

SI100B

Introduction to Information Science and Technology (Part 3: Electrical Engineering)

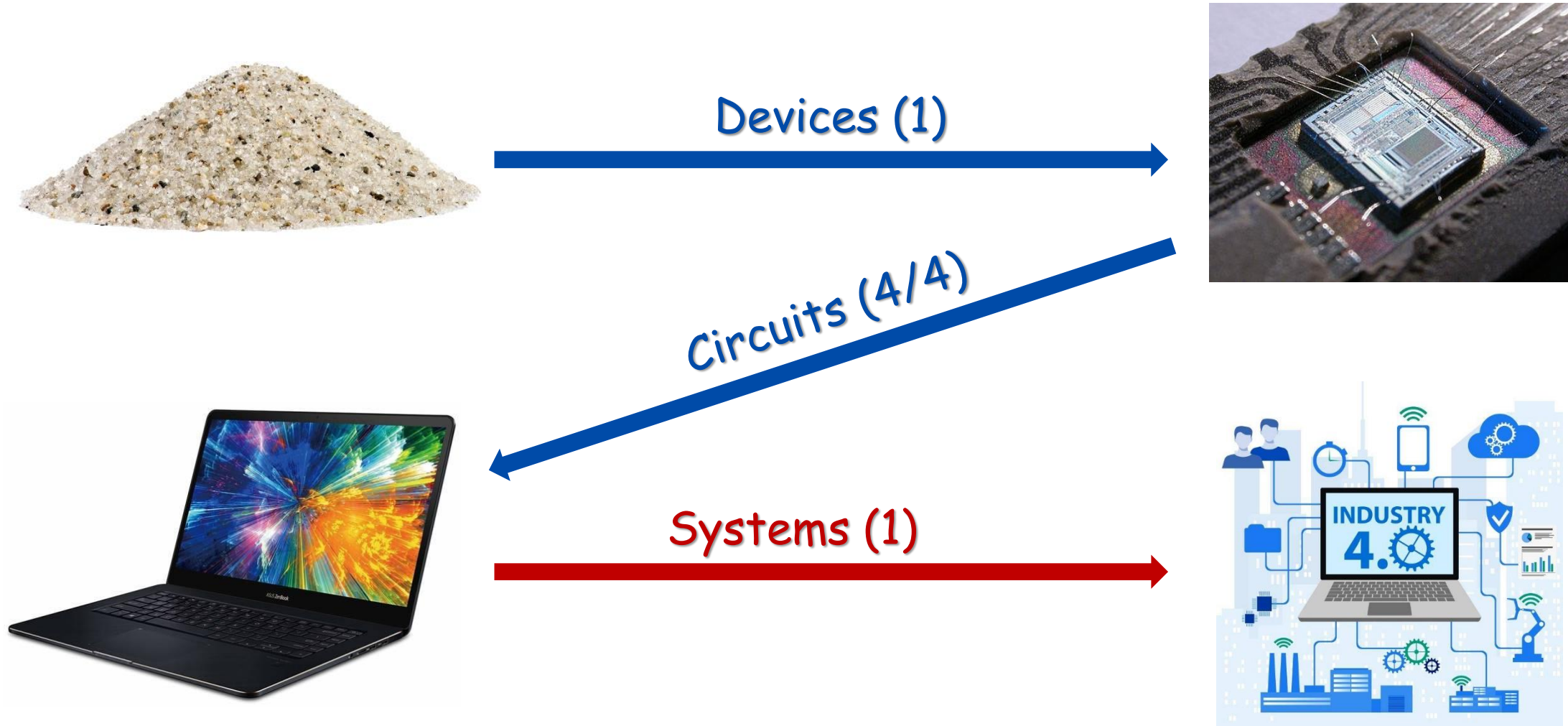
Lecture #7

Dynamic Systems and Control

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Nov. 5th, 2021

The Theme Story



(Pictures are from the Internet)

Study Purpose of Lecture #7

- 哲学 (bao'an) 三问
 - Who are you?
 - Where are you from?
 - Where are you going?

To answer those questions
throughout your life



(Pictures are from the Internet)

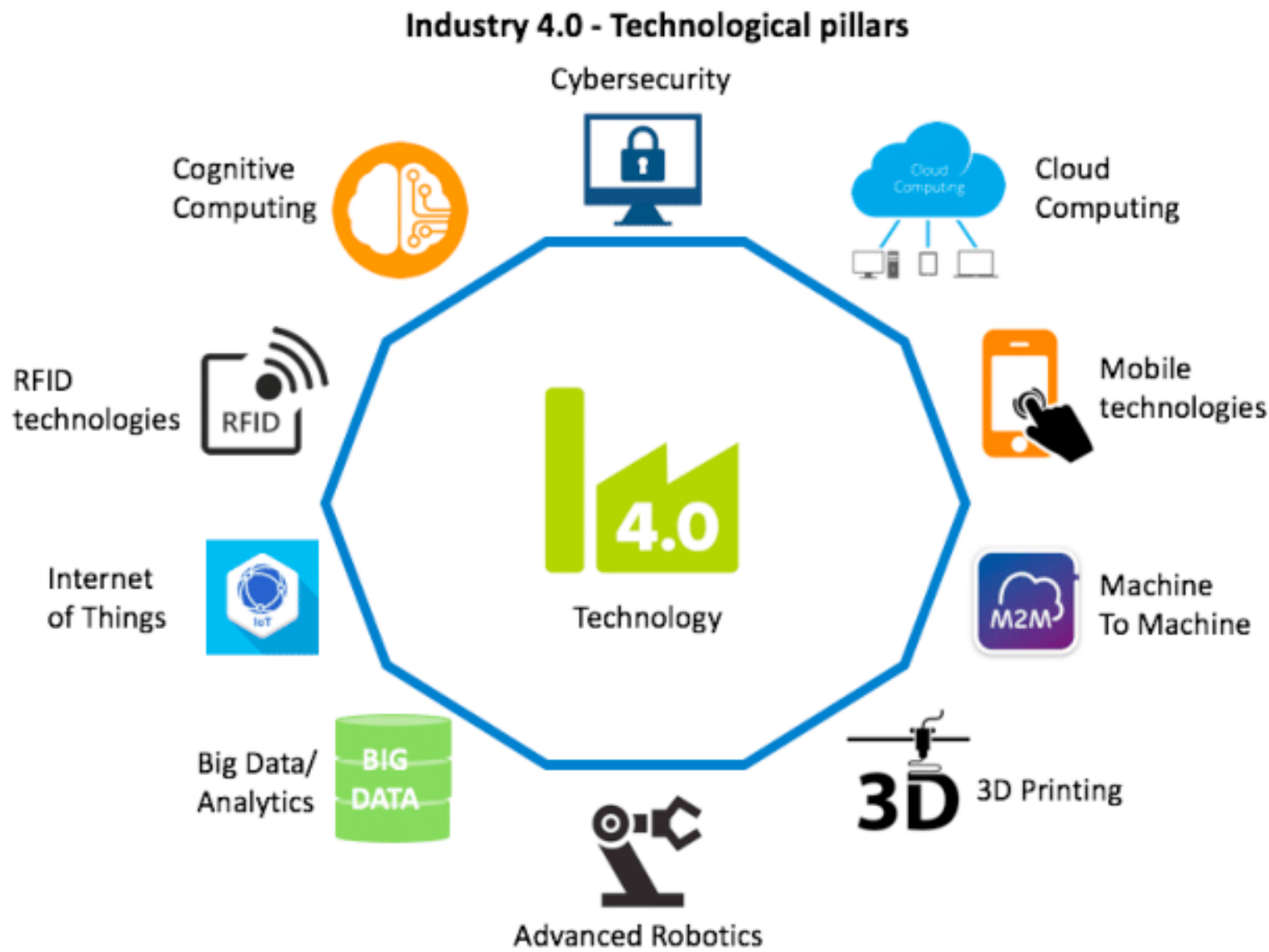
- In this lecture, we ask
 - How to model a dynamic system?
 - What is the principle of a feedback control system 反馈控制系统?
 - What are the features of future Internet of things (IoT) 物联网 and cyber physics systems (CPS) 信息物理系统 towards industry 4.0?



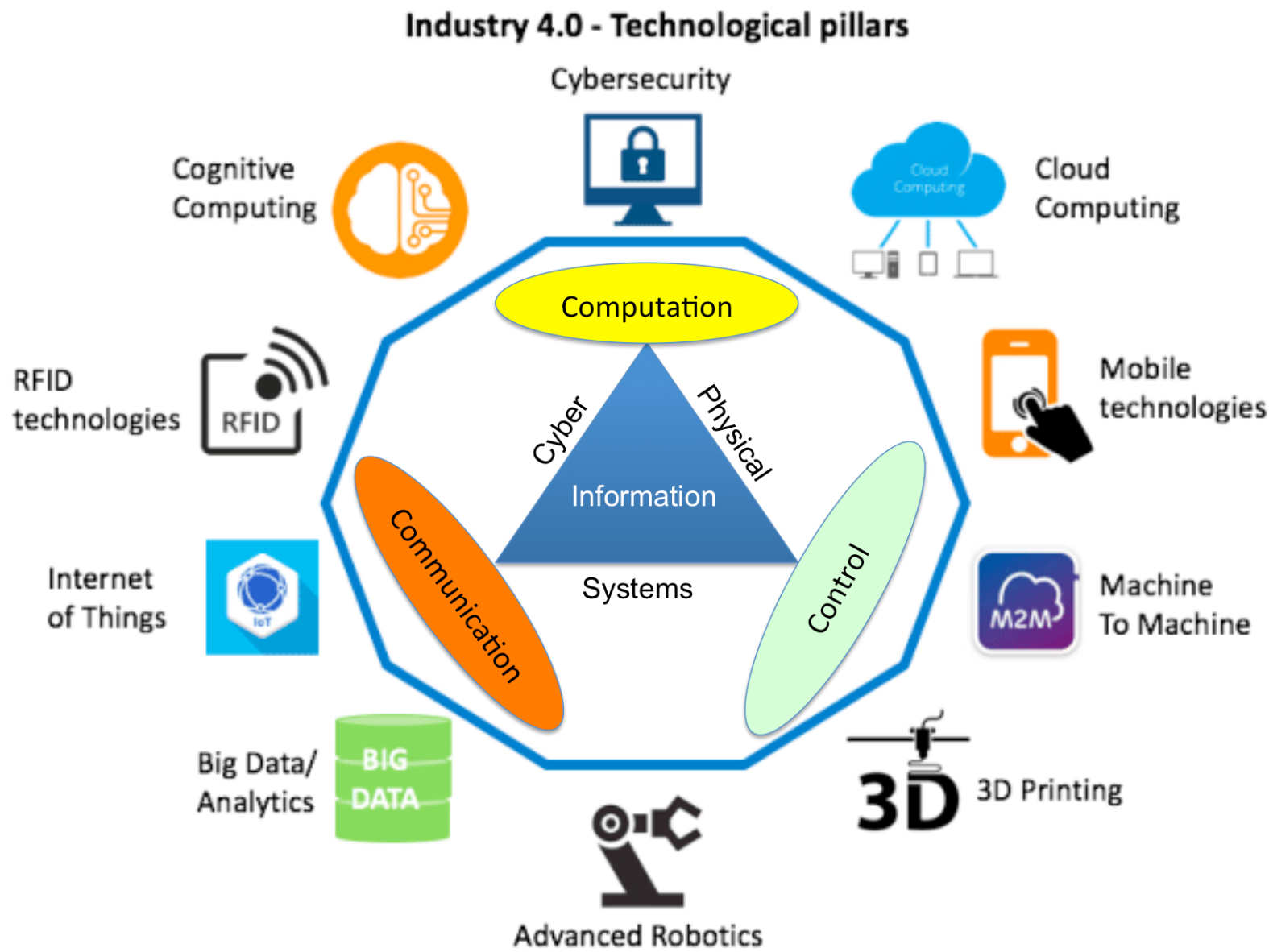
Lecture Outline

- **Control** and **connectivity** towards Industry 4.0
- Mathematical model of a dynamic system 数学模型
- Feedback control system 反馈控制系统
 - Block diagram
 - Examples
- Controller 控制器
- Cyber physical system (CPS) 信息物理系统
- Internet of things (IoT) 物联网

