Project

- Design a controller to keep the wheel in an upright position.

- Submit a Report
  - → Individual work
  - → Handwrite report, code + figures can be printed and submitted
  - → Due on 19.09.2022, in class. (Penalty for late submission)
  - → 25 marks
    - = 9 : organization
    - \+ 8 : design
    - \+ 8 : analysis.

Policy

- Project, Major, Minor, Quizzes → each 4 marks; → in class; → "surprise"; ↓ best 6/10

100 = 25 + 34 + 17 + 24

AUDIT PASS = 50

- Avoid Plagiarism. Penalty '0' marks, ...

[https://www.turnitin.com/static/plagiarism-spectrum/]

- **Books for Reference**

→ Astrom & Murray, Feedback Systems (online)

→ Friedland, Control System Design

- **Other Resources**

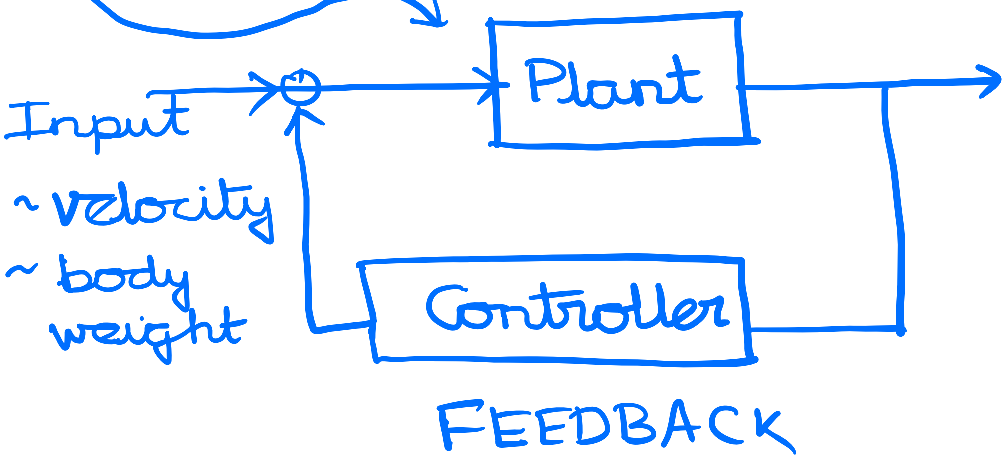
https://web.iitd.ac.in/~shaunak/sen/*.html

* = 2022Sem1_ELL333

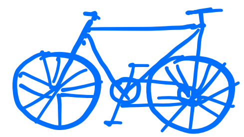
↳ 20, 19, 18

Bicycle ("Why bicycles do not fall", A. Schwab, TEDx.)

- ~ 60% "know" how to ride one
- Learn? ?
- Design Objective: Stay upright



Output ~ angle with vertical
~ steering angle



- ELL333 perspective: How to keep the bicycle up?

Top of the mind: 3 things

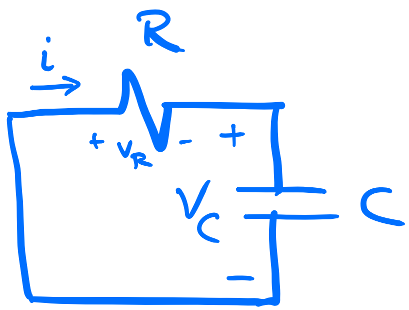
Multivariable

- Multiplicities in input, output, ... may make classical transfer function techniques difficult to apply.
- Examples:
  - Bicycle
  - "multiagent" collections robots, drones, social/networks
  - power networks
  -
- Challenges? in these systems versus a Single Input Single Output

Model

- Representation / Metaphor / Useful, wrong
  ↳ Mathematical

- RC circuit



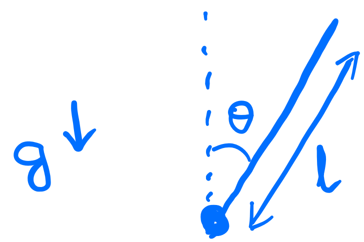
Model:
(Use: Given $V_c(0)$, what is $V_c(t)$?)

$V_R = -V_c$, $i = \frac{V_R}{R}$, $i = C\frac{dV_c}{dt}$

↑ "model" ↗ approximation by linearization

↳ $RC\frac{dV_c}{dt} + V_c = 0$

- Pendulum



Model:
Given $\theta(0)$, $\dot{\theta}(0) = 0$, what is $\theta(t)$?
$\in [0, 2\pi)$

$$\ddot{\theta} - \frac{g}{l}\sin\theta = 0$$ (Check!)

$\sin\theta \simeq \theta$ around $\theta = \pi$ $\Rightarrow$ $\ddot{\theta} + \frac{g}{l}\theta = 0$

- Similar "model" for bicycle

State

- State-space methods of design. ↙ this course
- "What is the state of the RC circuit?"
  pendulum
  bicycle

  ↳ Think

- Working notion: order of the differential equation.

Friedland, Pg 16
The state of a dynamic system is a set of physical quantities, the specification of which (in the absence of external excitation) completely determines the evolution of the system.

Astrom & Murray, Pg 40
One of the triumphs of Newton's mechanics was the observation that the motion of the planets could be predicted based on the current positions and velocities of all planets. It was not necessary to know the past motion. The state of a dynamical system is a collection of variables that completely characterizes the motion of a system for the purpose of predicting future motion. For a system of planets the state is simply the positions and the velocities of the planets. We call the set of all possible states the state space.

Polderman & Willems, Pg 115
State variables either show up naturally in the modelling process or they can be artificially introduced. State variables have the property that they parametrize the memory of the system, i.e., that they "split" the past and future of the behaviour.

A. Bensoussan, Pg 1-2
A key element is the state representation of dynamical systems, also called the internal representation.
The internal representation introduces the very important concept of state of the system. The idea is reminiscent of that of a knowledge model, in which one models as accurately as possible all the components of the system, starting with the physical laws that are involved. For instance, if a dynamical system is a rocket in flight, then one will use the laws of mechanics and possibly more advanced physical and chemical laws to describe the propulsion. The state will be the position and velocity of the center of the rocket, and there may be additional state variables.

08.08.2022

Solve

- Design f such that $q \to 0$ as $t \to \infty$.

$$M\ddot{q} + vC_1\dot{q} + (v^2 K_2 + gK_0)q = f, \quad q = \begin{bmatrix} \phi \\ \delta \end{bmatrix}, \quad f = \begin{bmatrix} T_\phi \\ T_\delta \end{bmatrix}$$

ϕ: balance angle, δ: steer angle, f: input

(A.L. Schwab & J.P. Meijaard, "A review on bicycle dynamics and rider control", Vehicle System dynamics: International Journal of Vehicle Mechanics and Mobility, 51(7), 1059-1090, 2013.)

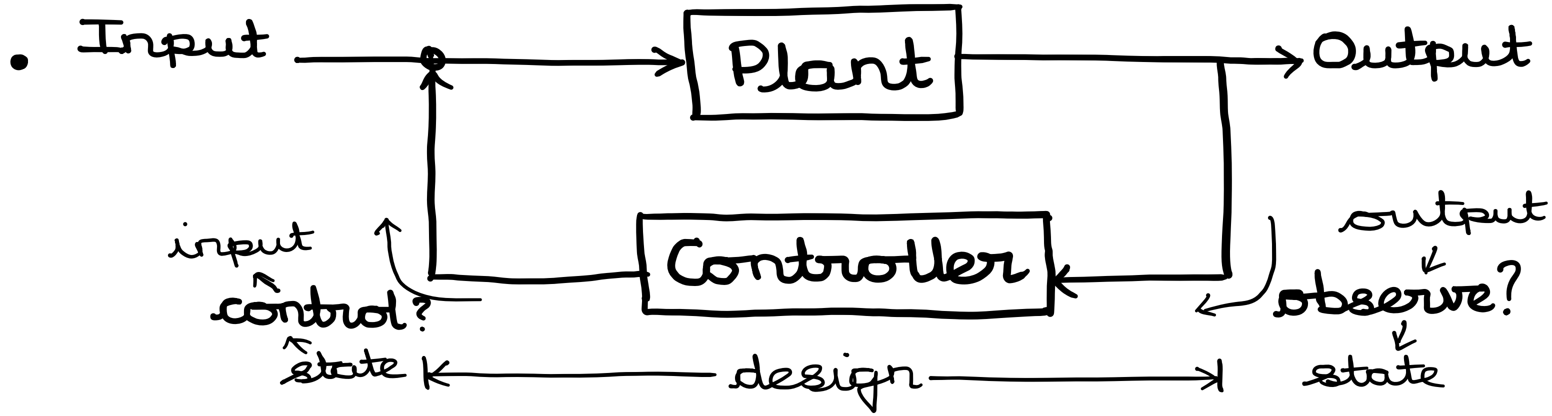
→ Laplace Transform, but initial condition?

→ quadratic equation ??

→ homogeneous equation (when $f = 0$)

Plan

model, solution?, input → state → output

- 

- Connections to Frequency domain, digital aspects

- Is the design optimal? robust?

  Extensions to networks, nonlinearities ...

  "Learn" the designs