MEEG 311 - Lecture 1
Vibration and Control

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28 August 2018

Goals:

- Give an overview of MEEG 311; course structure, administration
- Vibrations and control, why is this course different?
- Main concepts: systems, control, feedback
- Modeling of mechanical systems

Course Administration

MEEG 311: Vibration and Control
Fall 2018

Lectures: Tues. and Thurs. 11:00AM - 12:15PM, Willard Hall, Rm 319.
Discussions: Wed. 5:45 - 6:35PM, Gore Hall, Rm 117 (TA: Indrajeet Yadav)
Fr. 5:45 - 6:35PM, Sharp Lab, Rm 109 (TA: Justice Calderon)

Instructor: Prof. Ioannis Poulakakis
Office: 205 Spencer Lab
Email: poulakas@udel.edu
Office Hours: Wed. 10:30 AM – 12:00 PM

TAs:

Indrajeet Yadav (Indra)
Office: Spencer Lab, Rm 131
Email: indragt@udel.edu
Office Hours: Wed. 3-5pm

Justice Calderon
Office: Spencer Lab, Rm 131
Email: juscal@udel.edu
Office Hours: Mon. 11:30-1:30pm

Textbook: The course textbook is:
K. Ogata , *Modern Control Engineering*, Prentice Hall, fifth edition, 2010
Note: Additional course material, announcements, and assignment grades will be available electronically through Canvas.

Description: The course requires students to apply principles of engineering, basic science, and mathematics (particularly differential equations), to analyze and design control systems. The main part of the course deals with single-input-single-output (SISO) dynamical systems expressed by linear differential equations with constant coefficients. The course (i) introduces basic concepts for modeling such systems, (ii) reviews first- and second-order systems and (iii) discusses ways to modify their dynamical behavior through the use of feedback control designs. We discuss the concepts of stability, steady-state and transient performance, and we introduce frequency-based analysis tools such as the root locus and Bode diagrams.

Grading:

Class participation	10%
Weekly Homework (collected **before** the lecture begins)	20%
In-class Mid-Term Exam (tentatively scheduled at the **end of Oct.**)	30%
Final Exam (day/time fixed by the University)	40%

Note: Late homework is accepted no later than one day after the deadline and at the expense of a 20% penalty. HW solutions will be given soon after the due date. You are encouraged to discuss HW problems with other students to gain a better understanding into the subject material.

Email Policy: I will make every effort to reply to your emails within 24 hours. As a result, if you email me less than 24 hours before a problem set is due, I may not be able to respond in time. If you have a complicated question, it is better to arrange to meet me. Also, the TAs will be happy to answer questions.

Website: Registered students can reach the course web page at canvas.

Course syllabus:

- Lectures
- Office hours
- Textbook
- Grading
- Homework policy

- Class homepage at **CANVAS**:
  - Announcements
  - Homework/solutions
  - Handouts
  - Extra material

CHECK REGULARLY!!

Why is this course different?

Familiar:

- Scope: mechanical, electrical, thermal, fluid, …
- Aim: ***Analyze*** behavior
- Quantitative Methods e.g. explicit solutions of ODE's in time domain

New:

- Scope: mechanical, electrical, thermal, fluid, chemical, biological, financial systems (and any imaginable combination…)
- Aim: ***Shape*** behavior
- Qualitative Methods e.g. determine stability without explicitly solving the model

Common scientific backbone:

- Linear ODE's, complex numbers, Laplace transforms
- We will use vibrations as a "vehicle" to reach more abstract concepts in control.

Vibration and Controls

Vibration and Controls

… or "Control of (Linear) Dynamic Systems"

Vibration and Controls

… or "Control of (Linear) Dynamic Systems"

What is a “system”?

What is a "system"?

Merriam-Webster:

"A regularly **interacting or interdependent** group of items forming a unified whole:

A. (1): a group of interacting bodies under the influence of related forces *(2)* : an assemblage of substances that is in or tends to equilibrium <a thermodynamic *system*>

B. (1): a group of body organs that together perform one or more vital functions <the digestive *system*> *(2)* : the body considered as a functional unit

C. a group of related natural objects or forces <a river *system*>

D. a group of devices or artificial objects or an organization forming a network especially for distributing something or serving a common purpose <a telephone *system*> <a heating *system*> <a highway *system*> <a computer *system*>

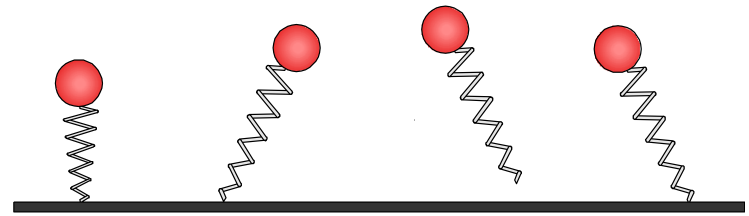
E. a major division of rocks usually larger than a series and including all formed during a period or era

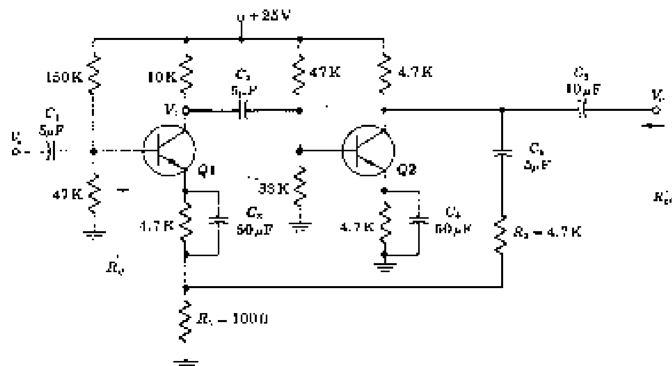
F. a form of social, economic, or political organization or practice <the capitalist *system*>"

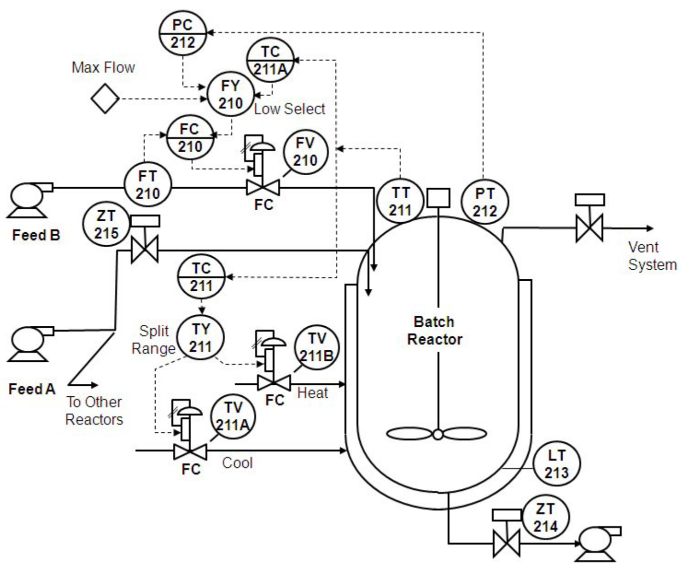
What is a "system"?