Industry 4.0



Industry 4.0



Control & communication

- Control technology



- Any relation with the AI trend?

To understand something with AI



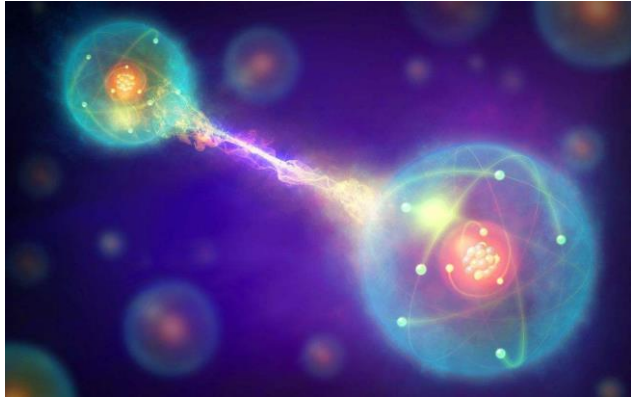
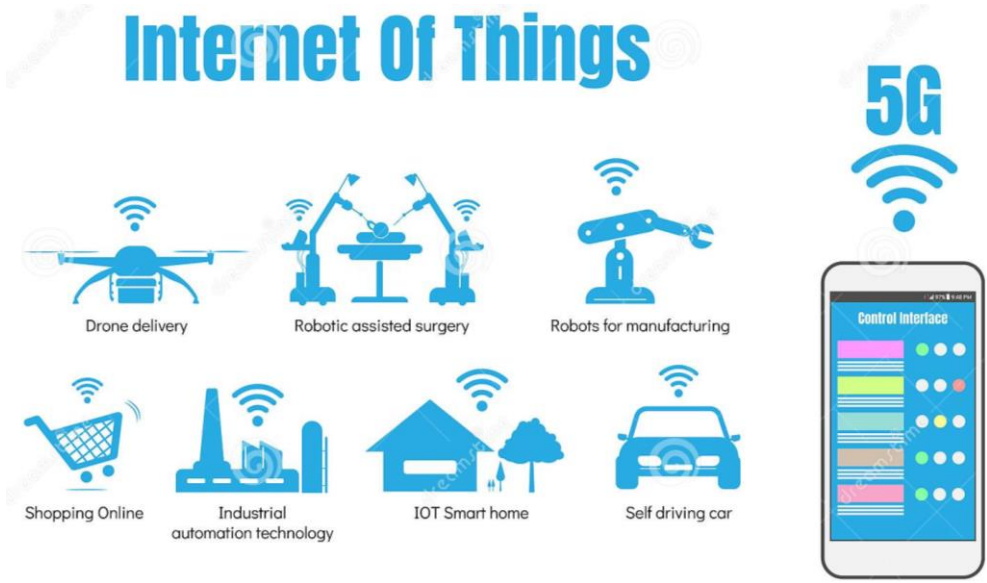
To control something with AI



- Communication

- Faster 更快, more 更多, safer 更安全

Internet Of Things



Mathematical models of systems

• Reference book

- Dorf, Richard C., and Robert H. Bishop. "Modern control systems (12ed)." Prentice Hall, 2010.



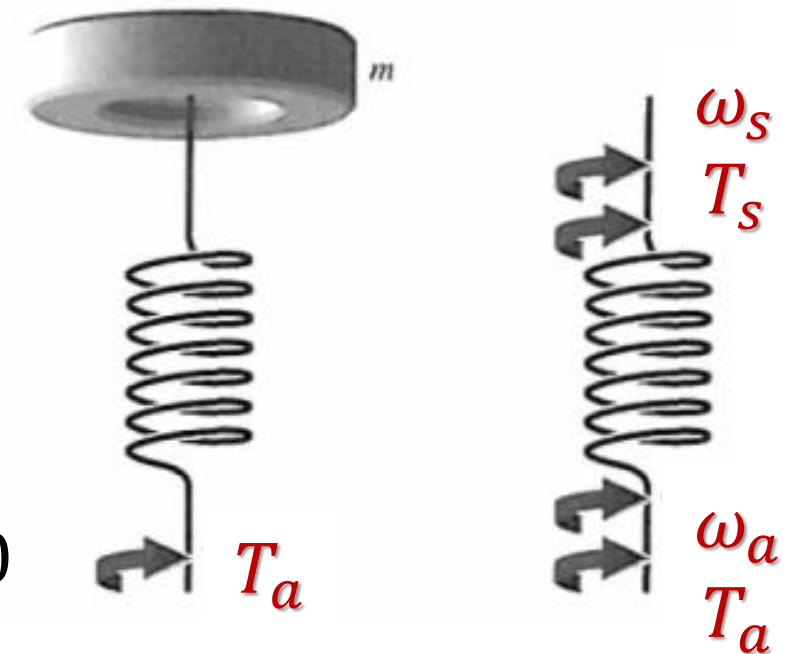
- Across-variable “跨变量” & through-variable “通过变量”
- Example: a torsional spring 旋转弹簧

Torque 力矩 equation:

$$T_a(t) - T_s(t) = 0$$

Rotational speed 转速 equation:

$$\omega(t) = \omega_s(t) - \omega_a(t)$$



Across- and through-variables

Table 2.1 Summary of Through- and Across-Variables for Physical Systems

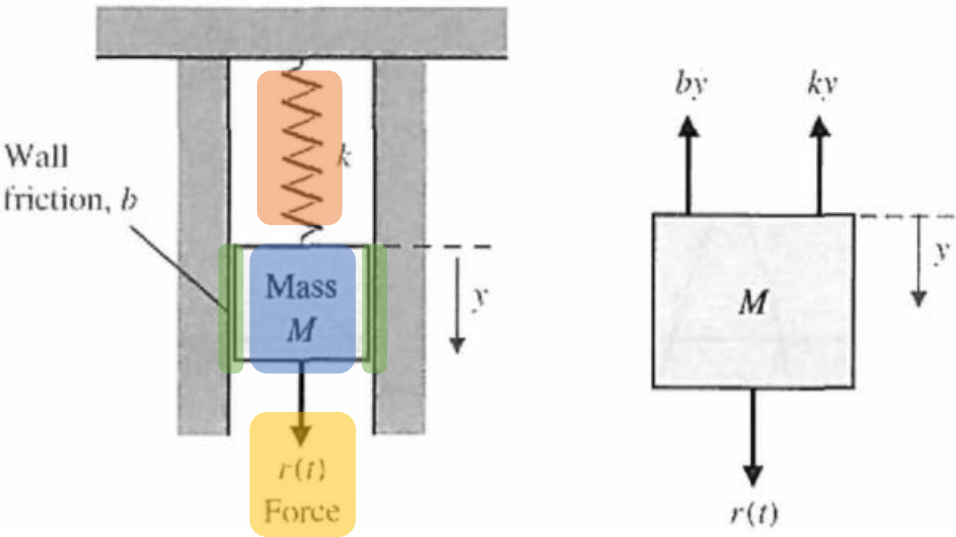
电学
力学平动
力学转动
流体
热学

System	Variable Through Element	Integrated Through-Variable	Variable Across Element	Integrated Across-Variable
Electrical	Current, i	Charge, q	Voltage difference, v_{21}	Flux linkage, λ_{21}
Mechanical translational	Force, F	Translational momentum, P	Velocity difference, v_{21}	Displacement difference, y_{21}
Mechanical rotational	Torque, T	Angular momentum, h	Angular velocity difference, ω_{21}	Angular displacement difference, θ_{21}
Fluid	Fluid volumetric rate of flow, Q	Volume, V	Pressure difference, P_{21}	Pressure momentum, γ_{21}
Thermal	Heat flow rate, q	Heat energy, H	Temperature difference, \mathcal{T}_{21}	

Dorf, Richard C., and Robert H. Bishop. "Modern control systems (12ed)." Prentice Hall, 2010.

Differential equations for dynamic modeling

Governing equation



Mass Damping Spring Force
质量 阻尼 弹簧 力

$$M \frac{d^2 y(t)}{dt^2} + b \frac{dy(t)}{dt} + ky(t) = r(t)$$

Table 2.2 Summary of Governing Differential Equations for Ideal Elements

Type of Element	Physical Element	Governing Equation	Energy E or Power \mathcal{P}	Symbol
Inductive storage	Electrical inductance	$v_{21} = L \frac{di}{dt}$	$E = \frac{1}{2} Li^2$	
	Translational spring	$v_{21} = \frac{1}{k} \frac{dF}{dt}$	$E = \frac{1}{2} \frac{F^2}{k}$	
	Rotational spring	$\omega_{21} = \frac{1}{k} \frac{dT}{dt}$	$E = \frac{1}{2} \frac{T^2}{k}$	
	Fluid inertia	$P_{21} = I \frac{dQ}{dt}$	$E = \frac{1}{2} IQ^2$	
Capacitive storage	Electrical capacitance	$i = C \frac{dv_{21}}{dt}$	$E = \frac{1}{2} Cv_{21}^2$	
	Translational mass	$F = M \frac{dv_2}{dt}$	$E = \frac{1}{2} Mv_2^2$	
	Rotational mass	$T = J \frac{d\omega_2}{dt}$	$E = \frac{1}{2} J\omega_2^2$	
	Fluid capacitance	$Q = C_f \frac{dP_{21}}{dt}$	$E = \frac{1}{2} C_f P_{21}^2$	
Energy dissipators	Thermal capacitance	$q = C_t \frac{dT_2}{dt}$	$E = C_t T_2$	
	Electrical resistance	$i = \frac{1}{R} v_{21}$	$\mathcal{P} = \frac{1}{R} v_{21}^2$	
	Translational damper	$F = bv_{21}$	$\mathcal{P} = bv_{21}^2$	
	Rotational damper	$T = b\omega_{21}$	$\mathcal{P} = b\omega_{21}^2$	
	Fluid resistance	$Q = \frac{1}{R_f} P_{21}$	$\mathcal{P} = \frac{1}{R_f} P_{21}^2$	
	Thermal resistance	$q = \frac{1}{R_t} T_{21}$	$\mathcal{P} = \frac{1}{R_t} T_{21}$	

Frequency-domain & time-domain expressions

$$M \frac{d^2 y(t)}{dt^2} + b \frac{dy(t)}{dt} + ky(t) = r(t)$$

- Transfer function 传递函数
 - Describing the dynamic relationship of the system in the **frequency domain** 频域

Laplace transform

$$Ms^2Y(s) + bsY(s) + kY(s) = R(s)$$

Input/output relation

$$\frac{\text{Output}}{\text{Input}} = G(s) = \frac{Y(s)}{R(s)} = \frac{1}{Ms^2 + bs + k}$$

- State variable & state equation 状态变量与状态方程
 - describing the present configuration of a system in the **time domain** 时域

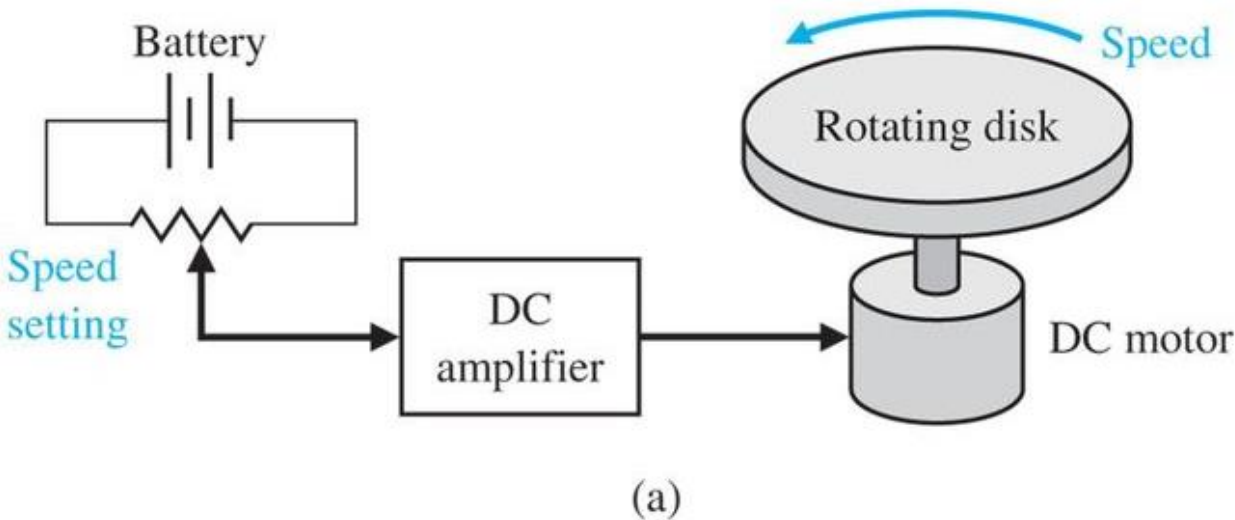
Define state vector

$$\mathbf{x} = \begin{bmatrix} y(t) \\ \dot{y}(t) \end{bmatrix} \quad \text{input vector} \quad \mathbf{u} = \begin{bmatrix} 0 \\ r(t) \end{bmatrix}$$

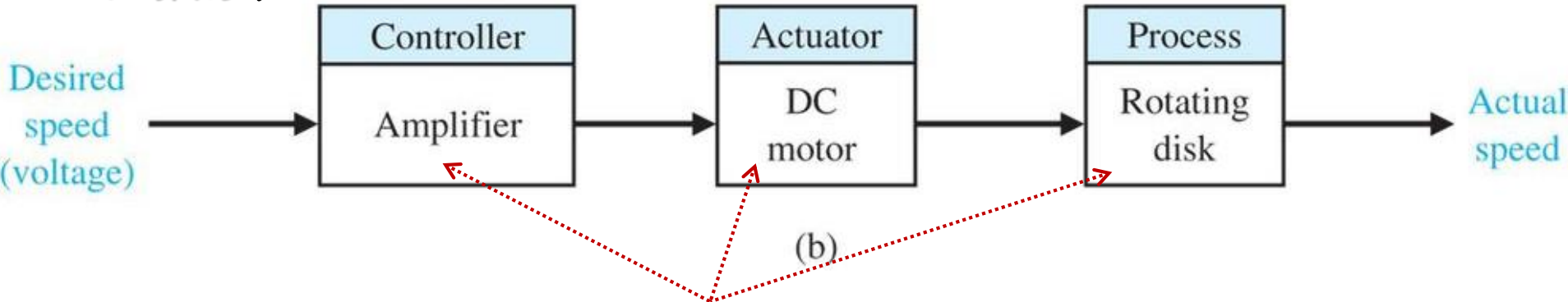
$$\dot{\mathbf{x}} = \frac{1}{M} \begin{bmatrix} 0 & 1 \\ -k & -b \end{bmatrix} \mathbf{x} + \frac{1}{M} \begin{bmatrix} 0 \\ 1 \end{bmatrix} \mathbf{u}$$

Block diagram 框图

A practical rotational speed control system



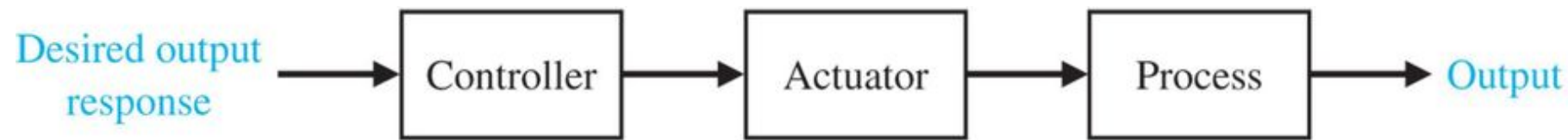
The corresponding block diagram
(**abstraction**工程抽象)



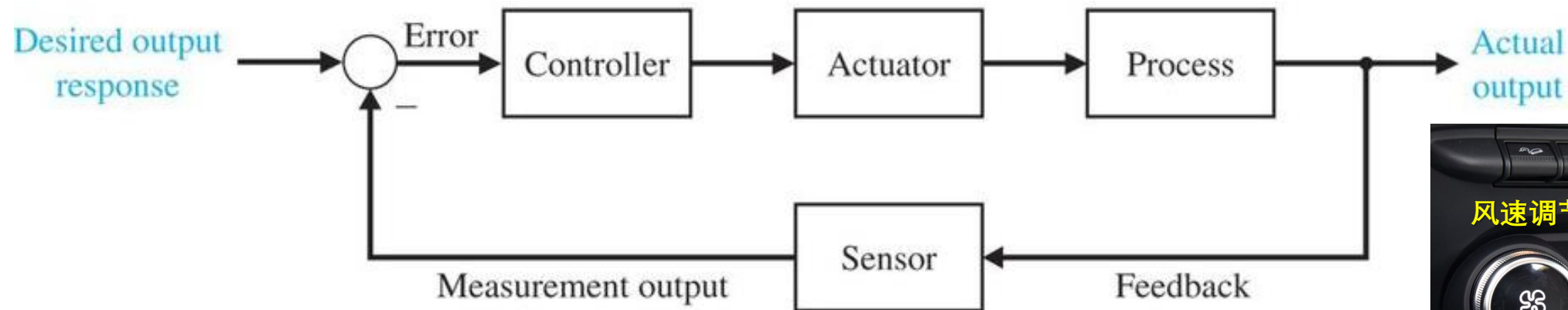
Representing a time-domain or frequency-domain (mathematical) model

Feedback control system

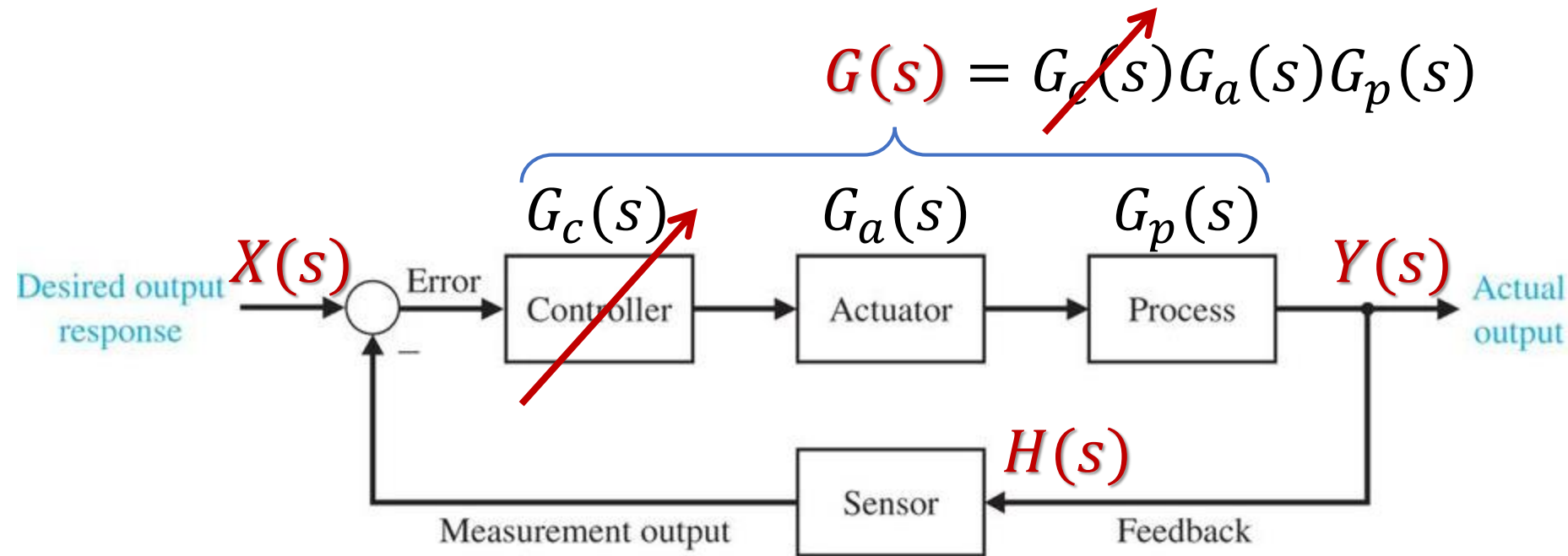
- Open-loop system 开环系统



- Close-loop system 开环系统



Mathematical model of feedback control system



Tuning the close-loop system characteristics by changing the controller characteristics
通过改变控制器的特性实现对闭环系统整体动态特性的调整

