

Antinomy between Schedulability and Quality of Control using a Feedback Scheduler

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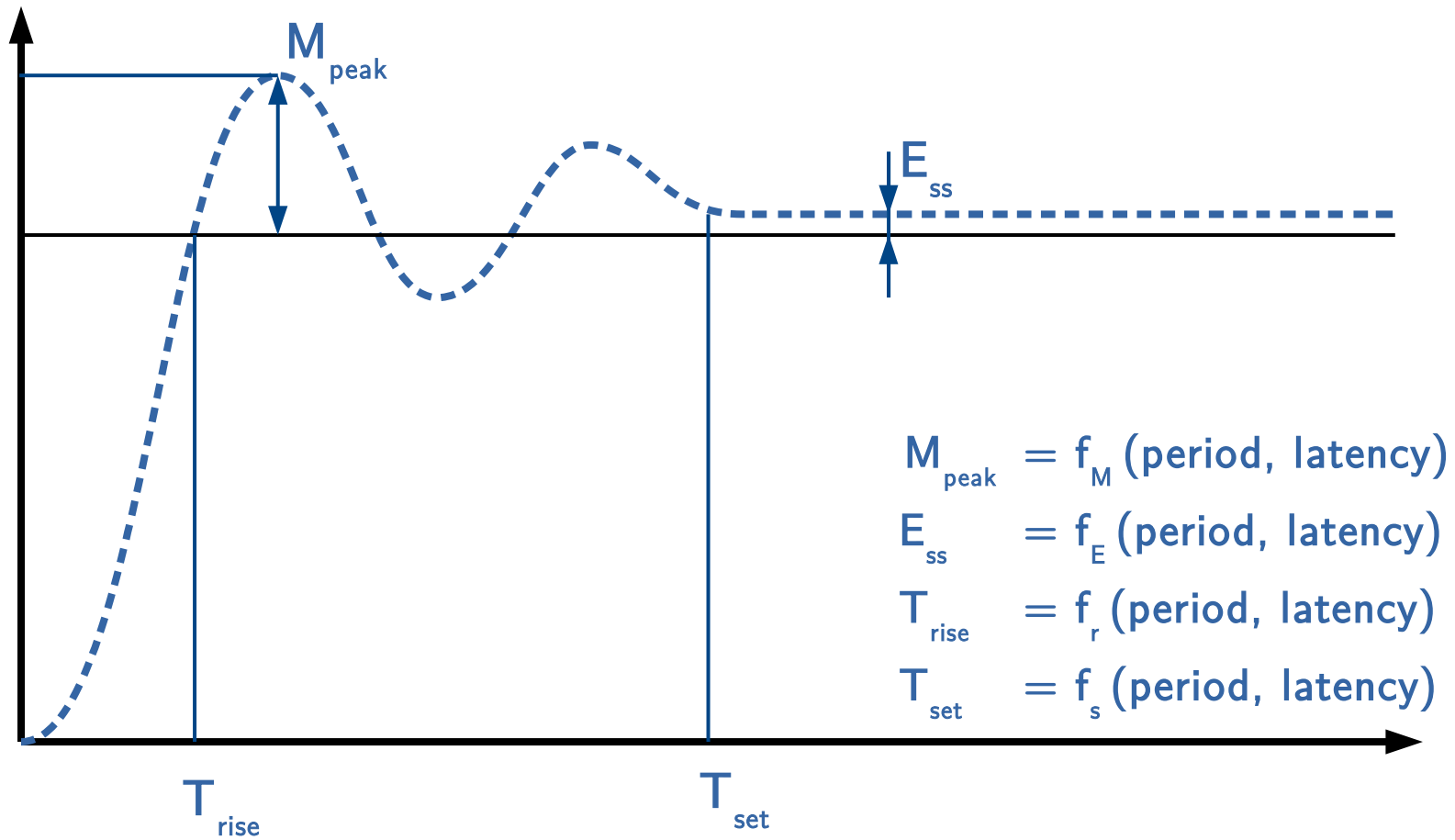
Speaker

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- Introduction
- Antinomy in co-design
- Scheduling artifacts characterization
- Conclusion

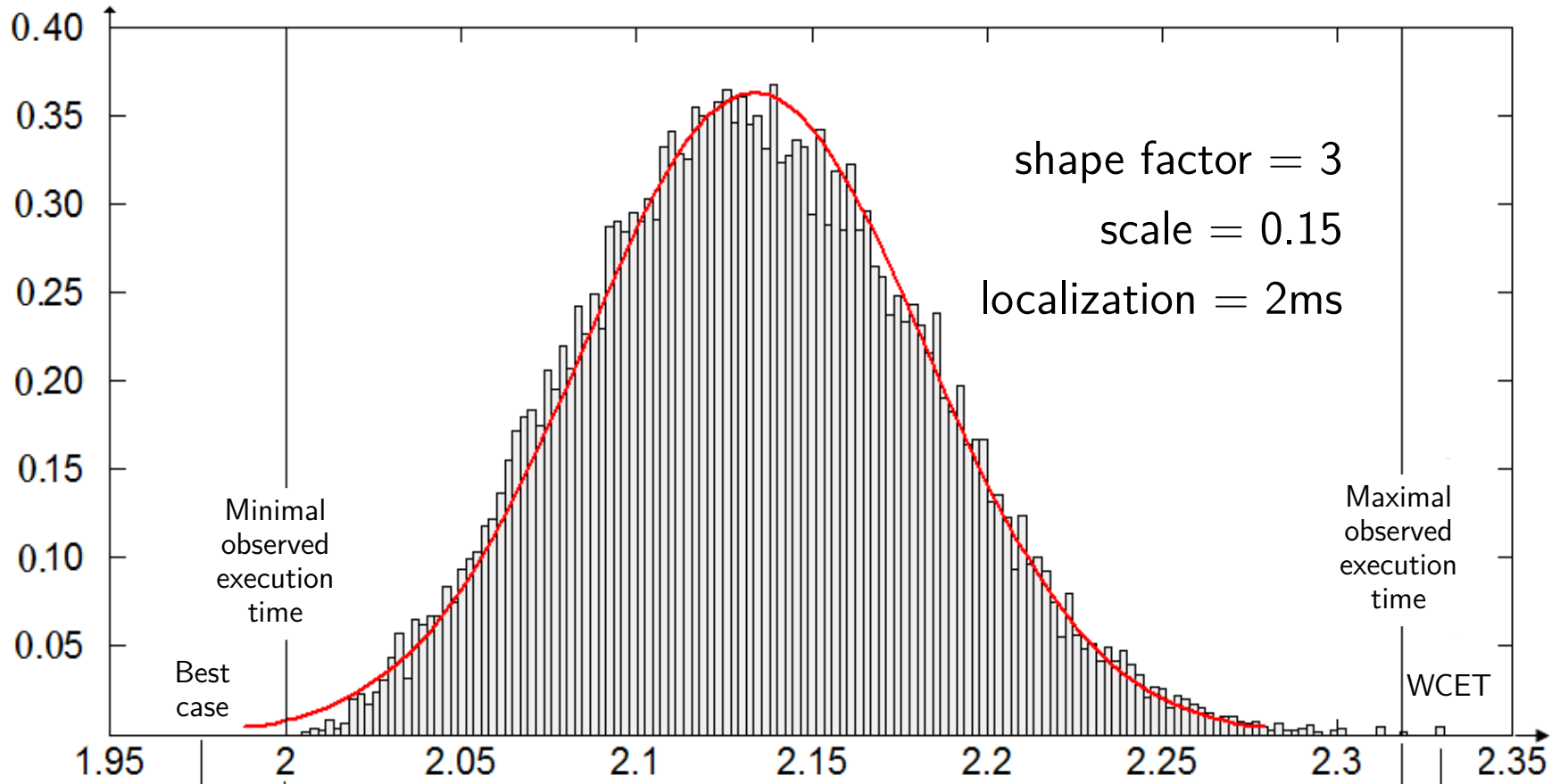
Traditional real-time scheduling models give poor support for scheduling/control co-design...

Off-line optimization



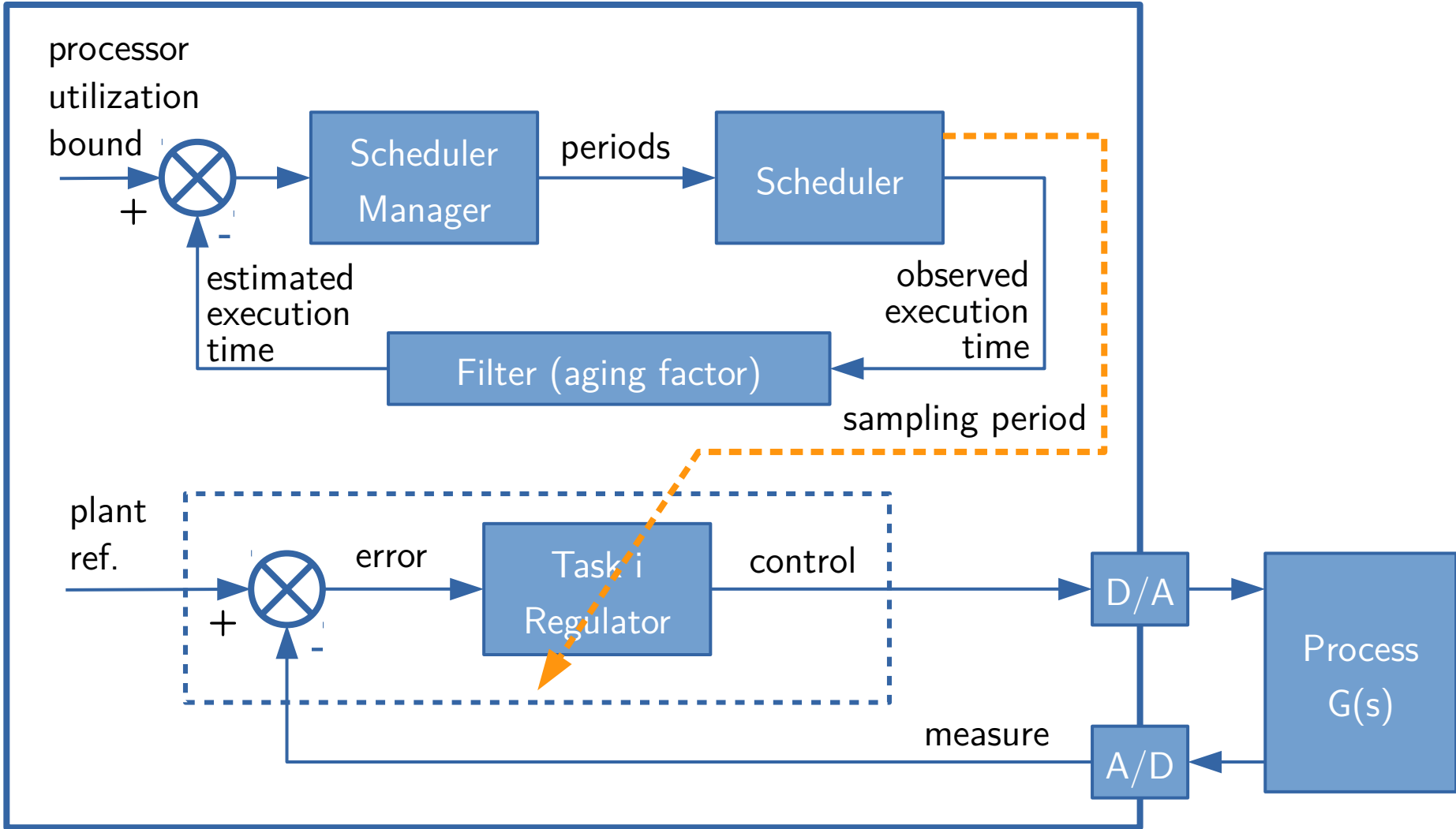
[Seto '96, Ryu '97]

RM scheduled periodic tasks with implicit deadlines



Execution times distribution following a Weibull law (given: best and WCET)

The feedback scheduler

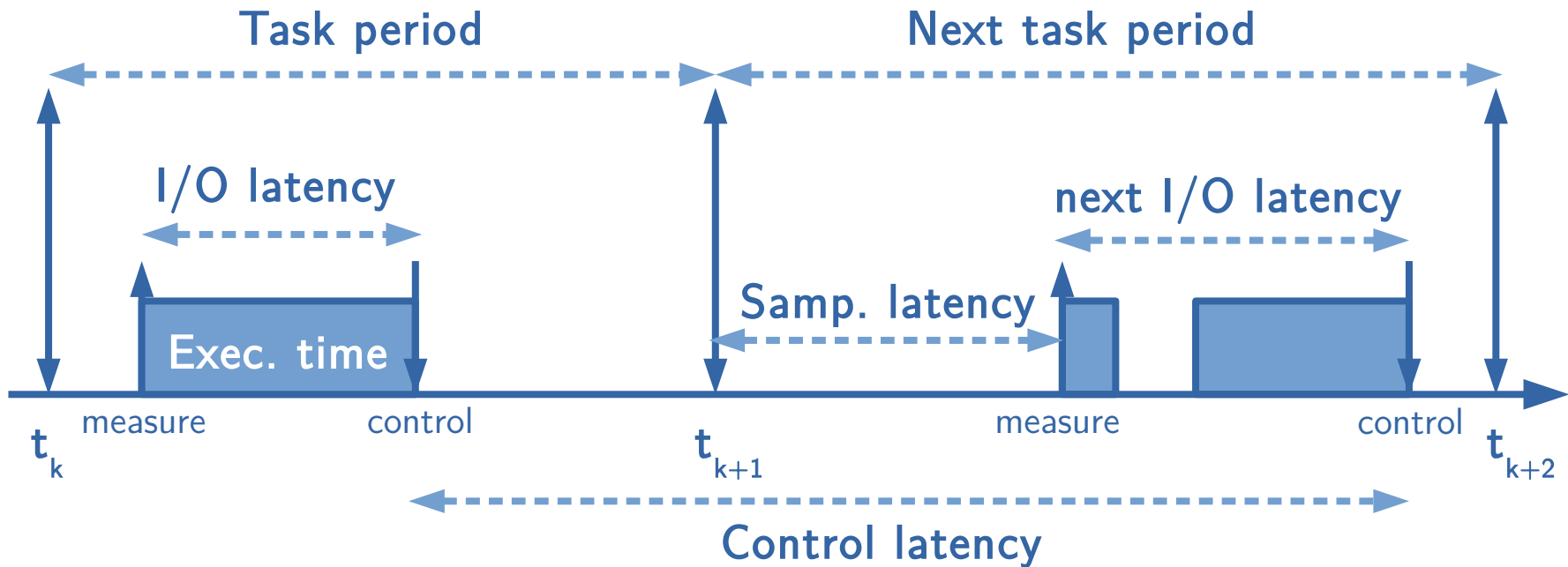


[Liu & Layland '73]

$$\sum U_i \leq n \left(2^{\frac{1}{n}} - 1\right)$$

[Bini '03] (hyperbolic condition)

$$\prod (U_i + 1) \leq 2$$

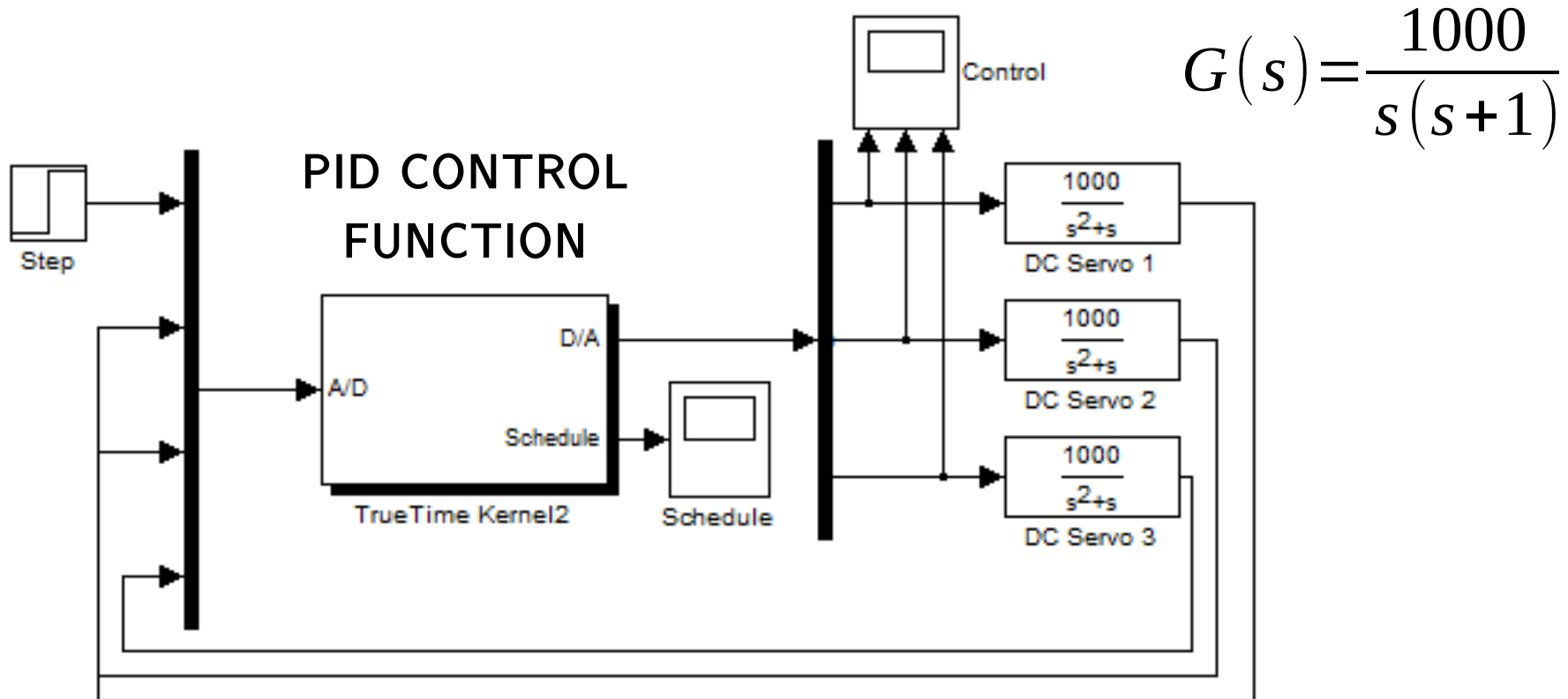


Sampling latency: higher priority task execution

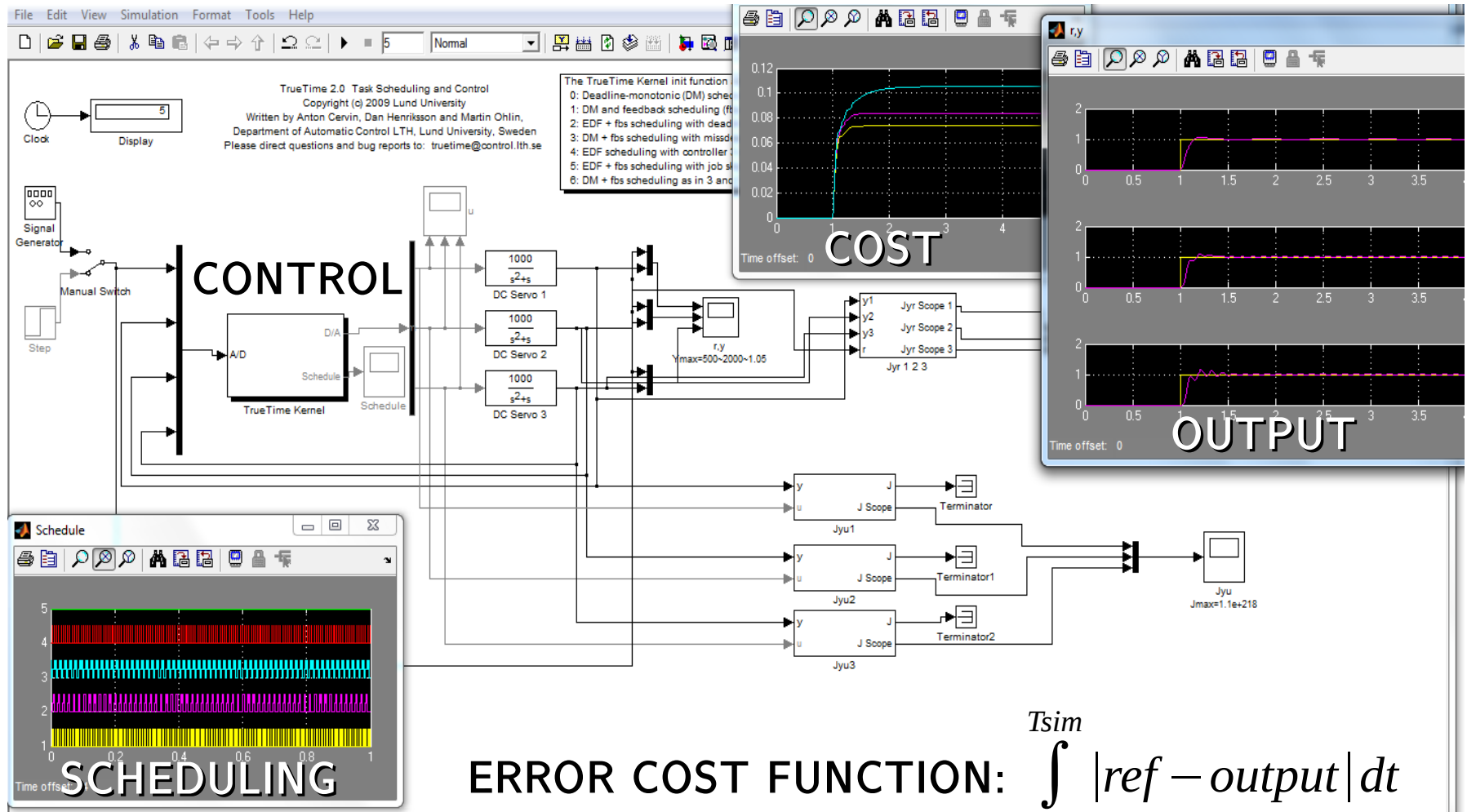
I/O latency: execution time + higher priority preemption

Scheduling artifacts: latencies and jitters...

- Three servo-motors with a PID regulator
 - Well known study case from [Åström & Häggglund]
 - Adaptive samples: backward difference for derivative
 - Controlled by a single processor computer
- Three inverted pendulums with cart
 - Another well studied benchmark [Åström & Furuta]
 - Strongly non linear three order coupled system
 - With cart: only horizontal moves



- Controller performance parameters: $(\omega_0, \xi) = (20, 0.707)$
- Use of adaptive samples in the PID



ERROR COST FUNCTION: $\int_0^{T_{sim}} |ref - output| dt$

*Minimizing tasks' period
improves quality of control...*

- Three periodic tasks: nominal period h_i^{nom} \rightarrow task priority (RM)
- Feedback scheduling: $h_i^{k+1} = \alpha h_i^k$ \rightarrow reach the utilization bound
- Execution time: $3 \leq C_i \leq 5$ ms (Weibull distribution)

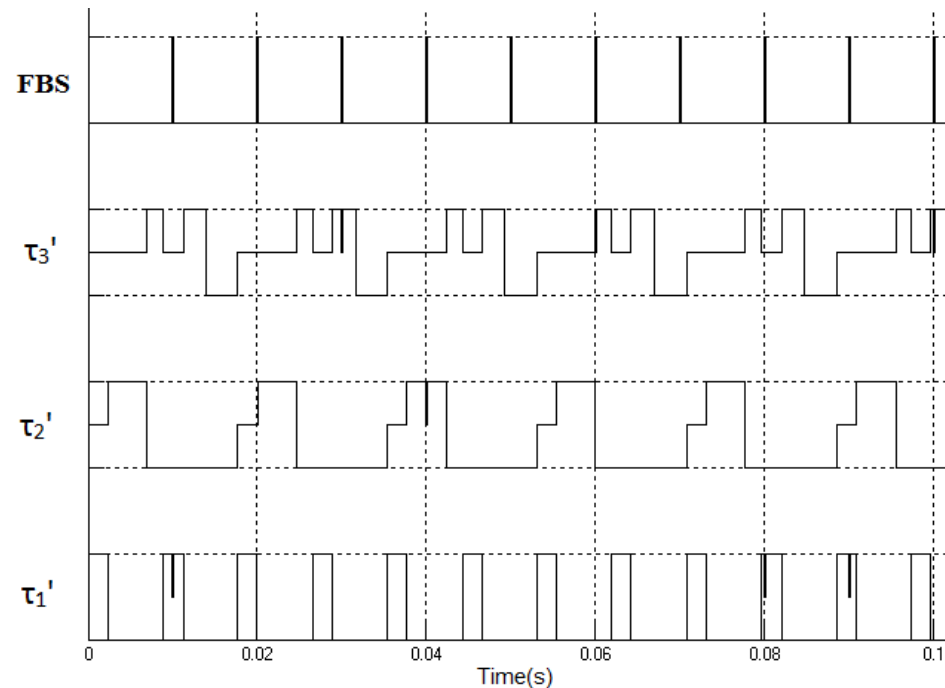
Bound	L&L test ($U < 0.69$)			Hyperbolic test			Threshold ($U = 0.5$)		
$h_i^{\text{nom}} =$ (4, 5, 6)	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3	τ_1	τ_2	τ_3
Error	0.063	0.065	0.64	0.060	0.062	1.35	0.088	768.7	$>10^8$
Sampling period (ms)	12.52	15.55	18.79	12.40	15.51	18.60	19.43	24.24	29.15
I/O latency (ms)	3.88	5.24	7.32	3.88	5.09	7.93	3.87	4.84	5.28

