

Laurea Specialistica in Ingegneria dell'Automazione

Sistemi in Tempo Reale

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Introduzione

Lecture

- Introduction

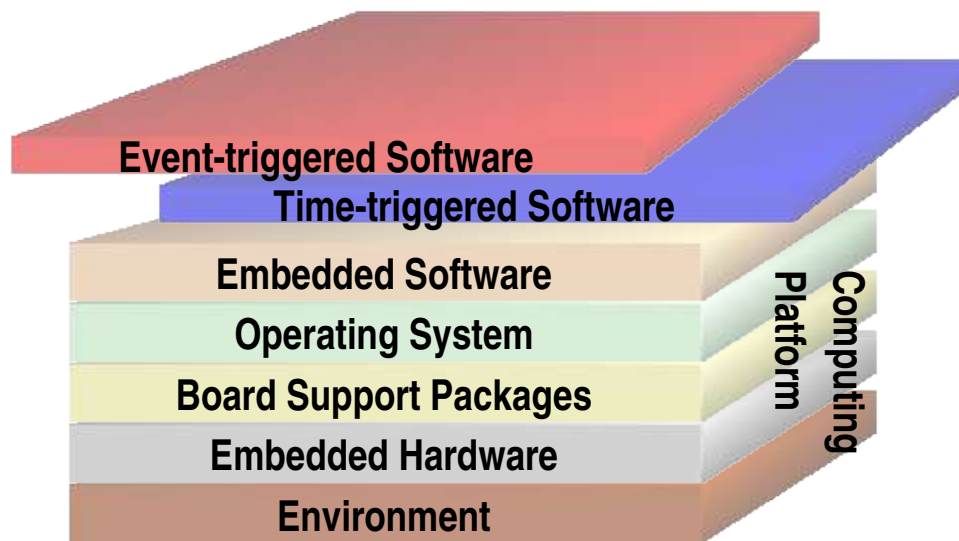
Outline

- Generalities
- The development flow
- An introductory example

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Real-time systems: what's in a name?



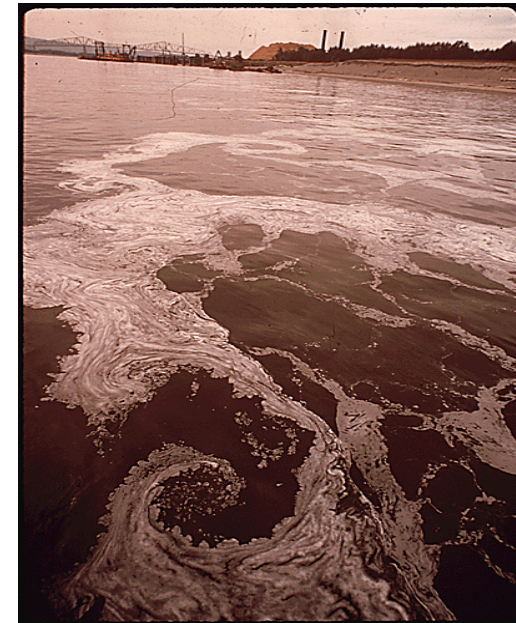
- A an embedded controller is a complex ensemble of software and hardware components:
 - Hardware devices
 - Software support components
 - Software applications
- Event-triggered and Time-triggered semantics are often intertwined

Why should a control engineer care about real-time software?



- The pure “springs” of control engineer:
 - instantaneous computations and communication
 - infinite bandwidth links and nodes
 - ideal sampling
 - infinite precision

- The polluted “delta” of system engineer
 - communication and computation take a (random) time
 - links and nodes have finite bandwidth
 - there is sampling and actuation jitter
 - information is quantised
- Performance can be severely degraded



Design

- **Design:** act of defining a system or a subsystem
- Usually design amounts to:
 - defining one or more models of the system
 - refining the models until a desired functionality is obtained
- Informal specification and design always lead to problems

Example

- Where is the problem in the following specification?

The system has two inputs, *reset* and *next*, and three outputs: *a*, *b* and *c*. Whenever *reset* appears, *a* is emitted. After this, the first *next* signal produces *b* and the second *next* signal produces *c*.

- What if *reset* and *next* are present together?

A formal model for design

- **Functional Specification**

- relations between inputs outputs, inputs and internal state
- describe the system's behaviour

- **Properties**

- a set of relations between inputs, outputs and states that should always hold true
- assertions on the system's behaviour

- **Performance indexes**

- Cost, reliability, speed, size...

- **Constraints**

– inequalities on performance indexes

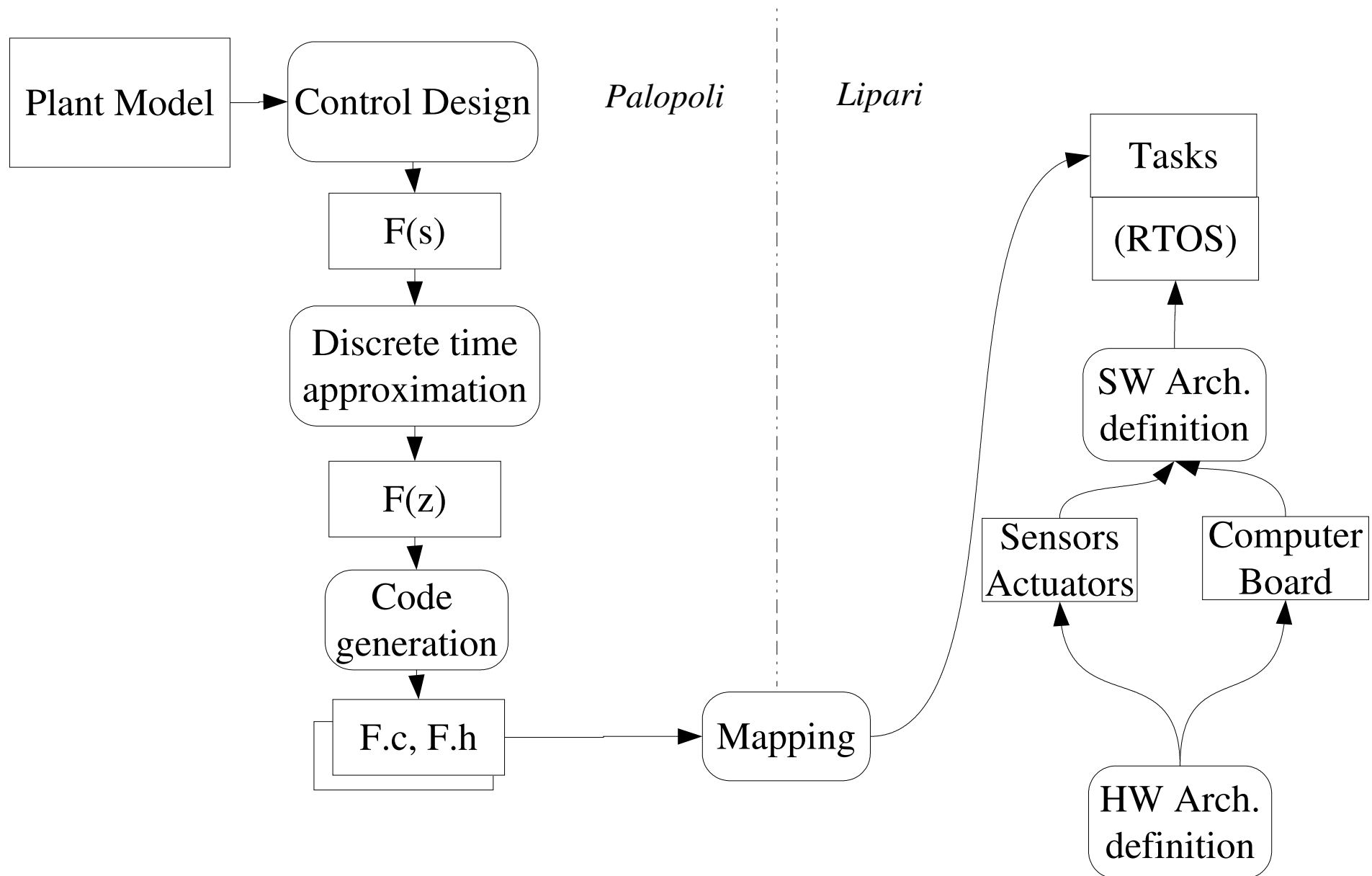
Our goal

- To devise design techniques and tools that preserve properties
 - If a property has been proved correct at a certain step, it has to be preserved in the next phases

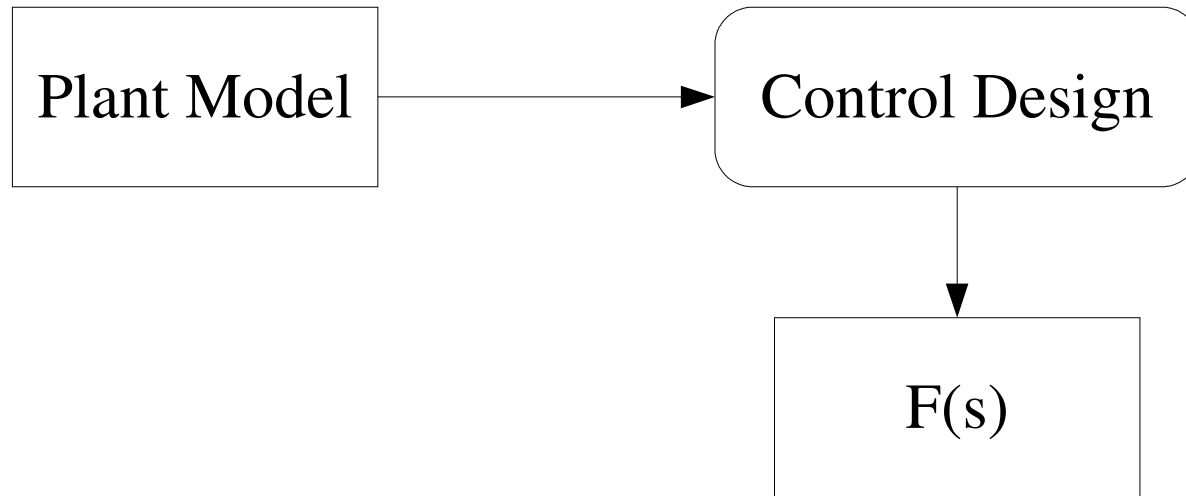
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A meet-in-the-middle approach

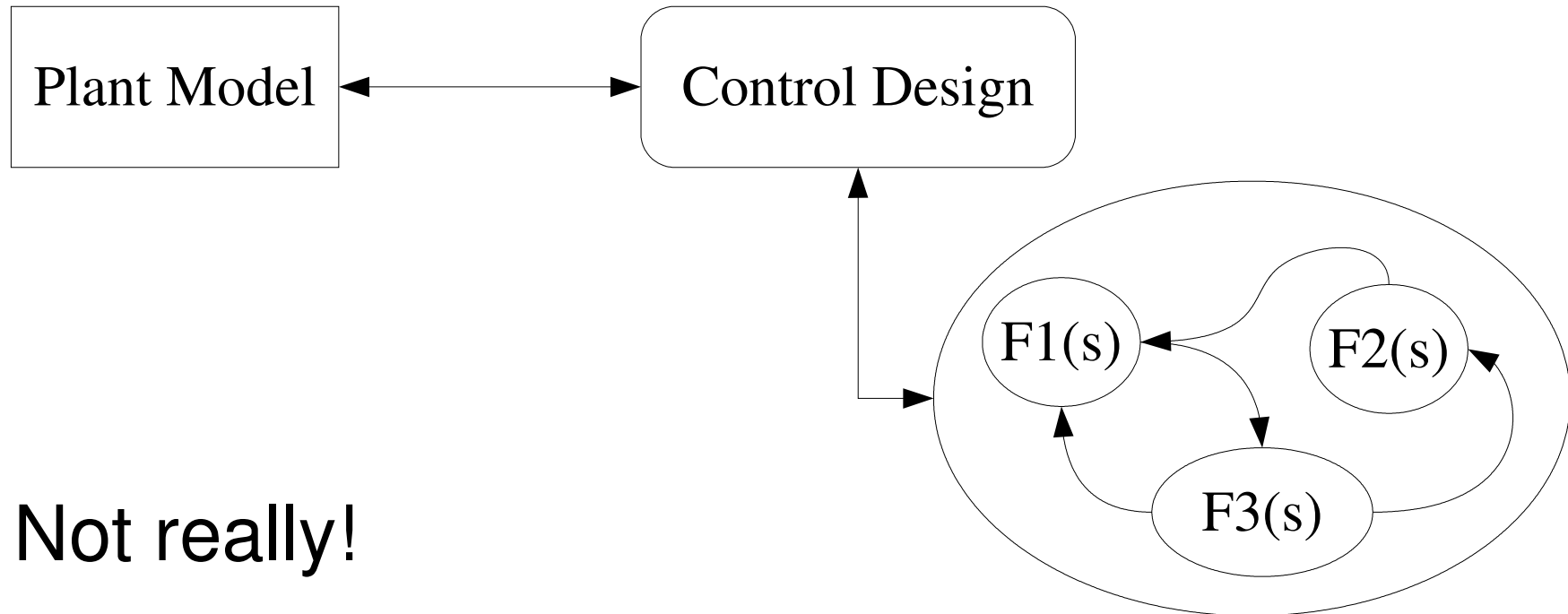


First step: control law design



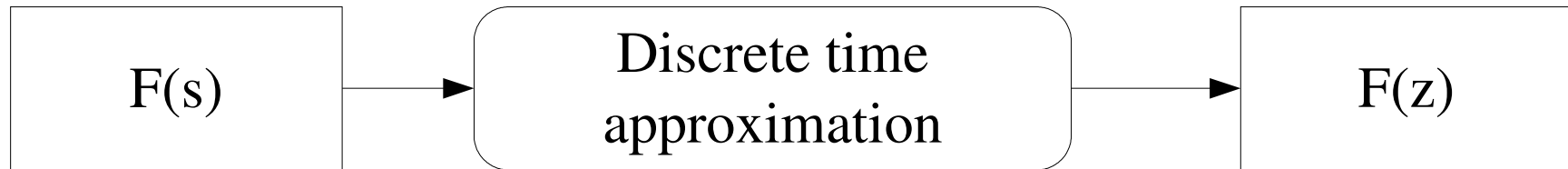
- Control law design: analytical and semi-analytical procedures
- Validation by Matlab/Simulink tools

Is that all?



- Not really!
- We can have multiple controllers to choose between according to the occurrence of certain events
- Combination of FSM + continuous time controller: **HYBRID systems**

Second Step: a discrete time model for the controller



- Problems
 - Effects of sampling
 - Choice of the sampling period
 - Numerical problems
- Matlab control toolbox is a nice friend...

Third step: generating C code



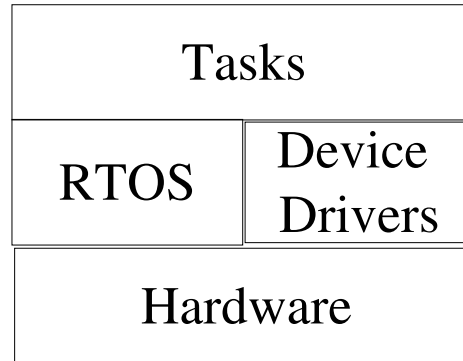
- This is easy, ain't it?
- No!
 - Quantisation (finite precision)
 - Computation delays!
- Done by hand or by CAD tools
 - RTW, Embedded Coder, Targetlink

Fourth step: mapping



- Critical passage
 - Scheduling delays and jitter
 - Enforcement of real-time constraints

Architecture selection

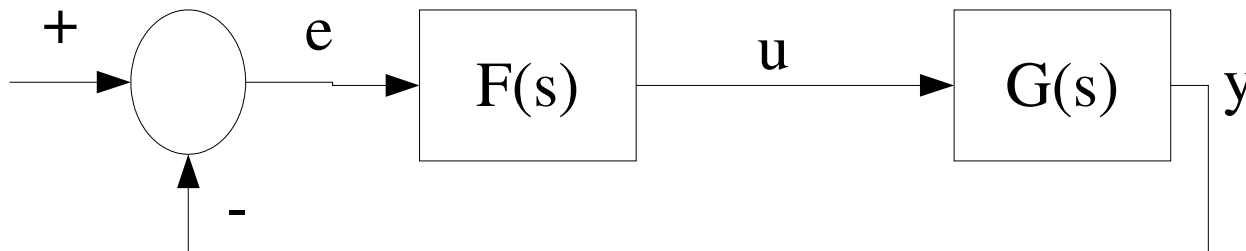


- Further delays
- Quantisation effects

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Example



$$G(s) = \frac{1}{s(s+1)}$$

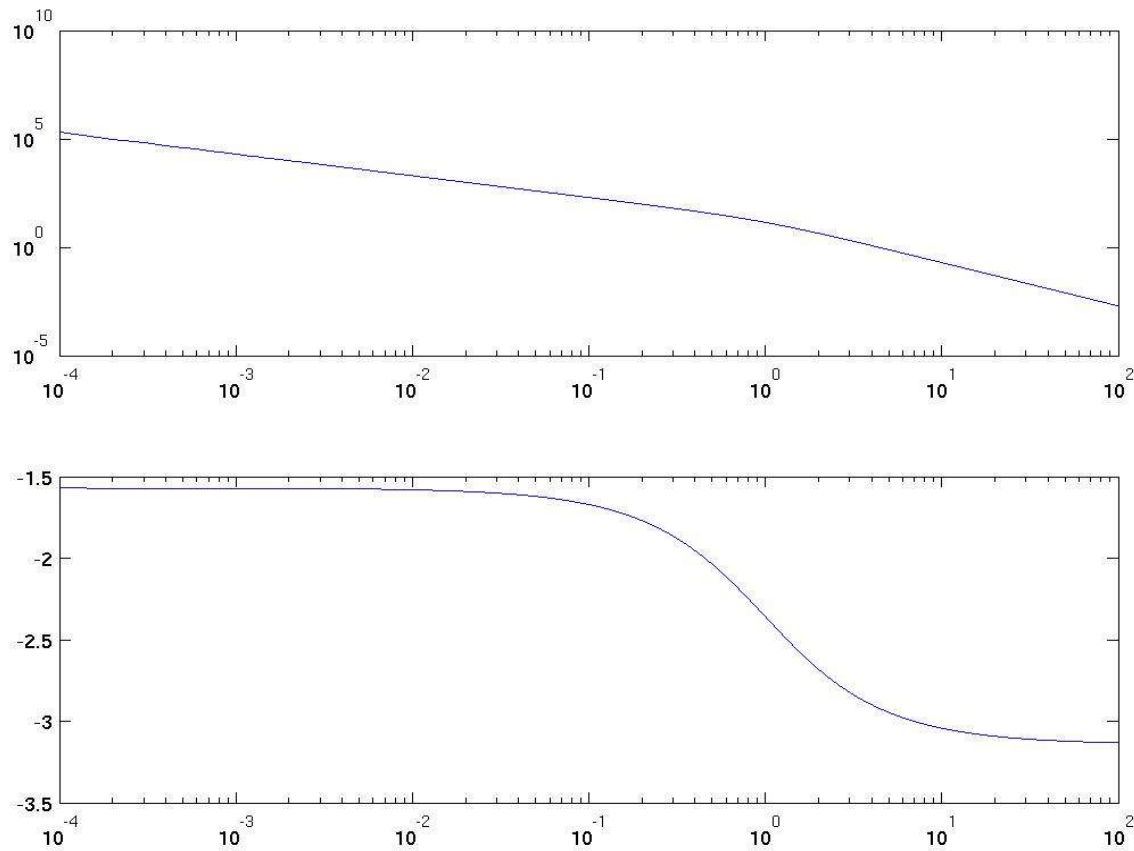
Recall definitions for 2nd order systems:

$$\frac{1}{s^2 + 2\zeta\omega_n s + \omega_n^2}$$

Natural frequency

Damping

Bode plot



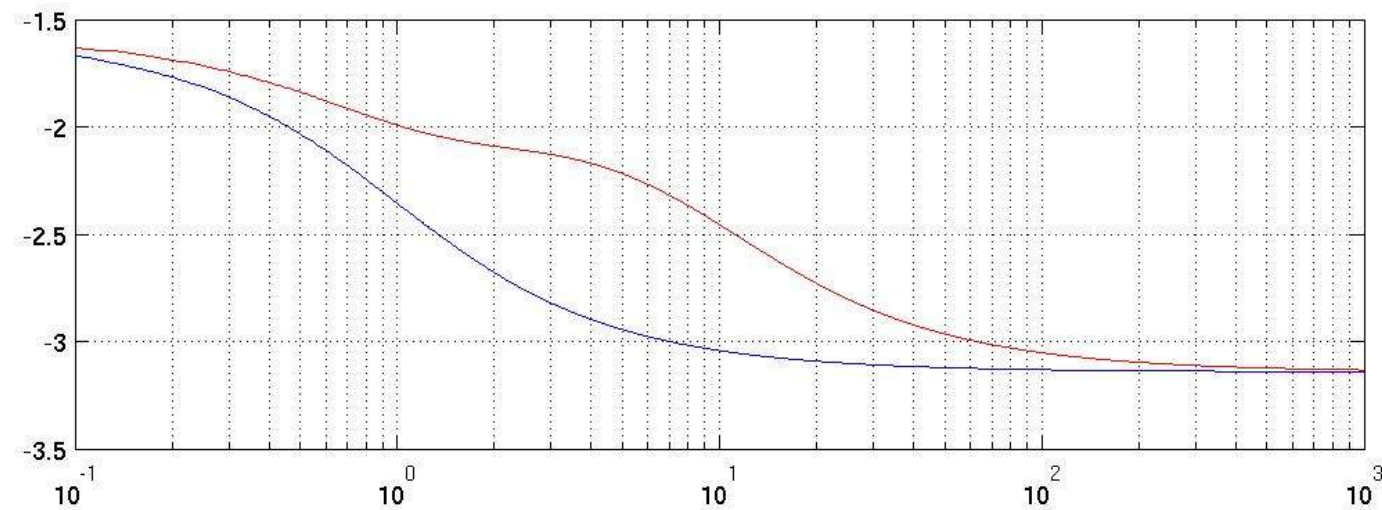
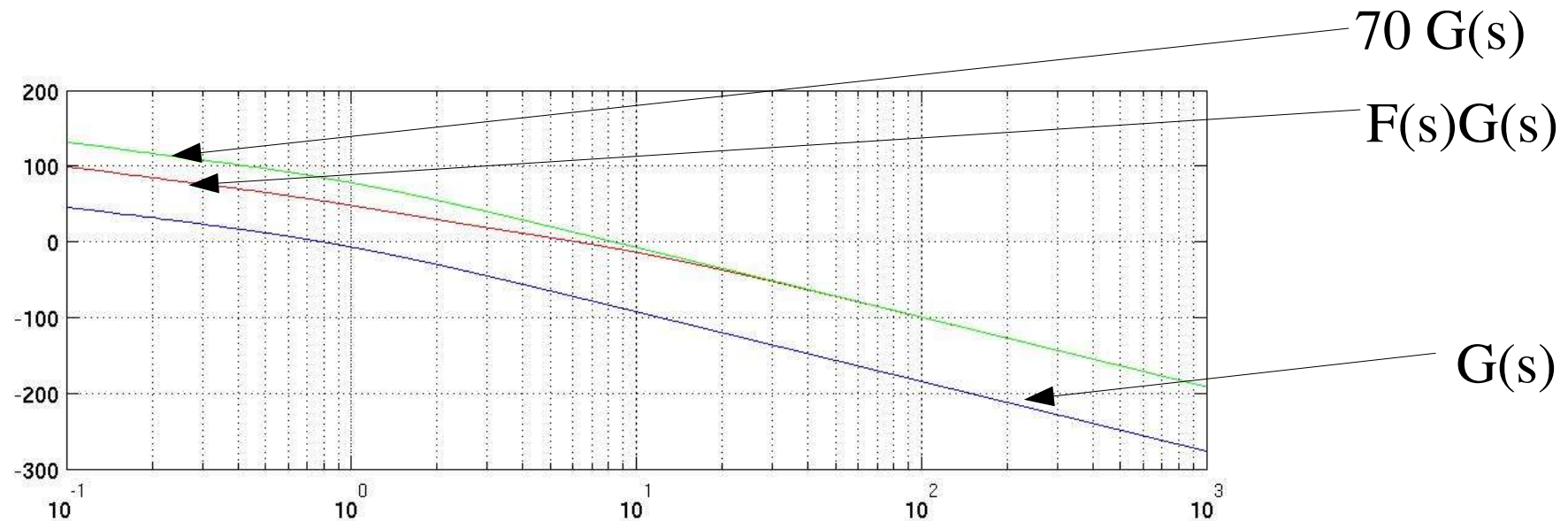
Phase Margin = 51°

Control design

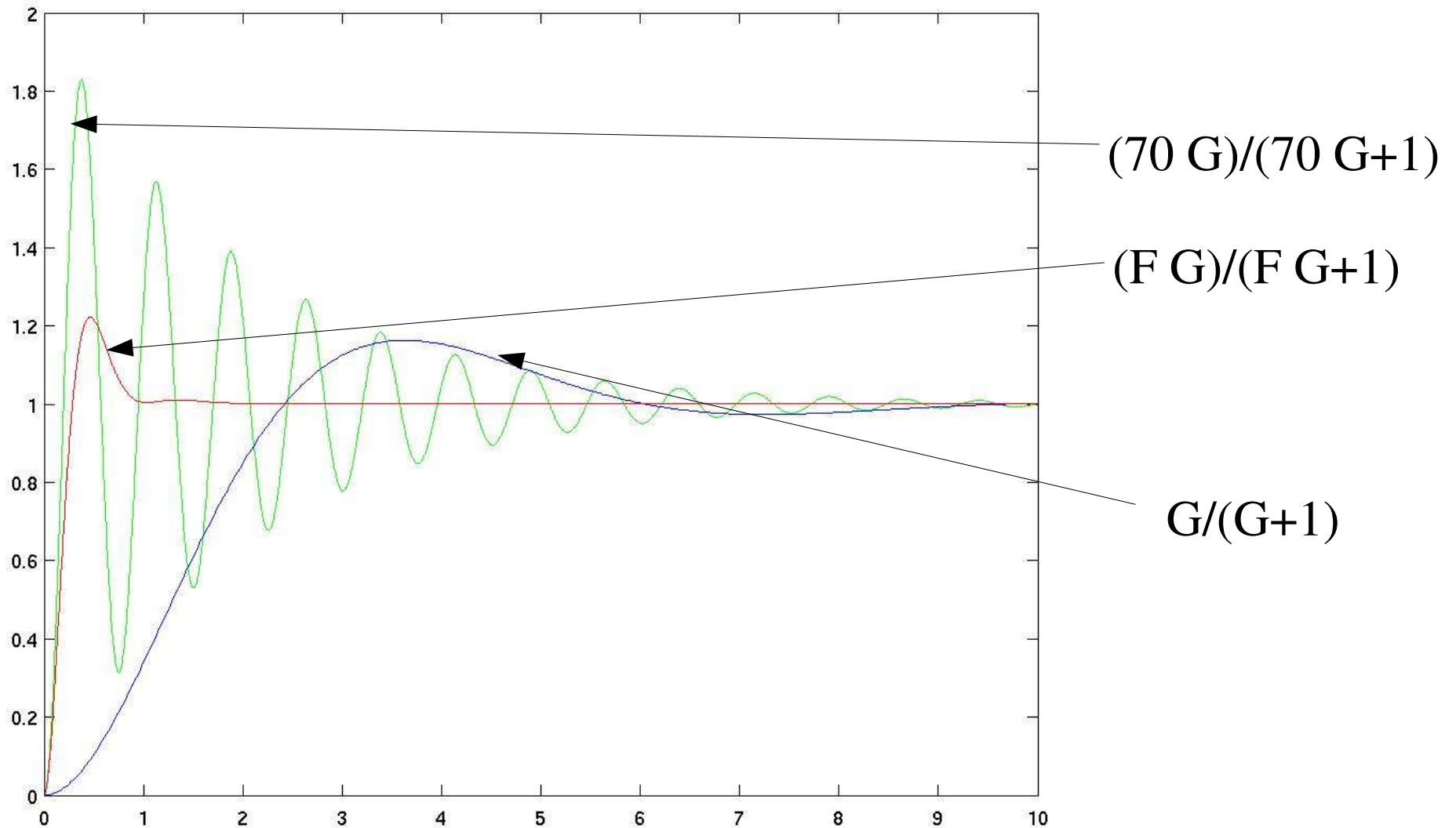
- We use a gain to increase the bandwidth
- A lead compensator around the cross over frequency helps us improve the phase margin

$$F(s) = 70 \frac{s+2}{s+10}$$

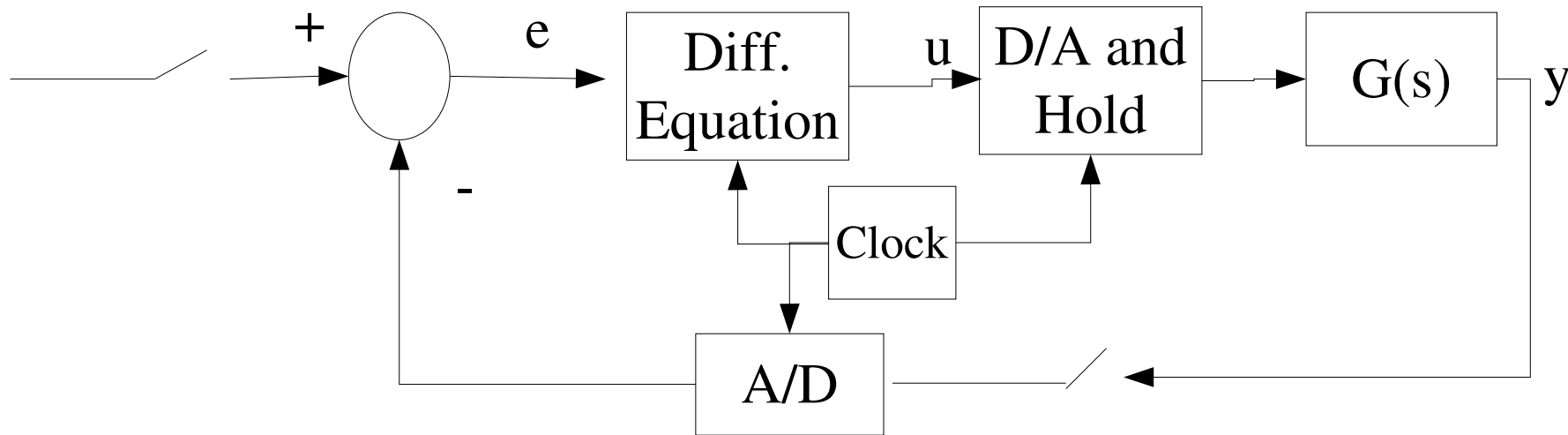
Bode plots



Step responses



Let's go to implementation



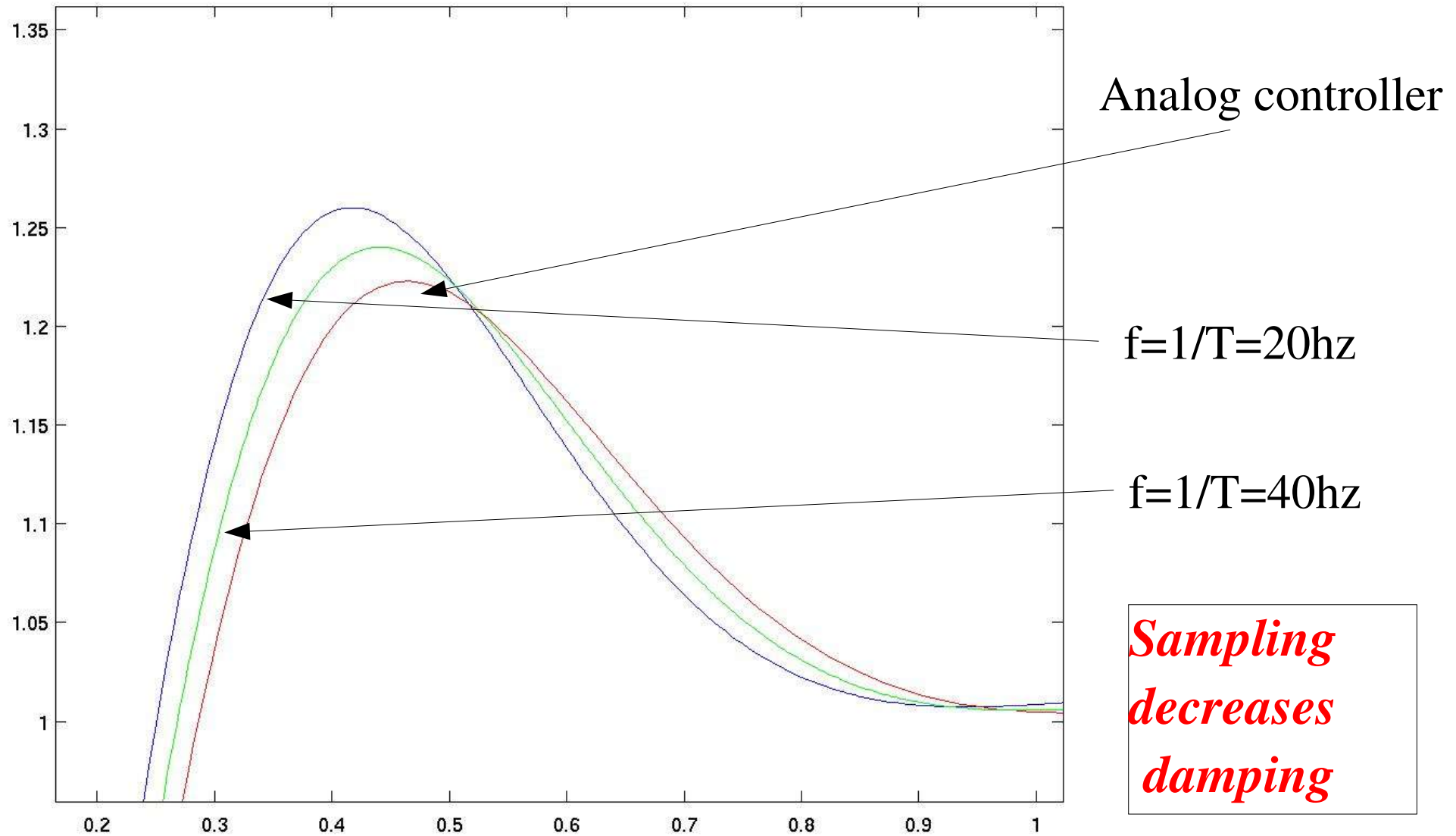
$$F(s) = \frac{U(s)}{E(s)} = 70 \frac{s+2}{s+10}$$

$$\dot{u} + 10u = 70\dot{e} + 140e$$

$$FW \text{ Euler Approximation: } \dot{u} \approx \frac{u_{k+1} - u_k}{T}, \dot{e} \approx \frac{e_{k+1} - e_k}{T}$$

$$u_{k+1} = (1 - 10T)u_k + 70e_{k+1} + (140T - 70)e_k$$

Step Responses



Why?

- The transfer function of a ZoH

$$Z(s) = \frac{1 - e^{-sT}}{s}$$

$$e^{-sT} \approx \frac{1 - sT/2}{1 + sT/2} \rightarrow Z(s) \approx \frac{T}{1 + sT/2}$$

- The ZoH results into a phase decrease of -
T/2
- The Phase Margin (PM) is reduced and so is
the damping $\zeta = \text{PM}/100$

Conclusions

- Sampling introduces an inherent delays
- There are problems for stability and performance (damping is reduced)
- We will present techniques to analyse and reduce these problems that will be presented through the course