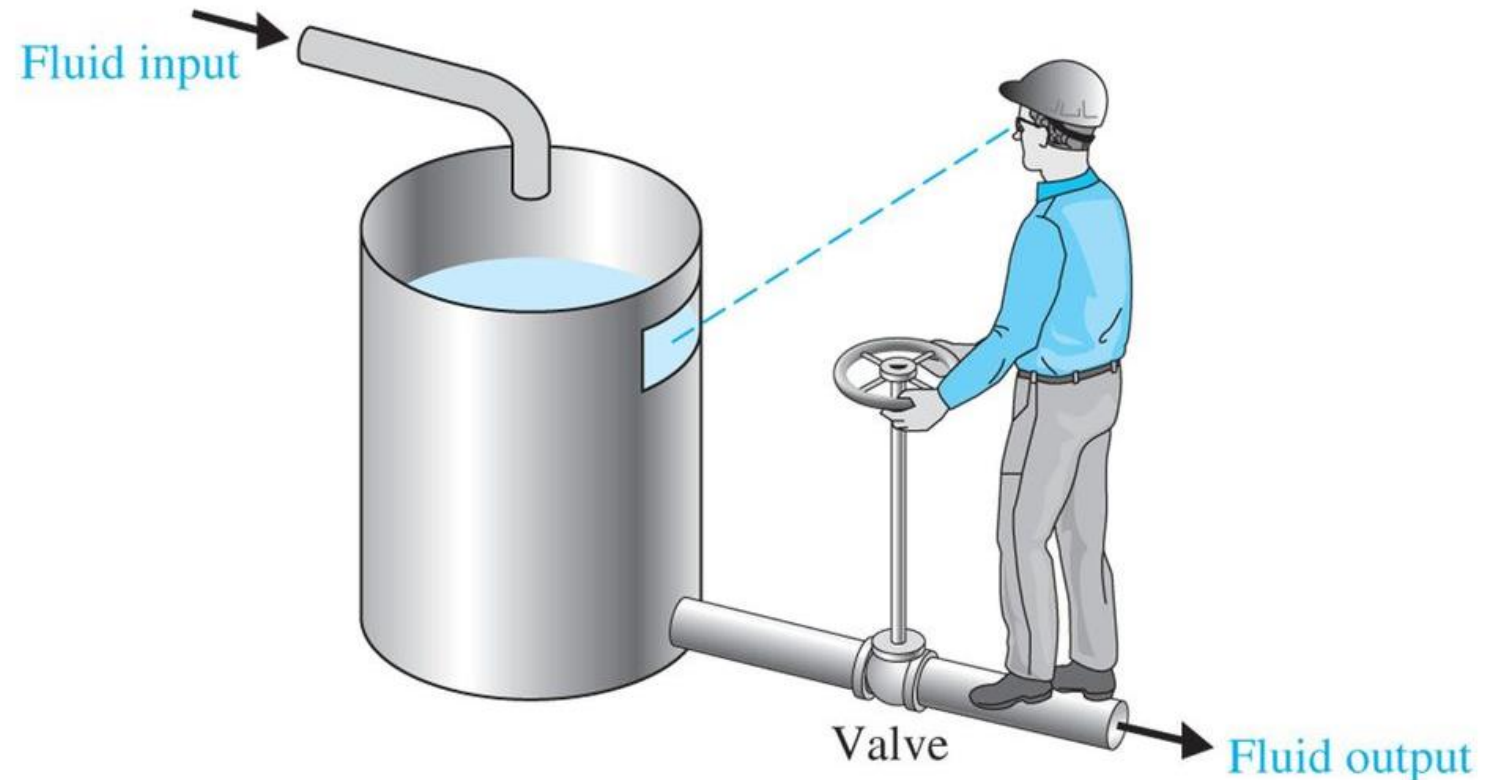
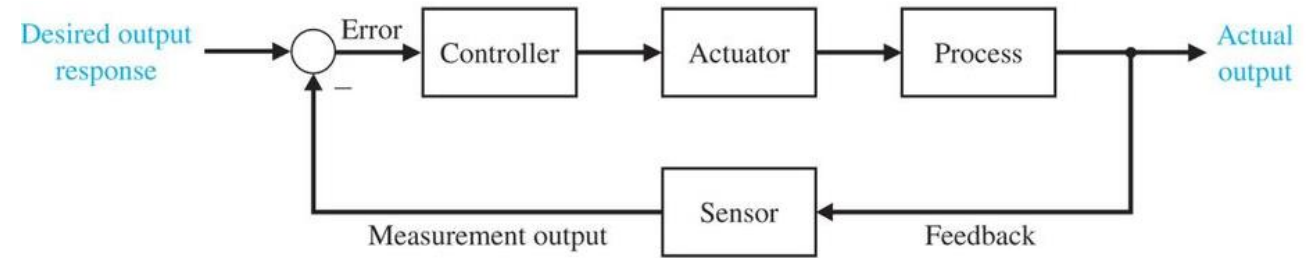
Open-loop gain $\frac{Y(s)}{X(s)} = G(s)$

Close-loop gain $Y(s) = G(s)[X(s) - H(s)Y(s)] \rightarrow \frac{Y(s)}{X(s)} = \frac{G(s)}{1 + G(s)H(s)}$

Example 1: manual control system

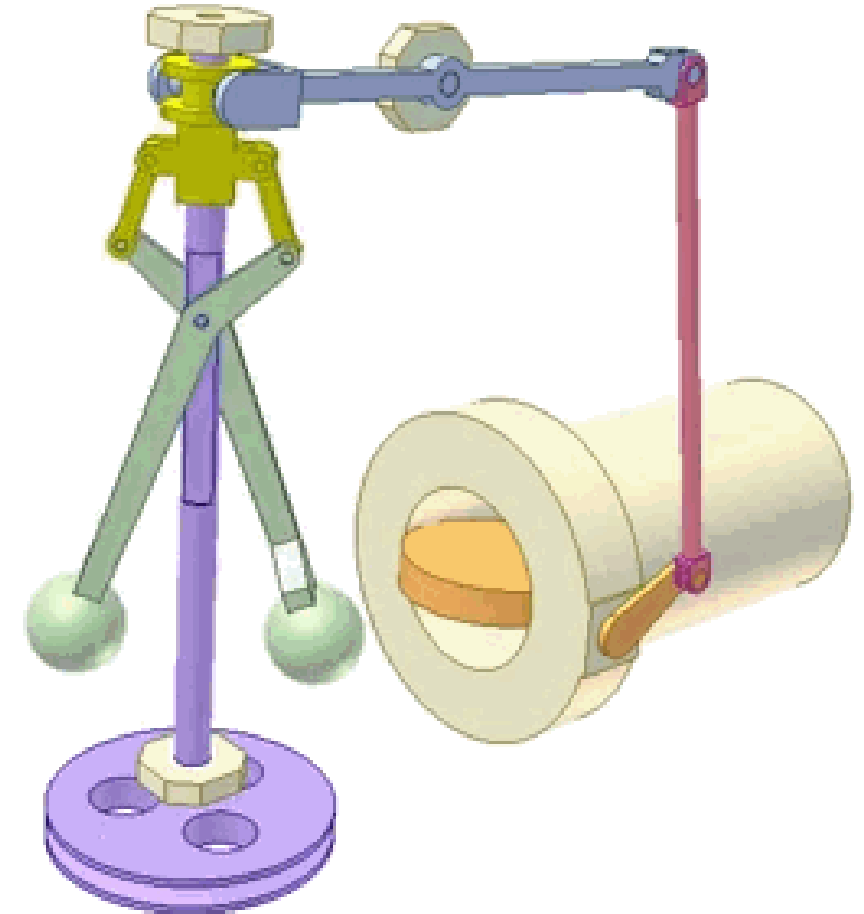
- In this manual control valve system, which one corresponds to the

- Process
- Actuator
- Sensor
- Controller
- Desire output
- Actual output
- Error

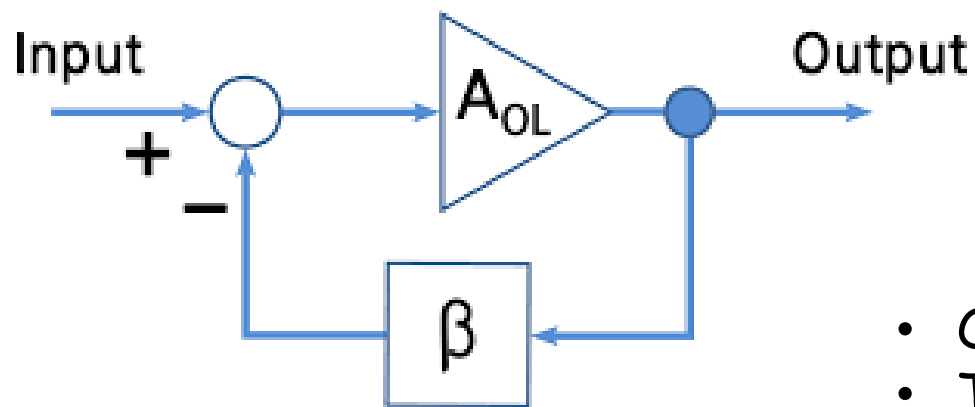
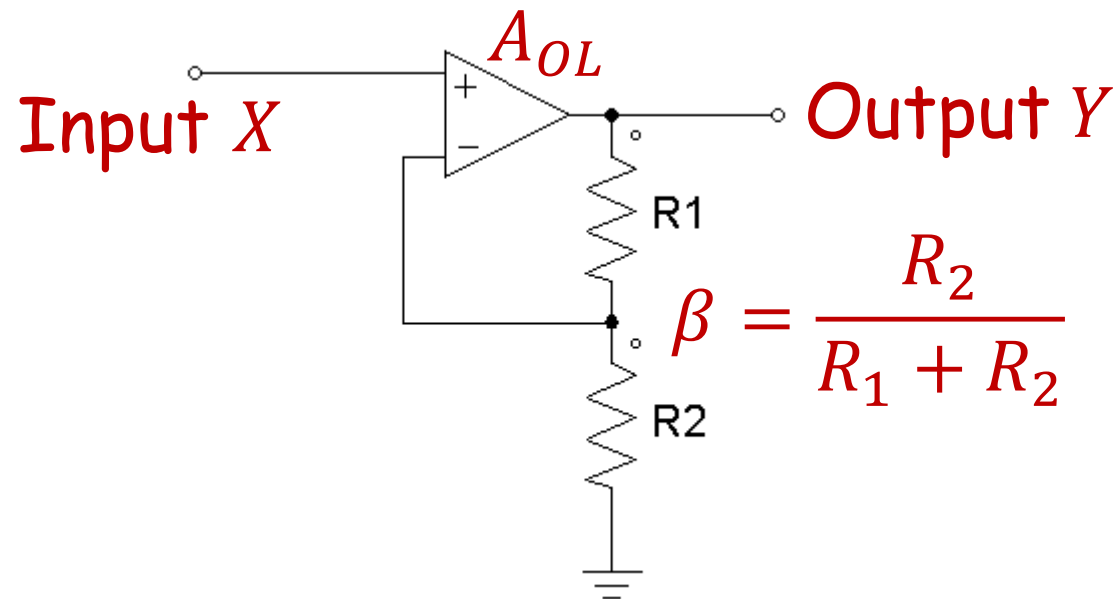


Example 2: Centrifugal governor

- A centrifugal governor is a specific type of governor with a **feedback system** that controls the speed of an engine by regulating the flow of fuel or working fluid, so as to maintain a near-constant speed.
- It uses the principle of **proportional control**
- **James Watt** designed his first governor in 1788 following a suggestion from his business partner Matthew Boulton



Example 3: Feedback amplifier



$$Y = A(V_+ - V_-)$$

$$= A(X - \beta Y)$$

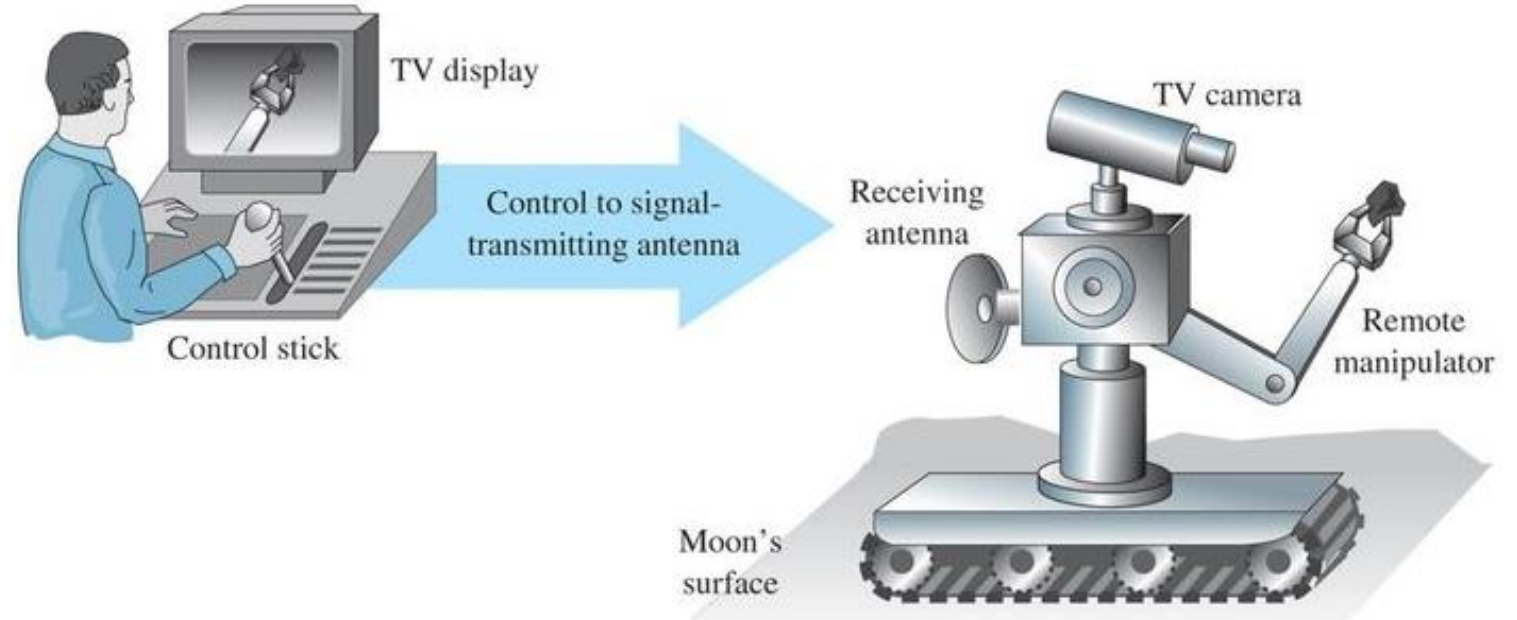


$$\frac{Y}{X} = \frac{A}{1 + A\beta}$$

$$\approx \frac{1}{\beta} \quad (\text{when } A \gg 1)$$

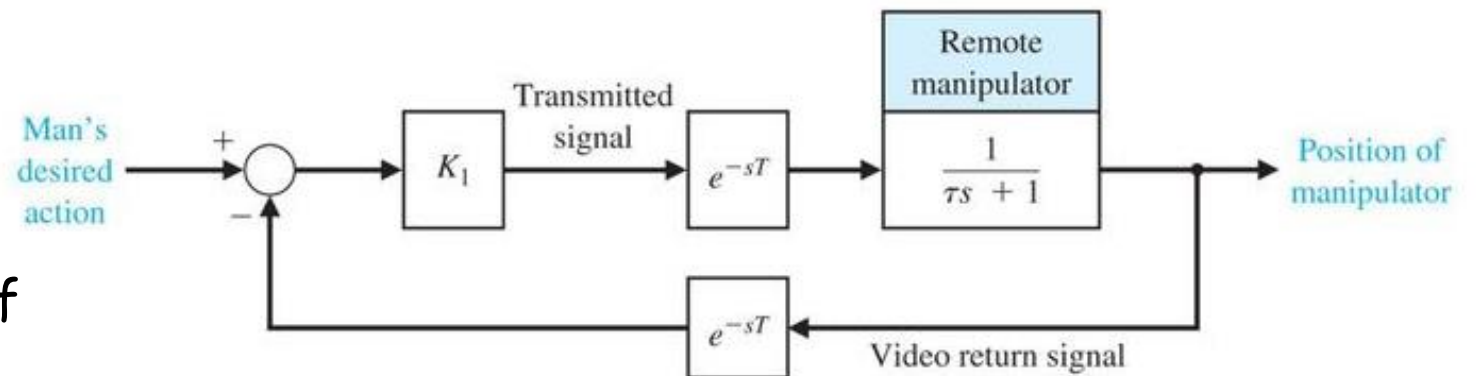
- Only considered the DC characteristics 静态增益
- The AC characteristics are more complicated

Example 4: Moon robot



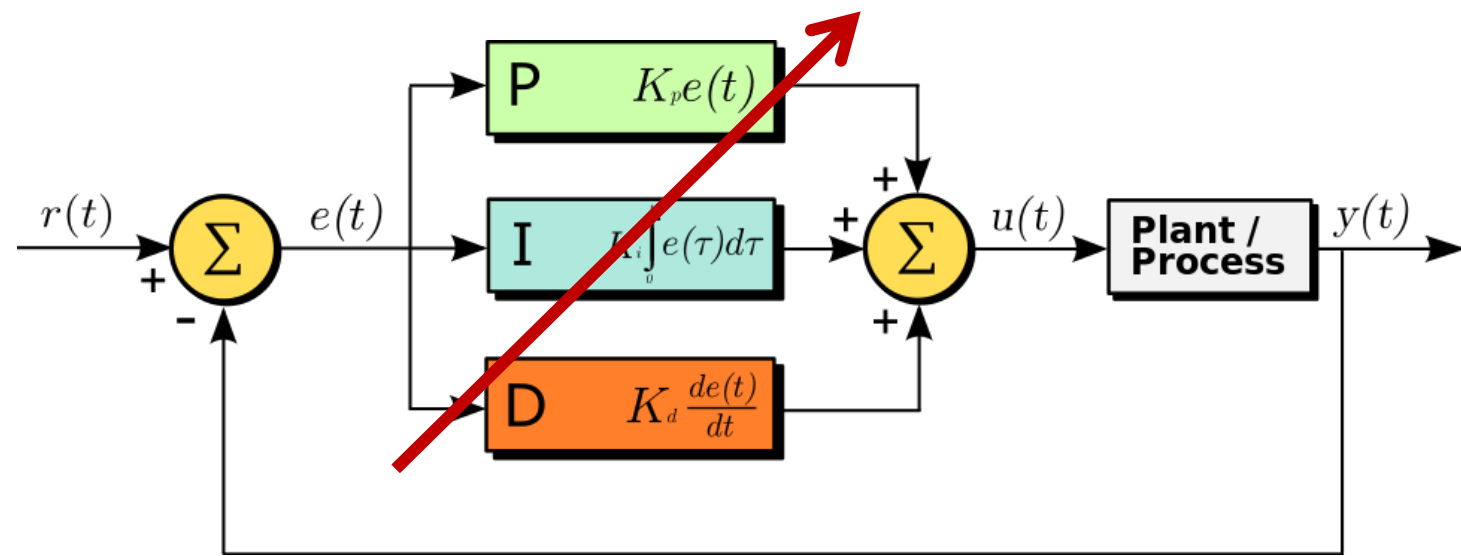
(a)

e^{-sT} models the time delay T in transmission of a communication signal



(b)

PID (比例、积分、微分) controller

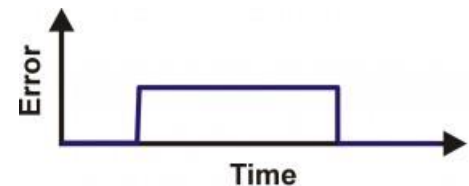


PID控制理论是由观察舵手的动作而来

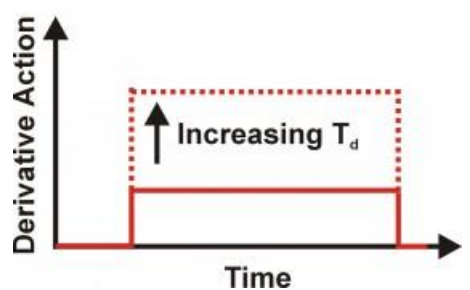
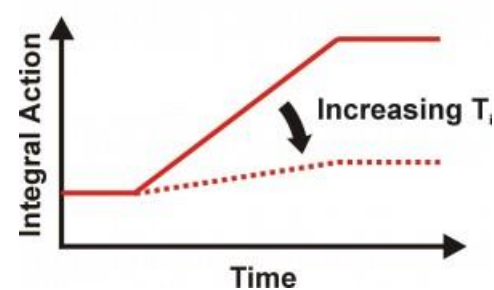
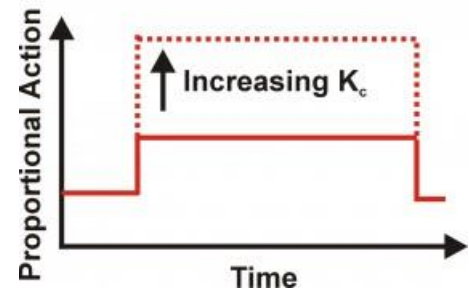
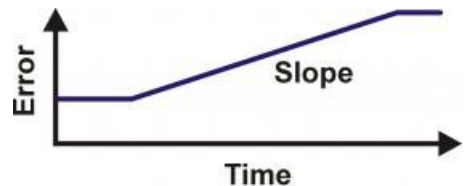
Current error
现在



Past error
过去

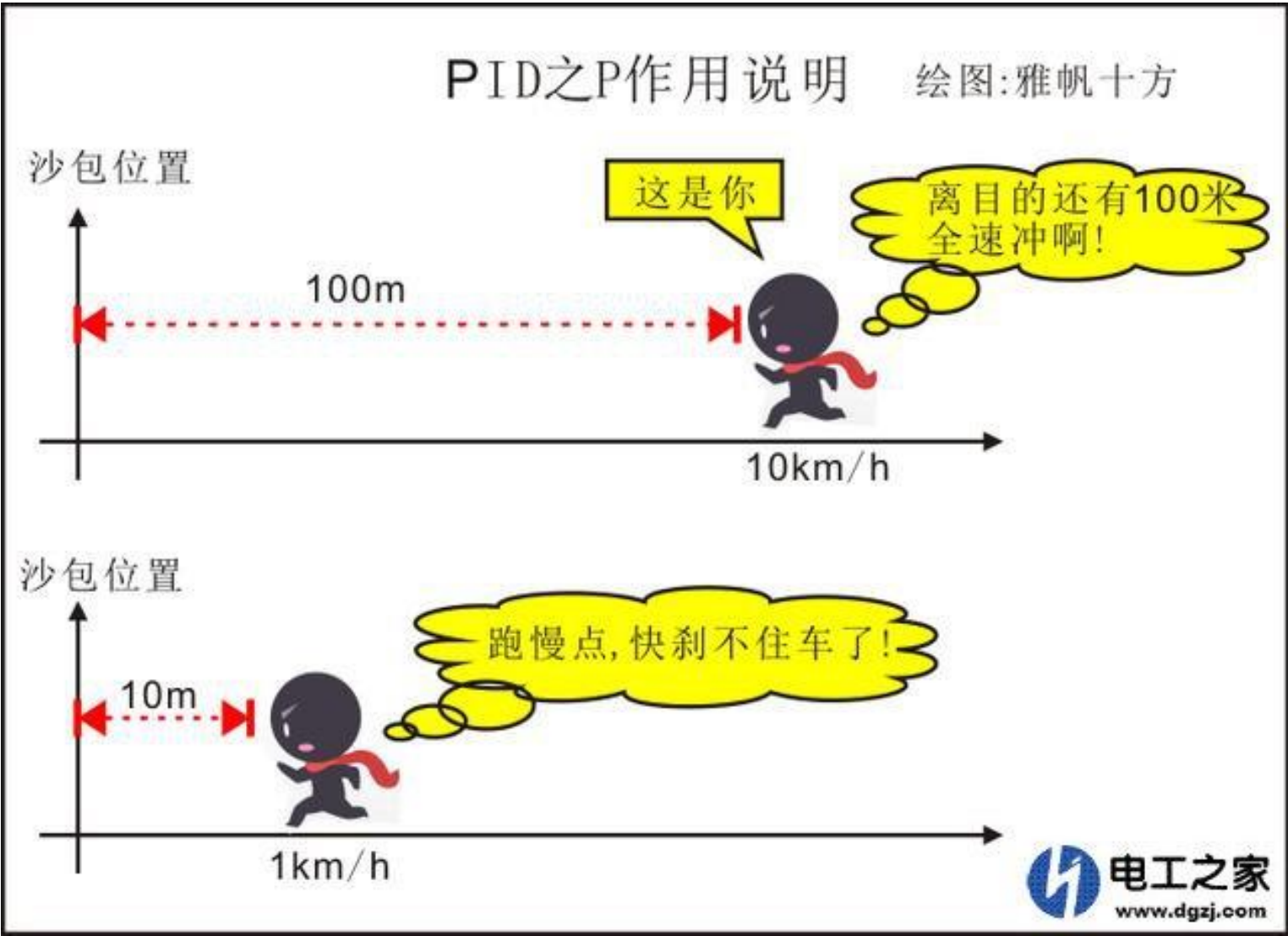


Future error
未来



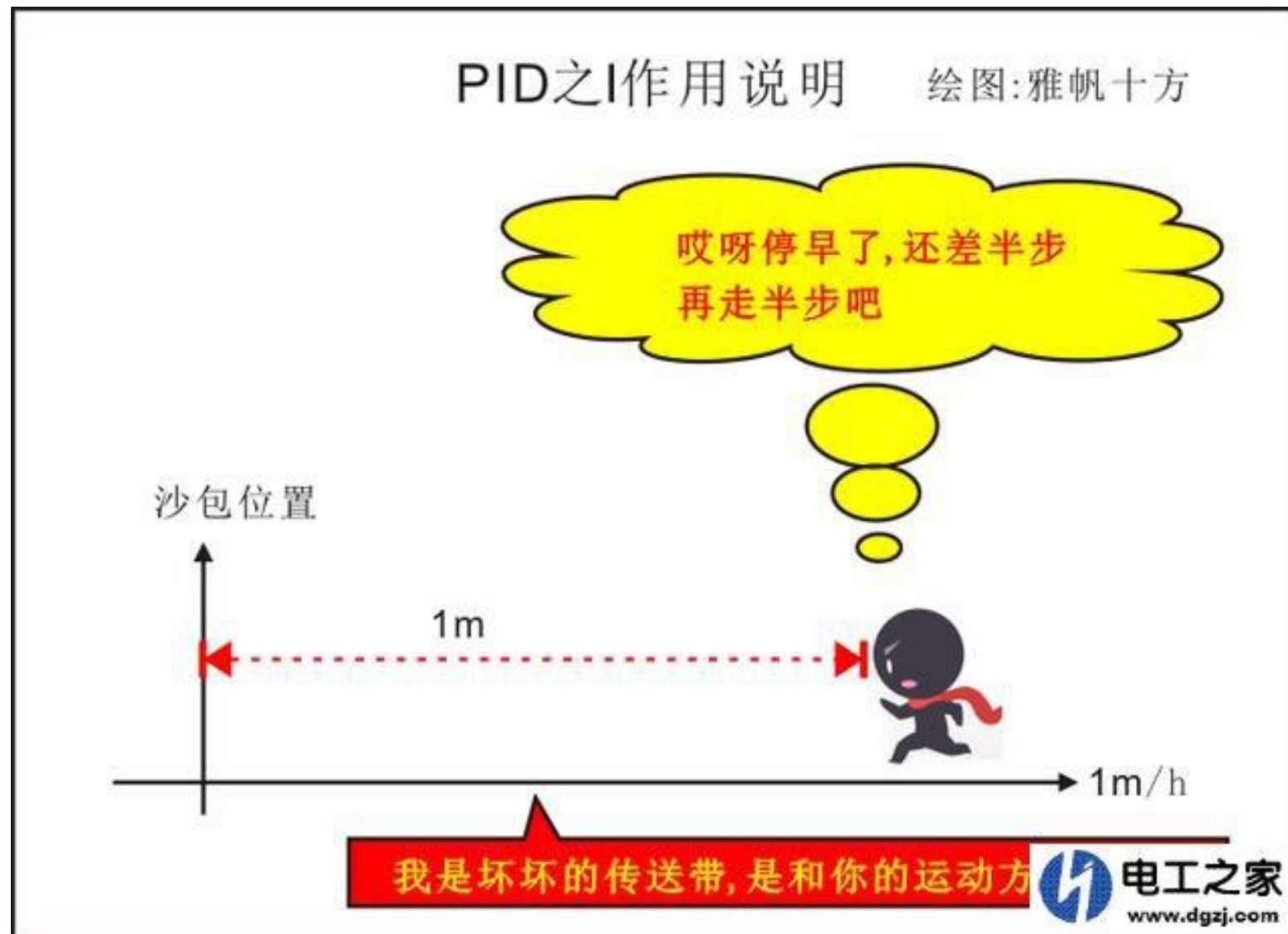
PID controller

Proportional
比例控制
考虑当前误差



(<https://www.dgzj.com/gongkong/99984.html>)

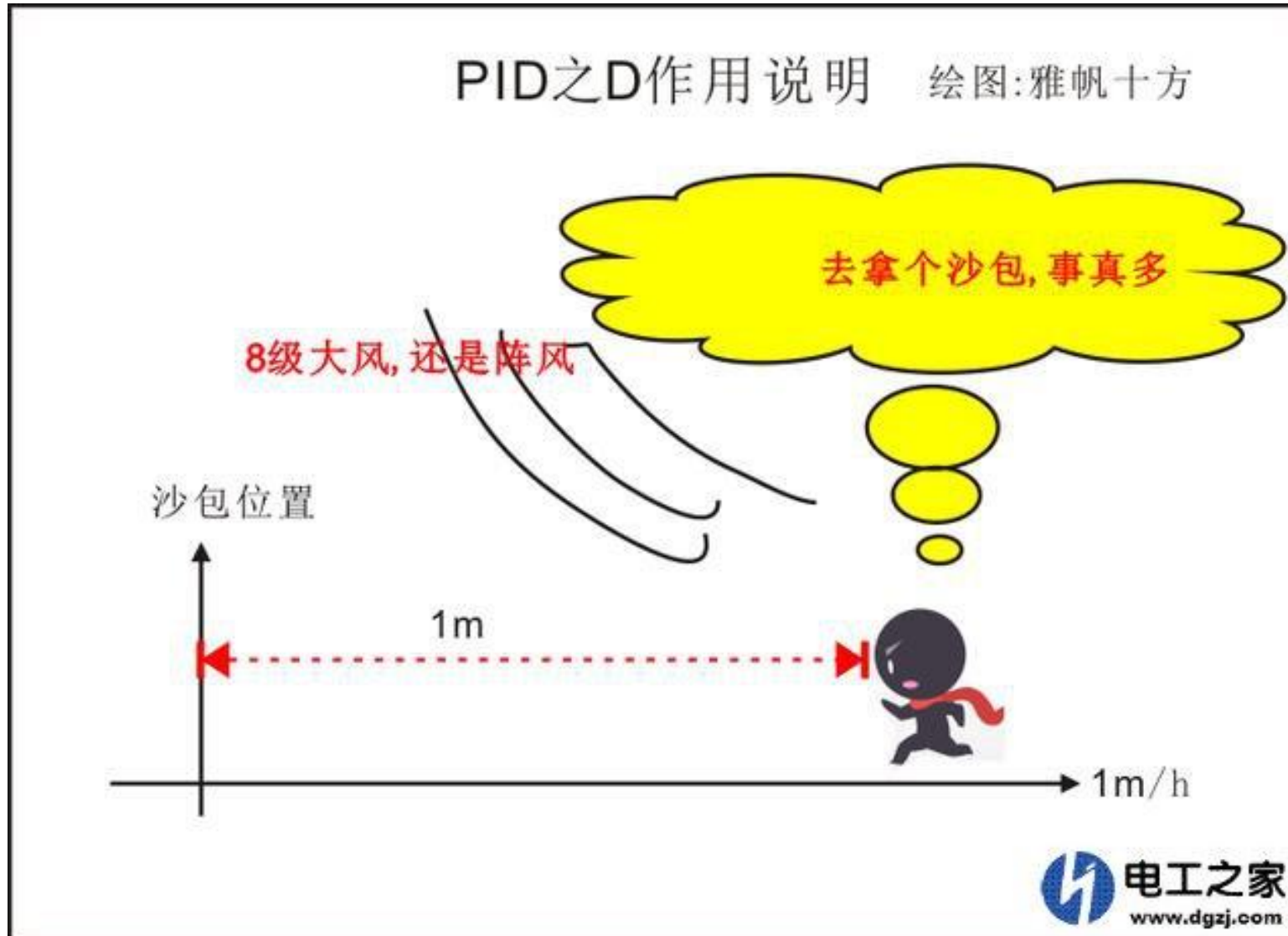
PID controller



Integral
积分控制
考虑过去误差

(<https://www.dgzj.com/gongkong/99984.html>)

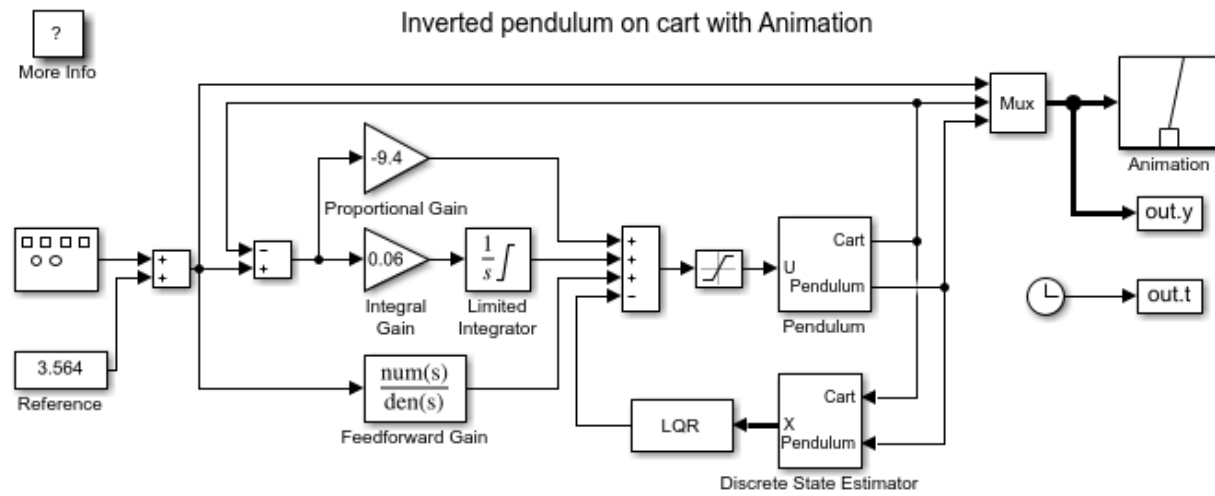
PID controller



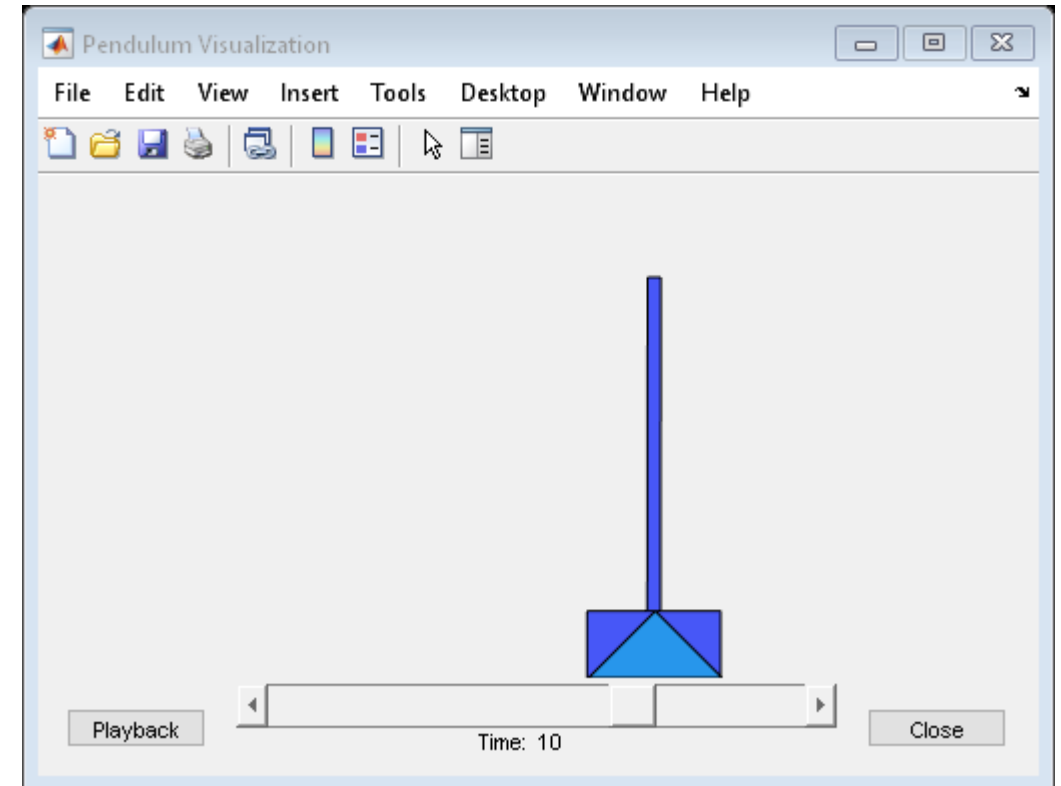
Derivative
微分控制
考虑将来误差

(<https://www.dgzj.com/gongkong/99984.html>)

Inverted pendulum example in Matlab



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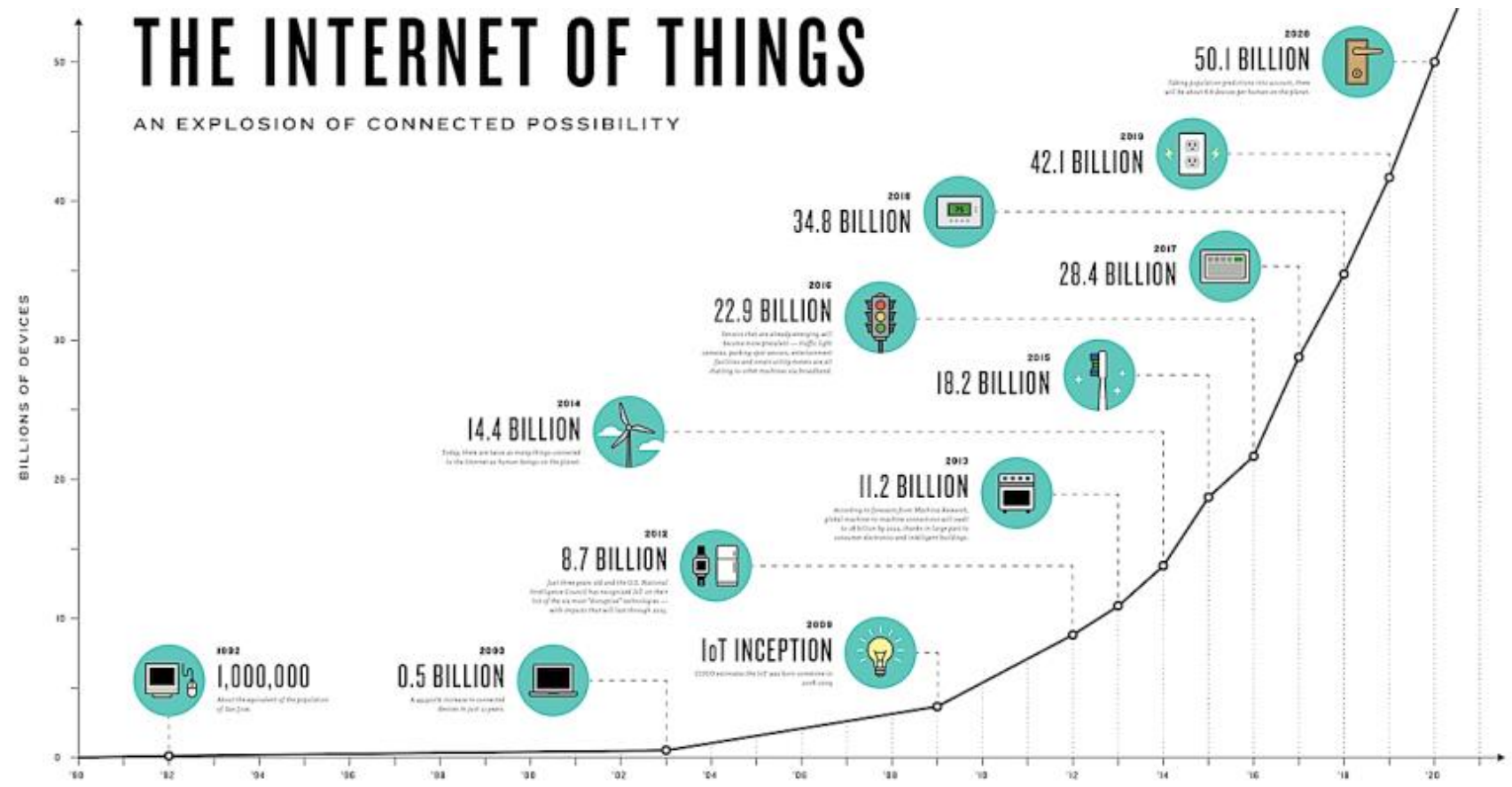