Scheduling artifacts (response time and jitter) increase when processor utilization increases (controller tasks periods decrease).

The degradation caused by these phenomena on a PID controller can be greater than the gain generated by the increase in sampling rate.

- Three servo-motors: periodic tasks τ_1 , τ_2 , τ_3
- Scheduled with RM (tie breaker: smallest task index)

	C_i	h_i^{nom}
τ_1	8.85	17.7
τ_2	8.85	17.7
τ_3	8.85	17.7



The antinomy illustrated

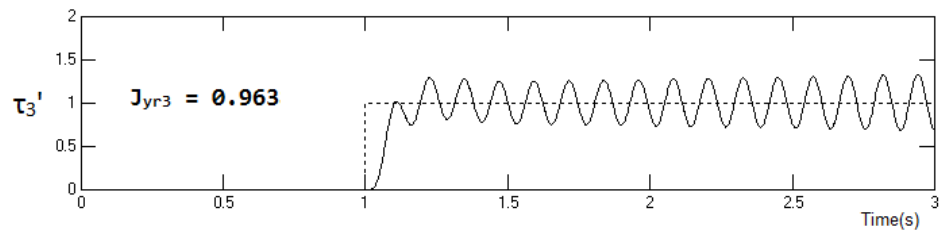
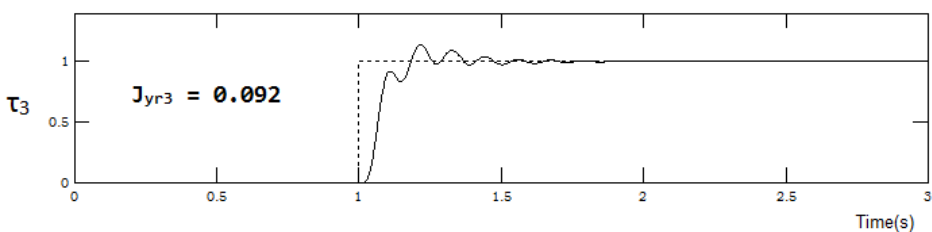
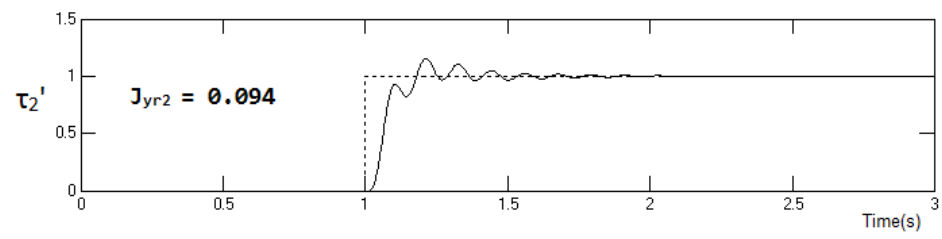
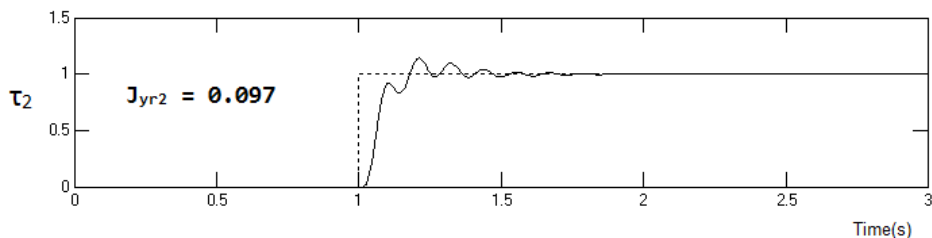
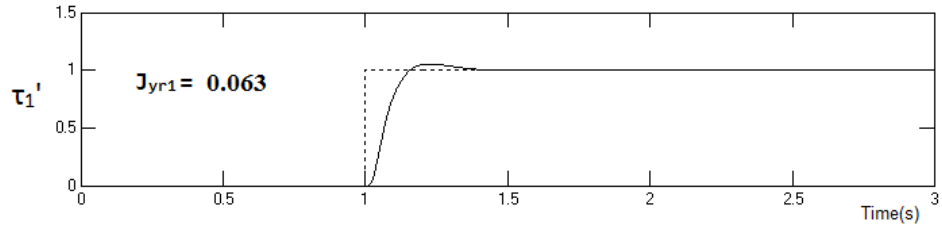
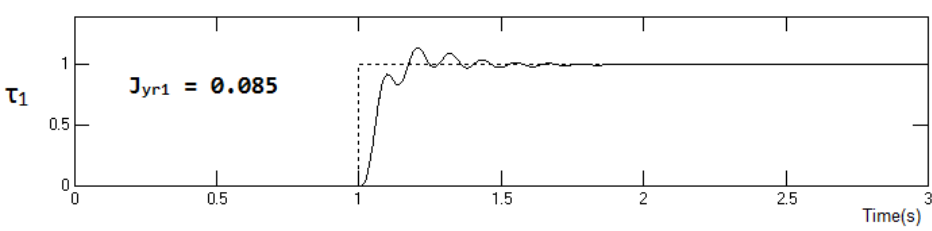
	C_i	h_i^{nom}
τ_1	4.6	17.7
$\tau_2 - \tau_3$	4.6	17.7

Same U_i but...



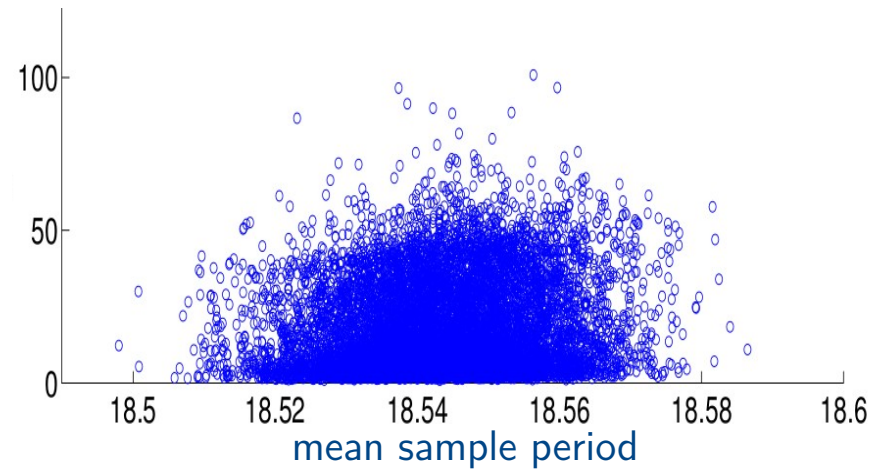
doubled pace for τ_1

	C_i	h_i^{nom}
τ_1	2.3	8.85
$\tau_2 - \tau_3$	4.6	17.7

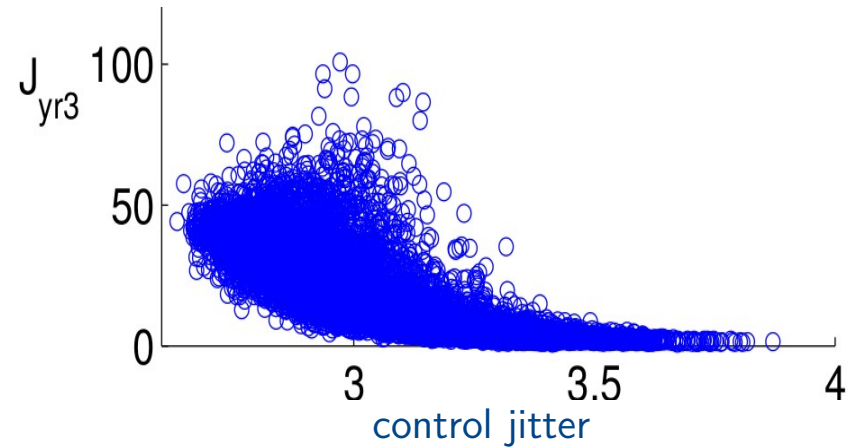
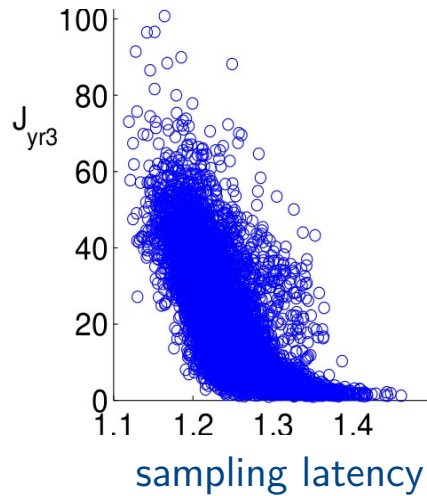
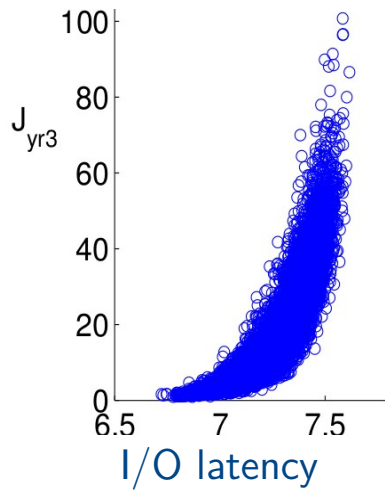


- Three servo-motors example

	C_i	h_i^{nom}	Mode	k	μ	λ
τ_1	3.4	6	3.2	3.1	0.2	3
τ_2		13	3.2	3.1	0.2	3
τ_3		14	3.2	3.1	0.2	3



Error cost function of
mean sample periods
for task τ_3



Error cost function of IO and sampling latencies for τ_3

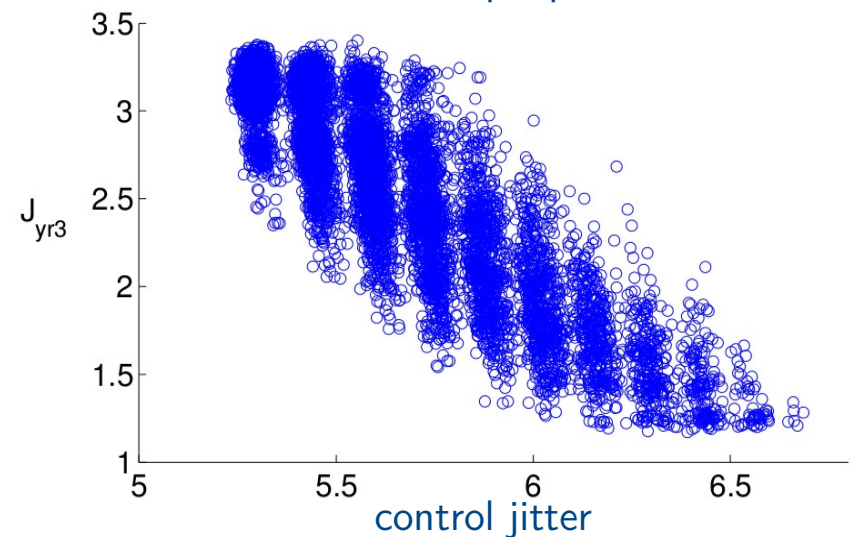
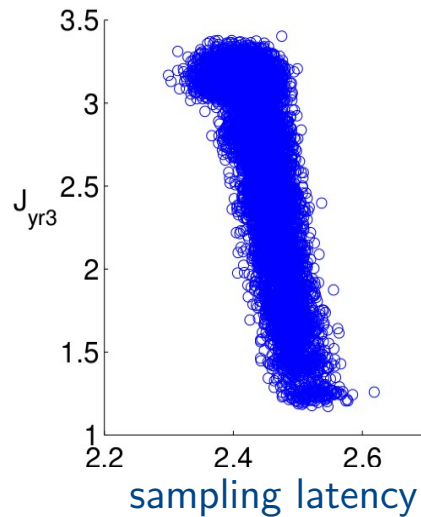
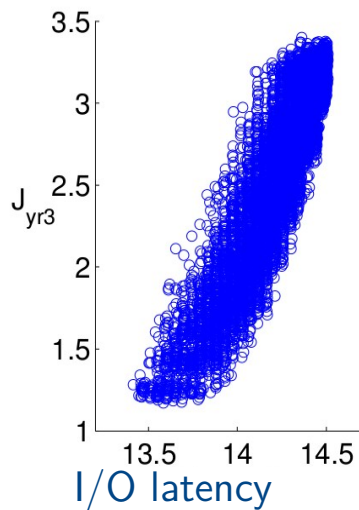
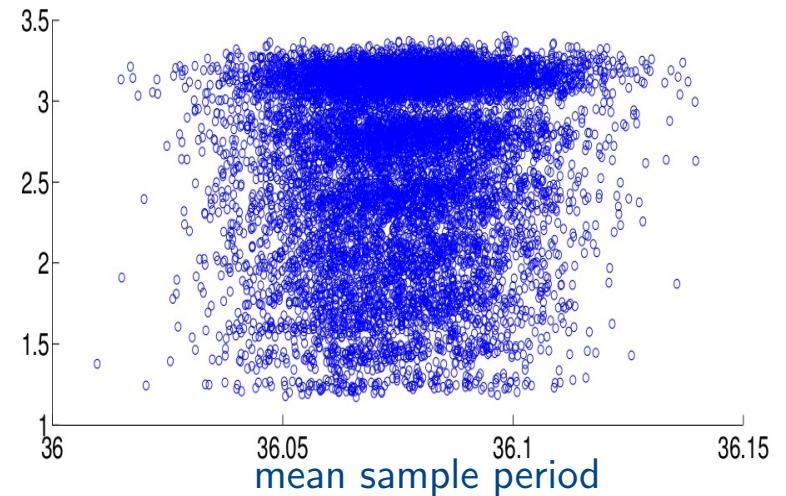
Linear correlation (SRS):
0.95 (I/O) and -0.81 (Samp)

Error cost function of control jitter for τ_3

Linear correlation (SRS):
-0.88

- Three inverted pendulum example

	C_i	h_i^{nom}	Mode	k	μ	λ
τ_1	3.4	6	3.2	3.1	0.2	3
τ_2		13	3.2	3.1	0.2	3
τ_3		14	3.2	3.1	0.2	3



- Do not (always) trust intuitive assumptions
- Impact of scheduling artifacts on QoC
 - Try to keep I/O latency low...
- Contribution
 - Identify scheduling parameters that deteriorate a real-time control when the lower priority task's frequency tends toward the closed-loop system bandwidth
- Perspective: guidelines for better co-design...



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Thank you for your attention