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

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28 September 2015

Goals:

- Give an overview of CDS 101/110: 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]

CDS 101/110 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 110 – 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 112 – Detailed design tools for control systems

- Optimization-based control (LQR, RHC/MPC, Kalman filters)

CDS 212/213 - Modern (robust) control design

- Operator-based approach to control; linear and nonlinear systems
- 212 = analysis, 213 = synthesis

Winter

CDS 140 - Introduction to Dynamical Systems

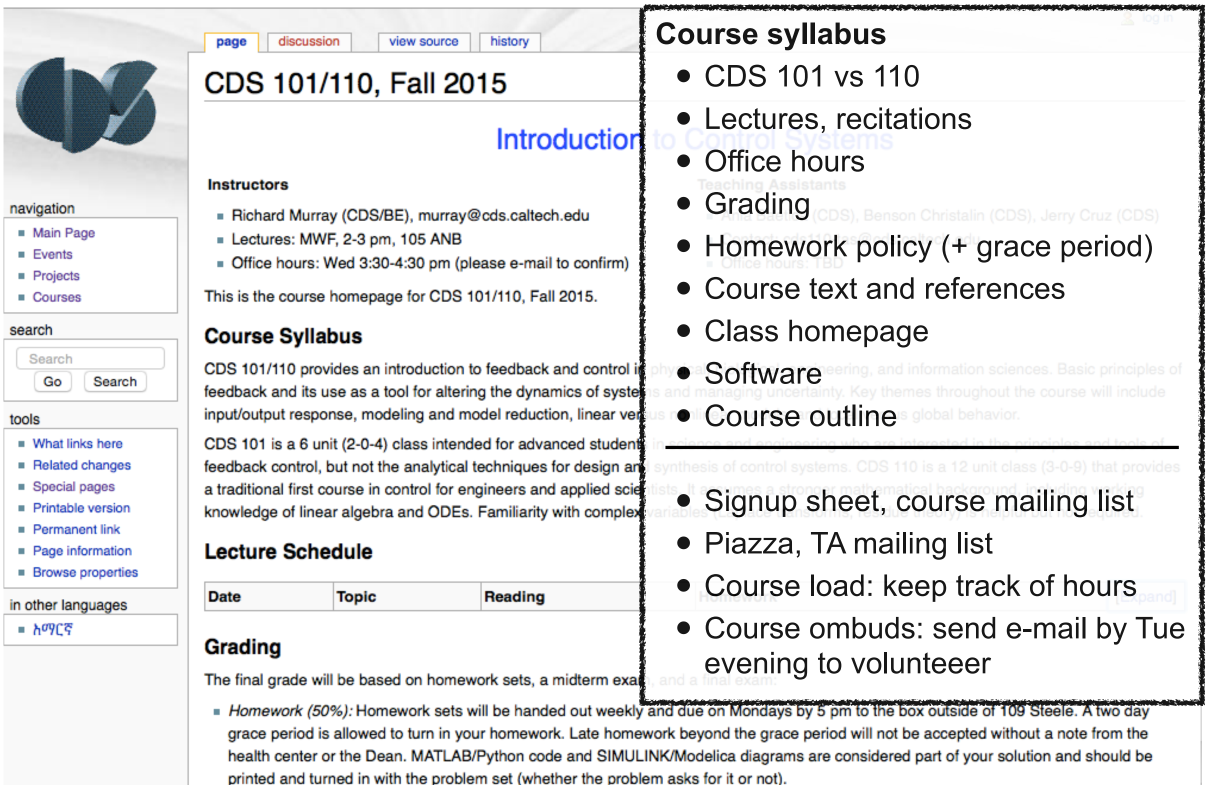
- Introduction to tools in dynamical systems

Spring

CDS Minor

- Undergrads: CDS 110, CDS 112, CDS 140, senior thesis
- Grad students: 54 units in CDS - usually CDS 110/112, CDS 140/240 + 2 electives

Course Administration



Course syllabus

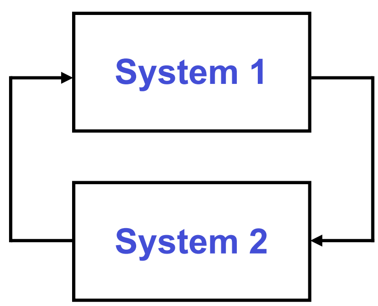
- CDS 101 vs 110
- Lectures, recitations
- Office hours
- Grading
- Homework policy (+ grace period)
- Course text and references
- Class homepage
- Software
- Course outline

- Signup sheet, course mailing list
- Piazza, TA mailing list
- Course load: keep track of hours
- Course ombuds: send e-mail by Tue evening to volunteeer

What is Feedback?

Merriam Webster:

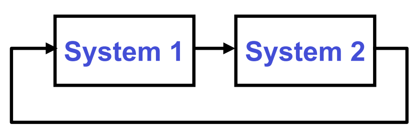
the return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action) [1920]



Feedback = mutual interconnection of two (or more) systems

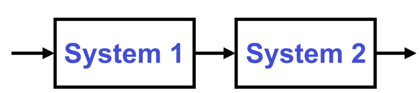
- System 1 affects system 2
- System 2 affects system 1
- Cause and effect is tricky; systems are mutually dependent

Terminology



Closed Loop

Feedback is ubiquitous in natural and engineered systems

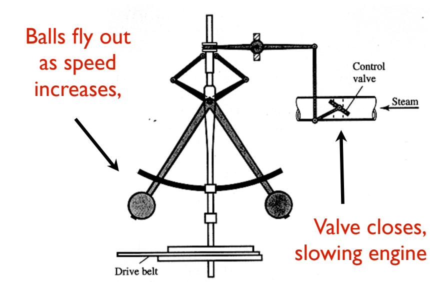


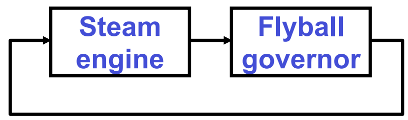
Open Loop

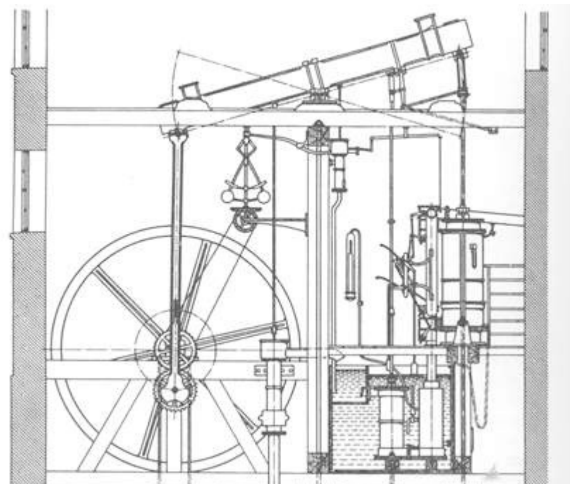
Example #1: Flyball Governor

“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


Courtesy Eric Klavins, U. Washington (2008)

Other Examples of Feedback

Biological Systems

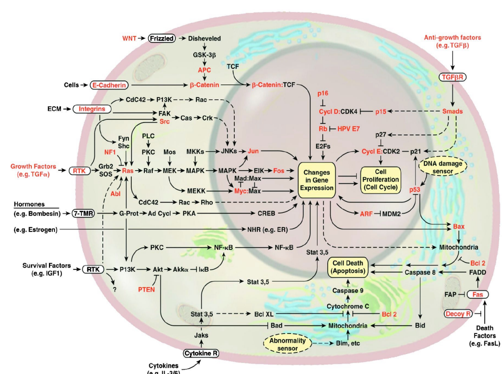
- Physiological regulation (homeostasis)
- Bio-molecular regulatory networks

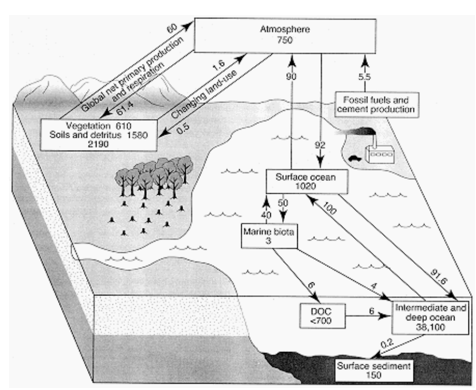
Environmental Systems

- Microbial ecosystems
- Global carbon cycle

Financial Systems

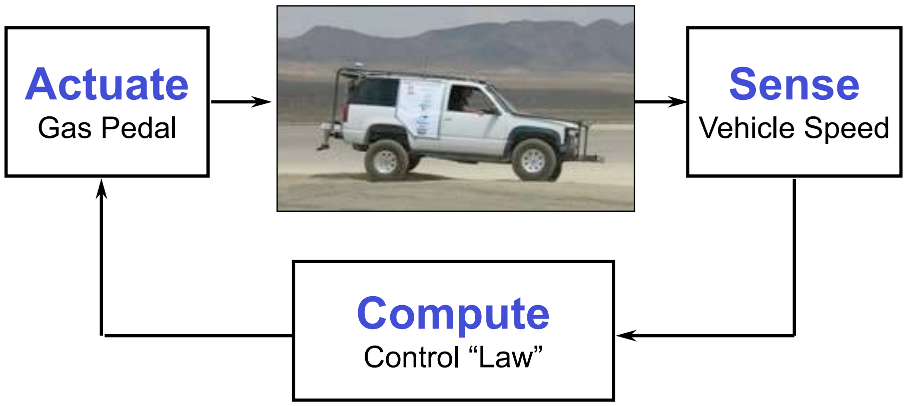
- Markets and exchanges
- Supply and service chains





Control = Sensing + Computation + Actuation

In Feedback "Loop"



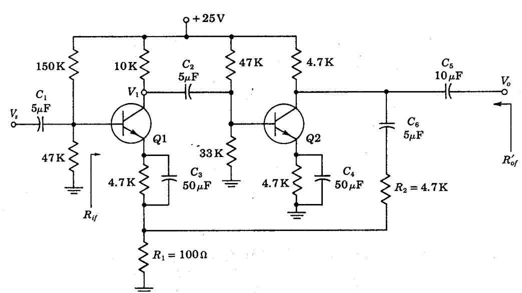
Goals

- 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)

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*

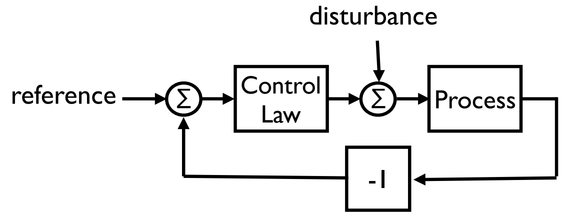


Design of Dynamics through Feedback

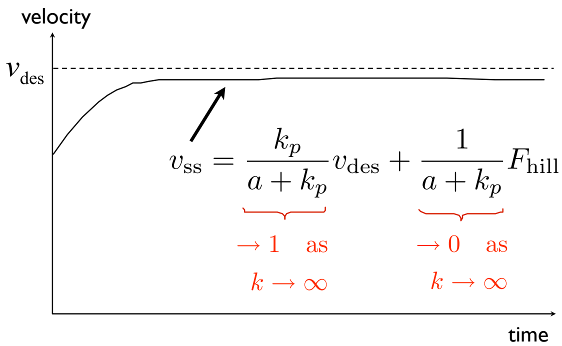
- Feedback allows the dynamics (behavior) of a system to be modified
- Example: stability augmentation for highly agile, unstable aircraft
- Key idea: interconnection gives *closed loop* that modifies natural behavior

X-29 experimental aircraft (NASA)

Example #2: Speed Control



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



Stability/performance

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

Disturbance rejection

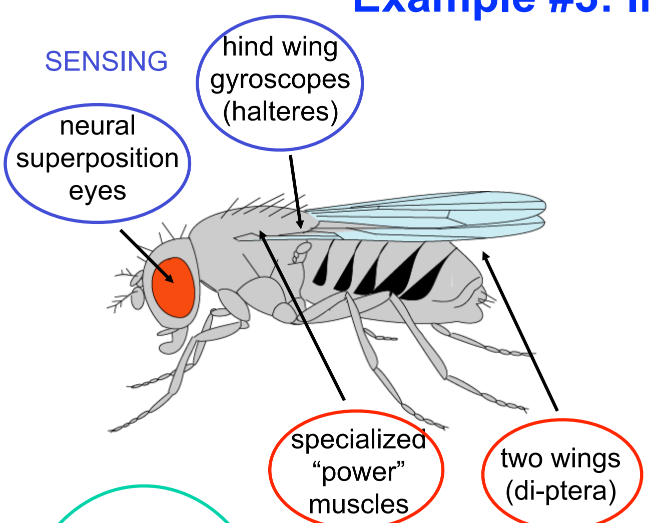
- Effect of disturbances (eg, hills) approaches zero as $k \to \infty$

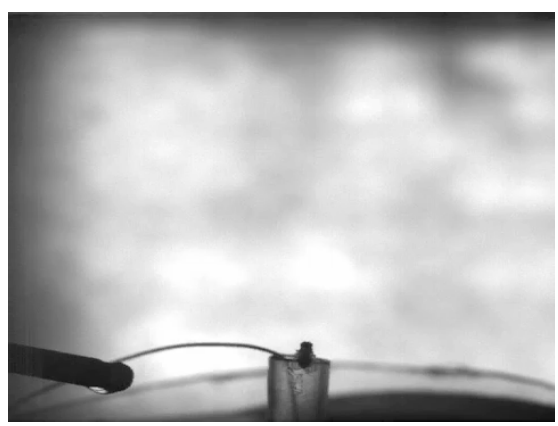
Robustness

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

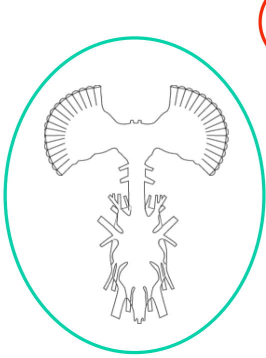
Example #3: Insect Flight

SENSING





ACTUATION



COMPUTATION

~500,000 neurons

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)

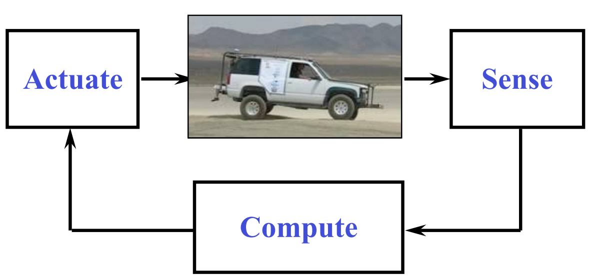
MATLAB Toolboxes

- 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)

Python Toolboxes

- scipy/numpy
- python-control

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: