Goals:

- Give an overview of CDS 101/110; describe course structure, administration
- Define feedback 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):

- Åström and Murray, *Analysis and Design of Feedback Systems*, Ch 1

Course Administration

Course syllabus

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

- Lecture DVDs: 102 Steele, Box G
- Course load: keep track of hours
CDS 101/110 Instructional Staff

Lecturer: Richard Murray (CDS)

Co-Instructors
• Anand Asthagiri (ChE)
• Tim Colonius (ME)
• Ali Hajimiri (EE)
• Steven Low (CS/EE)
• Hideo Mabuchi (Ph/CDS)

Head TA: Steve Waydo (ME)

TAs
• Domitilla Del Vecchio
• Asa Hopkins
• Haomiao "H" Huang
• Hao Jiang
• Morr Mehyar/Kevin Tang

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
• Searchable database of responses to mud cards and other frequently asked questions in the class
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

Feedback is ubiquitous in natural and engineered systems

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

http://www.heeg.de/~roland/SteamEngine.html
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 65 mph)
- Robustness: system tolerates perturbations in dynamics (mass, drag, etc)
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

Example #2: Cruise Control

\[
\begin{align*}
\dot{m}v &= -bv + u_{\text{engine}} + u_{\text{hill}} \\
u_{\text{engine}} &= k(v_{\text{des}} - v)
\end{align*}
\]

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

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

Robustness
- Results don’t depend on the specific values of \( b, m, \) or \( k \) for \( k \) sufficiently large
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

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
### Overview of the Course

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<thead>
<tr>
<th>Wk</th>
<th>Mon/Wed</th>
<th>Fri</th>
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<tbody>
<tr>
<td>1</td>
<td>Introduction to Feedback and Control</td>
<td>MATLAB tutorial, Steve W.</td>
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<tr>
<td>2</td>
<td>System Modeling</td>
<td>Linear algebra/ODE review, Steve W.</td>
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<td>3</td>
<td>Stability and Performance</td>
<td>Control of cavity oscillations, T. Colonius</td>
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<td>4</td>
<td>Linear Systems</td>
<td>Internet Congestion Control, S. Low</td>
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<tr>
<td>5</td>
<td>Controllability and Observability</td>
<td>Review for midterm, Steve W.</td>
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<td>Midterm exam</td>
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<td>6</td>
<td>Transfer Functions</td>
<td>Piloted flight, D. McRuer (tentative)</td>
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<td>7</td>
<td>Loop Analysis of Feedback Systems</td>
<td>Stability in Electronic Circuits, A. Hajimiri</td>
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<td>8</td>
<td>Frequency Domain Design</td>
<td>Molecular Feedback Mechanisms, A. Asthagiri</td>
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<tr>
<td>9</td>
<td>Limits on Performance</td>
<td>Thanksgiving holiday</td>
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<tr>
<td>10</td>
<td>Uncertainty Analysis and Robustness</td>
<td>Review for final, TBD</td>
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<td>Final exam</td>
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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:**