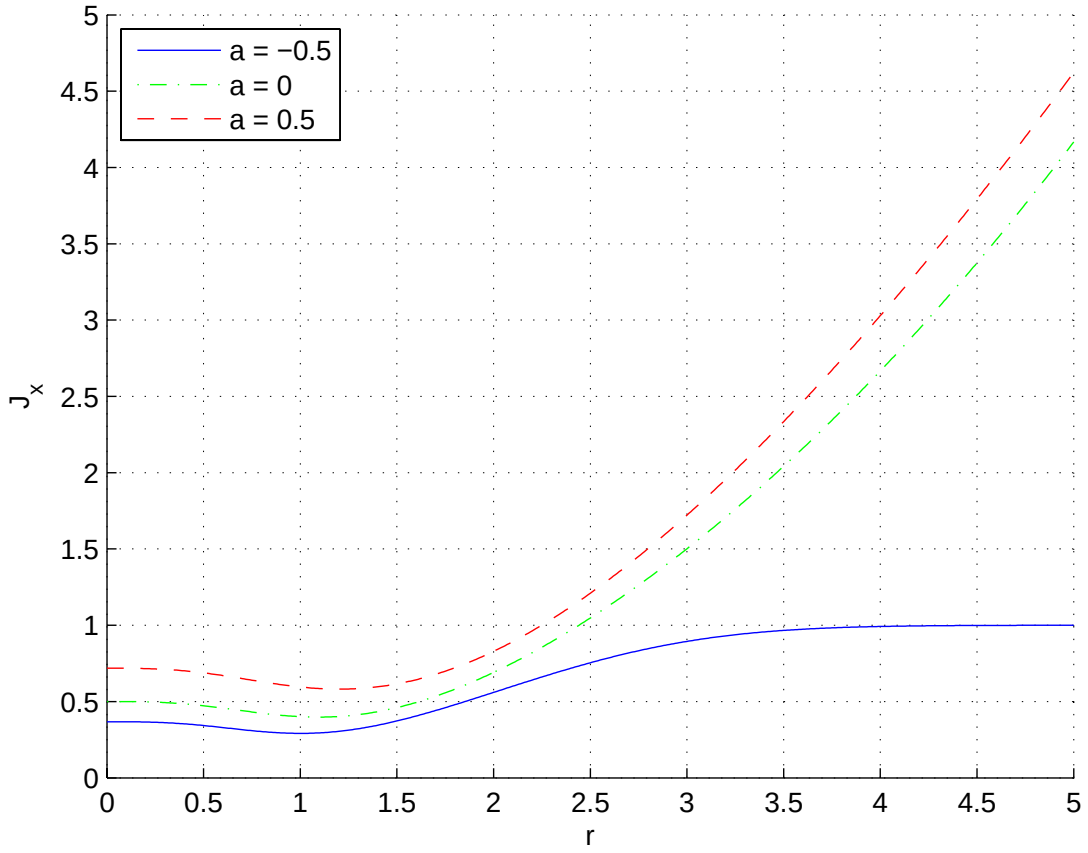
Event Patterns



Example: Sporadic Control (CT)



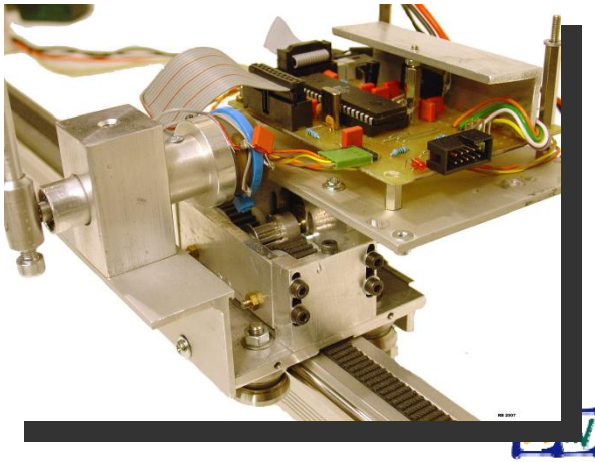
Optimal Choice of Threshold



- Local minimum for some r > 0
  - For small errors, it is better to wait than to control!

Summary

- Event-triggered control can reduce the process variance **and/or** the control frequency compared to periodic control
- Many hard theoretical problems, but approximate solutions avaialable at least for low-order systems
- Last year:
  - effects of delay, jitter and noise, limit cycle analysis, network scheduling (Lund)
  - event-based PI control (Lund, SSSA)
  - state estimation (Lund, KTH)
  - linear servo case study



Summary

- Output:
  - 1 journal article (Automatica), 4 conference publ (CDC*2, MTNS, ECC)
  - Invited session contribution (CDC)
  - Invited session proposal (ECC)
  - Licentiate thesis (Toivo Henningsson) (Swedish intermediate half way PhD thesis)