Control Systems I
Exercise 01

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General Info

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What are Control Systems?

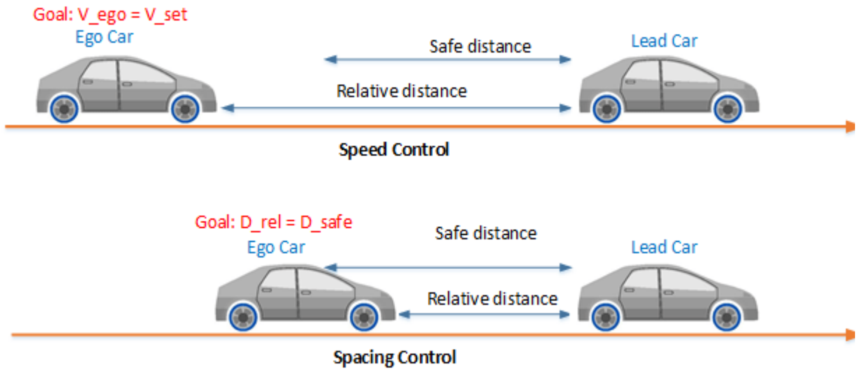
- Definition from Wikipedia:
  - «A **control system** manages, commands, directs, or regulates the *behaviour of other devices or systems* using **control loops**.»
  - Control: Targeted influence of physical, chemical or other quantities in a technical system.
  - Loops: Some sort of feedback.
  - System: Physical system we want to control (with or without a controller)

- **Our goal:** Regulate some quantity to a desired state/value:
  - Stabilize a system (keep it in safe regions, achieve desired behaviour)
  - Reach a certain performance criterion (speed, accuracy, energy consumption)
  - Robustness (perform well even with disturbances, noise or modelling errors)

What are Control Systems?

- What can be controlled?
  - In principle everything – feasibility and usefulness must be questioned

- Examples:
  - Heating System
  - Cruise Control
  - Inverted Pendulum
  - Robots
  - …



Control Systems 1

- **Modelling:** How do we mathematically describe the system we want to control?
  - Correct description of the physical system is very important.
    - What is relevant to keep track of?
  - Correct representation for unified theories and comparison of systems.

- **Analysis:** Understand the characteristics of a system.
  - What is the natural behaviour of the system?
  - Is the system stable or not?
  - Is the system controllable?

- **Synthesis:** How do we come up with a control signal/system?
  - Design of a feedback loop.
  - How do we achieve certain performance goals.

Control Systems 1

- Only **SISO** (single input single output) systems

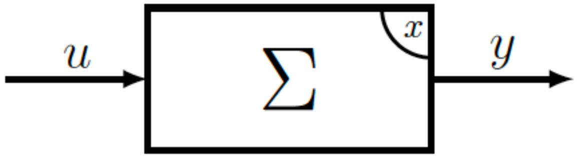
- Using **classical control** approaches (no Artificial Intelligence)
  - These classical control approaches are very important for future harder control problems!

- In Control System 1 a lot will be done in **frequency space** using the Laplace transform.
  - Hard to have an intuitive understanding
  - BUT simplifies the maths
  - -> Trust the formulas you are given!

- Computer tools are very important (not allowed for the exam), use them.
  - Notebooks will help you understand the topics on a more intuitive level.

What is a System?

- A **system** in Control Systems is an **operator** which defines a relationship between an input, an internal state and an output.



- **u, x and y** are in general **time variant** -> $u(t), x(t), y(t)$
- The general description of a system looks as follows: $y(t) = \Sigma\big(u(t), x(t)\big)$
  - $u(t)$ being the input
  - $x(t)$ being the internal states of the system (often not directly measurable)
  - $y(t)$ being the output
  - $\Sigma(t)$ being the system itself

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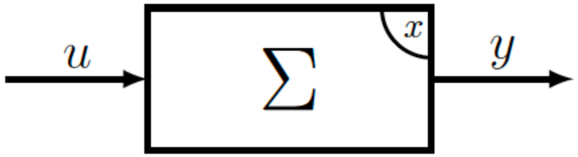
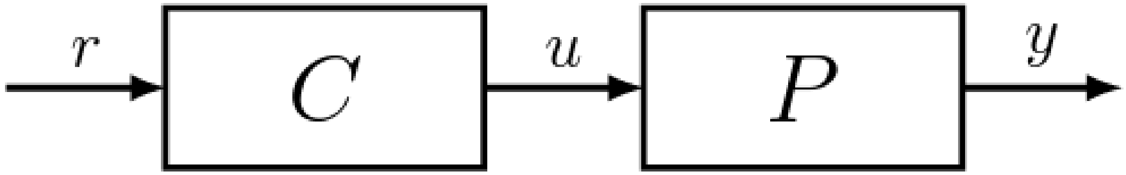


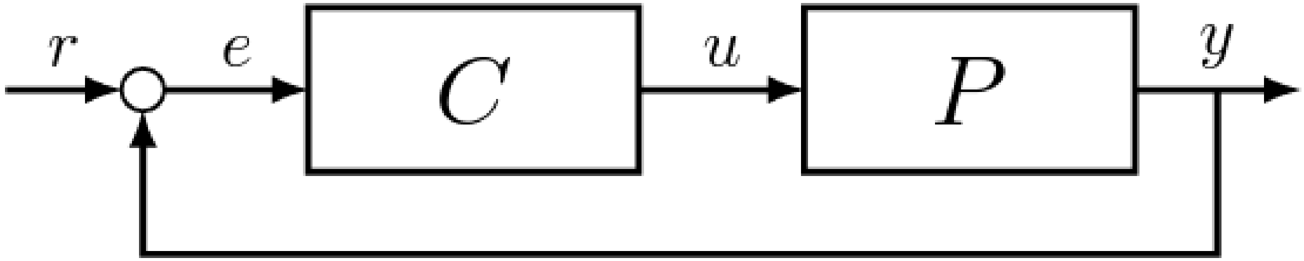
- The relationship between the input and output are in **differential equations** (more next week):
  - $\frac{d}{dt}x(t) = f\big(x(t), u(t)\big) \rightarrow y(t) = h\big(x(t), u(t)\big)$

Control System Architectures

- Feedforward:
  - Trying to balance a stick on your hand blindfolded and with gloves. -> very hard

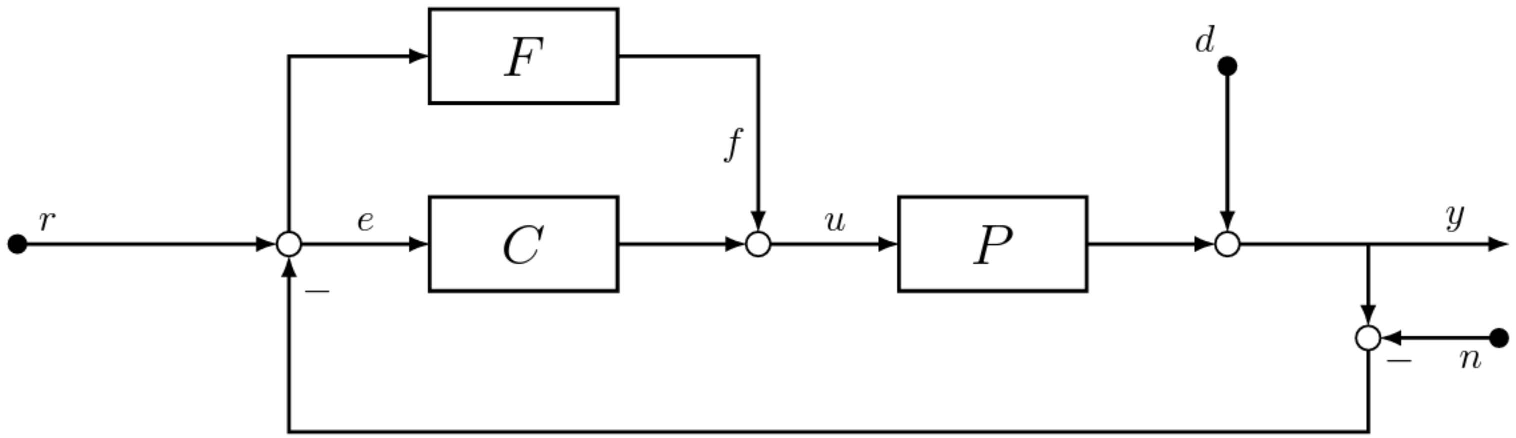


- Feedback:
  - Trying to balance a stick on your hand (eyes open and with gloves).



Control System Architectures

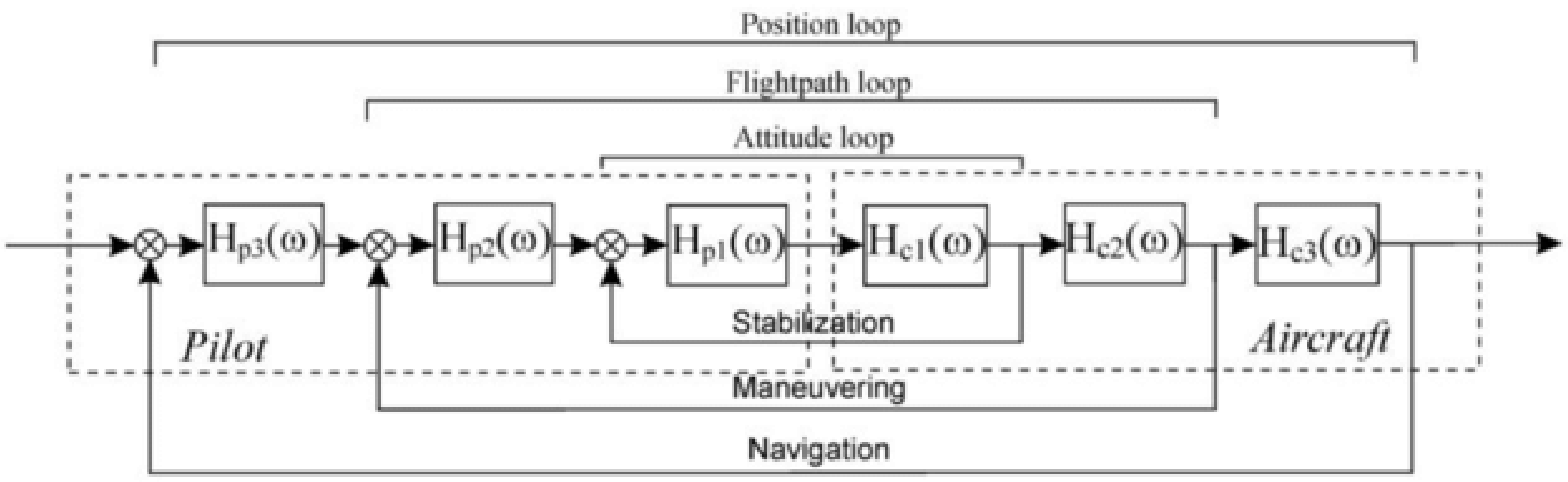
- Feedforward and Feedback
  - Balancing a stick in windy weather, knowing where the wind is coming from.



- r = reference value
- e = error signal
- C = controller
- F = feedforward
- u = control signal
- P = plant/system
- d = external disturbances
- n = measurement noise

Control System Architectures

- There is no limit to the complexity (not relevant for this course)!



- However, most loops can be looked separately using the tools learned in CS1.

Notebooks

- Weekly Python Notebooks in addition to the exercises
- Some theory parts for deeper understanding of the topics
- Some interactive examples to deepen the intuition or understanding of the subject
  - Play around with the sliders and options in the plots, they help a lot.
- See Moodle how to access them (I use VS-Code, but Google Collab does not require any setup)
- If you find any errors or would like to change anything, you can edit the notebook and create a pull request on Github.
  - If you have questions with that, just contact me or the head TA

Modelling Crash Course (More details next week)

- When modelling a system, we usually want to setup the Differential Equations governing the physics.
- For this you may lack the physical knowledge right now, but at the end of the semester your knowledge should be enough to model simple systems.

- Acceleration of a block:
- $u(t) = F(t), y(t) = v(t), F_R = b \cdot v(t)$ (Damper)
- Using Newton: $\sum F(t) = m \cdot a(t) \rightarrow a(t) = \frac{d}{dt}v(t) = \frac{d}{dt}y(t)$
- We get the following system:
  - $m \cdot \frac{d}{dt}y(t) = u(t) - b \cdot y(t) \Longrightarrow \Sigma\text{:}\ \frac{d}{dt}y(t) = -\frac{b}{m}y(t) + \frac{1}{m}u(t)$