



UNIVERSITY
OF APPLIED SCIENCES

BASIC CONTROL SYSTEMS

01 FUNDAMENTALS CONCEPTS

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WHERE STUDENTS MATTER



A SIMPLE CASE

I would like to grab a bottle of water.



A SIMPLE CASE

I would like to grab a bottle of water.

I list what I have to do.



A SIMPLE CASE

I would like to grab a bottle of water.

I list what I have to do.

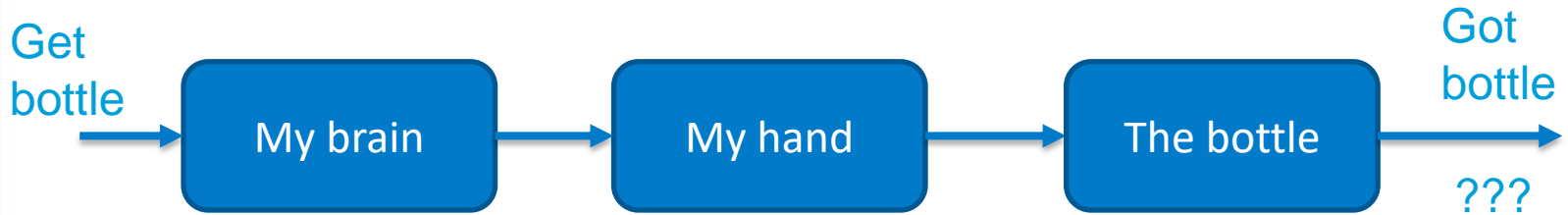
I wrap my hand around the bottle.

I apply force.

I grab bottle.



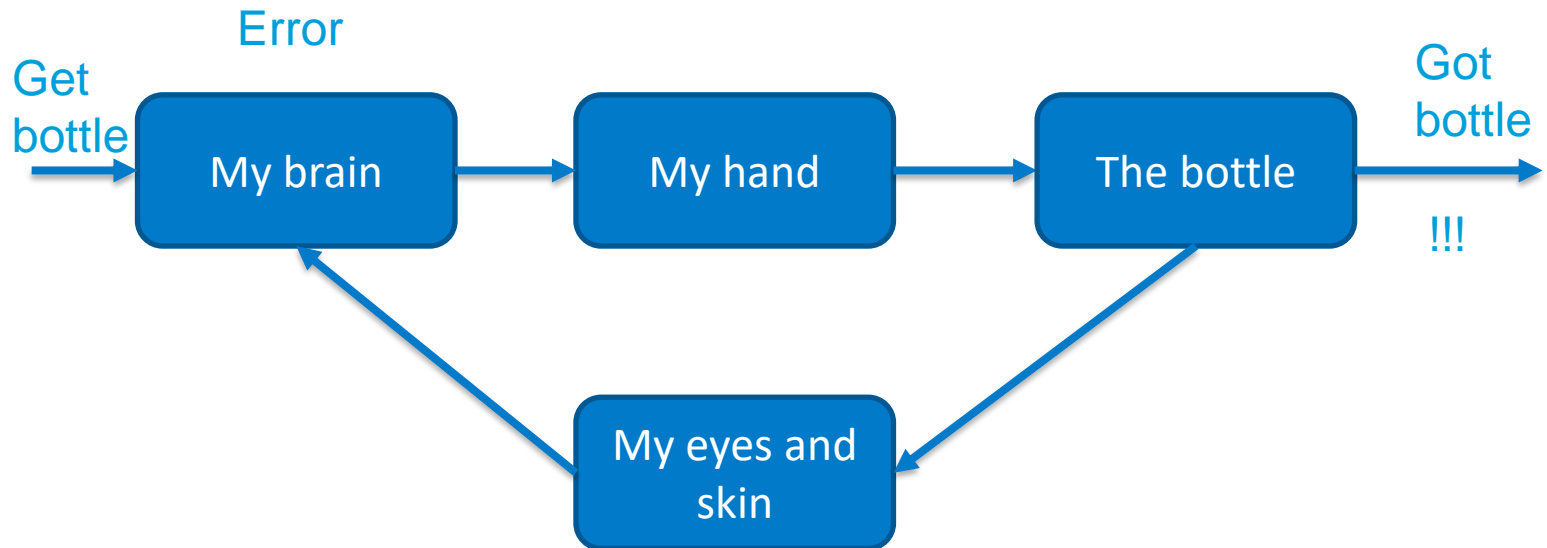
OPEN LOOP CONTROL SYSTEM



I don't know the force I need to apply,
I just grab,
I do not have my water.



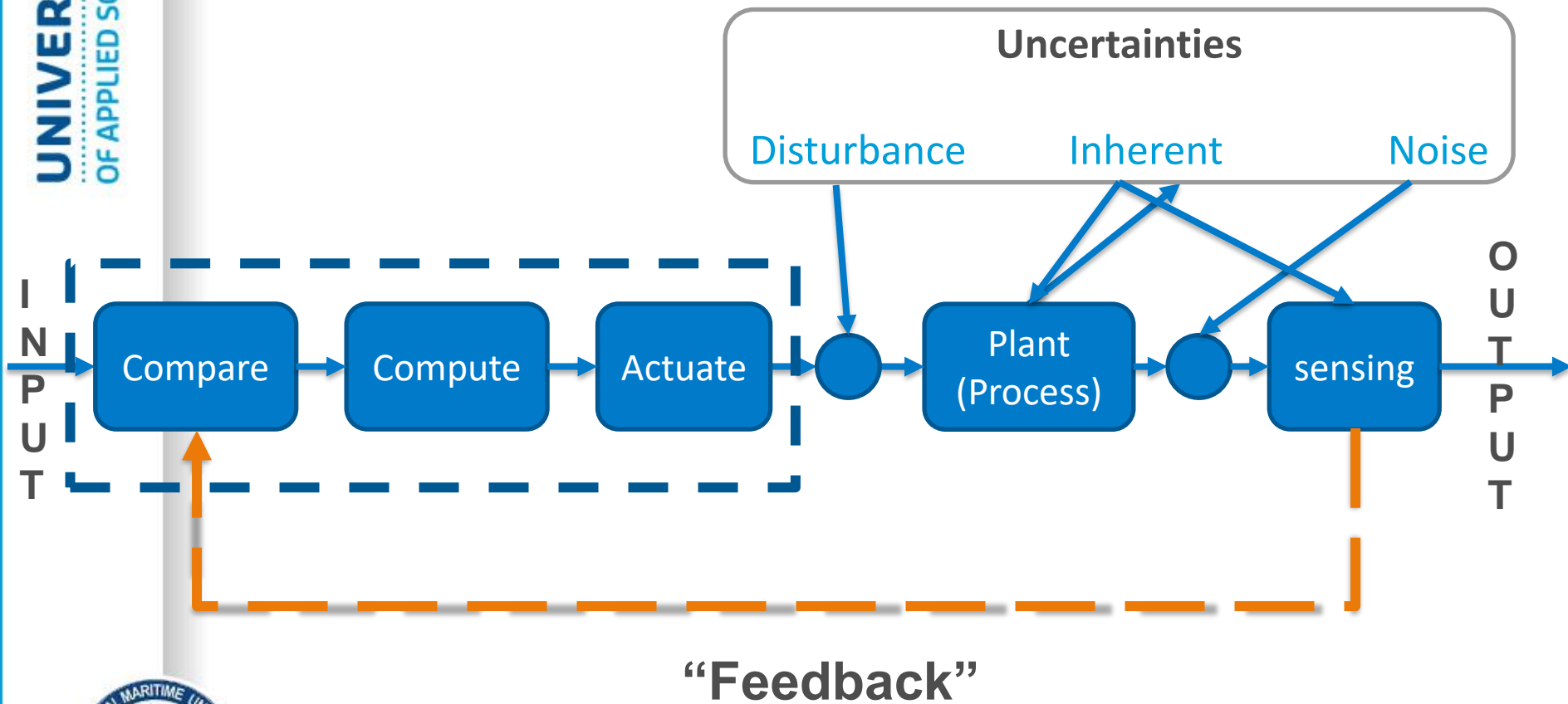
CLOSED LOOP CONTROL SYSTEM



I don't know the force I need to apply,
but I try, I feel, and I look,
I stop pressure when my hand apply just enough force,
I get my water.

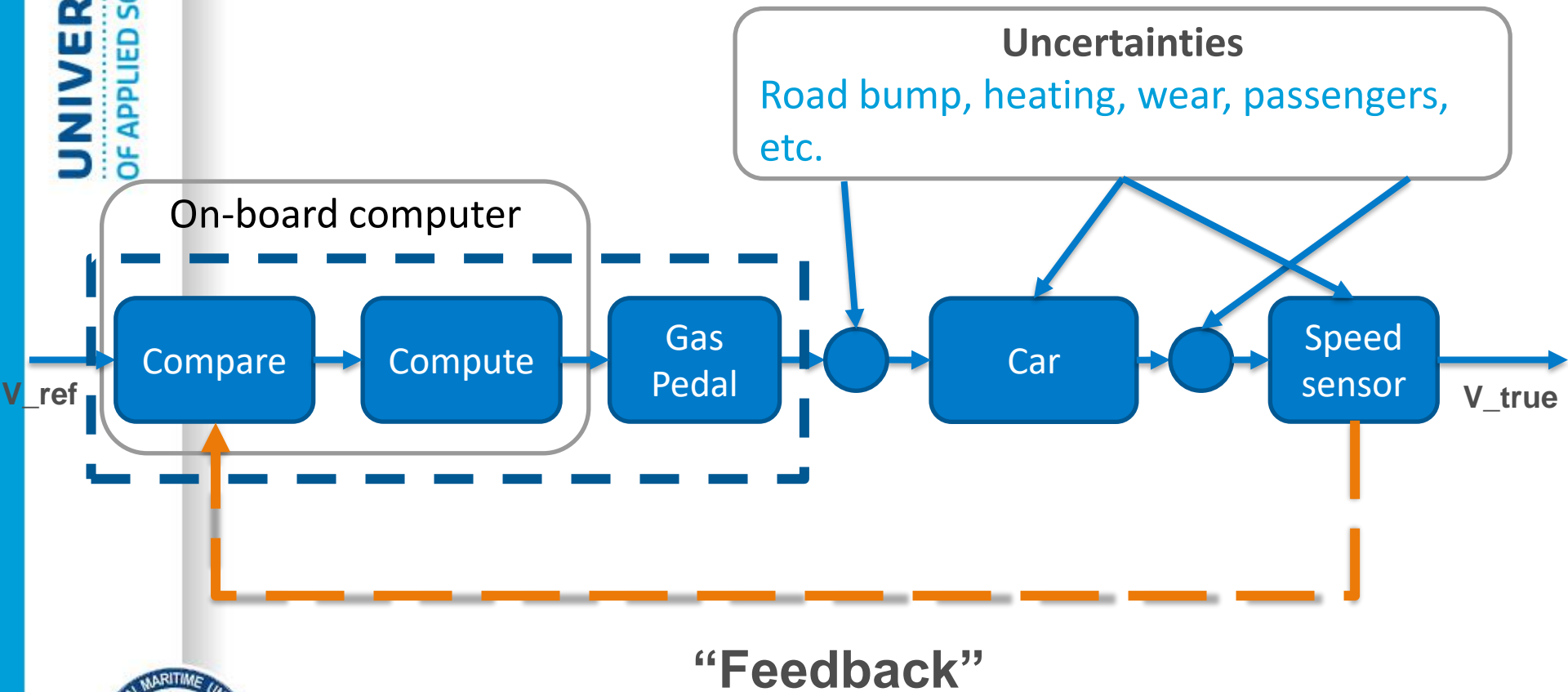


THE STANDARD MODEL OF A FEEDBACK CONTROL SYSTEM

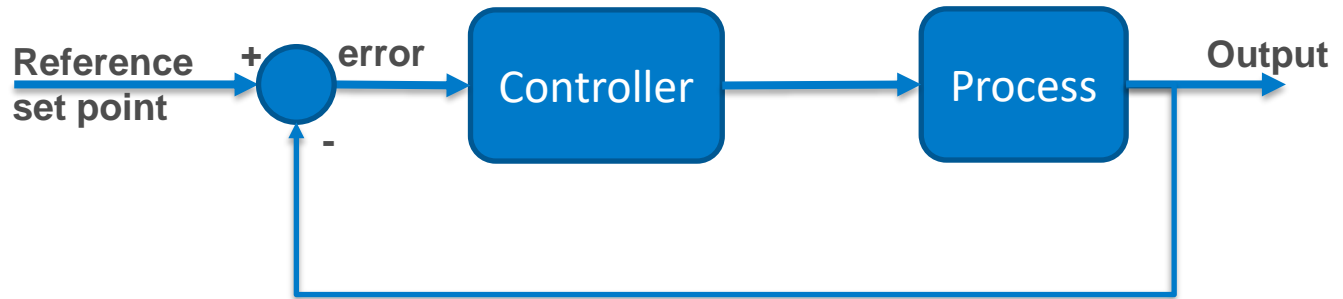




REAL WORLD EXAMPLE: CRUISE CONTROL OF A BUS

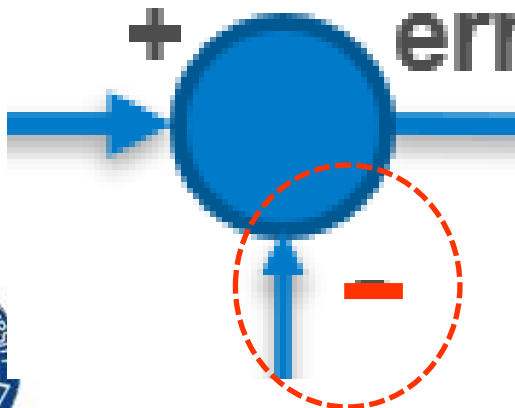
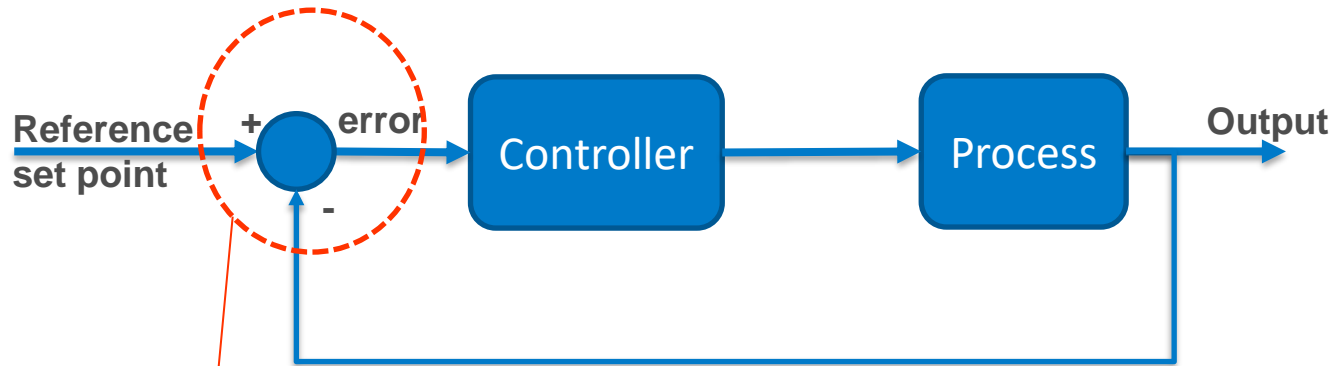


SIMPLE CLOSED LOOP CONTROL WITH UNIT FEEDBACK





SIMPLE CLOSED LOOP CONTROL WITH UNIT FEEDBACK



**Minus sign: negative feedback.
Plus sign: positive feedback**

We only work with negative feedback in this course.



WITH OR WITHOUT FEEDBACK

With feedback we can:

- deal with system dynamics
- be robust to uncertainty
- modular operation
- gain even more knowledge of environment

But the trouble feedback brings:

- increase complexity
- potential to bring unstable
- noise amplification





TRANSFER FUNCTION

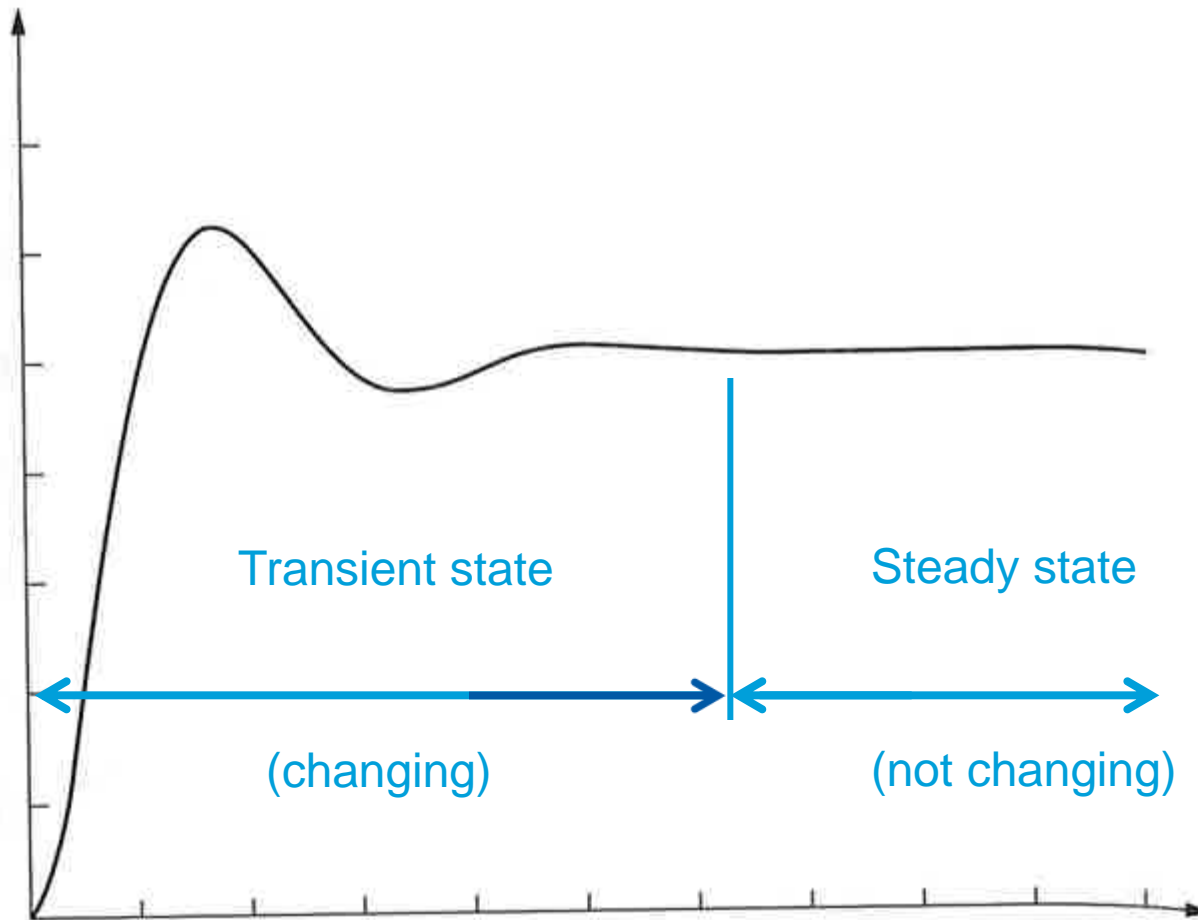
$$OUTPUT = INPUT * G(s)$$

$$G(s) = \frac{OUTPUT}{INPUT}$$

Blackbox



TRANSIENT & STEADY





CONTROL

(roughly explained)

The process of design & implementing algorithms in engineered target system to achieve a desired output or system state.

Typically you control a system using controller & control loops.



CONTROL

When there is uncertainty,
apply control!

SYSTEM

Generally,

An object or a series of interacting objects of your interest.

In which you usually can discover:

- Input(s)
- Output(s)
- Object(s) as “building block(s)”
 - The physical characteristics are **crucial**



SYSTEM - BRAINSTORM

Is a large piece of metal on the ground a system?

SYSTEMS - SCOPE OF THIS COURSE

We only deal with:

Causal LTI SISO systems

- **Causal:** output only depends on the past and present (input), not the future
- **L:** Linear systems or systems that can be linearized
- **TI:** Time-invariant
- **SISO:** Single Input Single Output



CAUSAL LTI SISO SYSTEMS

Properties:

Given a system that yields $x_{(t)} \mapsto y_{(t)}$

1. Homogeneity

$$\alpha \cdot x_{(t)} \mapsto \alpha \cdot y_{(t)}, \alpha \in \mathbb{R}$$

2. Additive

Given : $x_{1(t)} \mapsto y_{1(t)}$, $x_{2(t)} \mapsto y_{2(t)}$, we have:

$$(x_1 + x_2)_{(t)} \mapsto (y_1 + y_2)_{(t)}$$

3. Time invariance

$$x_{(t+a)} \mapsto y_{(t+a)}, a \in \mathbb{R}$$

4. Causality

the system remains stationary before t_0
(we almost always take $t_0 = 0$)

$\forall t_1 \neq t_2$ and $t_1, t_2 < t_0$, we have:

$$x_{(t_1)} = x_{(t_2)} \text{ and } y_{(t_1)} = y_{(t_2)}$$





SYSTEMS: THE KEY TAKEOUT

No matter how much we simplify,
we are working with **physical systems**.

The mathematical tools you see later,
are describing the **characteristics** of the **physical system**.

(最重要的是物理系统自身的特性！)





STABILITY

finite input



system

finite output

STABLE !

STABILITY (MATHEMATICAL DESCRIPTION)

Given a system $h(t)$,

for $h(t)$ to be stable, the impulse response of $h(t)$ should be absolutely integrable.

$$\int_{-\infty}^{\infty} |h(t)| dt < \infty$$

In our case, for causal systems:

$$\int_0^{\infty} |h(t)| dt < \infty$$

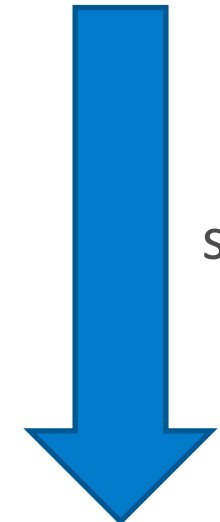


STABILITY – BIBO

More formally we have:

- Bounded-Input Bounded-Output (**BIBO**) stable
- Marginally stable
- Conditionally stable
- Uniformly stable
- Asymptotically stable
- Unstable

finite input



system

finite output⁸³

BEYOND STABILITY - OTHER CHARACTERISTICS

- Stability
- Robustness
- Sensitivity
- Observability
- Controllability
- Reachability
- Stabilizability
- Reconstructability
- Detectability
-



MODELLING

You have a physical system
You have learned some physics

Determine the input and output

Write the relevant equations

Derive the ODE

(Next step)

Solve it using Laplace transform





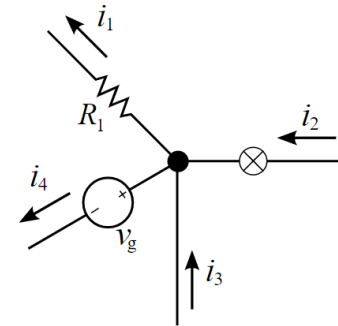
Modelling: Electric circuits

Kirchhoff's circuit laws deal with the conservation of charge and energy in electrical circuits.

Kirchhoff's current law:

The current entering any junction is equal to the current leaving that junction. $i_2 + i_3 = i_1 + i_4$

$$\sum_{k=1}^n I_k = 0$$

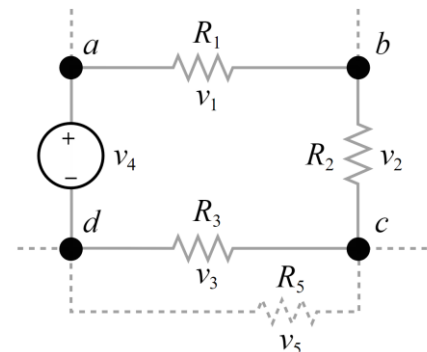


Kirchhoff's voltage law:

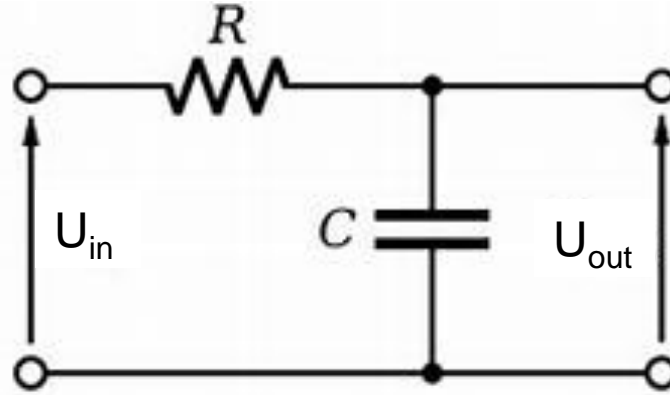
The sum of all the voltages around a loop is equal to zero.

$$v_1 + v_2 + v_3 + v_4 = 0$$

$$\sum_{k=1}^n V_k = 0$$



Modelling example: RC low-pass filter



This is a RC low-pass filter(LPF).

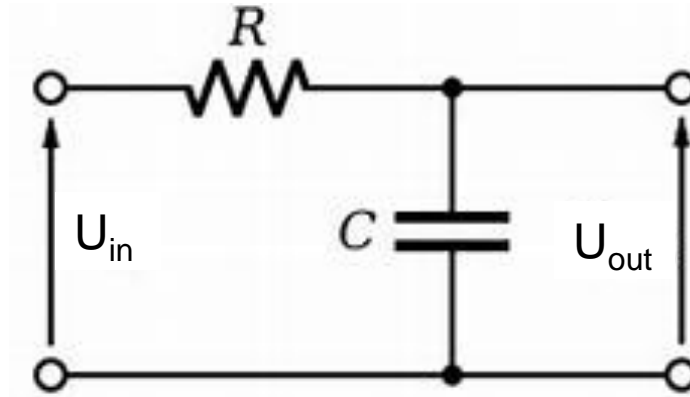
You have a voltage source U_{in} .

You want to know U_{out} ,the voltage after the RC-LPF.

You know R and C values. The initial condition is 0.

What should you do?

Modelling example: RC low-pass filter



Circuit analysis!

$$I_{total} = I_R = I_C$$

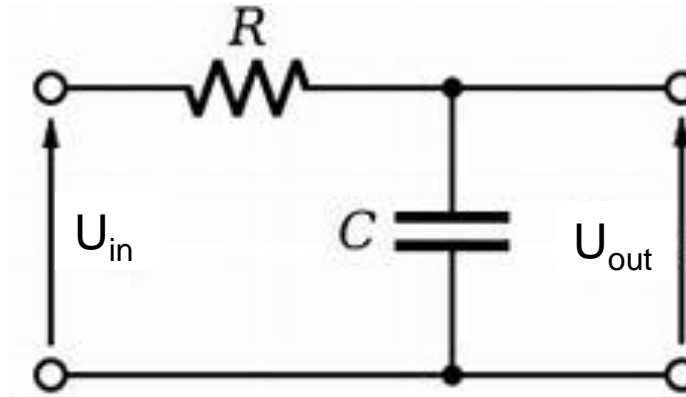
$$U_{in} = U_R + U_C = U_R + U_{out}$$

$$U_C = \frac{1}{C} \int_0^1 I(\tau) d\tau \Rightarrow I_C = C \frac{dU_C}{dt}$$

$$U_R = I_R R \Rightarrow I_R = \frac{U_R}{R}$$

$$\frac{U_R}{R} = C \frac{dU_C}{dt}$$

Modelling example: RC low-pass filter



Circuit analysis! -> Differential Equation!

$$\frac{U_R}{R} = C \frac{dU_C}{dt} \Rightarrow U_R = RC \frac{dU_C}{dt}$$

$$U_{in} = U_R + U_{out}, U_C = U_{out}$$

$$\Rightarrow U_{in} = RC \frac{dU_{out}}{dt} + U_{out}$$

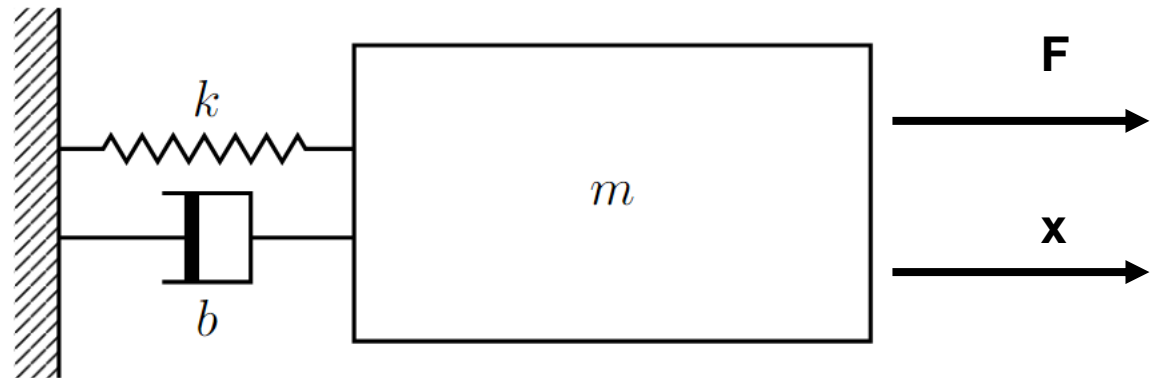


ELECTRICAL SYSTEMS – RLC CIRCUITS

	Voltage - Current
Resistor	$U(t) = I(t)R$
Capacitor	$U(t) = \frac{1}{C} \int_0^1 I(\tau) d\tau$
Inductor	$U(t) = L \frac{d I(t)}{d t}$



Modelling example: Mechanical system



The force applied on m is F .

The velocity of m is v .

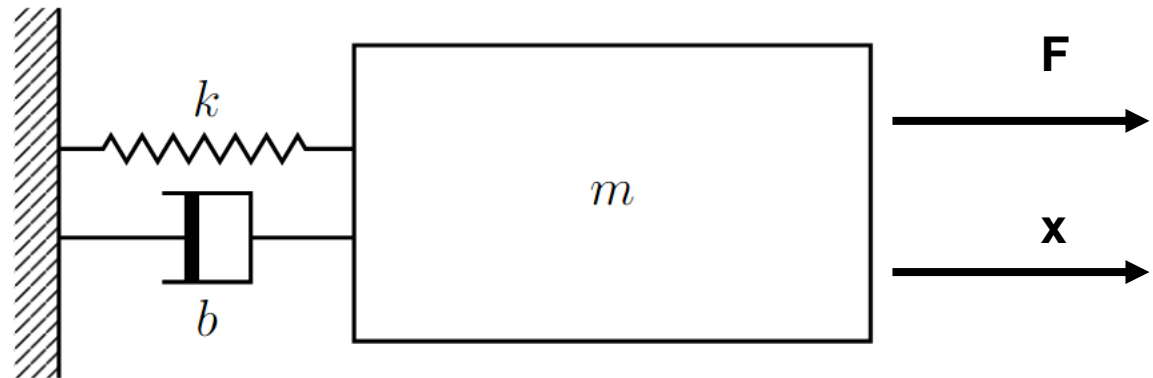
The displacement of m is x .

I pull the block m from sitting still, I want to know how it moves, in this case velocity.

Input F

Output v

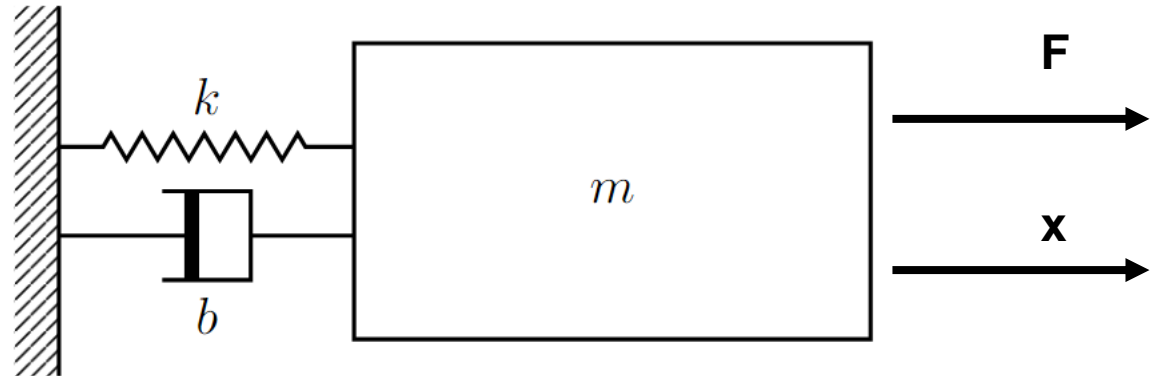
Modelling example: Mechanical system



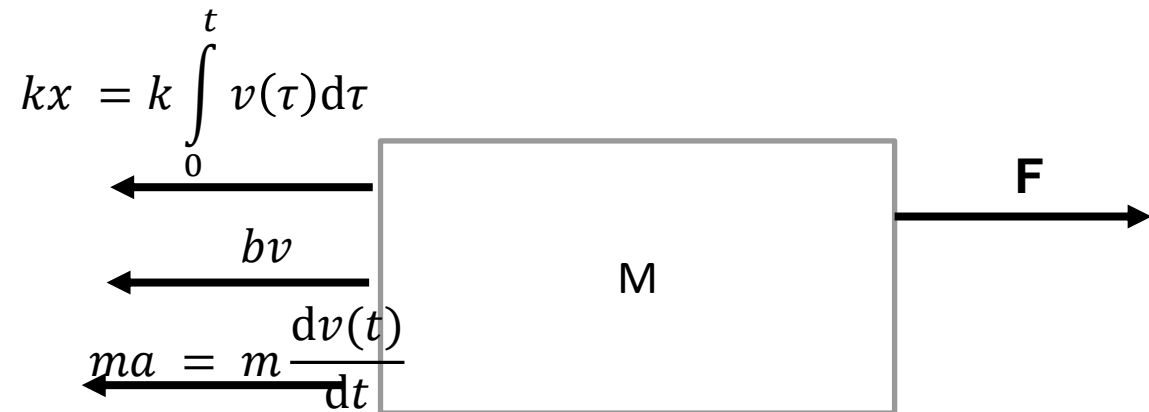
Analysis! Free body diagram.



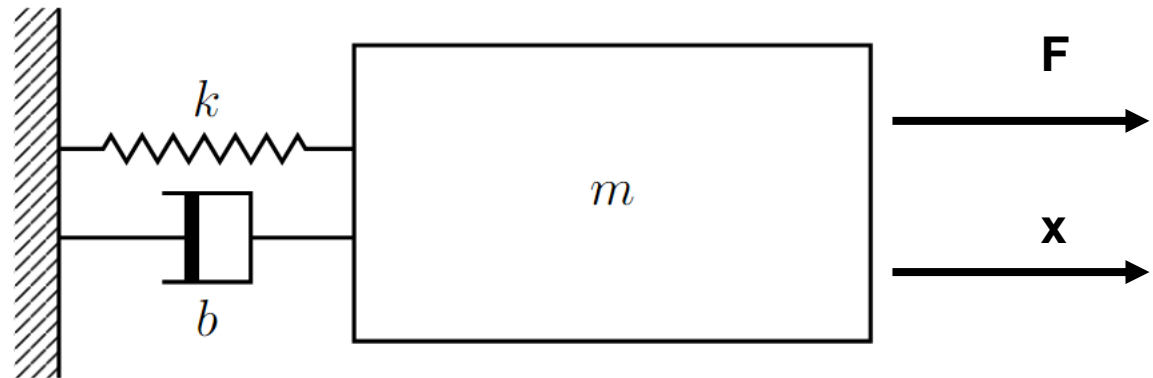
Modelling example: Mechanical system



Analysis! Free body diagram.



Modelling example: Mechanical system



Write differential equation

$$F(t) = k \int_0^t v(\tau) d\tau + bv(t) + m \frac{dv(t)}{dt}$$



MECHANICAL SYSTEMS – TRANSLATING SYSTEM

	Force - Velocity
Damper (Viscous friction)	$F = bv$
Spring	$F = k \int_0^t v(\tau) d\tau$
Mass (Inertia)	$F = m \frac{dv(t)}{dt}$





MECHANICAL SYSTEMS – TRANSLATING SYSTEM

	Force – Displacement
Damper (Viscous friction)	$F = b \frac{dx(t)}{dt}$
Spring	$F = kx$
Mass (Inertia)	$F = m \frac{d^2x(t)}{dt^2}$





SUMMARY

- Getting what we want from a system: **control**
- We like: **causal & linear** systems
- Open loop & closed loop control system
 - “The standard model”
- Still changing? Transient
- Stop changing? Steady
- (BIBO) Stability
- Modelling physical systems with ordinary differential equations.