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

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Goals:

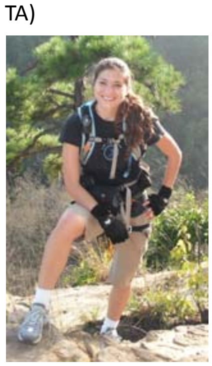
- Give an overview of CDS 101/110a: course structure & administration
- Define feedback systems and learn how to recognize main features
- Describe what control systems do and the primary principles of feedback

Reading:

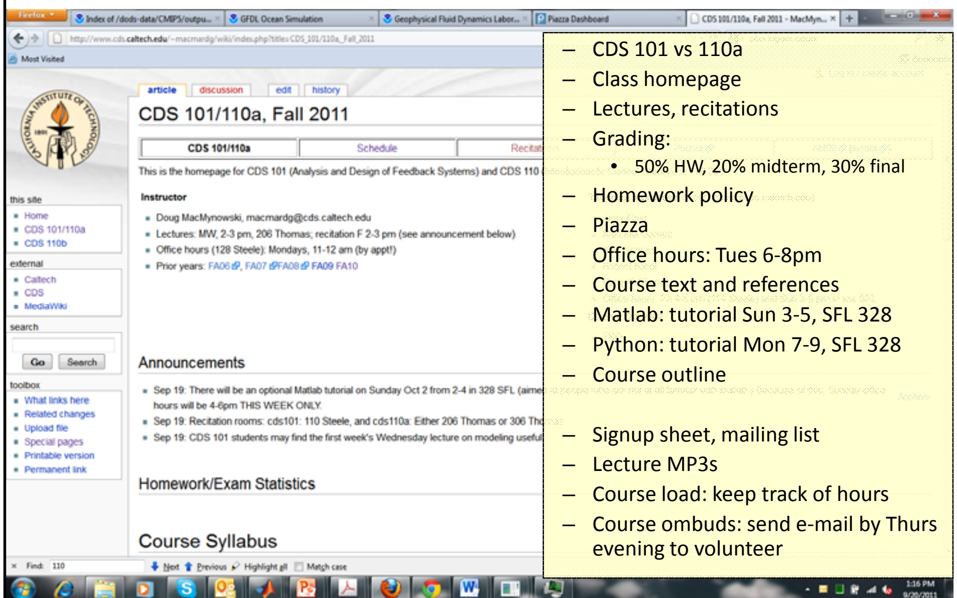
- Åström and Murray, *Feedback Systems: An Introduction for Scientists and Engineers*, Chapter 1 [30 min]

CDS 101/110
Instructional Staff


- Instructor:
  - Doug MacMartin (CDS)
  - Richard Murray (CDS, ME)
- TAs (cds110-tas@cds.caltech.edu)
  - Marcella Gomez (head TA)
  - Jerry Cruz
  - Scott Livingston
  - Krishna Shankar

Course Administration



- CDS 101 vs 110a
- Class homepage
- Lectures, recitations
- Grading:
  - 50% HW, 20% midterm, 30% final
- Homework policy
- Piazza
- Office hours: Tues 6-8pm
- Course text and references
- Matlab: tutorial Sun 3-5, SFL 328
- Python: tutorial Mon 7-9, SFL 328
- Course outline

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

Course Outline

1. Introduction to feedback, modeling
2. Dynamic behavior and stability
3. Linear systems

} DGM

4. State feedback, reachability and observability
5. Observability & Introduction to frequency domain
6. Transfer functions

} RMM

7. Loop analysis; Nyquist and stability under feedback
8. PID control (Proportional, integral, derivative)

} DGM

9. Loop-shaping
10. Control design and robustness

} RMM

- Monday lecture: 101 and 110a, powerpoint, overview for the week
- Wednesday lecture: optional for 101; blackboard, more detail & math
- Friday recitation *starting NEXT week (this week in 105 ANB)*
  - cds101: 110 Steele
  - cds110a: 206 Thomas and 306 Thomas