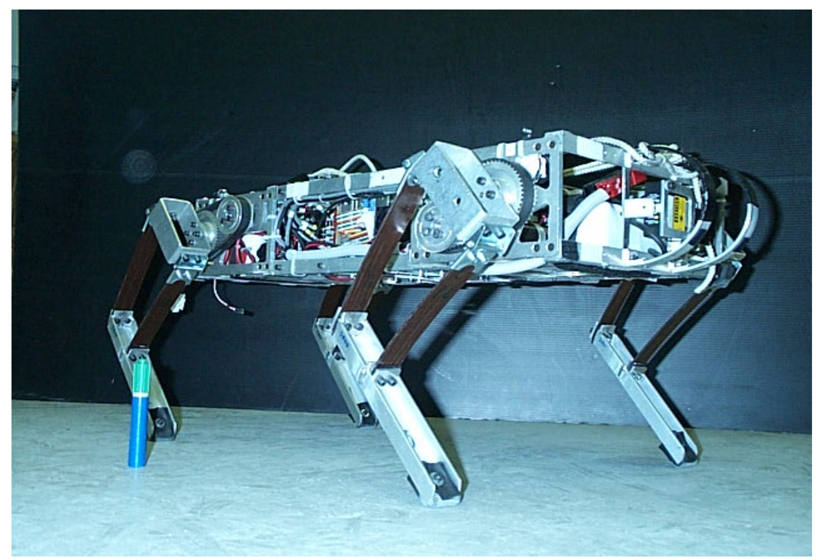
Engineering examples:

- Mechanical systems (masses, springs, dampers, forces etc.)
- Fluid/thermal systems (pneumatic, hydraulic, air-conditioning etc.)
- Electrical/electronic (resistors, capacitors, inductors, opamps etc.)
- Chemical reactors
- Many many others…

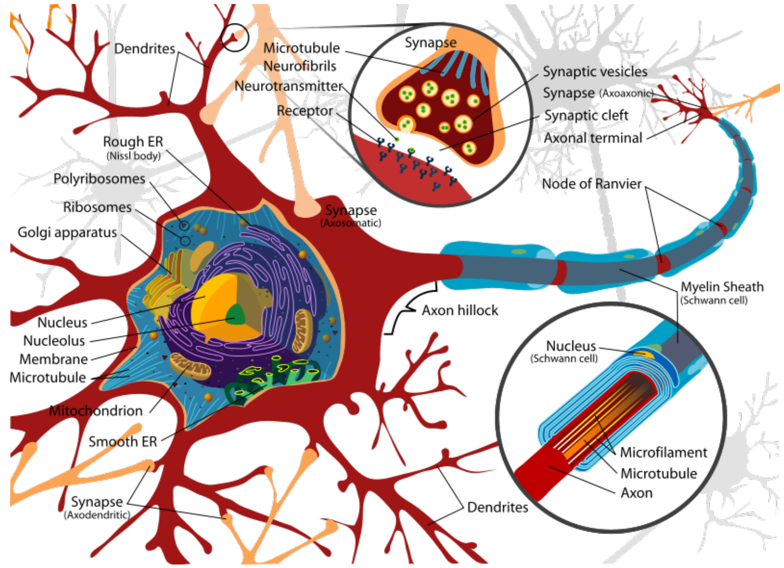








What is a “system”?



Biological Systems

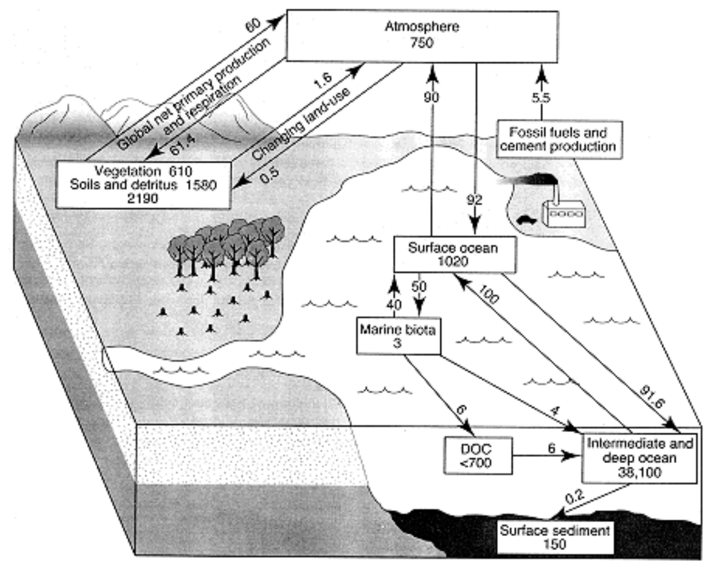
- Neurons and neural networks (electrically excitable cells that process and transmit)
- Bio-molecular regulatory networks

Environmental Systems

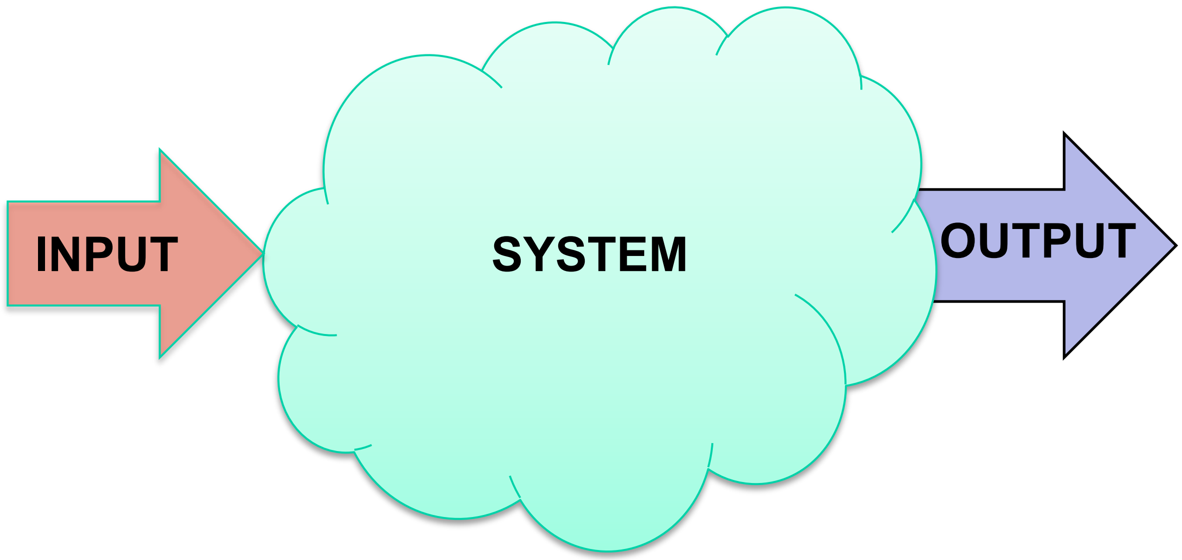
- Microbial ecosystems
- Global carbon cycle

Financial Systems

- Markets and exchanges
- Supply and service chains



What is a "system"?



(this is a just a convenient convention; but remember, nature does not specify what the inputs and outputs are…)

Vibration and Controls

… or "Control of (Linear) Dynamic Systems"

What is a "dynamic system"?

A system whose behavior changes with time; a system that is evolving in time

Key notion: The future evolution of the system depends on its **present and past** (only); that is, on where the system currently is and on where it used to be

Memory!

For those that took a course on Ordinary Differential Equations (ODE's), do you remember the notion of ***initial conditions***?

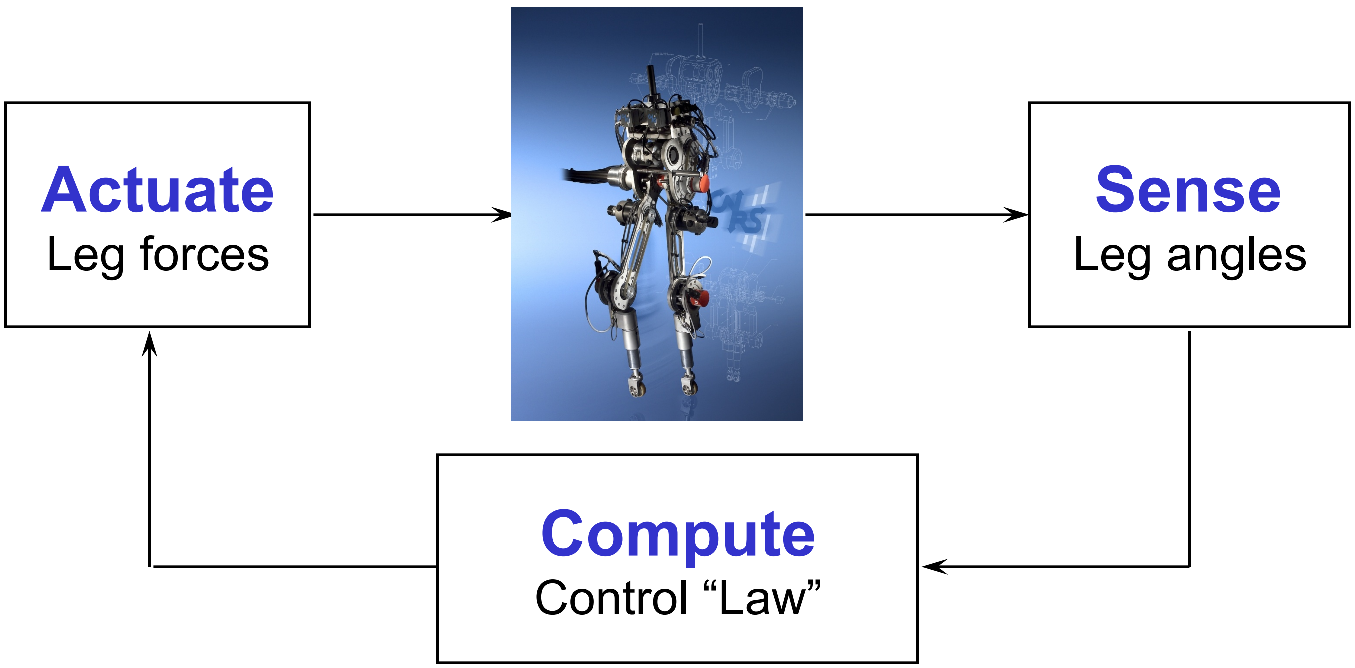
The examples considered thus far are dynamic systems.

Vibration and Controls

… or "Control of (Linear) Dynamic Systems"

What is “control”?

***Control* = Sensing + Computation + Actuation**



Goals

- Stability: system maintains desired operating point (torso upright, steady speed)
- Performance: system walks fast and its motions are natural
- Robustness: system tolerates perturbations in dynamics (mass, drag, etc)

What is “control”?

Control **= Sensing + Computation + Actuation**

Goals

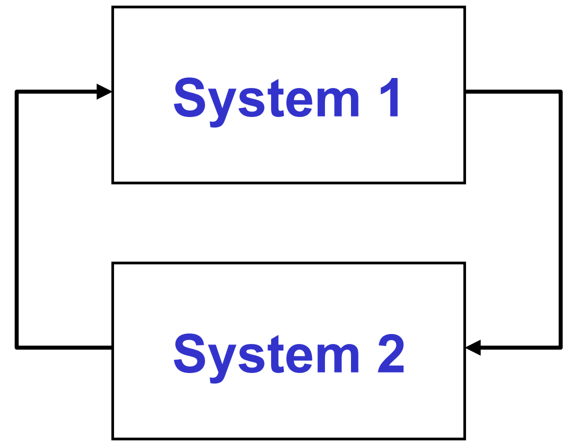
- Stability: system maintains desired operating point (torso upright, steady speed)
- Performance: system walks fast and its motions are natural
- Robustness: system tolerates perturbations in dynamics (mass, drag, etc)

Example: Not adequate "control" …

What is “feedback”?

Merriam-Webster:

the return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action) [1920]

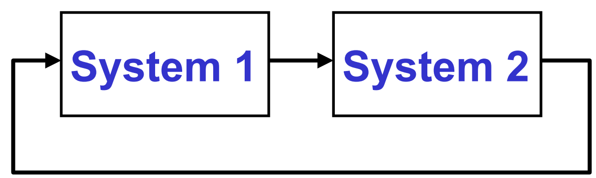


Feedback = mutual interconnection of two (or more) systems

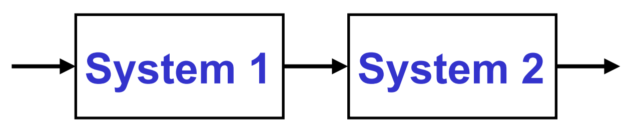
- System 1 affects system 2
- System 2 affects system 1
- Cause and effect is tricky; systems are mutually dependent

Feedback is ubiquitous in natural and engineered systems

Terminology



Closed Loop



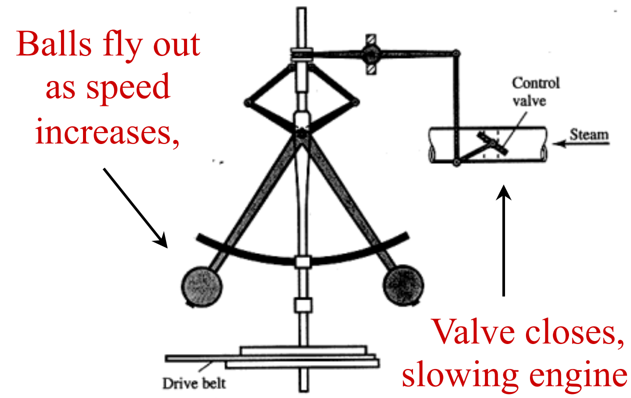
Open Loop

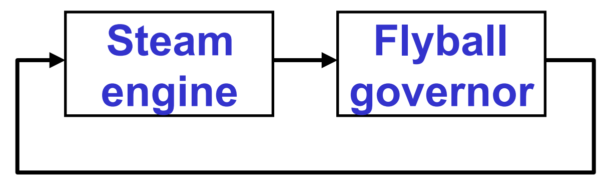
Examples of feedback control systems

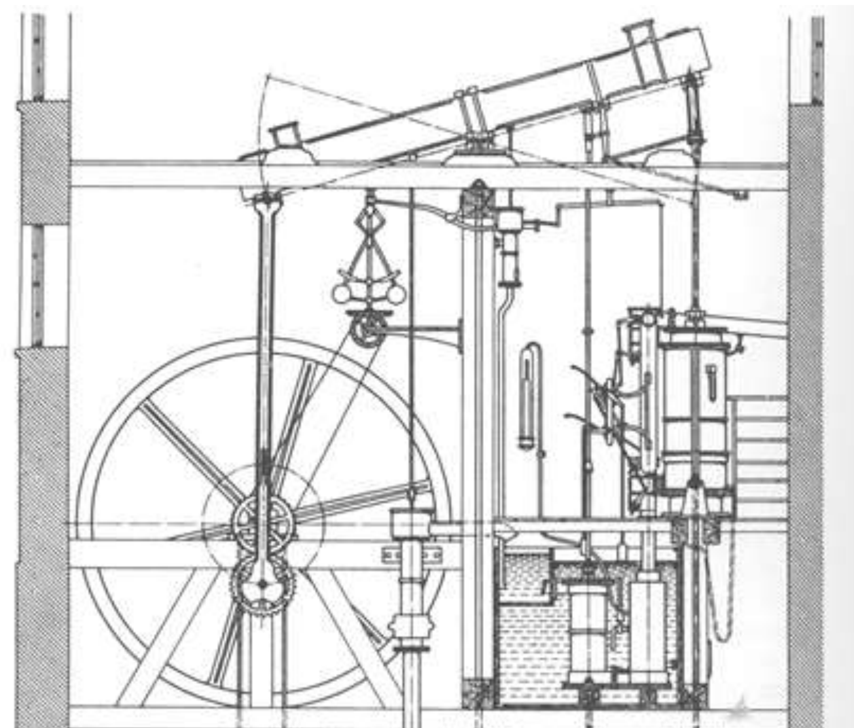
Example #1: Flyball Governor

"Flyball" Governor (1788)

- Regulate speed of steam engine
- Reduce effects of variations in load (disturbance rejection)
- Major advance of industrial revolution

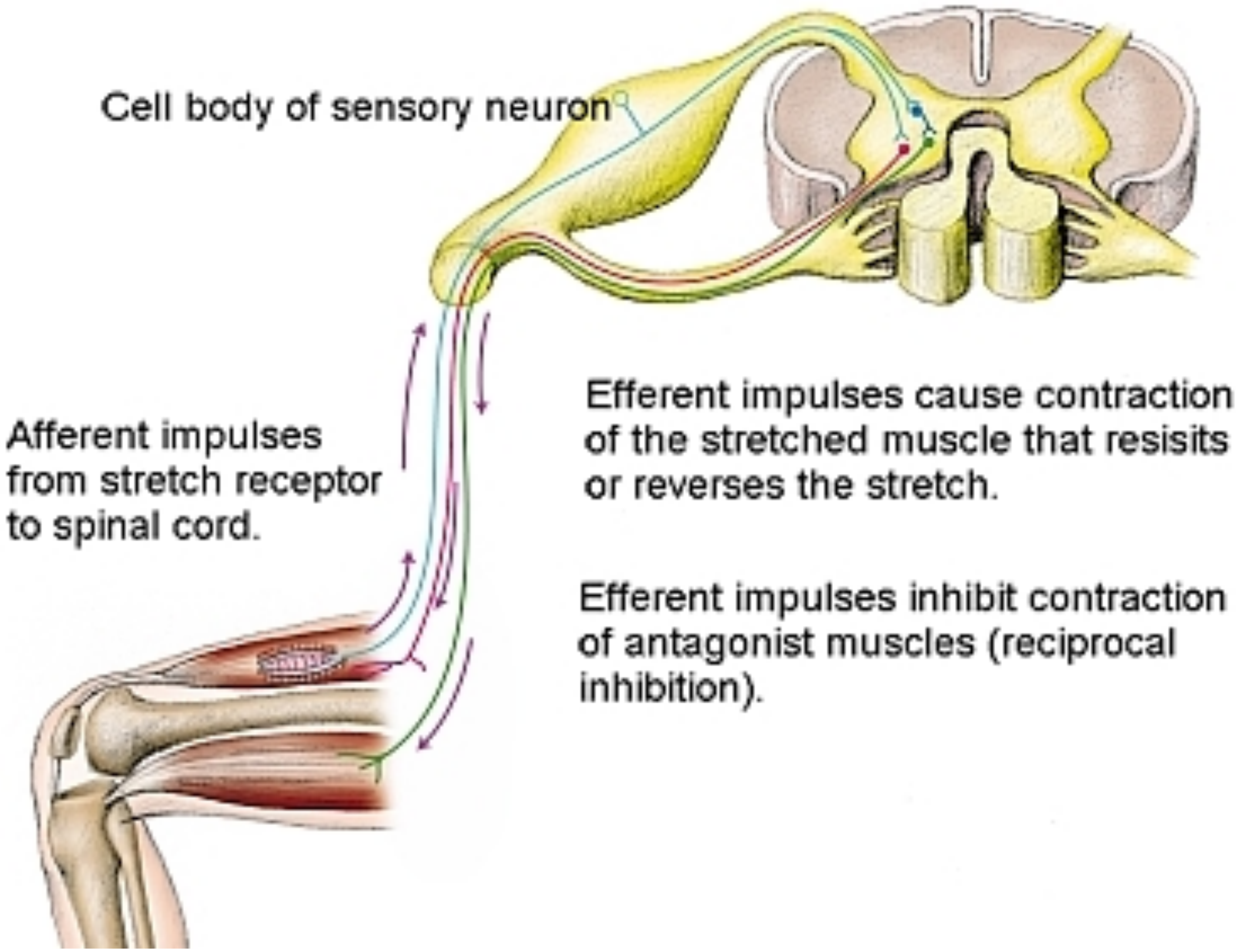




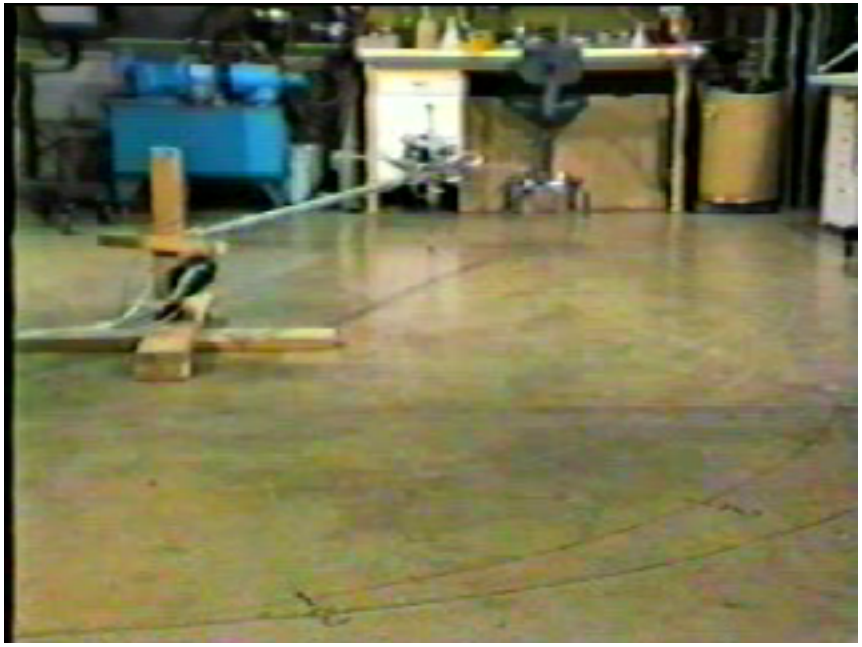


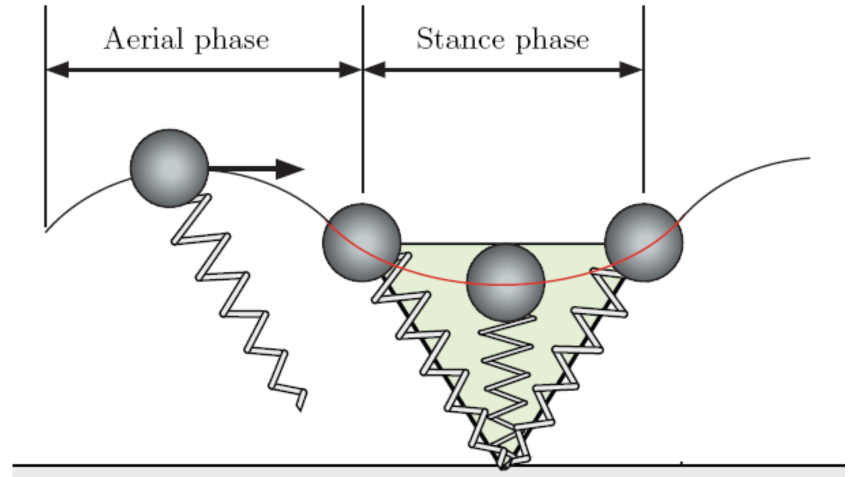
Boulton-Watt steam engine

Example #2: Stretch Reflex



Example #3: Hopping robot control





The control strategy

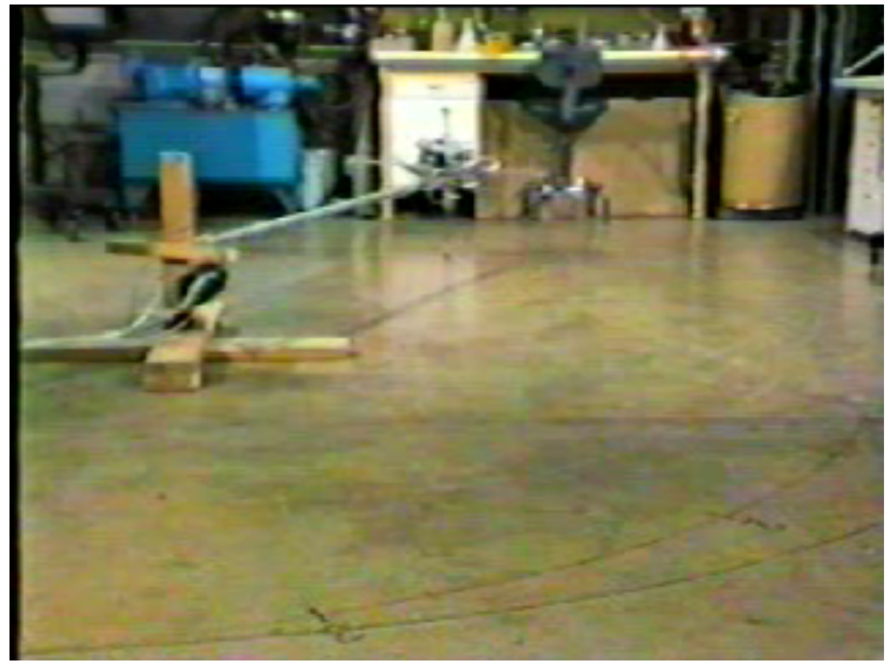
- Monitor robot's speed
- When the robots runs faster than the desired speed increase the angle of the leg prior to touchdown (when it is in the flight phase)
- Why? Part of the robot's forward kinetic energy is transferred to vertical hopping. Thus the robot decelerates and jumps higher!
- The opposite when the robot runs slower than the desired speed

Modeling Mechanical Systems

Modeling

An idealization of the system at various levels of complexity

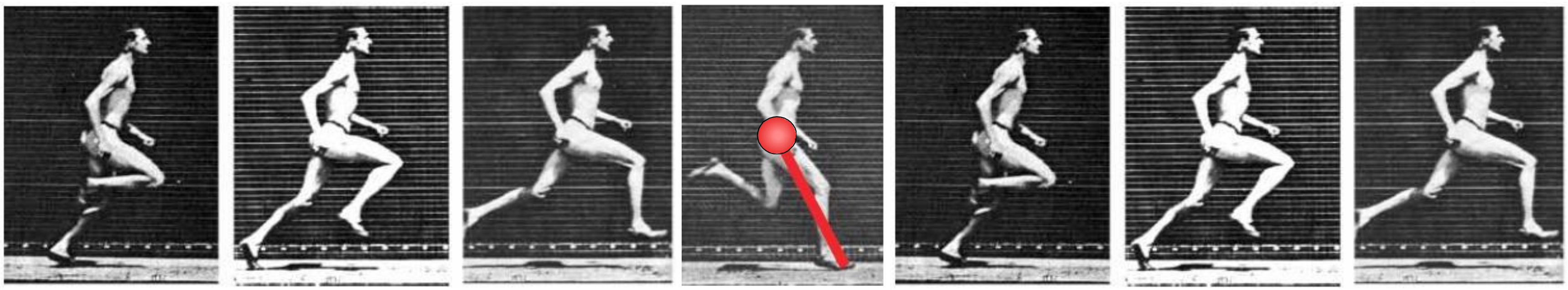
Example: Animal and robot running



Example: Animal and robot running

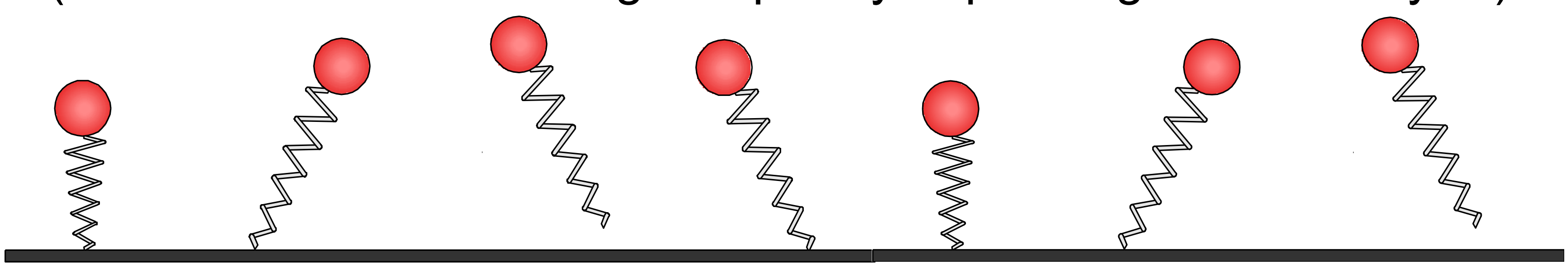
Underlying energy transformations:

- In running energy cycles back and forth between the ballistic energy in flight and spring compression in stance



Mathematical idealization:

- A model that captures the underlying energy transformations (various levels of modeling complexity depending on the analysis)



Modeling

An idealization of the system at various levels of complexity:

- System of (linear) ordinary differential equations
- Parameters (mass, spring constants etc.)
- Variables (position, velocity etc.)

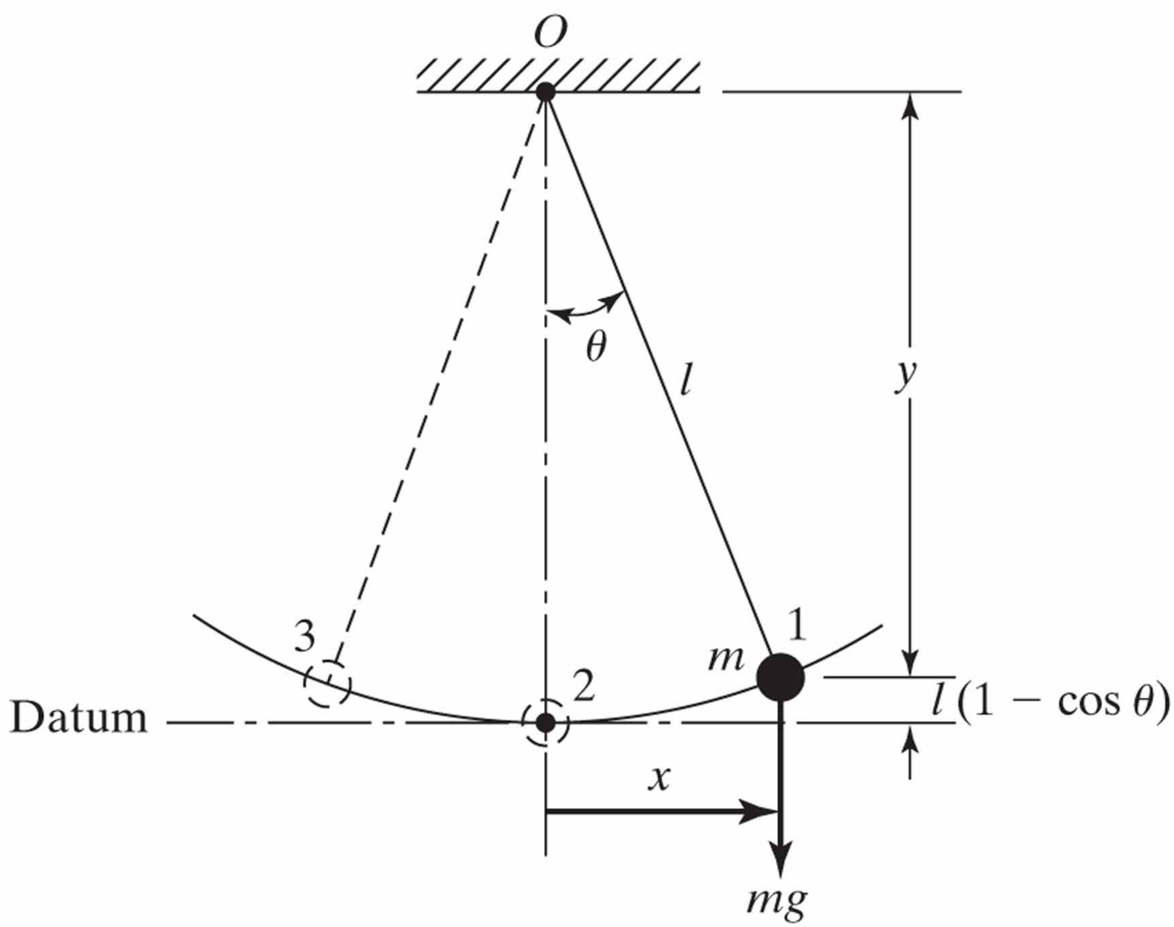
DoF (Degrees of Freedom), generalized coordinates:

- “The minimum number of coordinates to determine completely the positions of all parts of system”
- How many variables you need to describe configuration (snapshot)?

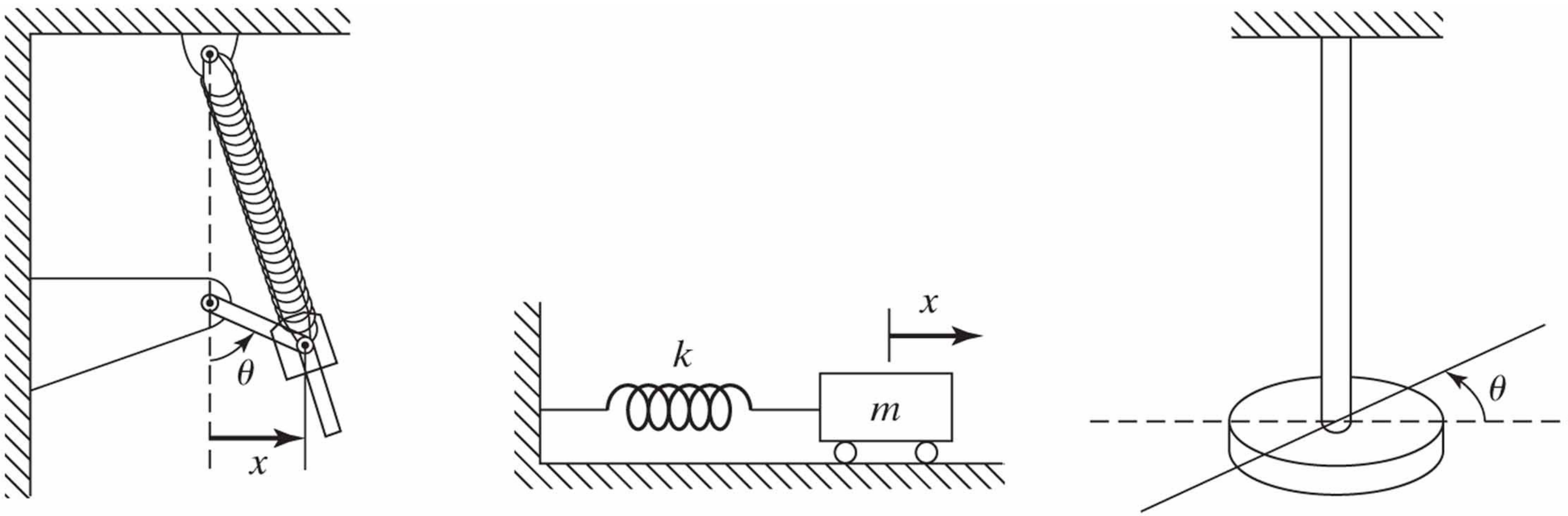
States:

- How many variables you really need to describe evolution

Modeling Example: The Pendulum



Modeling Examples

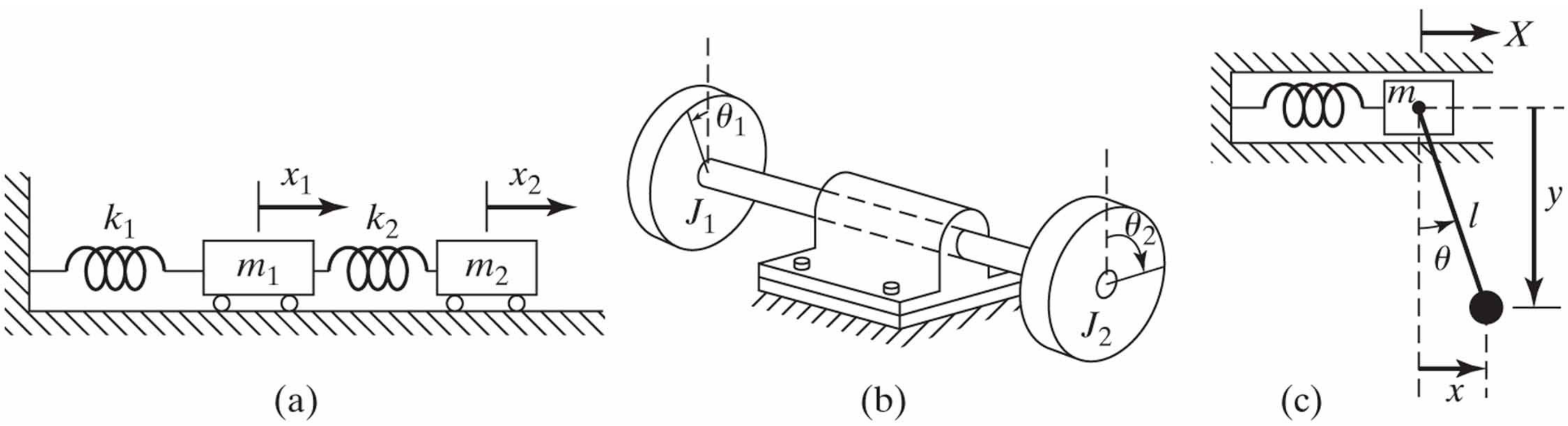


(a) Slider-crank-spring mechanism

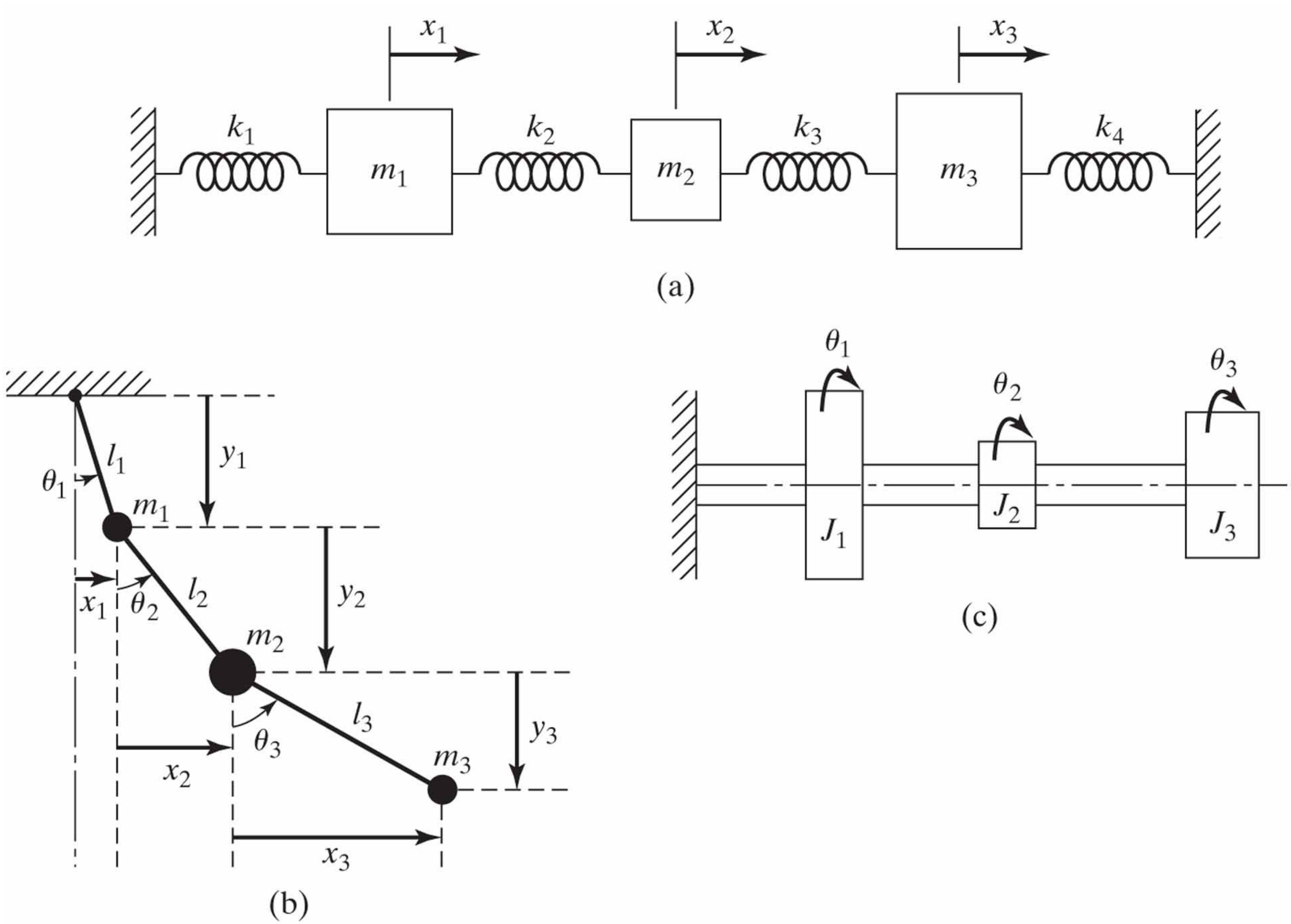
(b) Spring-mass system

(c) Torsional system

Modeling Examples



Modeling Examples



Modeling

***Model* = States + Inputs + Dynamics + Outputs**

States: capture the effect of the past in describing evolution

- Independent physical quantities (e.g., position, speed, voltage, current) that determine the state of the system (absent external excitation)

Inputs: describe external excitation

- Inputs are extrinsic to the system dynamics (externally specified)

Dynamics: describe state evolution

- Update rule for system's state
- Function of current state and any external inputs

Outputs: describe measured quantities

- Outputs are function of states and inputs (NOT independent quantities)
- Outputs are often a subset of the states

Various Levels of Modeling Details

Figure 1.17 Motorcycle with a rider—a physical system and mathematical model.