CDS 101: Lecture 1.1
Introduction to Feedback and Control

Richard M. Murray

29 September 2003

Goals:

- Give an overview of CDS 101/110; describe course structure, administration
- Define feedback/control systems and learn how to recognize main features
- Describe what control systems do and the primary principles of control

Reading (available on course web page):

- Astrom and Murray, *Analysis and Design of Feedback Systems,* Ch 1
- "For the Spy in the Sky, New Eyes", NY Times, June 2002.

Course Administration


CALIFORNIA INSTITUTE OF TECHNOLOGY
Control and Dynamical Systems

CDS 101 - Principles of Feedback and Control
CDS 110 - Introductory Control Theory
ChE 105 - Process Control
Fall 2002

Instructor
R. Murray, 107 Steele
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Co-instructors
M. Dickinson
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H. Mabuchi
D. MacMartin

Teaching Assistants
Sean Humbert (head TA), jshumber@cds
Tim Chung, Lars Cremean,
Zhipu Jin, Shreesh Mysore
Office hours: Fridays, 3-5 pm, 135 Steele

Lectures
M2-3, W1-3, 102 Steele
F2-3, 102 Steele (optional)

CDS 101 vs CDS110a/ChE 105

Lectures

Grading

- Homework: 50%
- Midterm exam: 20%
- Final exam: 30%

Homework policy

Course syllabus

- CDS 101 vs CDS 110ab
- Lectures
- Grading
- Homework policy
- Course text and references
- Office hours
- Class homepage
- Software
- Course outline

- Video tapes: 102 Steele, Box G
- Course load: keep track of hours

CDS 101/110 Instructional Staff

Lecturer: Richard Murray (CDS)
- Overall course management

Co-Instructors
- Michael Dickinson (BE/Bio)
- Steven Low (CS/EE)
- Hideo Mabuchi (Ph/CDS)
- Doug MacMartin (CDS)

Head TA: Lars Cremean (ME)
- Coordinate course infrastructure, TAs

TAs
- Michael Reiser (BE)
- Demetri Spanos (CDS)
- Abhishek Tiwari (EE)
- Stephen Waydo (CDS)

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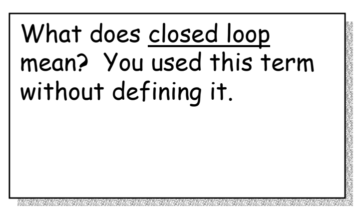
Mud Cards

Mud cards
- 3 x 5 cards distributed at each lecture
- Describe "muddiest" part of the lecture
- Turn in cards at end of class
- Responses posted on FAQ list by **8 pm** on the day of the lecture (make sure to look!)

Class FAQ list
- Searchable database of responses to mud cards and other frequently asked questions in the class



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CDS 101/110/111 Course Sequence

CDS 101 – Introduction to the *principles* and *tools* of control and feedback
- Summarize key concepts, w/ examples of fundamental principles at work
- Introduce MATLAB-based tools for modeling, simulation, and analysis

CDS 110a – Analytical understanding of key concepts in control
- Detailed description of classical control and state space concepts
- Provide knowledge to work with control engineers in a team setting

Fall

CDS 110b – Detailed design tools for control systems
- Estimation and robust control tools for *synthesis* of control laws

Winter

CDS 111 – Implementation of control systems for engineering applications
- Lab-based *implementation* of computer control on physical systems

Spring

CDS Minor: CDS 110, CDS 140, Senior thesis or Ae/CDS 125

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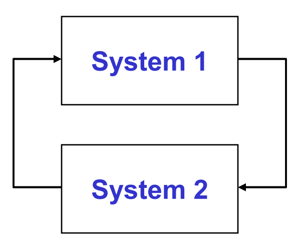
What is Feedback?

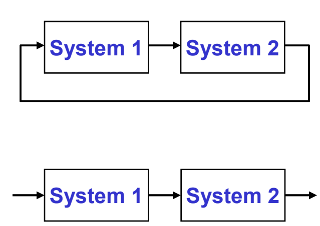
Miriam Webster:

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

Terminology



Closed Loop

Open Loop

Feedback is ubiquitous in natural and engineered systems

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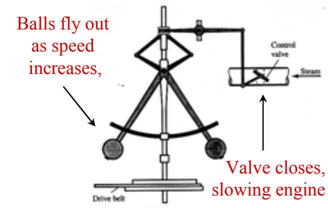
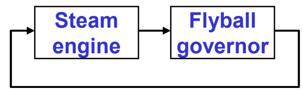
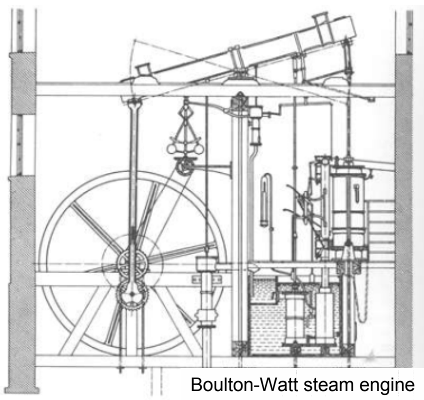
Example #1: Flyball Governor

"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

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Other Examples of Feedback

Biological Systems

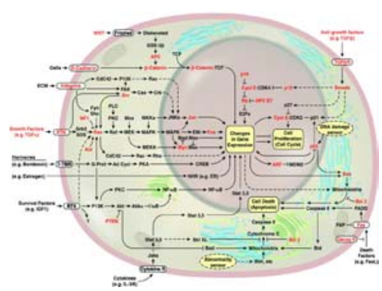
- Physiological regulation (homeostasis)
- Bio-molecular regulatory networks

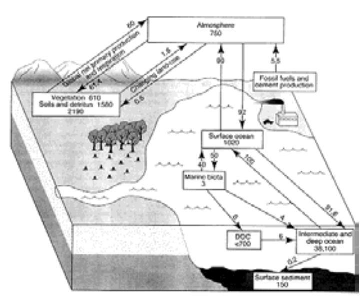
Environmental Systems

- Microbial ecosystems
- Global carbon cycle

Financial Systems

- Markets and exchanges
- Supply and service chains





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Control = Sensing + Computation + Actuation

In Feedback "Loop"

Actuate
Gas Pedal

Sense
Vehicle Speed

Compute
Control "Law"

Goals

- Stability: system maintains desired operating point (hold steady speed)
- Performance: system responds rapidly to changes (accelerate to 65 mph)
- Robustness: system tolerates perturbations in dynamics (mass, drag, etc)

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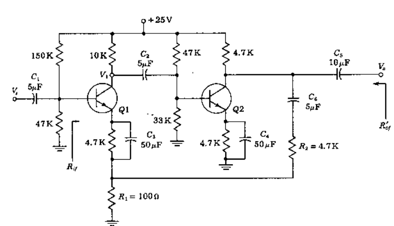
Two Main Principles of Control

Robustness to Uncertainty through Feedback

- Feedback allows high performance in the presence of uncertainty
- Example: repeatable performance of amplifiers with 5X component variation
- Key idea: accurate *sensing* to compare actual to desired, correction through *computation* and *actuation*



Design of Dynamics through Feedback

- Feedback allows the dynamics of a system to be modified
- Example: stability augmentation for highly agile, unstable aircraft
- Key idea: interconnection gives *closed loop* that modifies natural behavior

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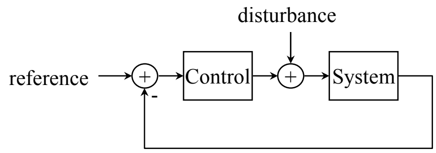
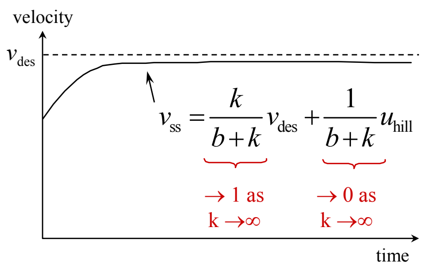
Example #2: Cruise Control

$$m\dot{v} = -bv + u_{\text{engine}} + u_{\text{hill}}$$
$$u_{\text{engine}} = k(v_{\text{des}} - v)$$





Stability/performance

- Steady state velocity approaches desired velocity as k → ∞
- Smooth response; no overshoot or oscillations

Disturbance rejection

- Effect of disturbances (hills) approaches zero as k → ∞

Robustness

- Results don't depend on the specific values of *b, m,* or *k* for *k* sufficiently large

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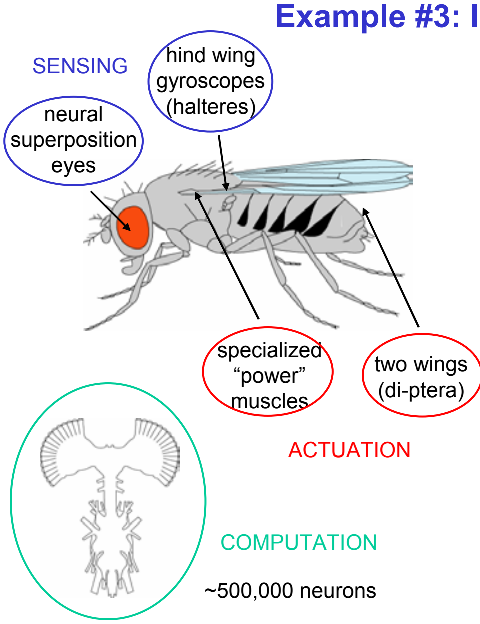
Example #3: Insect Flight



More information:

- M. D. Dickinson, Solving the mystery of insect flight, *Scientific American,* June 2001
- CDS 101 seminar : Friday, 10 Oct 03

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Modern Engineering Applications of Control

Flight Control Systems
- Modern commercial and military aircraft are "fly by wire"
- Autoland systems, unmanned aerial vehicles (UAVs) are already in place

Robotics
- High accuracy positioning for flexible manufacturing
- Remote environments: space, sea, non-invasive surgery, etc.

Chemical Process Control
- Regulation of flow rates, temperature, concentrations, etc.
- Long time scales, but only crude models of process

Communications and Networks
- Amplifiers and repeaters
- Congestion control of the Internet
- Power management for wireless communications

Automotive
- Engine control, transmission control, cruise control, climate control, etc
- Luxury sedans: 12 control devices in 1976, 42 in 1988, 67 in 1991

AND *MANY* MORE...

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Control Tools

Modeling
- Input/output representations for subsystems + interconnection rules
- System identification theory and algorithms
- Theory and algorithms for reduced order modeling + model reduction

Analysis
- Stability of feedback systems, including robustness "margins"
- Performance of input/output systems (disturbance rejection, robustness)

Synthesis
- Constructive tools for design of feedback systems
- Constructive tools for signal processing and estimation (Kalman filters)

MATLAB Toolboxes
- SIMULINK
- Control System
- Neural Network
- Data Acquisition
- Optimization
- Fuzzy Logic
- Robust Control
- Instrument Control
- Signal Processing
- LMI Control
- Statistics
- Model Predictive Control
- System Identification
- μ-Analysis and Synthesis

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Overview of the Course

Wk	Mon/Wed	Fri
1	Introduction to Feedback and Control *Review of ODEs and linear algebra*	MATLAB tutorial, Lars Cremean
2	System Modeling	Insect flight control, Michael Dickinson
3	Stability and Performance	Internet congestion control, Steven Low
4	Linear Systems	Control of CELT, Doug MacMartin
5	Controllability and Observability *Midterm exam*	Review for midterm, Lars Cremean
6	Transfer Functions	Animal sensory systems, Michael Dickinson
7	Loop Analysis of Feedback Systems	Closed-loop atomic magnetometry, Hideo Mabuchi
8	Frequency Domain Design	Aerospace control systems, TBD
9	Limits on Performance	Thanksgiving holiday
10	Uncertainty Analysis and Robustness *Final exam*	Review for final, Steve Waydo

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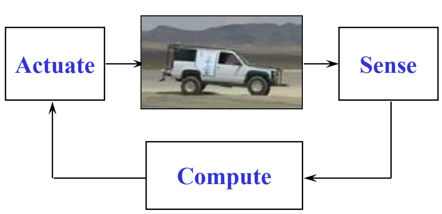
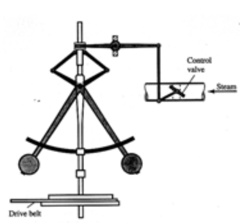
Summary: Introduction to Feedback and Control

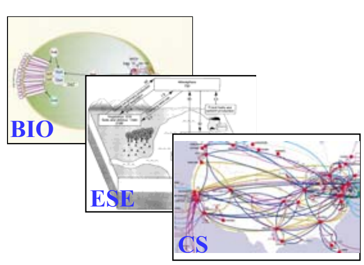


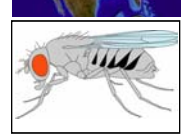
Control =
Sensing + Computation + Actuation

Feedback Principles
- Robustness to Uncertainty
- Design of Dynamics

Many examples of feedback and control in natural & engineered systems:







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