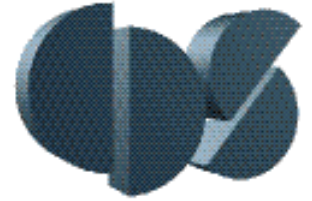




Teaching CDS 101: Principles of Feedback and Control



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**Control and Dynamical Systems
California Institute of Technology**

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Outline

- I. Course overview**
- II. Teaching mechanisms**
- III. Future plans**
- IV. Discussion**

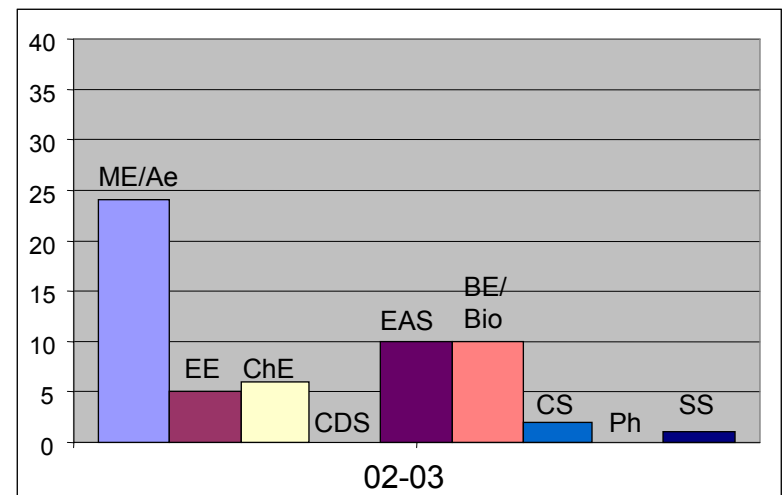
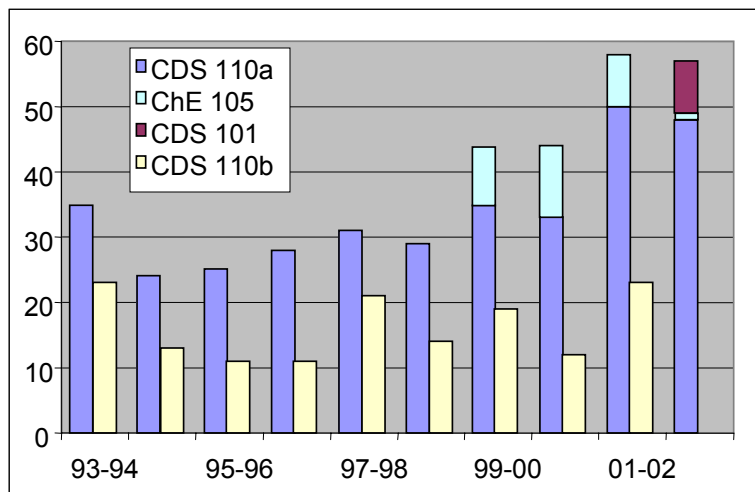
Course overview

CDS 101 is a new course on “Principles of Feedback and Control”

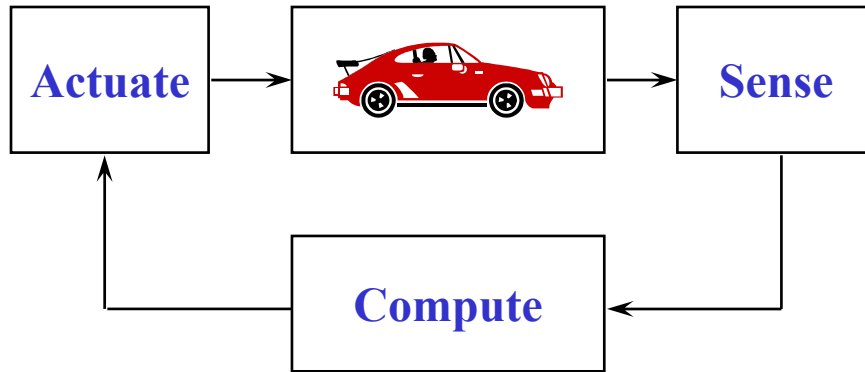
- Aimed at a broad audience of scientists and engineers
- Focused on teaching principles and computer tools (MATLAB based)
- Format:
 - Monday: powerpoint lecture on concepts, with examples and experiments
 - Friday: optional lectures by Caltech faculty on current applications

Co-taught with CDS 110, a traditional engineering course on control

- Monday lectures are shared; additional lectures on Wed for CDS 110



Summary: Introduction to Feedback and Control



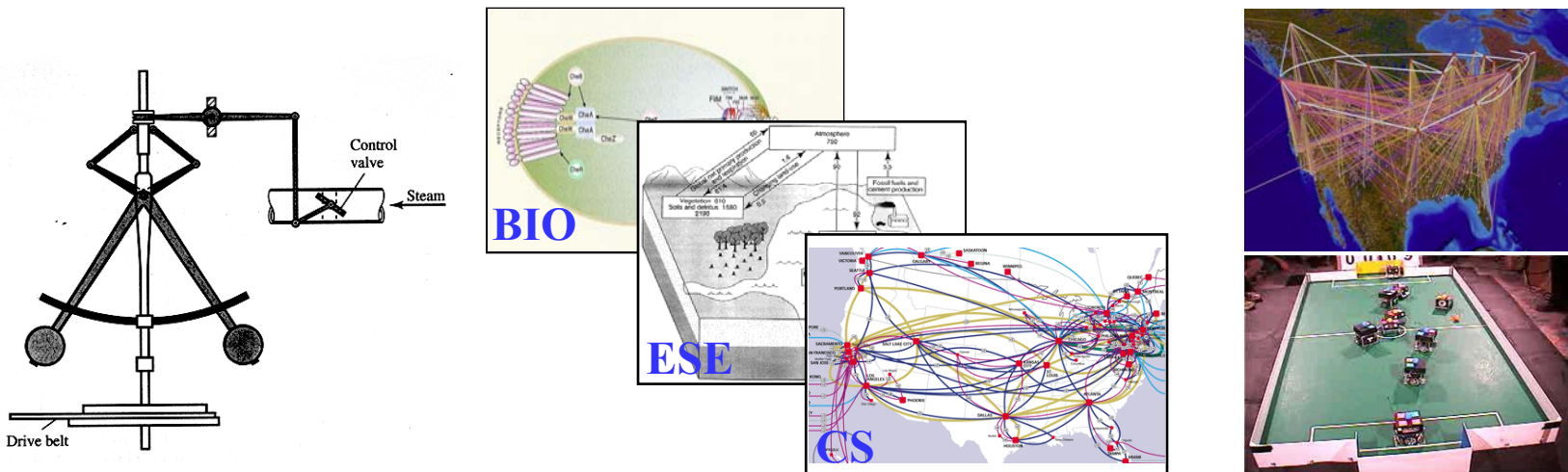
Control =

Sensing + Computation +
Actuation

Feedback Principles

- Robustness to Uncertainty
- Design of Dynamics

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



Fall 2002 Topic Overview

Wk	Date	Topic	Concepts	Friday lecture
1	9/30	Introduction + administration	Feedback, control, mud cards	MATLAB tutorial
2	10/7	System modeling	ODEs, diff eqs, FSM + examples	Insect flt $t \rightarrow n$ (MD)
3	10/14	Stability and performance	Stability, global vs local, step/freq resp	Aerospace (UTRC?)
4	10/21	Linear systems	Matrix exp, e-values, linearization	Congestion Ctrl (EK)
5	10/28	Controllability + midterm	Controllability, state space feedback	Midterm review (SH)
6	11/4	Freq response, xfer functions	DGM on Wed?	Bio S/A (MD)
7	11/11	Loop stability	Nyquist	Keck/CELT (DGM)
8	11/18	Control design I	Loop shaping	Q fbk control (HM)
9	11/25	Control design II	PID Astrom	<i>Thanksgiving</i>
10	12/2	Robustness + final	DFT framework Garen	Final review (SH)

Course Text

- CDS 101: CDS Panel report, Astrom
- CDS 110: Astrom, Packard (?)

Course Software

- MATLAB/SIMULINK (heavy use)

CDS 101 Lecture Techniques

Powerpoint presentations

- Allows better presentation of main concepts, including pictures, graphics, simulations, videos, etc
- Copies of slides are available at the beginning of each lecture
- Presentations are available on the web, including movies

Videos

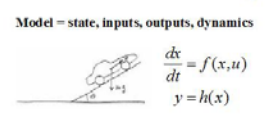
- Substantial use of videos in the lectures; mainly tied to Caltech research

Experiments

- Physical systems are used to illustrate the main concepts
- Shows that the theory we are talking about makes a difference in the real world
- Relatively limited use this term; plan to increase for next term (ala Ph 1)

Lecture 2.1: System Modeling

Model = state, inputs, outputs, dynamics

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

$$\frac{dP_E}{dt} = \sum_{\mathcal{P}} W_{\mathcal{P}}(H', H) P_{\mathcal{P}} - W_{\mathcal{H}}(H, H') P_{\mathcal{H}}$$

Principle: Choice of model depends on the questions you want to answer

```
function dydt = f(t,y, k1, k2, k3, m1, m2, b, omega)
u = 0.00315*cos(omega*t);
dydt = [
y(3);
y(4);
-(k1+k2)/m1*y(1) +
k2/m1*y(2);
k2/m2*y(1) - (k2+k3)/m2*y(2)
- b/m2*y(4) + k3/m2*u ];
```

7 Oct 02 R. M. Murray, Caltech CDS 0



CDS 101 Teaching Features

CDS Precourse

- 2 day tutorial on modeling, ODEs, linear algebra the week before classes start
- Designed to bring students up to speed on underlying math
- Attended by 25 students; mainly in biology/bioengineering

Course web page

- All course information (lectures, reading, homework) available via course homepage

Course Instructional Staff

- 4 co-instructors: course planning, optional lectures
- 5 TAs: Homework, office hours, mud cards, grading

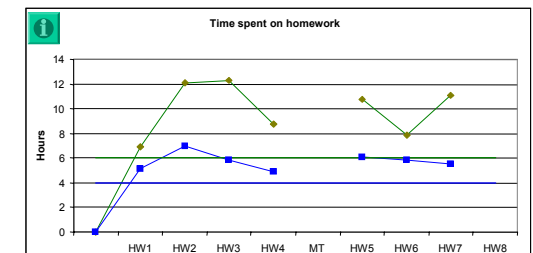
Lecture Videos and Remote Instruction

- All lectures available in VHS and online to students

Student Feedback Mechanisms

- Mud cards (lectures); time spent on HW; e-mail to TAs, prof; course surveys (3)

The screenshot shows the course website for "CDS 101: Principles of Feedback and Control". The page is titled "Lecture 1: Introduction to Feedback and Control" and is dated "30 September 2002". There are navigation tabs for "Lecture", "Reading", "FAQ", "Homework", and "Software". The "Lecture Overview" section states: "This lecture provides an overview of the basic ideas in feedback and control, including the major principles of feedback and many examples of applications. The goal of this lecture is to introduce some of the basic ideas in feedback systems and provide examples that will allow students to identify and recognize control systems in their everyday world. CDS 101/110 course administration is also covered in the second half of the lecture." Below this, there is a "Lecture Presentation" link. The "Reading Material and Handouts" section lists "Handouts from lecture" which include "Copy of Lecture", "Course syllabus", and "Homework #1 + course survey". There is also a "Required reading" section.



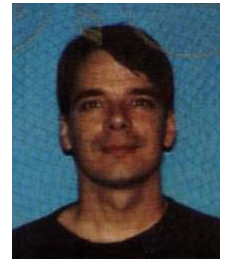
Instructional Staff

Lecturer: Richard Murray (CDS)

- Overall course management

Co-Instructors

- Michael Dickinson (BE)
- Eric Klavins (CS)
- Hideo Mabuchi (Ph)
- Doug MacMartin (CDS)



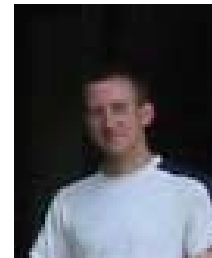
Warning: objects in picture may be 10 years older than they appear.

Head TA: Sean Humbert (ME)

- Coordinate course infrastructure + TAs

TAs

- Lars Cremean (ME)
- Tim Chung (ME)
- Zhipu Jin (EE)
- Shreesh Mysore (CDS)



Mud Cards

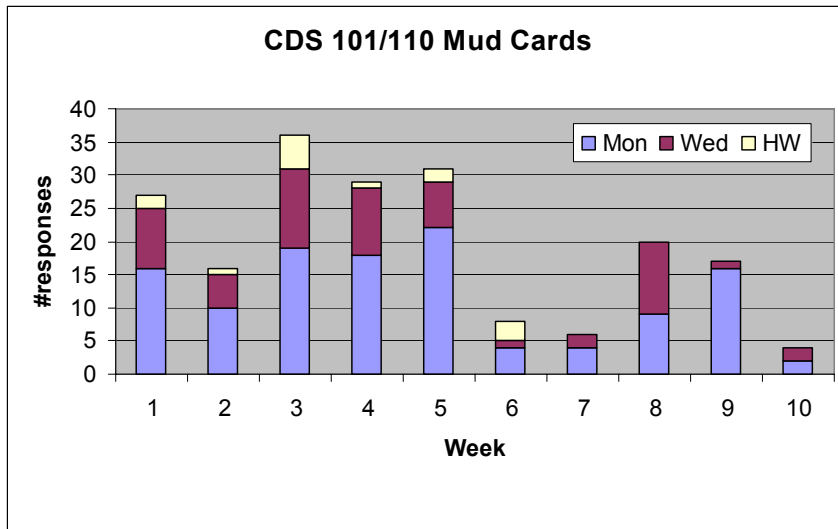
Mud cards

- 3 x 5 cards distributed at each lecture
- Describe “muddiest” part of the lecture
- Turn in cards at end of class
- Responses posted by 8 pm on day of lecture

Class FAQ list

- Searchable database of responses to mud cards and other questions from class

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



CDS 101: Principles of Feedback and Control

Lecture 1: Introduction to Feedback and Control

30 September 2002

[Lecture](#) [Reading](#) **FAQ** [Homework](#) [Software](#)

Lecture Overview

This lecture provides an overview of the basic ideas in feedback and control, including the major principles of feedback and many examples of applications. The goal of this lecture is to introduce some of the basic ideas in feedback systems and provide examples that will allow students to identify and recognize control systems in their everyday world. CDS 101/110 course administration is also covered in the second half of the lecture.

[Lecture Presentation](#)

Reading Material and Handouts

Handouts from lecture

- [Copy of lecture](#)
- [Course syllabus](#)
- [Homework #1 + course survey](#)

Required reading

Student Surveys

Background Survey

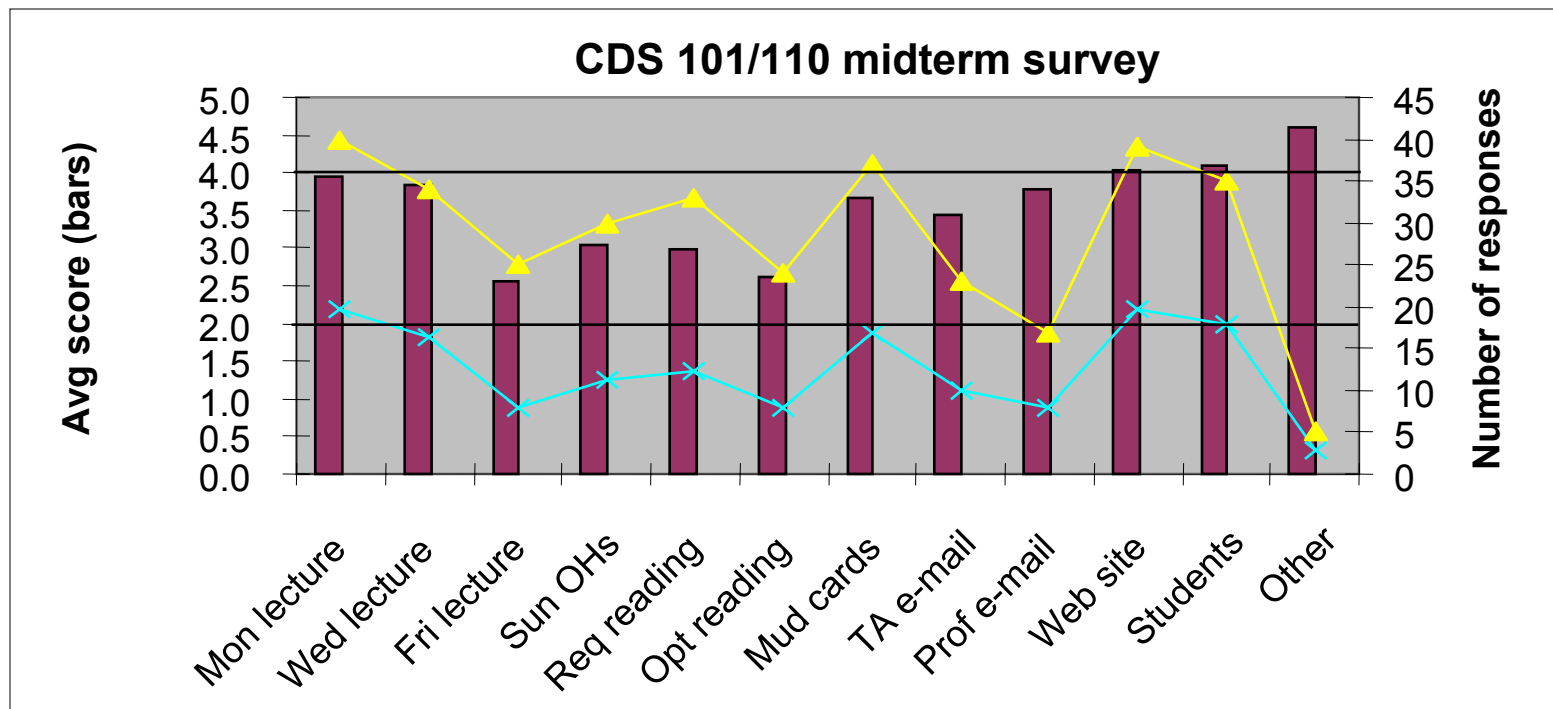
- Identify year, options, courses taken, topics that students are familiar

Midterm Survey

- Evaluate teaching mechanisms + ask for comments on improvements

Final Survey

- Check on familiarity with topics, updated teaching mechanisms, comments



Summary and Next Steps

CDS 101 version 1.0 is shipped

- Very positive experience with first iteration of the class
- Format seemed to work well and was well received
- Major areas for improvement: slow down lectures, increased help with MATLAB

CDS 101 version 1.1 plans

- Add remote instruction component (with UTRC)
- Increased use of classroom experiments
- Continuous improvement on classroom processes

Discussion

- What other ideas should we consider?
- Are there tools for supporting the teaching methods we are using?
- How do we transfer these ideas to other classes?