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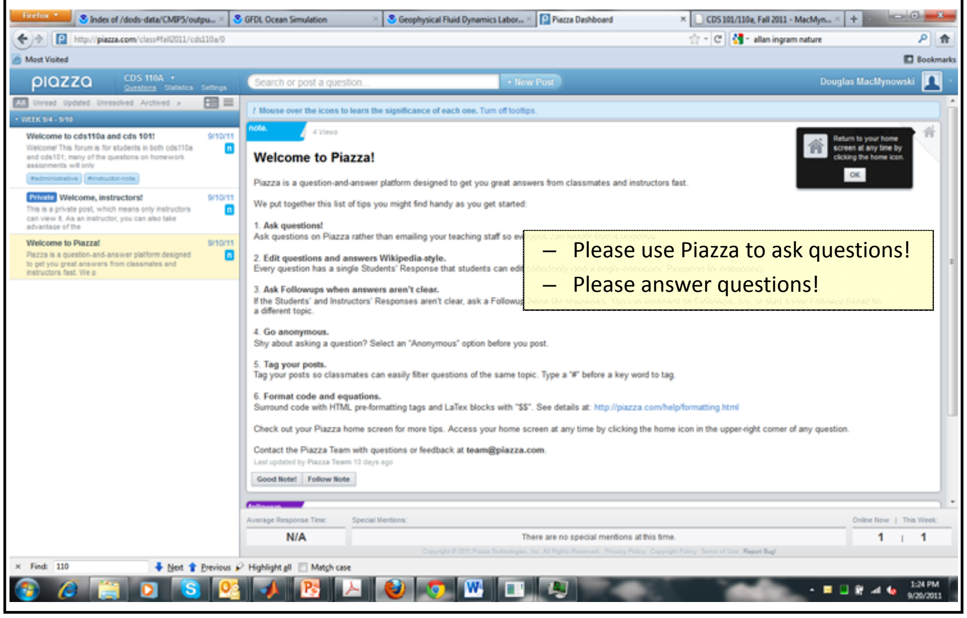
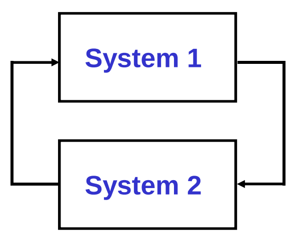
Piazza: Website for Questions

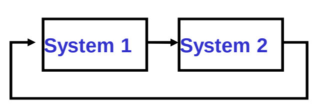


What is Feedback?

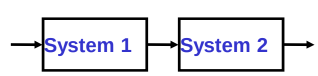
- Merriam Webster:
  - The return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action) [1920]
- Feedback = mutual interconnection of two (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
- ***Control: we get to design feedback!***



Terminology



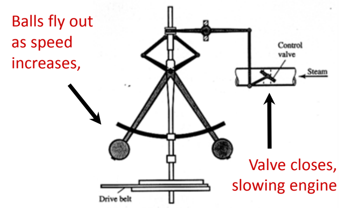
Closed Loop

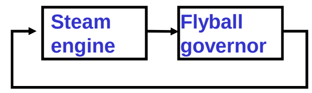


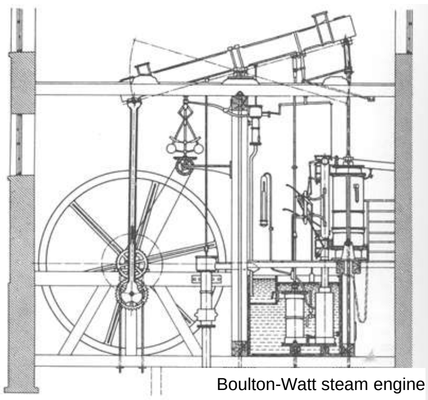
Open Loop

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

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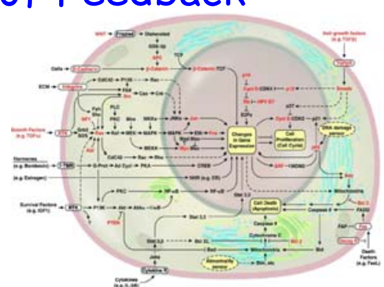
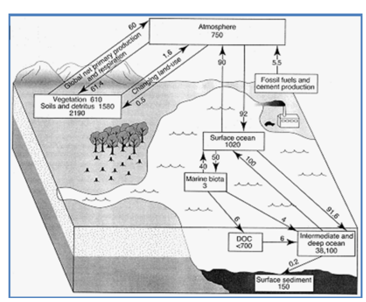
Other Examples of Feedback

- Biological Systems
  - Physiological regulation (homeostasis)
  - Bio-molecular regulatory networks
- Environmental Systems
  - Microbial ecosystems
  - Global climate change
- Financial Systems
  - Markets and exchanges
  - Supply and service chains





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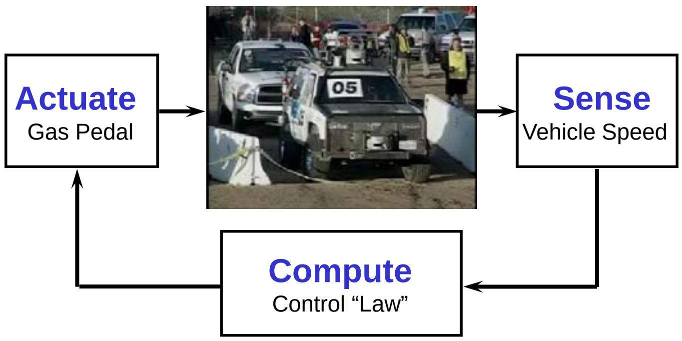
Control = Sensing + Computation + Actuation

In Feedback “Loop”



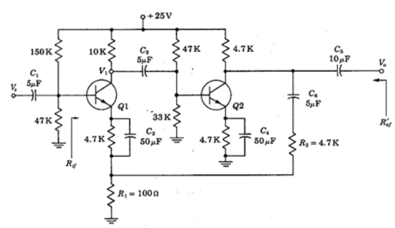
Goals

- 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)

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

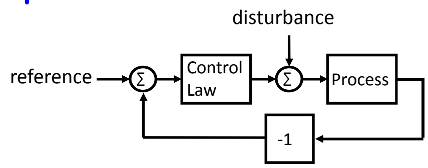
Two Main Principles of Feedback

- 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



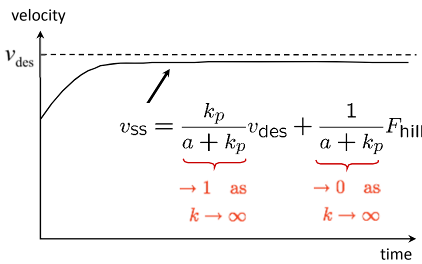
X-29 experimental aircraft (NASA)

Example #2: Speed Control



$$m\dot{v} = -av + F_{\text{eng}} + F_{\text{hill}}$$

$$F_{\text{eng}} = k_p(v_{\text{des}} - v)$$



- 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

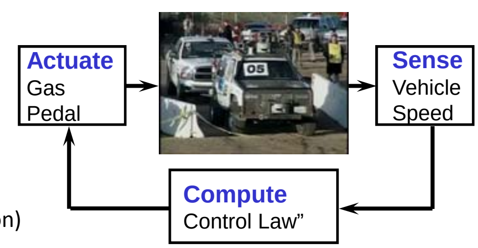
Modeling

- Control design is based on *models* of the system
  - Model does not need to be perfect, but "good enough"
  - Capture input-output behaviour
- Describe time evolution
  - Continuous-time (ODE)

$$\dot{x} = \frac{dx}{dt} = f(x, u)$$

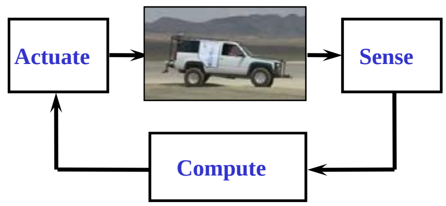
  - Discrete-time (difference equation)

$$x_{k+1} = x[k+1] = x(t_{k+1}) = f_d(x_k, u_k)$$



- In second half of quarter we will move to frequency-domain:
  - What is the response of the system to sinusoidal inputs?

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: