# Systems Engineering/Process Control L1

- What is Systems Engineering/Process Control?
- Graphical system representations
- Fundamental control principles

Reading: *Systems Engineering and Process Control:* 1.1–1.4

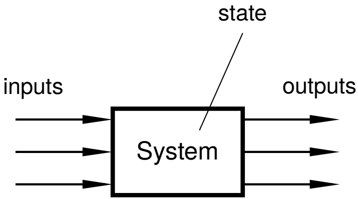
# What is Systems Engineering?

Systems Engineering is about **dynamical systems**

- How can dynamical systems be modeled?
- How to understand behavior of complex interconnected systems?
- How to make a system behave as desired?

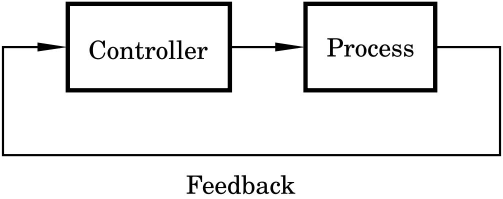
# What is a dynamical system?

- **Dynamical** systems have a “memory” — an **inertia**
- Outputs do not directly depend on the inputs; there is an inertia
- Are often modeled abstractly using block diagrams:



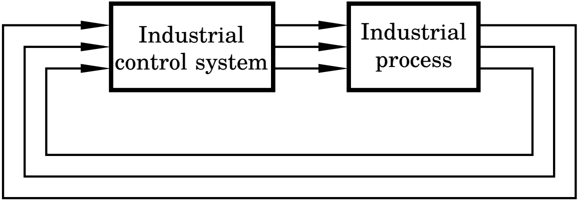
# What is control?

- It is about dynamical systems with **feedback**
- Objective: control system (process) to make it behave as desired
- Schematic figure of a feedback system:



# What is process control?

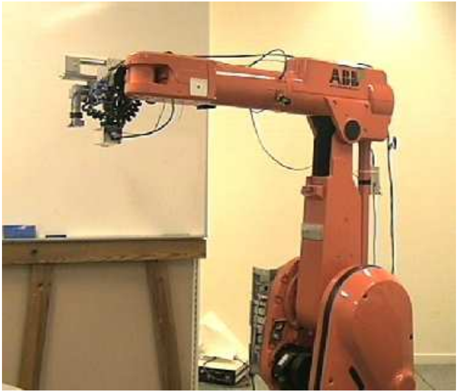
- Control of industrial processes to achieve desired behavior
- Typical objectives: Safety, predictability, profitability




Feedback

# Control applications - Industrial robots

ABB IRB 2000




- No. of axes: 6
- Max load: 10 kg
- Range: 1542 mm
- Repetition accuracy: $\pm$0.1mm
- Mass: 350 kg

**Design compromise:** Power, speed, stiffness, repeatability **vs.** cost, weight, power consumption

# Stabilization

Many systems need stabilization using control to work as desired

- Airplanes
- Bicycles
- Segways
- Rockets
- Exothermic reactions
- ...

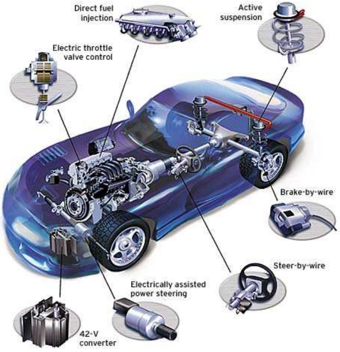
# Inverted pendulum problems

- Segway/swagway/monowheel
- Space-X space-craft landing:
  [https://www.youtube.com/watch?v=hulMgWJV3e8, 2017]

- Fundamental control problem: Balance an inverted pendulum

# Cars

- Motor control
- Power transmission
- (Adaptive) **Cruise control**
- Anti-spin systems
- Lane assistance
- Parking assistance
- …



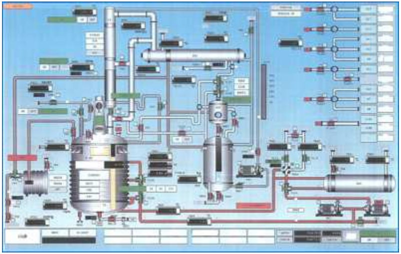

# Quadrocopters etc

[https://vimeo.com/110346531]

[Raffaello D'Andrea, Institute for Dynamic Systems and Control, ETH, Switzerland, 2015]

# Process industry

Perstorp ABs chemical production site in Stenungsund



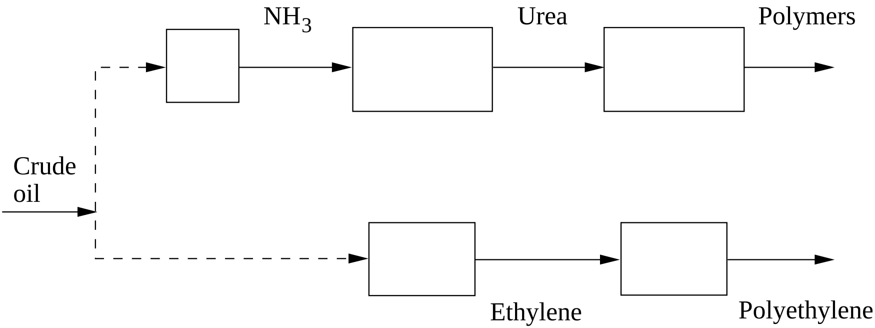
Schematic figure of a process plant

# Graphical process representations

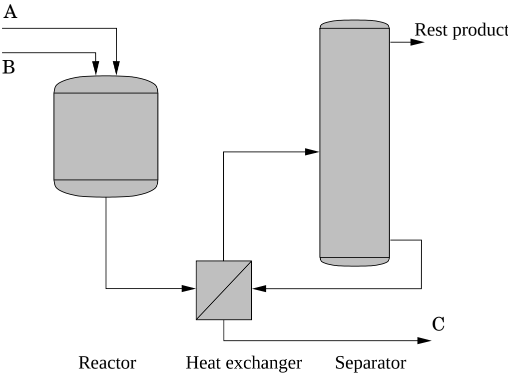
- General process layouts
- Process flow sheets
- Process and instrumentation (P/I) diagrams
- Block diagrams

# General process layout

- Crude sketch of material flow for polymer/polyethylene manufacturing

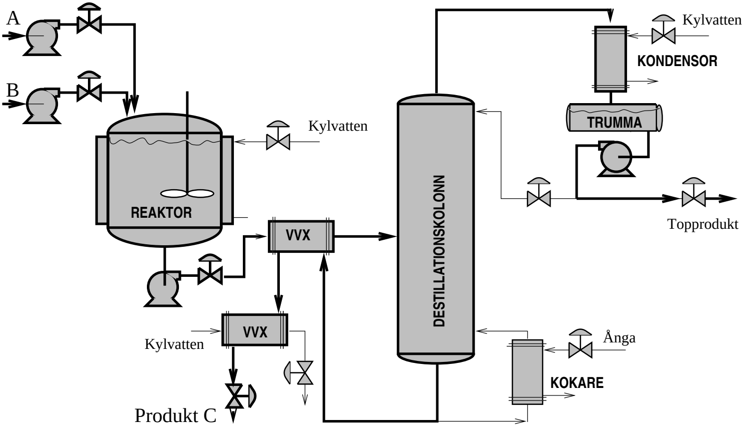


# Process flow sheet



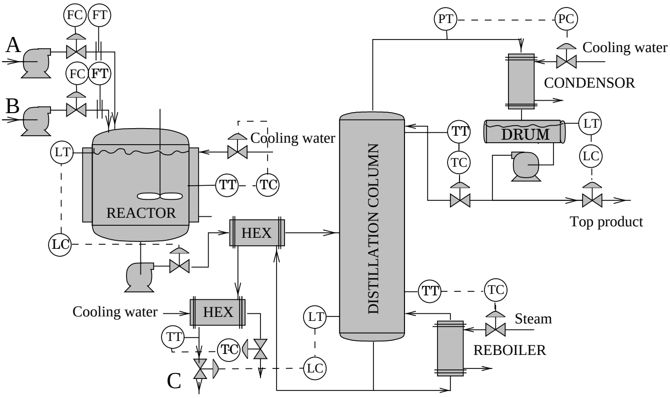

- product flows
- important unit operations
- fundamental sequence of operations

# Detailed process flow sheet




- all important flows
- all units (e.g., pumps, valves)
- “all” steps (including, e.g., reboilers, condensators)

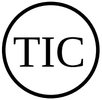
# Process and instrumentation diagram (P/I-diagram)




Detailed process flow sheet with:

- instruments (sensors, controllers, actuators)
- all information flows (e.g., measurement to controller)

# Instrument symbols




First letter: **Quantity**

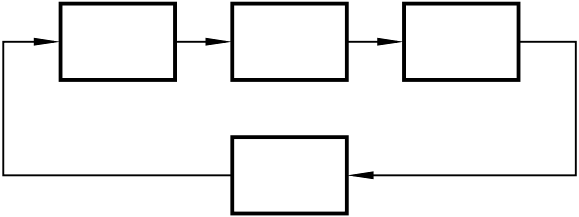
- T = temperature
- L = level
- F = flow
- P = pressure
- (C/Q = concentration)
- (X = power)

Second (and third) letter: **Function**

- T = transmitter (sensor)
- C = controller
- I = indicator
- R = recorder
- A = alarm

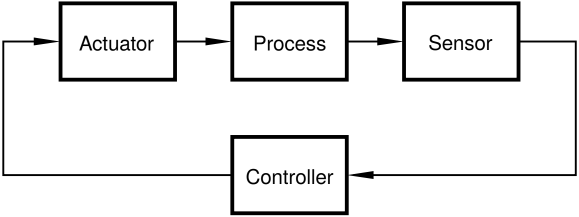
Standardized in *ISA Standard S5.1*

# Block diagram



- Block diagrams reflect *information flow* between system parts
- May *not* coincide with physical flows of system
  (there may not even be any physical flows in the system)
- So the arrows transmit *information*
- Can draw different block diagrams for same system depending on:
  - desired level of detail
  - purpose of control

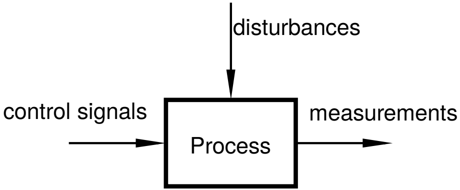
# Control system parts




- Process (or system/plant)
  - Represents what we want to control
- Sensor/transmitter
  - Measures what happens in the process
- Controller
  - Decides how the process is controlled
- Actuator
  - Can influence the process

Often sensors and actuators are not drawn, but are included in the process

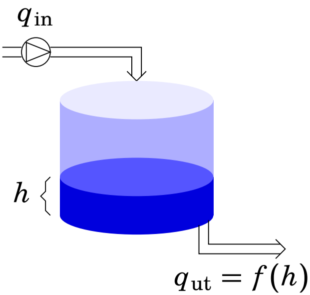
# Block diagram for one process




- *Control signals*: Affect process and can be freely manipulated. (often called *inputs* or *manipulated variables*)
- *Disturbances*: Affect process but cannot be manipulated.
- *Measurements*: Contain information about system quantities (often called *outputs* or *measurement signals*)

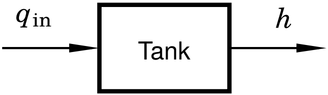
# Example: Tank process

Reality:




- We control the inflow $q_{\text{in}}$
- We measure the height $h$

Block diagram:



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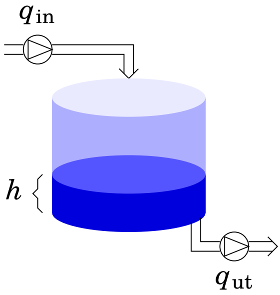
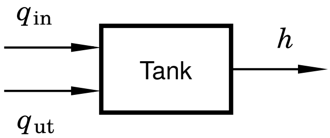



- We control:
  - the inflow $q_{in}$
  - the outflow $q_{ut}$
- We measure the height $h$

Block diagram:



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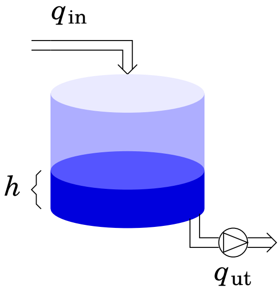


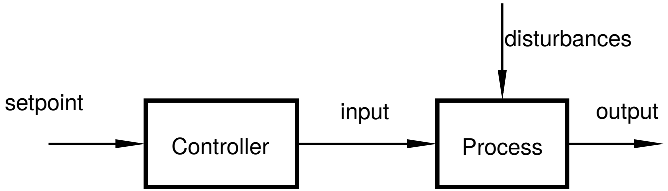

- We control the outflow $q_{\text{ut}}$
- We measure the height $h$
- The inflow $q_{\text{in}}$ is a disturbance (that we cannot manipulate)

Block diagram:

# Fundamental control principles

- Open-loop control / feedforward
- Closed-loop control / feedback

# Open-loop control




- The controller tries to steer the output to the setpoint (reference)
- Does not get information from the process (feedback)
- Only information (feedforward) from the setpoint
- Open-loop system

# Pros and cons with open-loop control

Pros:

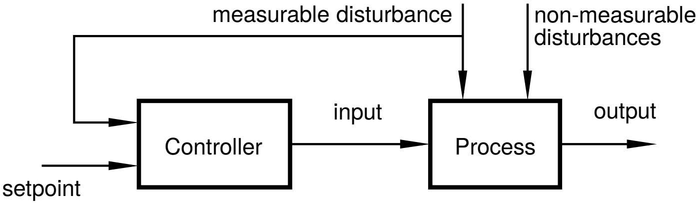
- Simple
- Does not require any sensors

Cons:

- Works only for stable processes
- Good performance requires very accurate model of the system
- Cannot compensate for unknown disturbances and model errors

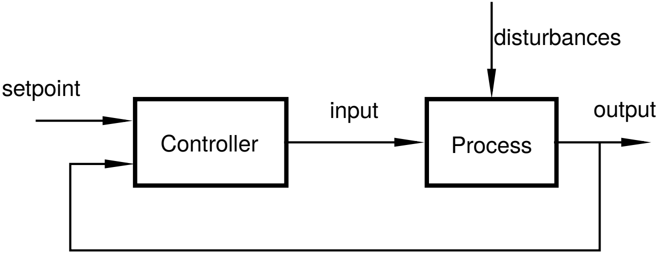
# Open-loop control with feedforward

If a disturbance is measurable, we can feedforward from it:




- Requires sensors (to measure disturbance)
- Requires model of how the disturbance affects the process
- Cannot compensate for other disturbances and model errors

# Closed-loop control




- Feedback from output
- Controller steers output towards setpoint
- Closed-loop system

# Pros and cons with closed loop control

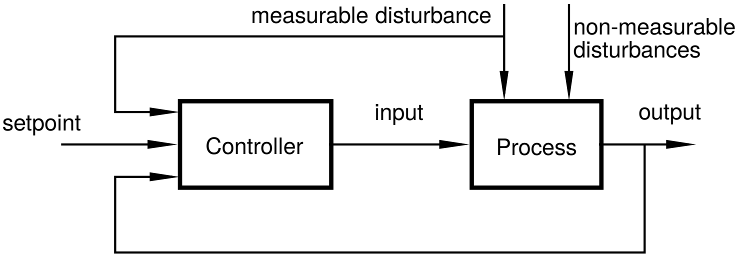
Pros:

- Can reduce disturbance sensitivity, increase speed, improve accuracy
- Can stabilize an unstable system
- It is often enough with a crude model of the system
- Can make new products and solutions possible!

Cons:

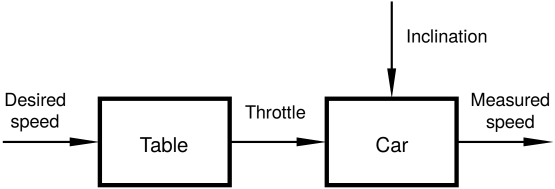
- Requires sensors (for the feedback)
- Can cause oscillatory behavior and instability
- Measurement disturbances are fed back to the process

# Closed-loop control with feedforward



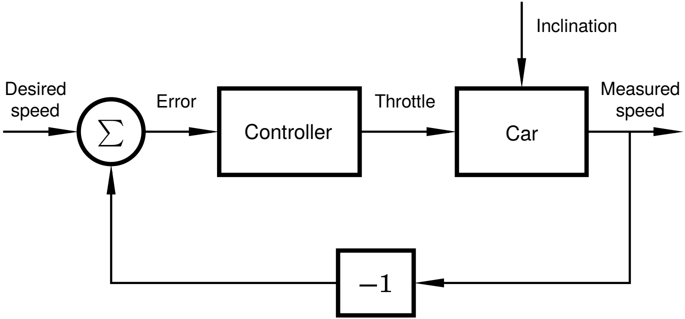

- Measurable disturbances can be compensated using feedforward
- Other disturbances and model errors compensated using feedback

# Example: Open loop (feedforward) cruise control



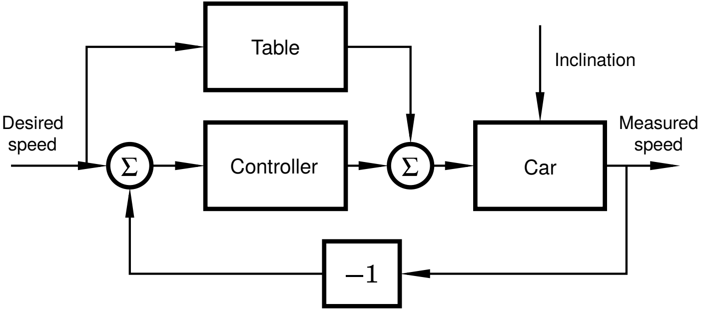

- Open-loop control
- Problems?

# Example: Cruise control with feedback




- Closed-loop control
- Controller:
  - Error $> 0$: increase throttle
  - Error $< 0$: decrease throttle
  - (But how much?)

# Example: Cruise control with feedback and feedforward




- Both proactive and reactive
- Could also feedforward from:
  - inclination (GPS)
  - distance to car in front (radar/camera)