Highlights from Year 2 – A Quick Glance

Smörgåsbord

Tapas

Outline

- Highlights related to CoDesign Tools – Martin Törngren, KTH
- Embedded Control Design – Alfons Crespo – UPVLC
- Conclusions from the ”Workshop on Interaction Between Control and Embedded Electronics in Automotive Industry” – Karl-Erik Årzén
- New European Projects
- Technical Highlights:
  - Recent advances in event-based control – Karl-Erik Årzén
  - 6 Project Examples

Control for embedded systems - Platforms

Co-design tools

- Individual tool development
- Point integration of tools
- Extended tool survey, including tool characterization

Invited session at Computer Aided Control Systems Design Conference, Munich, Oct. 2006

Towards systematic model/tool integration and management

- Survey
- Cross-cluster cooperation
- Initiatied ARTIST2 synchronization
  - Which tools are availabe? Needs and potential for cooperation and integration?

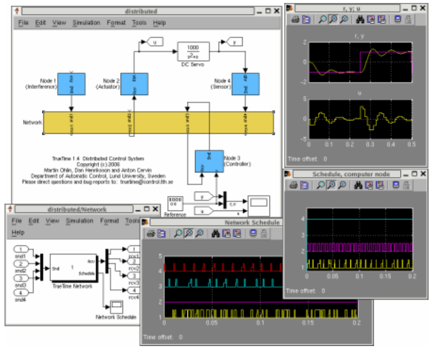
Tool developments, individual and integration

Jitterbug: http://www.control.lth.se/~lincoln/jitterbug/

- GUI in development

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

- Version 1.4 released (1.5 on its way)
- > 2,000 downloads of 1.3



Torsche: http://rtime.felk.cvut.cz/scheduling-toolbox/

AIDA/Saint

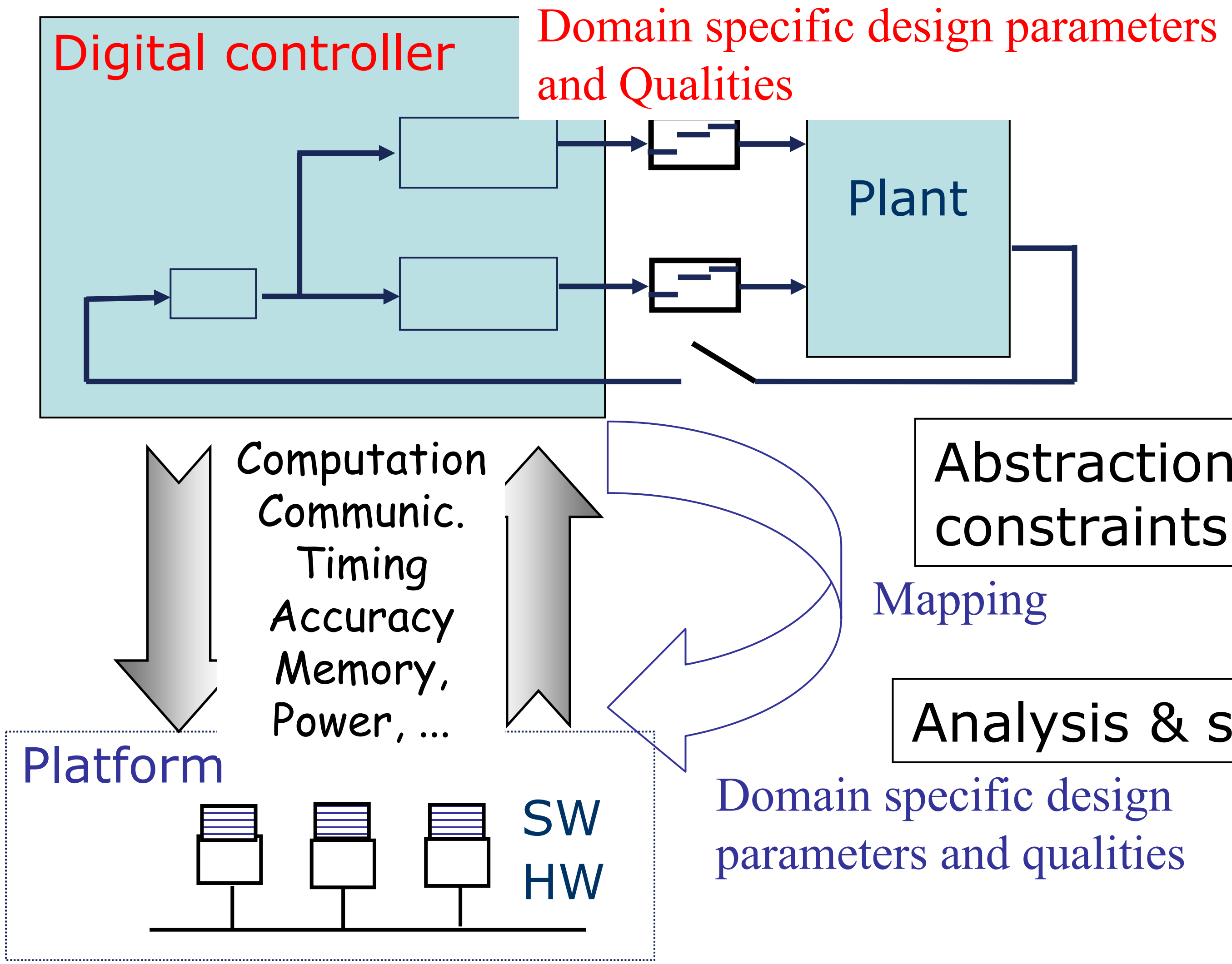
Use-case demonstrations of point tool integration

- TrueTime – co-simulation --- results as inputs to Jitterbug – analytic measures of control performance
- Torsche – response time analysis --- results as inputs to Truetime co-simulation
- Simulink, UML tools, PDM database for system configuration and architectural design

Extended tool survey – Co-design of control systems and their real-time implementation

- Industrial model based development, perspective
- Tools from closely related domains
  - Aires, Metropolis, Giotto, HIP-Hops, Sildex, Syndex, TT-Tech tool suite, …
  - Analytical verification, Distributed systems, Safety & reliability
- Detailed overview and characterization of selected tools
  - AIDA, Jitterbug, ORCCAD, Ptolemy II, RTSIM, Syndex, Targetlink, Torsche, TrueTime
- Discussion: Trends and challenges
  - Complementary tool functionality
  - Opportunities for joint work, need for ARTIST2 synchronization

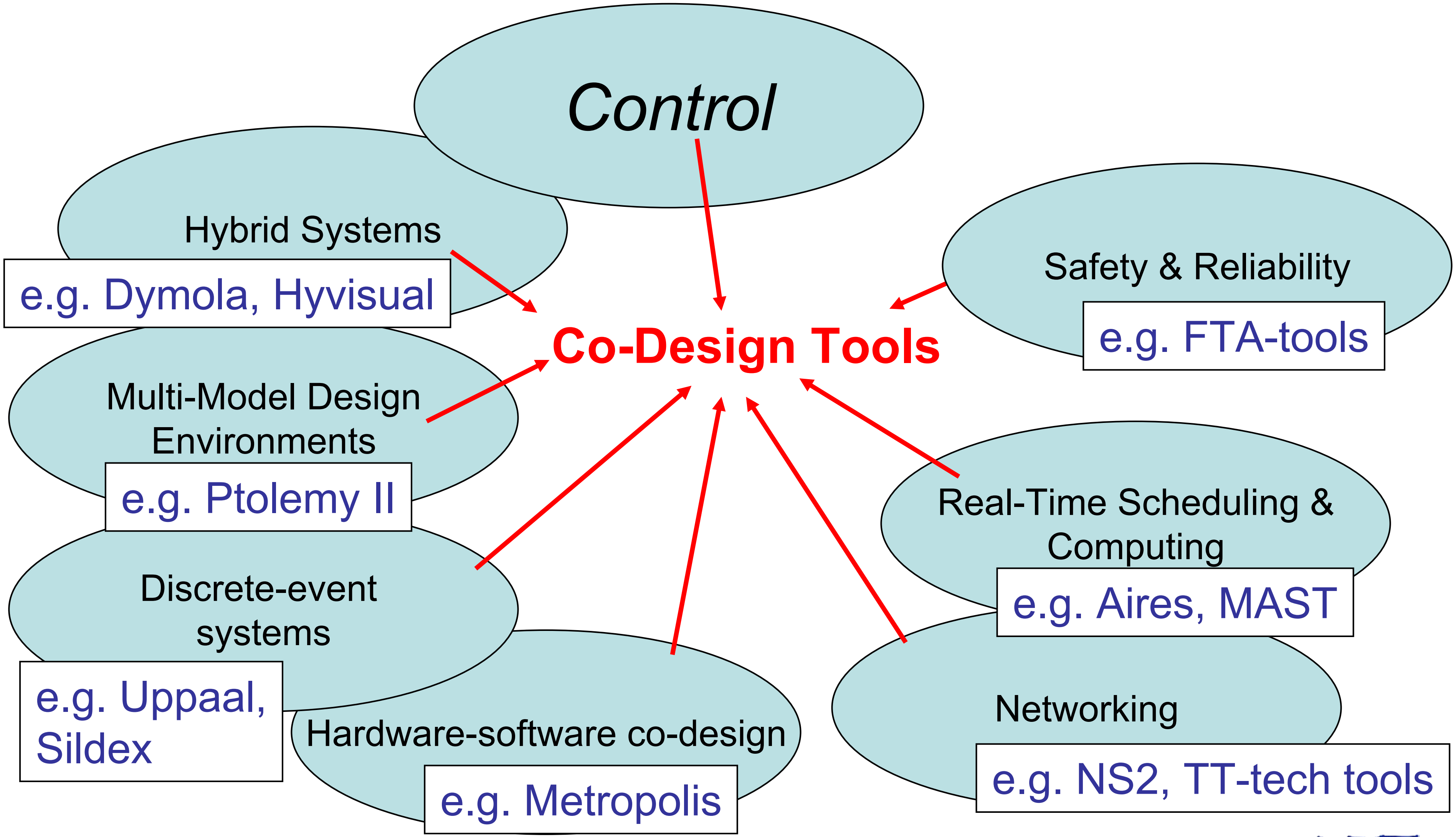
Characterizing co-design tools



Abstraction, constraints & views

Analysis & synthesis

Control-platform co-design



Model and tool integration survey

Coarse grouping of approaches:

- Modeling languages; e.g. SysML, UML2, AADL, EAST-ADL
- Model & tool integration; e.g. ToolNet, GeneralStore, Fujaba, MIC
- Information management; e.g. PDM tools, SystemWeaver, ModelCenter

Domain/discipline origins, different focus, tailorability

Engineering and information management dimensions

Several integration (process) and product decomposition (architecture) patterns

APIs, Formats, Model transformations, Information models/languages

Product analysis and synthesis

Adaptability, Configuration management, consistency, views, work-flow management

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Common framework definition

- *A **common framework** of the **control parameters** that can be influenced by an embedded control system implementation*

- ***Real time operating systems criteria** that can be adjusted to **increase the robustness** of the control system*

Common framework of the control parameters

Parameters analysis:

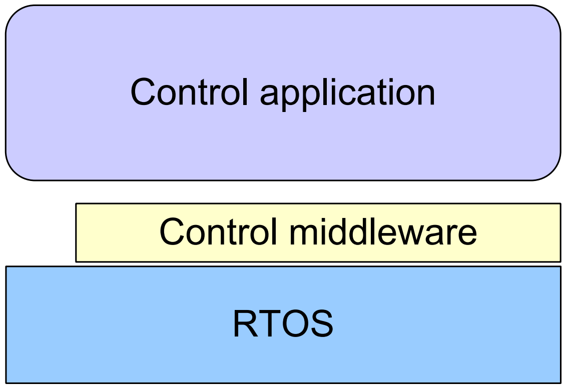
- **Structural**. Linked to the control structure.
  - single/multiple loop, adaptive, coordinated, fault tolerant
- **Requirements / Performance**
  - Temporal aspects, frequency, cost indexes, control effort
- **Operational**
  - Timing Parameters, Latencies, Data availability, Event based control.
- **Computational**
  - Fixed-time computation, Variable-time computation, Optional parts: reasoning, optimization

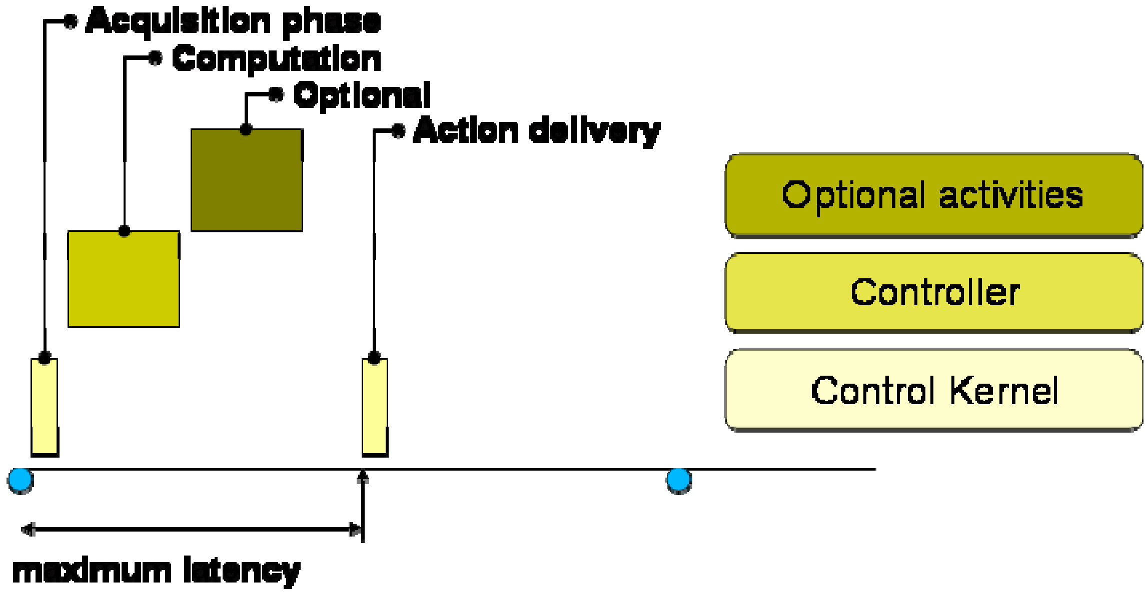
Control Design

- Performances: Control effort
- Sampling pattern:
  - Sampling period, Multirate operation, Nominal delays, Delays interval, Sensed data availability, Control data availability
- Control strategy:
  - Alternative controllers, Refining (optional) tasks, Controllers transfer policy, Internal information updating
- Timing Parameters:
  - Priority, Relative deadline, Execution time distribution, Response time, Input / Output jitter, Control server period and budget, …
- Real-time operating system support
  - Scheduling policies, control kernel support,

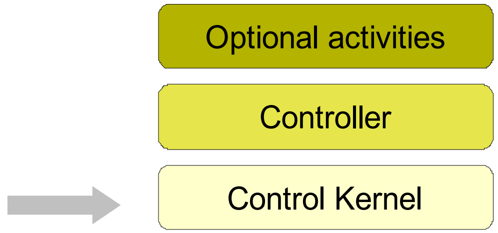
Control Implementation

- To provide a specific middleware for control applications and a scheduling scheme to execute complex control applications





Control kernel



Functionalities

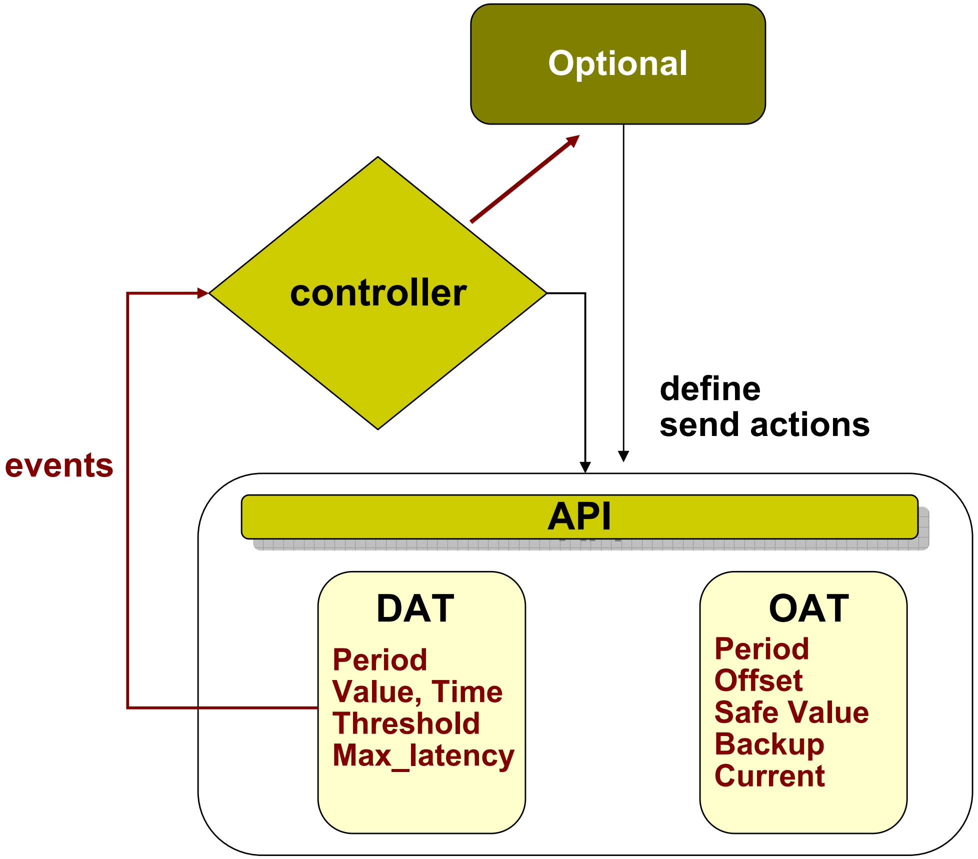
- **Ensuring control action (CA) delivering** at time even if the calculated action for this period has not been updated. In this case, a **backup control action** has to be delivered
- **Data acquisition** of major signals. A **past data** is considered **better than a delayed data**
- **Transfer to new control structure**: Control system provides several regulators that can be used in different situations
- **Communication facilities**

Control scheme

Optional activities

Controller

Control Kernel



RTOS support: Implementation

- A new RTOS **eRTLinux (Partikle core)** has been developed by UPVLC
  - POSIX Compliant
  - Control Kernel support
  - Control Server support
  - C, C++, Ada, RTJava
- It can be **deployed** for three targets:
  - Linux process
  - Stand-alone (bare machine)
  - XtratuM domain (system partition with temporal and spatial isolation)

The control middleware is under development.

Control Kernel features

- **Control kernel extracts** the **basic control services** and defines a middleware for control purposes
- The scheduling scheme that support this architecture permits the execution of the control kernel and control loops
- Different scheduling policies can be applied to different control levels
- The control kernel obtains an improvement with respect to the CPU use when the system is in stable conditions
- The control kernel can be implemented in hardware or in a RTOS
- The CPU saving allows the execution of optional parts to improve the control answer or to recalculate predictive models

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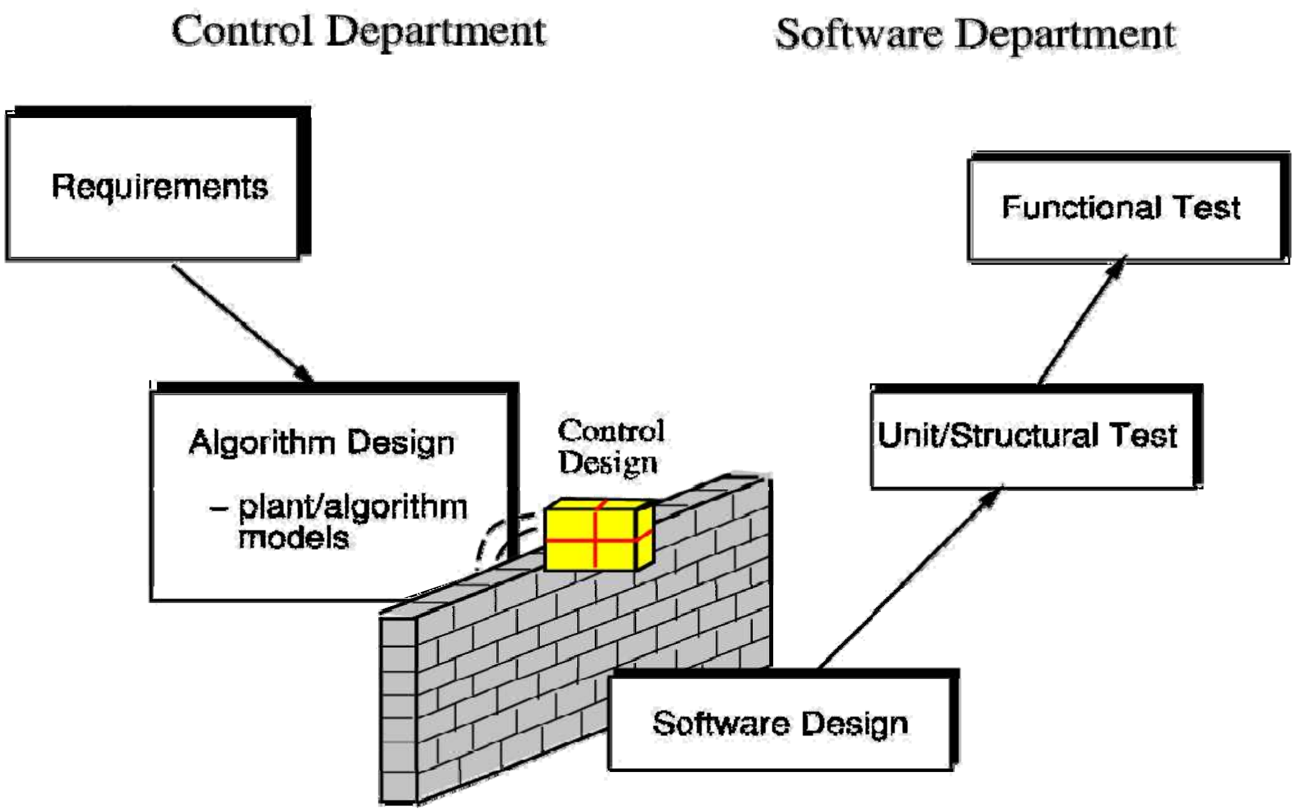
Conclusions from the Workshop on Interaction Between Control and Embedded Electronics in Automotive Industry

- Co-located and integrated with the ”Beyond Autosar” workshop
- Organized jointly with the RT Components cluster (Albert Benveniste and Werner Damm)
- Three keynote presentations:
  - Stefan Kowalevski, RWTH Aachen (Bosch)
  - Karl-Erik Årzén
  - Carlos Canudas de Wit, LAG Grenoble
- Panel discussion

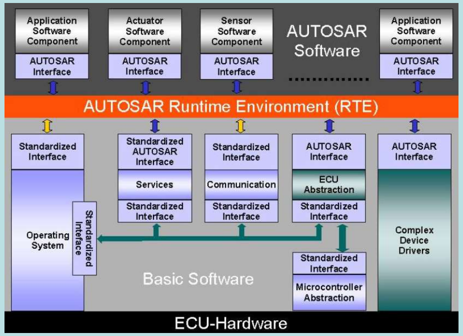
Conclusions

- There is a still a misunderstanding between control & software engineers in the automotive industry



Different Worlds

Software Community



OMG

UML2

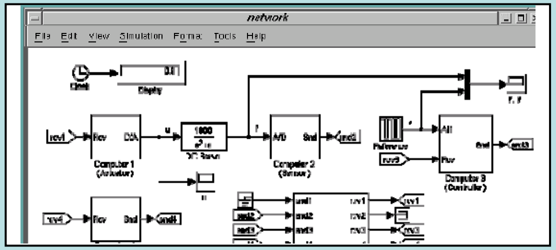
SysML

Marte

MDA

EAST ADL

Control Community



Modelica

Simulink components

Real-Time Workshop

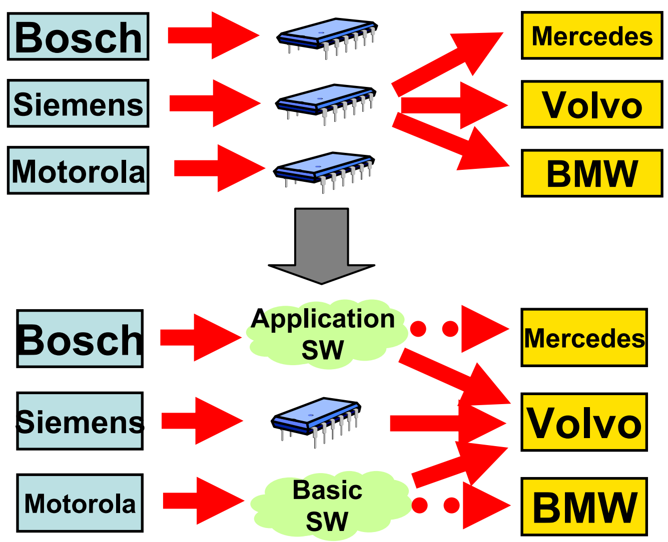
Stateflow

Model-based design

?

Conclusions

- The move from federated to integrated architectures will have large consequences for automotive control
- The needs of control should have strong influence on the integrated architectures
  - Control is absolutely essential in modern cars
    - Powertrain, emissions, vehicle dynamics, safety systems, …
  - Control gives performance, safety, and low emissions



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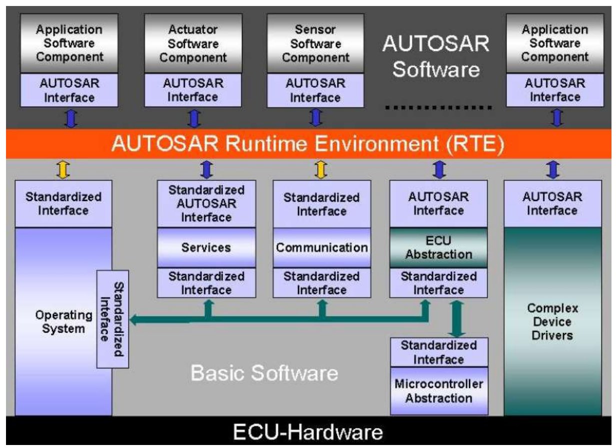


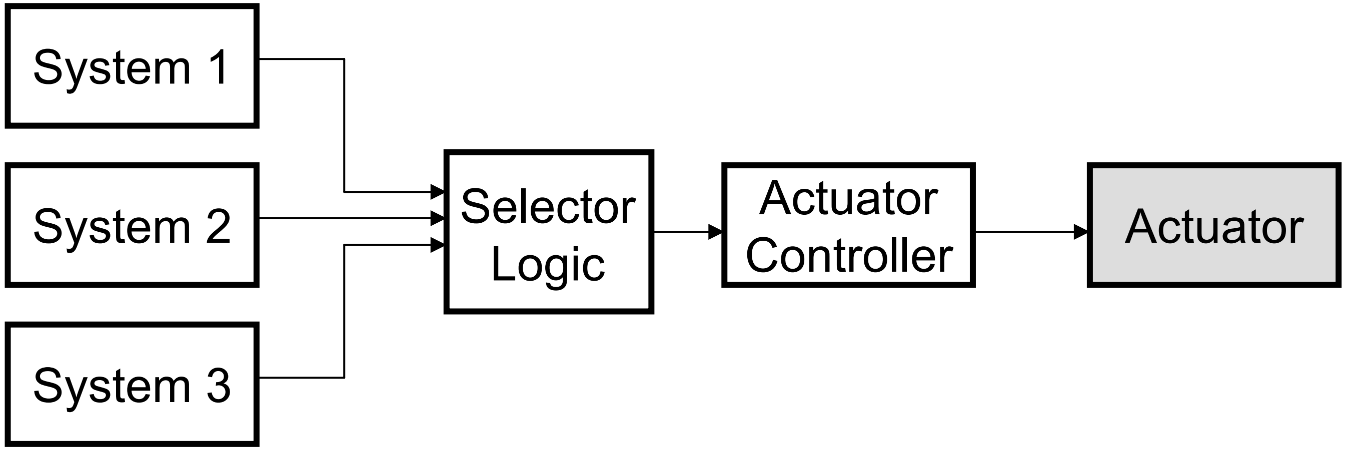
Consequences for Control

- A sensor will be used by several systems
  - part of the vehicle platform, or
  - part of one system but made available to other systems, possibly using middleware techniques

⇒ **Sensor components will be special**

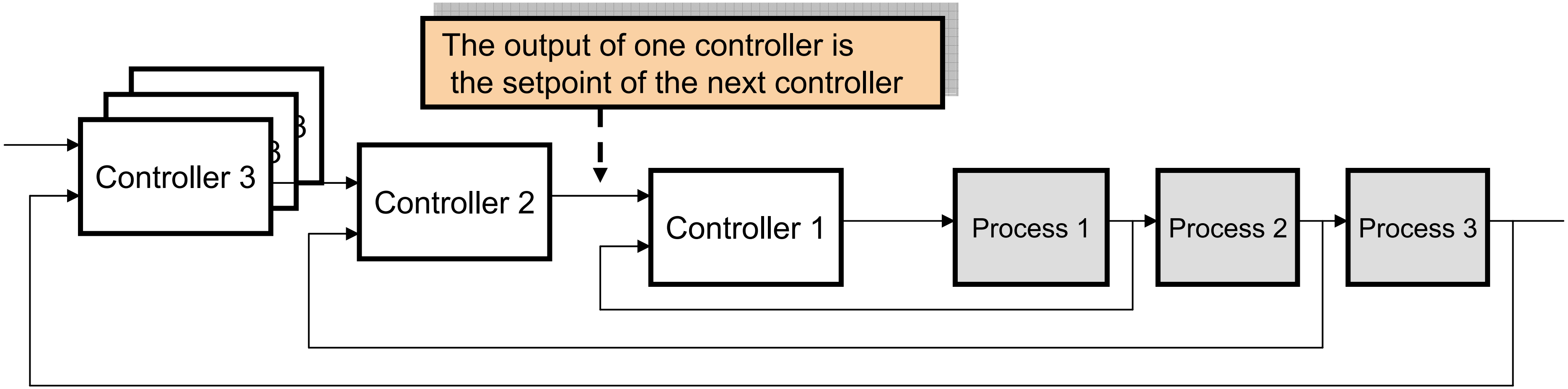
- The same actuator will be used by several systems
  - Brakes will be used by intelligent cruise control, lane following system, collision avoidance system, ESP, anti-rollover, sidewind compensation, ..

⇒ **Actuator components will be special**



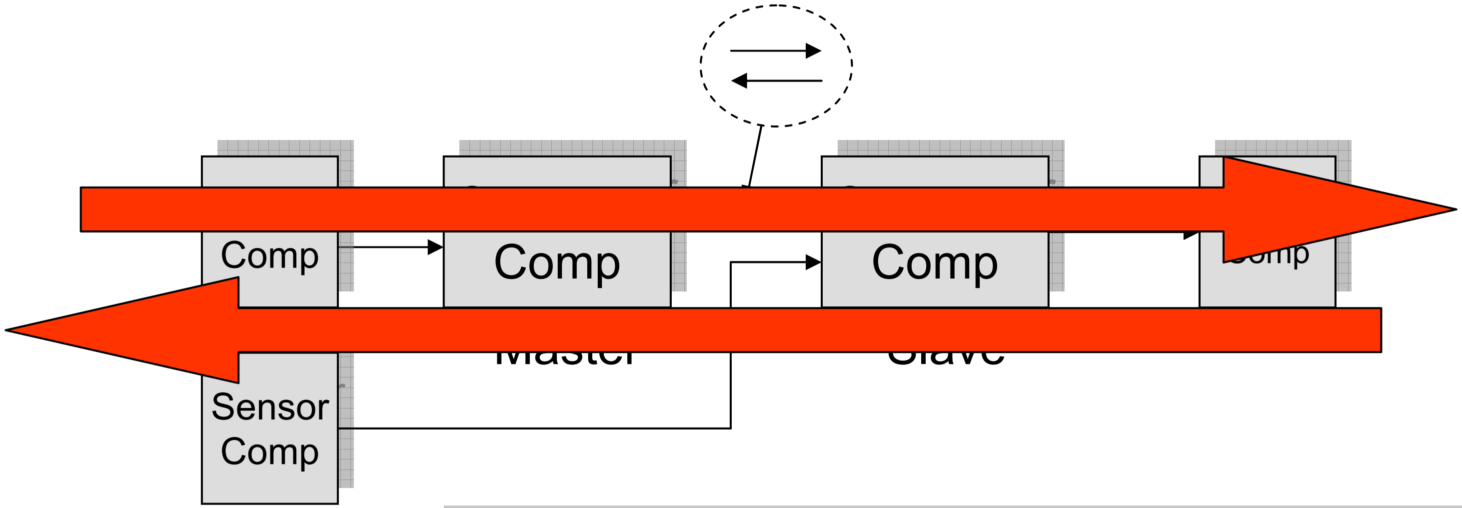
Consequences for Control

- Cascaded control structures will dominate
  - hierarchical, layered
- The different controller components will be part of different systems residing on the same or on separate ECUs



Conclusions

- There are no clear-cut answers on the ET/TT debate from a control perspective
  - It is an advantage if sampling is time-triggered
    - Ex. multi-input controllers with sensors at different nodes
  - It is an advantage if actuation is event-triggered
    - A short but varying input-output latency is almost always better from a control performance point of view than a long but constant latency, also if the latter is compensated for
    - Specially important in multi-layer cascade structures



Conclusions

- The move from a federated to an integrated architecture opens up new possibilities for automotive control
  - The constraints of the federated system architectures have had a strong impact on how the control systems currently are structured
  - With an integrated architecture new ways of structuring the control systems are possible
- Take a completely new look upon how the overall control system for a car ought to be structured, including powertrain control, chassis control, safety systems, etc.

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New European Projects

- Service-Oriented CRoss-layer infrAstructure for Distributed smart Embedded deviceS (SOCRADES) – EU/IST IP
  - Schneider Elec. (coord), **ABB**, Siemens, **KTH**, …..
- Framework for Real-time Embedded Systems based on ContRacts (FRESCOR) – EU/IST STREP
  - Universidad de Cantabria, University of York, Scuola Superiore Sant´Anna, TU Kaiserslautern, **UPVLC, CTU**, ENEA, ….
- Smart Embedded Network of Sensing Entities (SENSE) – EU/IST STREP
  - ARC Seibersdorf, **UPVLC**, PARAGON, University of Galati, University of Patras, TUW, University of Krakow….
- Advancing Traffic Efficiency & Safety through SW Technology (ATESST) – EU/IST STREP
  - **Volvo, VCC**, Mecel, Daimler, Etas, SiemensVDO, Carmeq, Volcano/MentorGraphics, Mecel/Delphi, CEA, **KTH**, TUB
- Dynamically Self-Configuring Automotive Systems (DYSCAS) – EU/IST STREP
  - **Volvo**, Bosch, Daimler, Movimento, Systemite, **KTH**, C-Lab (Paderborn), Univ. of Greenwich
- European Leadership in System Modeling and Simulation through advanced *Modelica* Libraries (EUROSYSLIB) – ITEA 2 proposal
  - Dassault Systèmes (coord), INRIA, EDF, DLR, Fraunhofer, Siemens, **Lund, ..**

New Project: FRESCOR

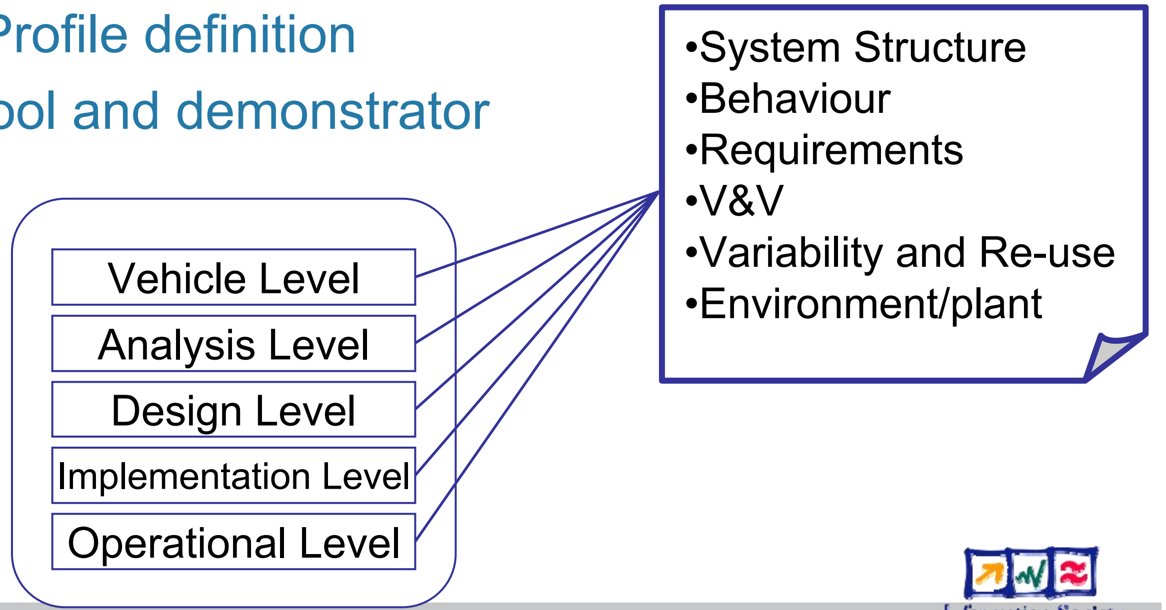
- Framework for Real-time Embedded Systems based on ContRacts
  - EU/IST STREP started 01.06.2006 (three years)
  - 10 partners including Universidad de Cantabria, University of York, Scuola Superiore Sant´Anna, TU Kaiserslautern, **UPVLC, CTU**, ENEA, ….
  - 4,26 M€
- Define, implement and provide support to a contract model that specifies which are the application requirements with respect to the flexible use of the processing resources in the system.
- Control parameters and execution support for control applications are included in the contract requirements
  - Strong connection to the framework activity within this cluster

New Project: SENSE

- Smart Embedded Network of Sensing Entities
  - EU/IST STREP started 01.09.2006 (three years)
  - 9 partners including ARC Seibersdorf, **UPVLC**, PARAGON, University of Galati, University of Patras, TUW, University of Krakow….
  - 1,7 M€
- To create a system in which distributed embedded devices cooperate to form and maintain a self-consistent global world view from local sensor information and which is robust to the addition and removal of devices from the network.
- Development of the embedded system platform incorporating both acoustic and visual sensors and data processing.
- Prototype: International Airport Krakow and Balice prototype. Control of objects (luggage, ….), personal movement, …

New Project: ATESST

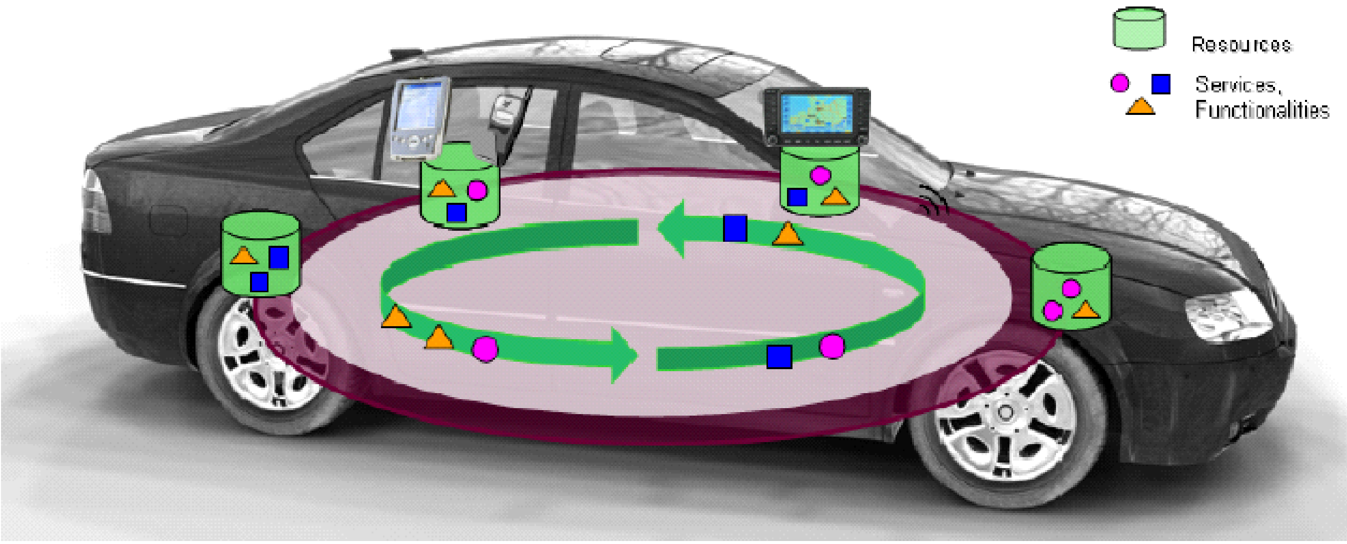
- Advancing Traffic Efficiency & Safety through SW Technology
  - EU/IST STREP (2006-2008) – 4 M€
  - **Volvo, VCC**, Mecel, Daimler, Etas, SiemensVDO, Carmeq, Volcano/MentorGraphics, Mecel/Delphi, CEA, **KTH**, TUB
- Background:
  - Architecture Description Language for Automotive Embedded Systems, EAST ADL 2.0
- Alignment: SysML, AADL, AUTOSAR and MARTE
- Dissemination by UML2 Profile definition
- Methodology, prototype tool and demonstrator



New Project: DYSCAS

- Dynamically Self-Configuring Automotive Systems
  - EU/IST STREP (2006-2008), 3,5 M€
  - **Volvo**, Bosch, Daimler, Movimento, Systemite, **KTH**, C-Lab (Paderborn), Univ. of Greenwich
- A middleware for automotive embedded systems with support for configurational flexibility, scalability and automotive constraints.
- **Use cases**: Optimal resource utilization, External hardware integration (plug-and-play), Fault-tolerance, Remote diagnostics and maintenance

Vision



New Project: SOCRADES

- Service-Oriented CRoss-layer infrAstructure for Distributed smart Embedded deviceS
  - EU/IST FP6 IP
  - 3-years project started 01.09.2006
  - 15 Partners incl. Schneider Elec. (coord), **ABB**, Siemens, **KTH**, ...
  - Total Budget: 13.7 M€
- Focus areas:
  - Industrial Automation
  - Networked Embedded Systems (wired and wireless)
  - Web Services technology

Schneider Electric (Project co-ordination)

ABB

European Center for Mechatronics

ARM®

BOLIDEN

FlexLink®

ifak

KTH VETENSKAP OCH KONST ROYAL INSTITUTE OF TECHNOLOGY

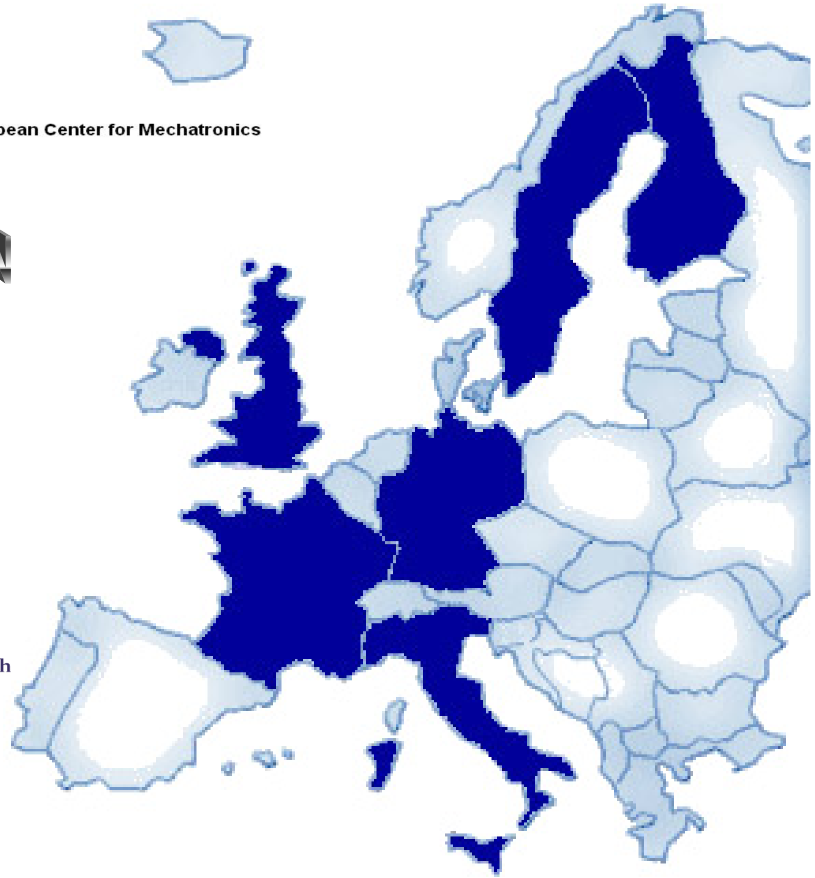
Loughborough University

LULEÅ TEKNISKA UNIVERSITET

POLITECNICO MILANO

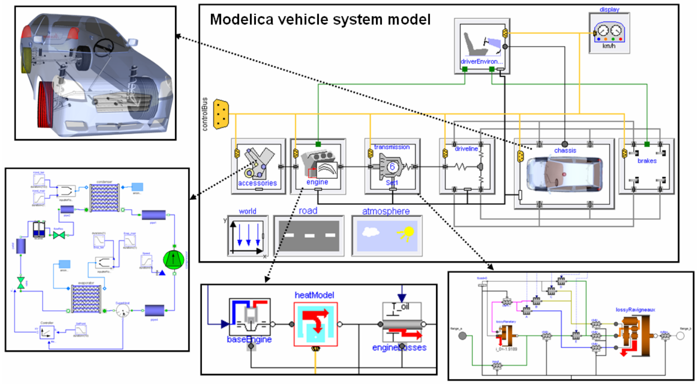
SIEMENS

TAMPERE UNIVERSITY OF TECHNOLOGY



New Project Proposal: EUROSYSLIB

- European Leadership in System Modeling and Simulation through advanced *Modelica* Libraries
  - ITEA2 proposal under evaluation
  - 21 partners incl Dassault Systèmes (coord), INRIA, EDF, DLR, Fraunhofer, Siemens, **Lund Univ**.
  - 23,1 M€ (9.6 M€ Funded) over three years
- Modelica
  - Multi-domain modeling and simulation
  - Equation-oriented acausal object-oriented models



- Project:
  - Library development within the Mechanical, Electrical and Electronics, Thermofluid, Control, Safety and Automotive domains
  - Establish *Modelica* as ***The European System Modeling Language***
    - Compare with SysML
  - Lund University part
    - Real-time network simulation library based on the network simulation facilities of TrueTime

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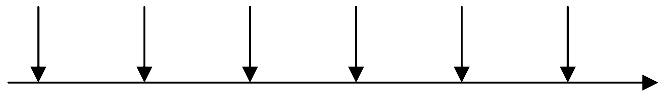
Recent Advances in Event-Based Control

- Control almost always assumes and requires **periodic** sampling
  - Well-developed theory



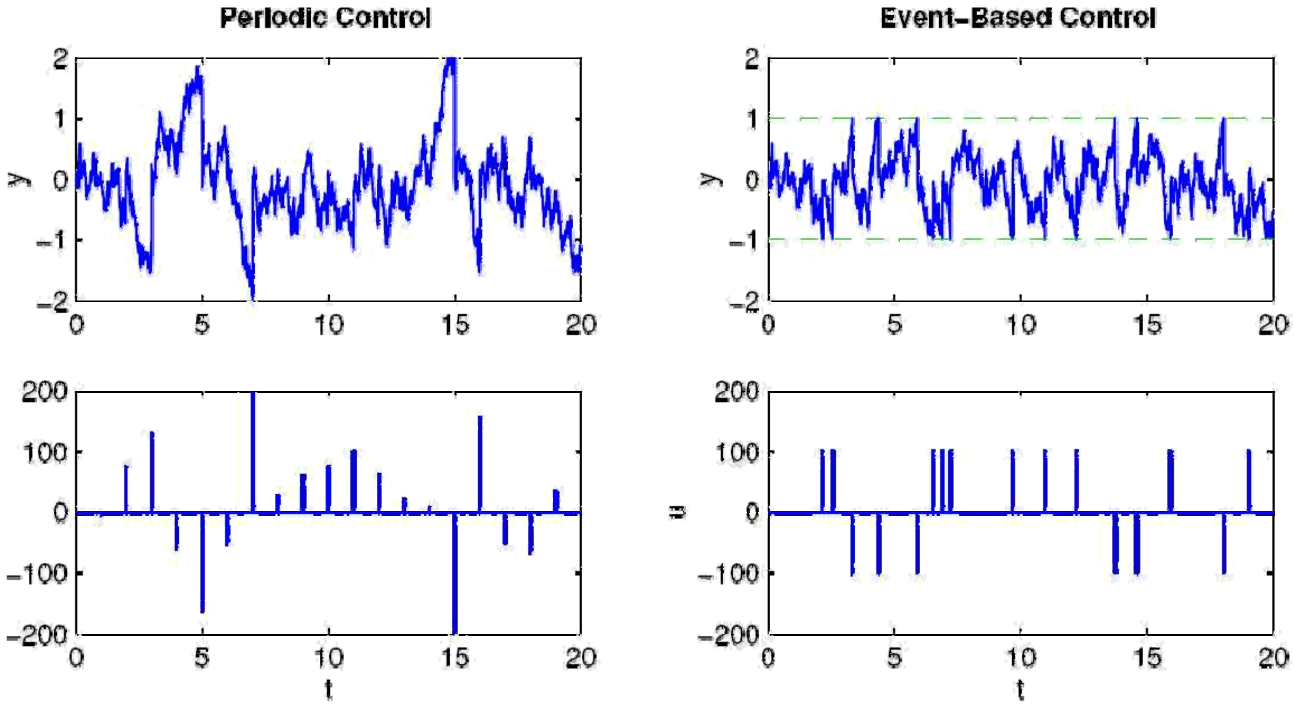
- Cornerstone for large part of real-time systems

- However, what if we relax this assumption?
  - Sample and control only when an **event** has occurred, e.g., a threshold crossing
  - Most likely closer to how nature performs feedback
  - Several practical observations have reported that event-based control can perform as good or better than time-based control
  - But, very very little theory

Previous Work

[Åström and Bernhardsson, 1999]

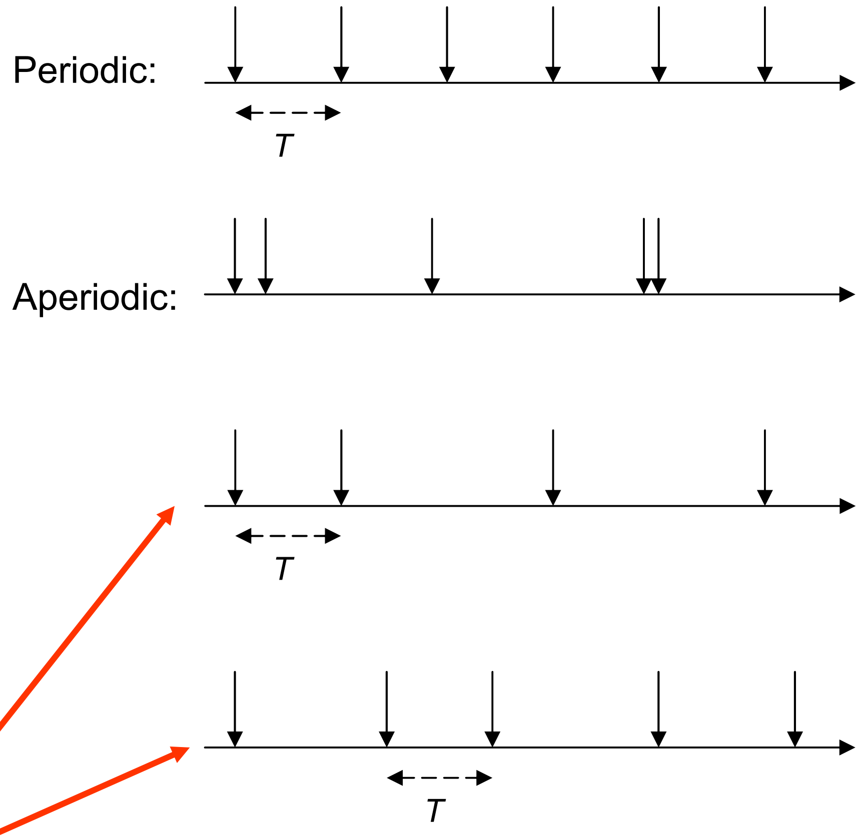
- Aperiodic event-based control of first-order stochastic systems
- Reduction of variance by a factor 3 for an integrator systems, assuming the same average sampling interval



- However, sampling infinitely often is not realistic

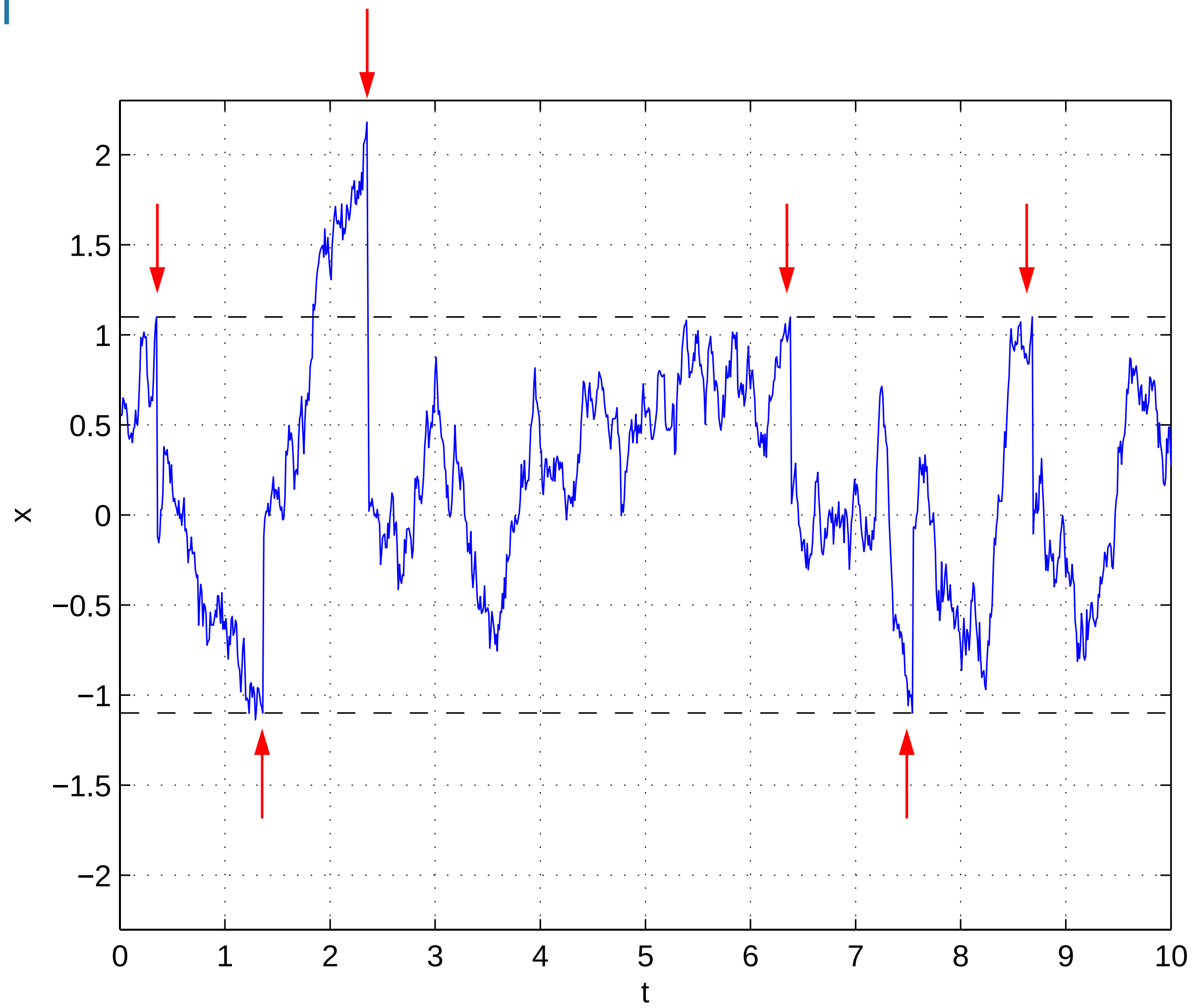
Sporadic Event-Based Control

- Recent work by Johannesson, Henningsson and Cervin, Lund
- First-order stochastic system
  - dx = a x dt + u dt + dw
  - w – Wiener process with unit incremental variance
- Apply impulse control when |x| > r
  - State is reset to zero
  - Dirac-pulse control signal
- **Sporadic Event-Based Control**
  - Minimum inter-event time → finite utilization factor
- Two versions:
  - Discrete-time measurements (DT)
  - Continuous-time measurements (CT)



Example: Sporadic Control (CT)

- T = 1



Cost Function

$$J = \underbrace{\lim_{t\to\infty} \frac{1}{t} \int_0^t x^2(\tau)\, d\tau}_{J_x} + \rho \underbrace{\lim_{t\to\infty} \frac{1}{t} N_u(0,t)}_{J_u}$$

J_x = State cost

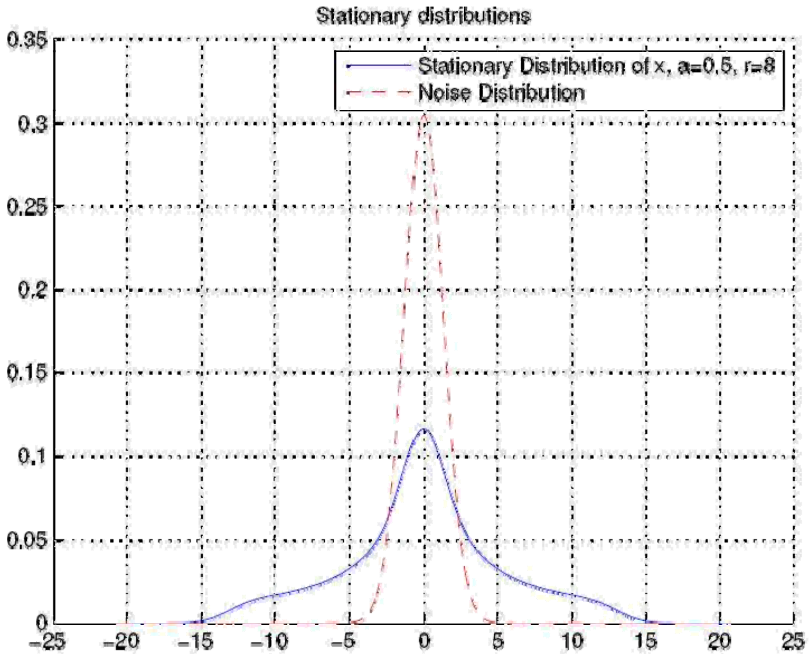
- Stationary process variance

J_u = Control cost

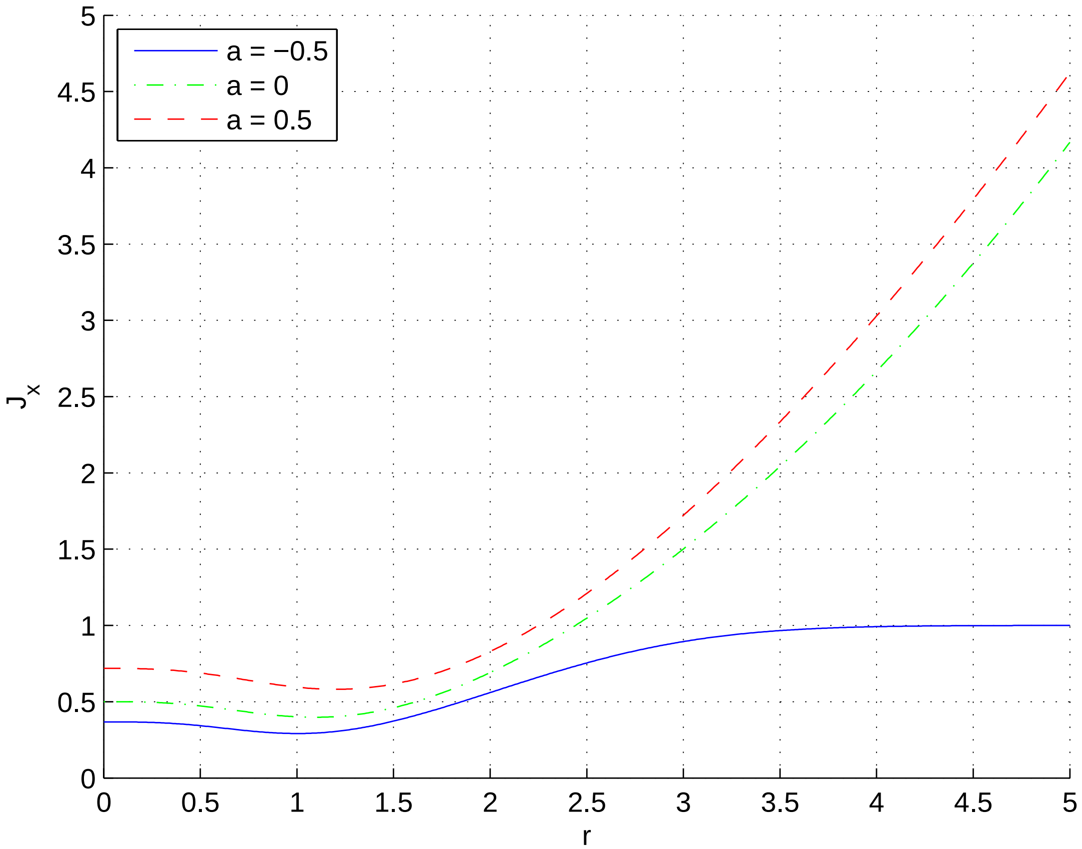
- Average number of events / time unit

Solution Principle

1. Find stationary distribution of *x* as function of *r*
   - No analytical solutions found
   - Approximated by piecewise polynomials (CT case)
   - Approximated by discretization (DT case)
2. Calculate $J_x(r)$ and $J_u(r)$
3. Choose *r* to minimize $J = J_x + \rho J_u$

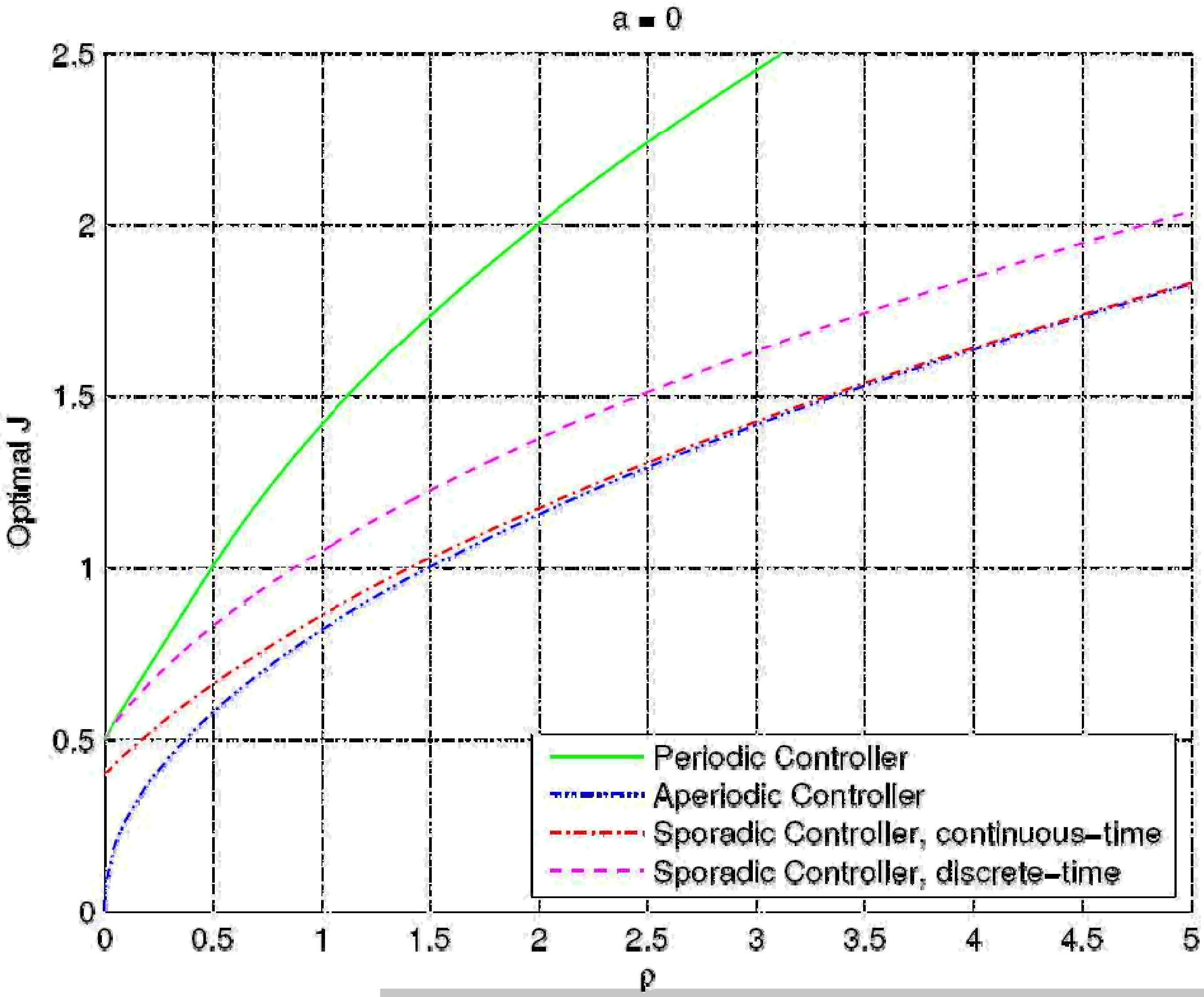


Optimal Choice of Threshold under Sporadic Control (CT)



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

Optimal Cost for the Integrator



Conclusions

- Sporadic control can reduce the process variance **and/or** the control frequency compared to periodic control
- More realistic than aperiodic event-based control
- Many interesting further problems for higher-order systems
  - When to generate events?
  - What control actions to apply?
  - Event-based observers (MSc thesis by Toivo Henningsson)
- Applications:
  - Applications where sampling and computation are costly
    - Networked embedded control systems with limited bandwidth
    - Inventory control
  - Applications that are event-based, but are approximated by continuous-time models
    - ”Liquid” models of queueing systems in server systems

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1: Optimal controller period selection under FP scheduling

Partners: SSSA (Bini) & Lund (Cervin)

Context:

- A set of periodic control tasks executing on a single CPU under fixed priority scheduling

Background:

- Traditionally, D <= T for control tasks
- Leads to processor under-utilization

Approach:

- Explore what control performance is possible to gain by moving outside the FP schedulability bound
- Optimal period assignment using combination of
  - Simple analytical upper bounds on response times R
  - Control cost functions V(T,R)

Minimize $\sum V_i(T_i, R_i)$

subject to $\sum \frac{C_i}{T_i} \leq 1$

Conclusion: Utilization = 1 is optimal under FP scheduling

Status: Ongoing work

2: Control task jitter reduction

Partners: Lund (Cervin) & SSSA (Buttazzo)

Background:

– Jitter in input/output latency causes poor control performance

Approach:

– Comparative assessment and evaluation of three different jitter control schemes – mixed task set (control and non-control)
  - Task splitting (high-priority input/output subtasks)
  - Deadline shortening (raise the priority of the control tasks)
  - Non-preemptive scheduling

Conclusion:

– Deadline shortening typically gives the best control performance and is also the easiest to implement
  - Exception: Task splitting works better for system with very poor stability margins

Status: Under submission

3: Control task model evaluation

Partners: UPVLC (Lluesma et al) & Lund (Cervin et al)

Background:

- Splitting a control task into subtasks may reduce input/output latency and jitter
- Several alternative approaches

Approach:

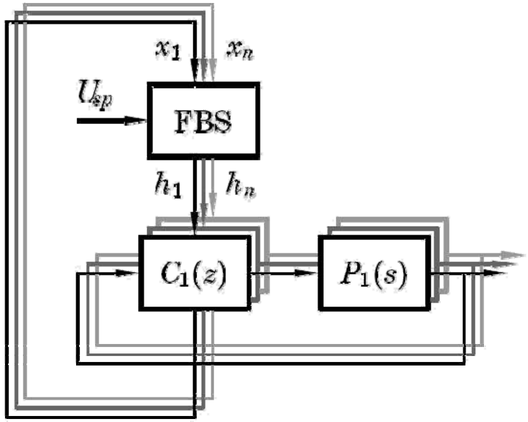
- Comparative evalulation of four task models:
  - Standard task model (single task)
  - CalculateOutput + UpdateState (CO_US)
  - Initial, Mandatory and Final (IMF)
    - Sampling (M), Computations (L), Actuation (H)
  - Initial, CO, Final, US (ICOFU)
- Evaluated on a large set of plant models
- Control performance evaluated using the Jitterbug and TrueTime tools from Lund

Conclusions:

- CO_US and ICOFU give best performance

Status: Presented at IEEE CACSD’06 and at the RTCSA’06

4: Feedback Scheduling of Control Tasks



Partners:

- UPC (Castañé, Martí) & Lund (Henriksson, Cervin)

Background:

- Feedback scheduling of CPU time can improve control performance and increase resource utilization

Previous work:

- On-line scaling of task periods such that the total performance is optimized (Eker, Hagander, Årzén – 2000)
  - Actual performance of the individual loops not taken into account
- Feedback scheduling using feedback from plant states (Henriksson, Cervin - 2005)

Current work:

- Extensions to
  - Arbitrary linear controllers incl,e.g., state observers & PID
  - More efficient on-line optimization
  - Experimental verifications

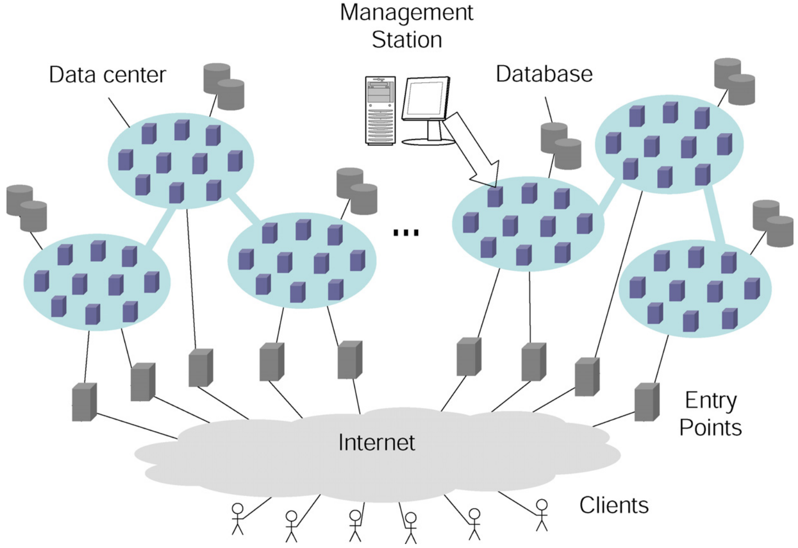
Status: Presented at ECRTS'06

5: Distributed Resource Allocation in Server Clusters for QoS

Partner: KTH (Johansson et al)

Context:

- Large scale web server clusters
- Multiple services are offered, each with its own QoS objectives
- Each server provides one service at a time
- *Service selection* dynamically allocates cluster resources to services



Approach:

- Resource allocation problem formulated as as a discrete utility maximization problem
- Efficient centralized algorithm developed
- Three suboptimal decentralized (local) schemes proposed and evaluated

Status: Will be presented at IEEE CDC'06

6: Code optimization for FPGAs

- **Partner:** CTU (Hanzalek, Sucha)
- High-level **synthesis of control algorithms**
  - algorithm description in Matlab like language
  - off-line scheduling
  - automatic code generation (Handel C or VHDL)
- Specific HW architecture – **FPGAs**
  - high degree of parallelism
  - dedicated units (e.g. floating point)
  - pipelining, shared memory, reconfiguration
- **Optimality -** objective is to find a feasible schedule with minimal C_{max}
  - iterative algorithms (IEEE RTAS)
  - iterative algorithms. with imperfectly nested loops (Journal of VLSI Signal processing systems)