Key in the command:

```
>> openExample('simulink_general/penddemoExample')
```

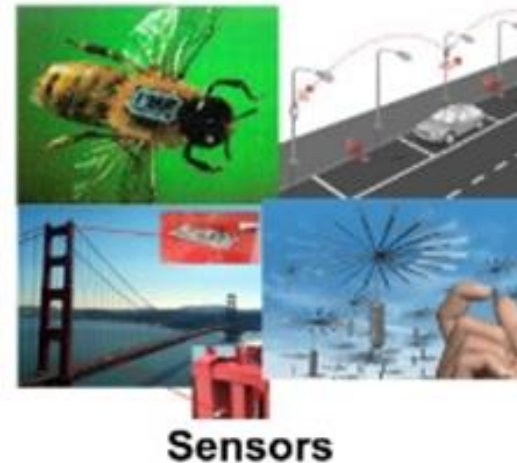
Internet of Things (IoT) 物联网

- The Internet of Things (IoT) is the internetworking of physical devices, vehicles, buildings, and other items—embedded with electronics, software, sensors, actuators, and network connectivity that enable these objects to **collect and exchange data**



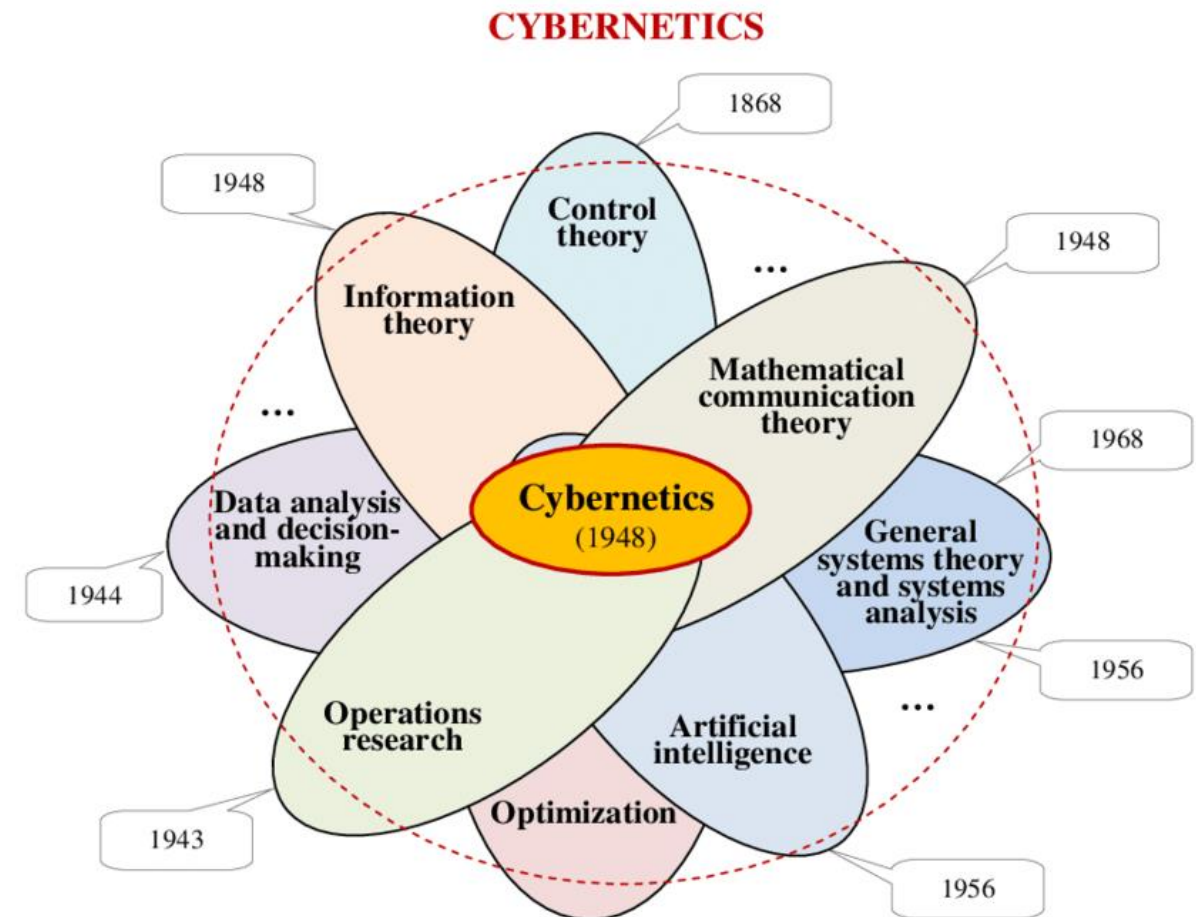
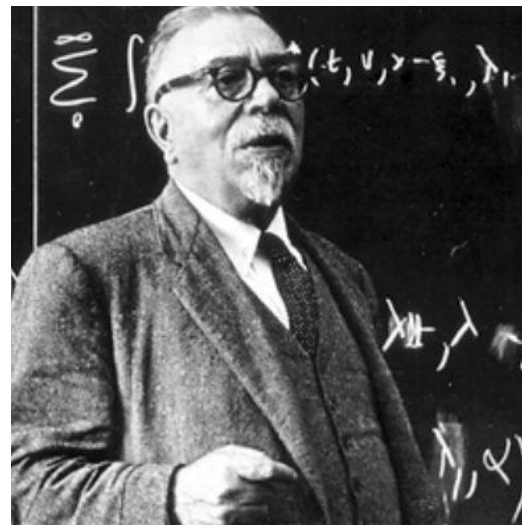
Cyber Physical Systems (CPS) 信息物理系统

- In cyber-physical systems, **physical** and **software** components **are deeply intertwined**, able to operate on different spatial and temporal scales, exhibit multiple and distinct behavioral modalities, and interact with each other in ways that change with context.

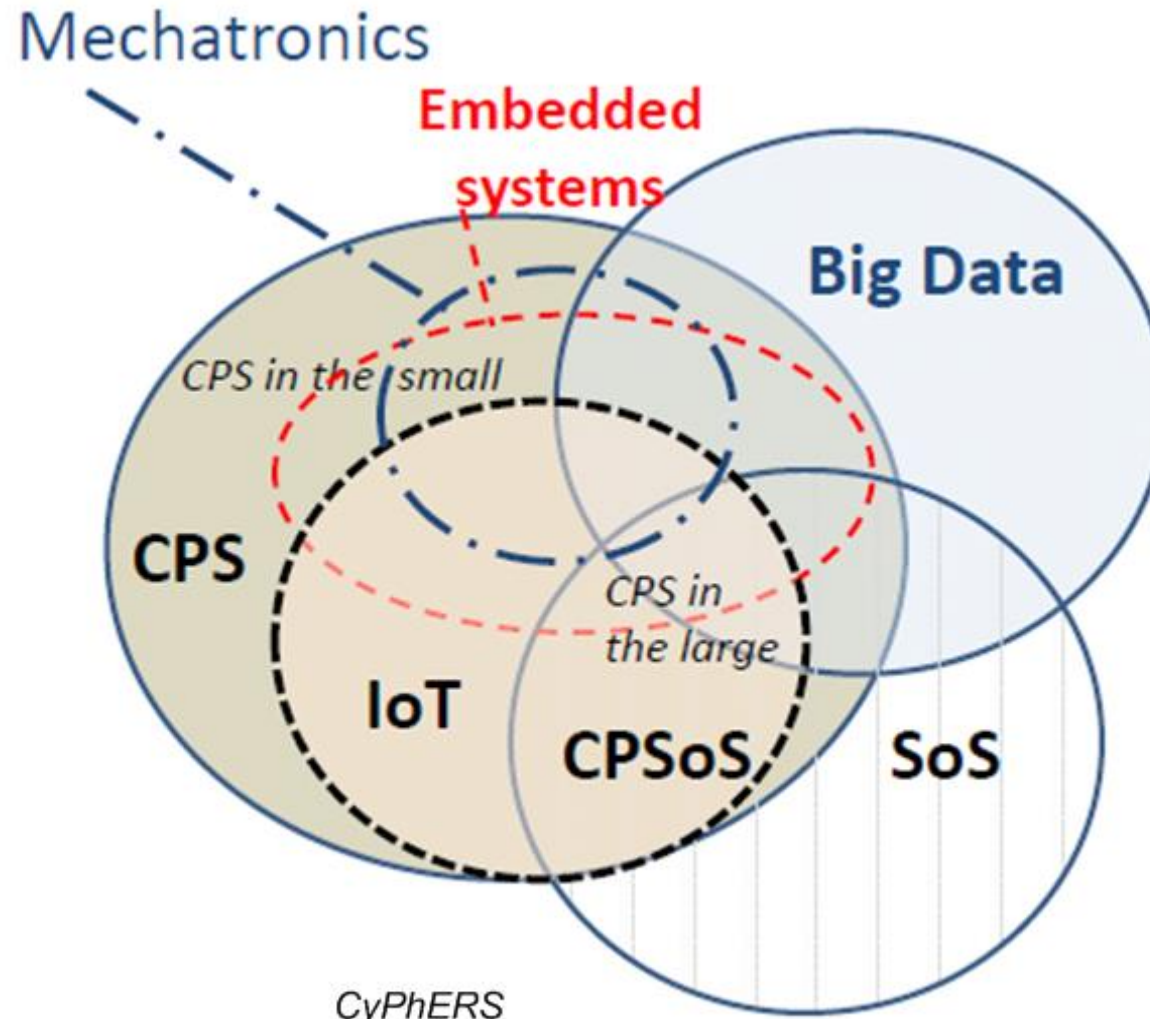


Cybernetics 控制论

- Cybernetics is a transdisciplinary approach for exploring **regulatory systems** 调节系统—their structures, constraints, and possibilities.
- Norbert Wiener 维纳 defined cybernetics in 1948 as "**the scientific study of control and communication in the animal and the machine.**"



The future trend of CPS



CyPhERS
Cyber-Physical European Roadmap & Strategy
CPS: Significance, Challenges and Opportunities
<http://www.cyphers.eu/sites/default/files/D5.2.pdf>

- Embedded systems 嵌入式系统
- Internet of Things (IoT) 物联网
- Industrial Internet 工业互联网
- System of systems (SoS) 系统集成
- Industry 4.0 工业4.0
- Internet of Everything (IoE) 万物互联
- Smart Everything 智能万物

≈ Cyber-physical systems 信息物理系统

Getting ready for your future study

- The emphases on **(3C)**
 - **computation** 计算,
 - **control** 控制, and
 - **communication** 通信
- in our EE curriculum

