CDS 101/110a: Lecture 1.1
Introduction to Feedback & Control

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30 September 2009

Goals:
- Give an overview of CDS 101/110/210: course structure & administration
- Define feedback systems and learn how to recognize main features
- Describe what control systems do and the primary principles of feedback

Reading:
- Åström and Murray, *Feedback Systems: An Introduction for Scientists and Engineers*, Chapter 1 [30 min]

Course Administration

Course syllabus
- CDS 101 vs 110a vs 210
- Lectures, recitations
- Office hours
- Grading
- Homework policy (+ grace period)
- Course text and references
- Class homepage
- Software
- Course outline

- Signup sheet, mailing list
- Lecture MP3s
- Course load: keep track of hours
- Course ombuds: send e-mail by Thurs evening to volunteer

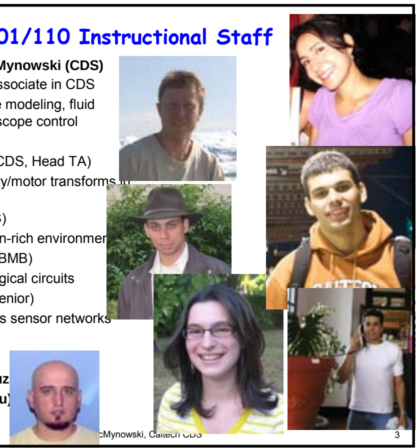
http://www.cds.caltech.edu/~macmardg/wiki/index.php?title=CDS_101/110a%2C_Fall_2009

CDS 101/110 Instructional Staff

Instructor: Doug MacMynowski (CDS)
- Senior Research Associate in CDS
- Research in climate modeling, fluid dynamics, and telescope control

TAs
- Francisco Zabala (CDS, Head TA)
  - Characterize sensory/motor transforms in organisms
- Andrea Censi (CDS)
  - Robotics, information-rich environments
- Ophelia Venturelli (BMB)
  - Engineering of biological circuits
- Noele Norris (EE, senior)
  - DARPA GC, wireless sensor networks
- Aristo (EE)

- **CDS 212: Genti Buzi**
- **(genti@caltech.edu)**



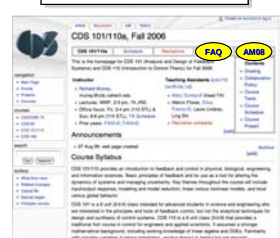
Mud Cards

Mud cards
- 3 x 5 cards passed out at beginning of each lecture
- Describe "muddiest" part of the lecture (or other questions)
- 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
- Responses to mud cards and other frequently asked questions in the class
- Previous FAQs available on AM wiki

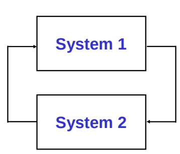
AMwiki
- Additional exercises, FAQs, examples

What does closed loop mean? You used this term without defining it.



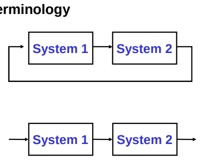
What is Feedback?

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

Terminology

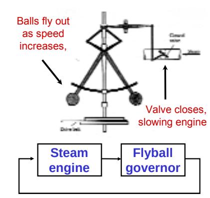


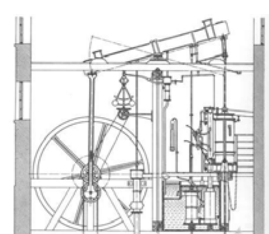
Feedback is ubiquitous in natural and engineered systems

Control: we get to design feedback!

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





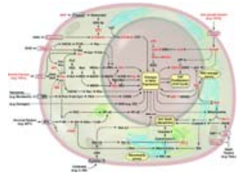
Boulton-Watt steam engine

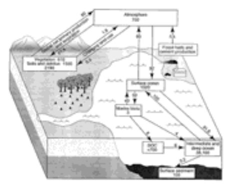
Other Examples of Feedback

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





Control = Sensing + Computation + Actuation

In Feedback "Loop"

Actuate
Gas Pedal

Sense
Vehicle Speed

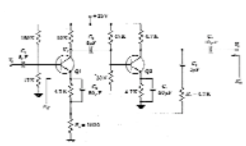
Compute
Control "Law"

Goals
- Stability: system maintains desired operating point (hold steady speed)
- Performance: system responds rapidly to changes (accelerate to 6 m/sec)
- Robustness: system tolerates perturbations in dynamics (mass, drag, etc)

(Note: this class will only deal with *feedback* or *closed-loop* control)

Two Main Principles of Feedback

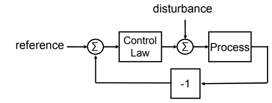
Robustness to Uncertainty through Feedback
- Feedback allows high performance in the presence of uncertainty
- Example: repeatable performance of amplifiers with 5X component variation
- Key idea: accurate *sensing* to compare actual to desired, correction through *computation* and *actuation*



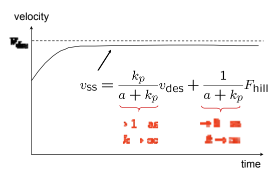
Design of Dynamics through Feedback
- Feedback allows the dynamics (behavior) of a system to be modified
- Example: stability augmentation for highly agile, unstable aircraft
- Key idea: interconnection gives *closed loop* that modifies natural behavior


X-29 experimental aircraft (NASA)

Example #2: Speed Control



$$m\dot{v} = -av + F_{\text{eng}} + F_{\text{hill}}$$
$$F_{\text{eng}} = k_p(v_{\text{des}} - v)$$



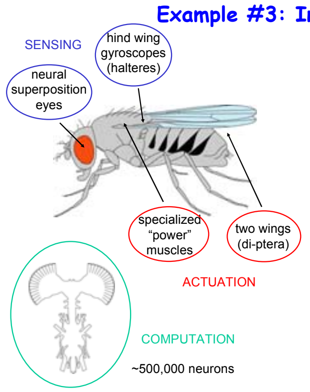
$$v_{ss} = \frac{k_p}{a+k_p}v_{\text{des}} + \frac{1}{a+k_p}F_{\text{hill}}$$

Stability/performance
- Steady state velocity approaches desired velocity as $k \to \infty$
- Smooth response; no overshoot or oscillations

Disturbance rejection
- Effect of disturbances (eg, hills) approaches zero as $k \to \infty$

Robustness
- Results don't depend on the specific values of a, m or k_p, for k_p sufficiently large

Example #3: Insect Flight



More information:
- **M. H. Dickinson, Solving the mystery of insect flight, *Scientific American*, June 2001**

Control Tools

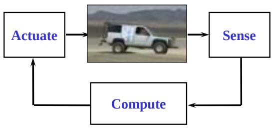
Modeling
- Input/output representations for subsystems + interconnection rules
- System identification theory and algorithms
- Theory and algorithms for reduced order modeling + model reduction

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
- Systems biology (SBML)

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: