EECE 360 - Systems and Control

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Electrical and Computer Engineering

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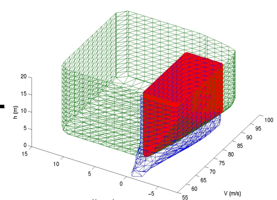
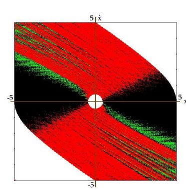
Your Instructor

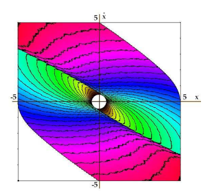
- B.S., Princeton University, 1998
- M.S., Ph.D., Stanford University, 2000 and 2004
- Postdoc, Sandia National Labs (USA)
- Assistant Prof. in ECE at UBC since 2006
- Visiting researcher at NASA Ames, Honeywell
- Policy experience at US National Academies; US Nat'l Ecological Observatory Network (NEON)

Research



- Hybrid control systems
- Aircraft flight management systems
- Biological / Biomedical modeling and control
- User-interfaces for hybrid systems
- Research website: *http://www.ece.ubc.ca/~moishi*

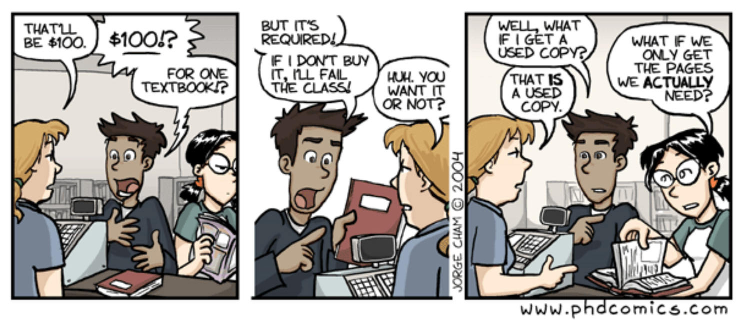




Practical Information

- Textbook: R. Dorf and R. Bishop, *Modern Control Systems, 11th Edition*, Prentice Hall.

  http://www.prenhall.com/dorf



Practical Information

- Textbook: R. Dorf and R. Bishop, *Modern Control Systems, 11th Edition*, Prentice Hall.
  `http://www.prenhall.com/dorf`
- Recommended reading:
  - G. F. Franklin, J. D. Powell and A. Emami-Naeini, *Feedback Control of Dynamic Systems*, Addison-Wesley.
  - K.Ogata, *Modern Control Engineering*, Prentice Hall.

Acknowledgement

- Many of the slides were originally developed by Professor Guy Dumont, who taught EECE360 Section 101.
- Some slides were modified by Professor Michael Davies and by Professor Z. Jane Wang.
- However, different slides, problem sets, course policies, and exams were used in each EECE 360 Section.

How To Succeed In This Course

- Before Class
  - Review material (notes and textbook) from previous class
  - Preview material (textbook and notes if available) to be covered
- During Class
  - Arrive on time
  - Attend all classes and tutorials
  - Pay attention, take notes and ask questions if needed
- After Class
  - Review material (notes and textbook)
  - Identify and understand key issues
  - Do all the problem sets assigned, and check your answers with posted solutions.

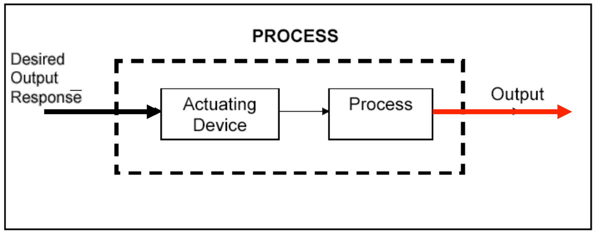
Motivation

A control system is an interconnection of components forming a system that will provide a desired system response.

Components
Structure
Functionality

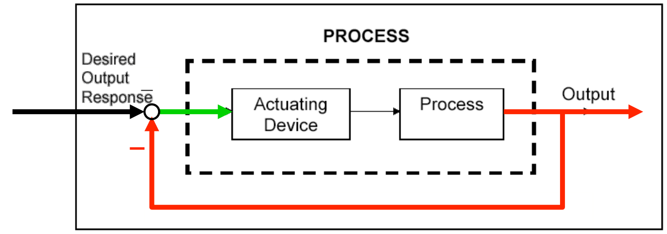
- Control is:
  - a **key enabling technology** in all branches of engineering.
  - used whenever some quantity, such as temperature, altitude or speed, must be made to behave in some desirable way over time.

Open-Loop vs. Closed-Loop Control



Open-Loop Control

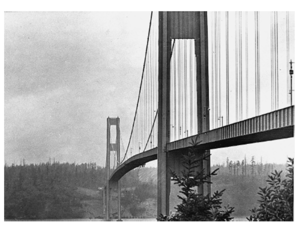
Open-Loop vs. Closed-Loop Control



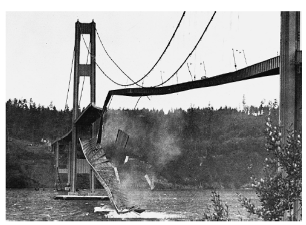
Closed-Loop Control

Why Stability is Important

Tacoma Narrows bridge: July 1, 1940 – Nov. 7, 1940.



Wind-induced oscillations



Catastrophic failure

Applications of Control

- Industrial plants
  - Manufacturing and assembly lines
  - Power plants
- Goals:
  - Maximize efficiency
  - Minimize environmental impact
  - Meet all quality specifications
- Most modern industrial plants could not operate without control systems

Applications of Control

- Transportation
  - Automobiles (cruise control, lane keeping)
  - Civil jet aircraft (autopilots; air traffic control)
  - Traffic signals, highway monitoring
- Robotics
  - Dextrous manipulation, haptics
  - RC cars and gliders
  - Research submarines
  - Smart wheelchairs

Applications of Control

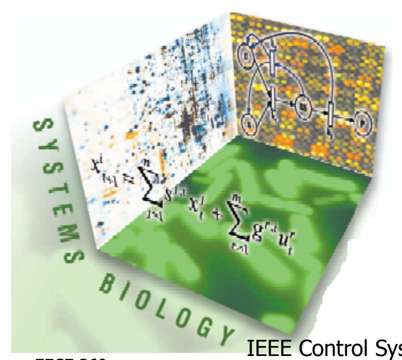
- Provides performance otherwise unattainable
  - Feedback amplifier
  - Military aircraft autopilots
  - Disk drives and CD players
  - Cellular telephones
  - ABS in cars
  - Prosthetics
- Environments humans can’t tolerate
  - Mars Rover
  - Satellites (including GPS)
  - Underwater exploration and research

Applications of Control

- Biological systems
  - Cell regulation mechanisms
  - Population dynamics
  - Epidemiology
- Economic systems
  - Inflationary mechanisms
  - Fiscal policies
- Biomedical systems
  - Bone development and morphology
  - Sleep cycles, SAD
  - Faulty feedback mechanisms in Parkinson’s disease

Example

Biology
Statistics
Control Theory
→ Systems Biology



IEEE Control Systems Magazine

Systems biology is an emergent field that aims at system-level understanding of biological systems.

- Focus on systems that are composed of molecular components
- Understanding of structure, dynamics, control methods, and design method of the system

Example: A Tale of Two Cells

- How negative feedback is used by (amoeba) *D. discoideum* cells to remain responsive to wide changes in the mean level of chemo-attractant.
- How (yeast) *S. cerevisiae* uses positive feedback loops to stabilize the polarization orientation.

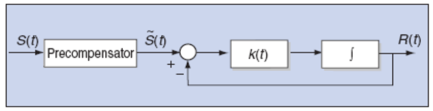


Figure 10. *Integral feedback interpretation of the LEGI model. The adaptation mechanism of the LEGI model exhibits integral feedback control with a precompensator; see (23). The signal $\tilde{S}$ includes a constant component and a decaying part.*

$$\frac{\mathrm{d}R(t)}{\mathrm{d}t} = -k_{-r} I(t) \left(R(t) - \tilde{S}(t) \right), \qquad (23)$$

where $\tilde{S}(t) := k_r E(t)/k_{-r} I(t)$. Moreover,

$$\tilde{S}(t) = \frac{k_r E(t)}{k_{-r} I(t)} = \frac{k_e k_{-i} k_r}{k_{-e} k_i k_{-r}} + \underbrace{\frac{k_e k_{-i} k_r}{k_{-e} k_i k_{-r}} \left(\frac{(e^{-k_{-e}t} - e^{-k_{-e}t})(S(0) - S(\infty))}{e^{-k_{-i}t}(S(0) - S(\infty)) + S(\infty)} \right)}_{\text{transient}}.$$

Responding to directional cues: a tale of two cells [biochemical signaling pathways], by Paliwal, S.; Lan Ma; Krishnan, J.; Levchenko, A.; Iglesias, P.A.; IEEE Control Systems Magazine, vol 24(4) , pp. 77-90, Aug. 2004

Implementation of Control

- Embedded microprocessors observe signals from sensors and provide command signals to electromechanical actuators.
- Designers use computer-aided design software (e.g., Matlab)
- Design usually tested on simulations before implementation
- Control engineering requires a thorough understanding of the application area

Foundations and Methods

- The study of dynamical systems is central to control engineering
- Feedback is a key concept
- Firm mathematical foundations
  - Differential or difference equations
  - Laplace and z-transforms
  - Fourier transform
  - Stability theory

Challenges in Control

- Autonomous systems able to function in presence of significant uncertainty and failures
- Autonomous land, underwater, air and space vehicles
- Highly automated manufacturing
- Intelligent robots
- Highly efficient and fault tolerant voice and data networks
- Reliable electric power generation and distribution
- Seismically tolerant structures
- Highly efficient fuel control for a cleaner environment

Course Content

- Mathematical models (ODE, transfer function, state-space)
- Feedback control (characteristics, performance, and stability)
- Frequency domain analysis and design
- State feedback
- Robustness

Goals of the Course

- Identify how control is used in engineering systems
- Identify benefits of feedback
- Analyze and predict common behaviors of dynamical systems with feedback
- Apply relevant mathematical theory
- Solve simple control design problems
- Use relevant computational tools
- Recognize difficult control problems