CDS 101: Lecture 1.1
Introduction to Feedback and Control

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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 feedback

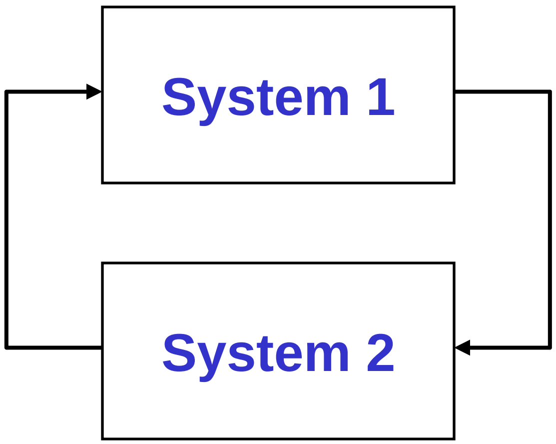
Reading (available on course web page):

- Åström and Murray, *Analysis and Design of Feedback Systems,* Ch 1 (available from course web page)

What is Feedback?

Miriam Webster:

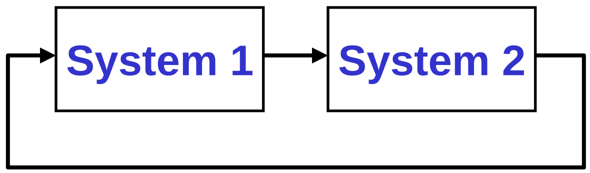
the return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action) [1920]



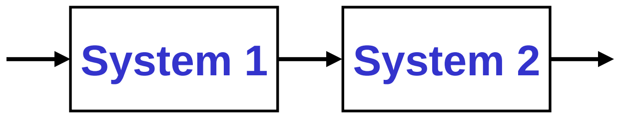
Feedback = mutual interconnection of two (or more) systems

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

Terminology



Closed Loop



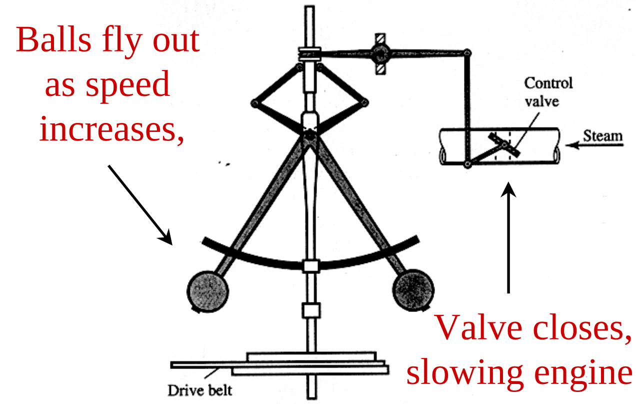
Open Loop

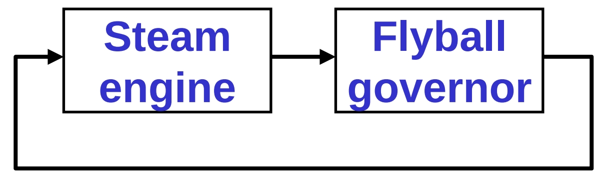
Feedback is ubiquitous in natural and engineered systems

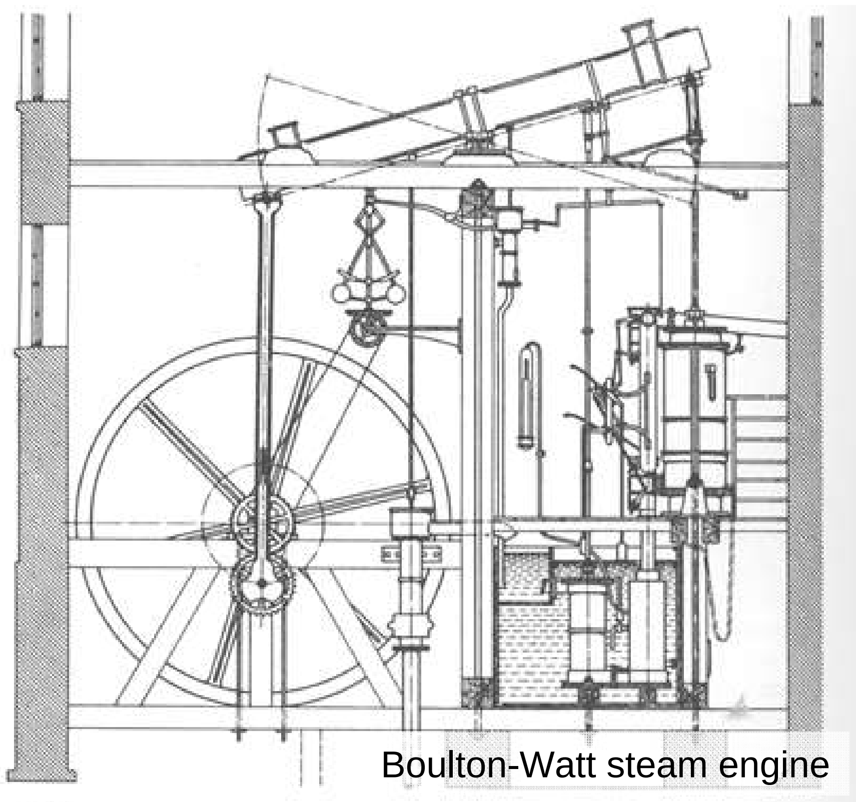
Example #1: Flyball Governor

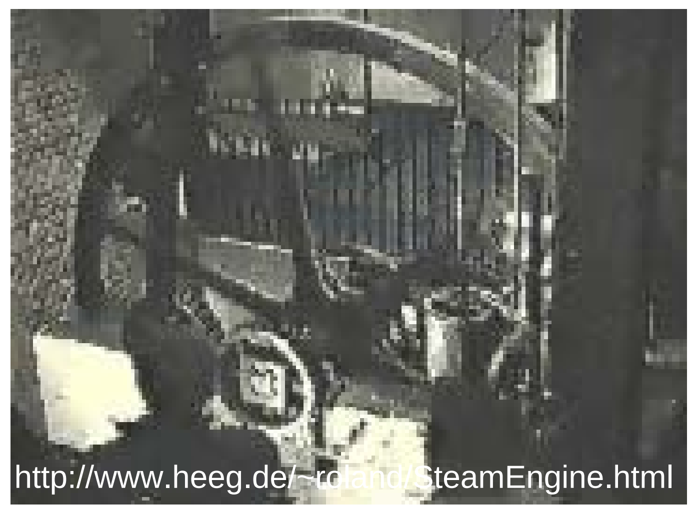
"Flyball" Governor (1788)

- Regulate speed of steam engine
- Reduce effects of variations in load (disturbance rejection)
- Major advance of industrial revolution






Boulton-Watt steam engine


http://www.heeg.de/~roland/SteamEngine.html

Other Examples of Feedback

Biological Systems

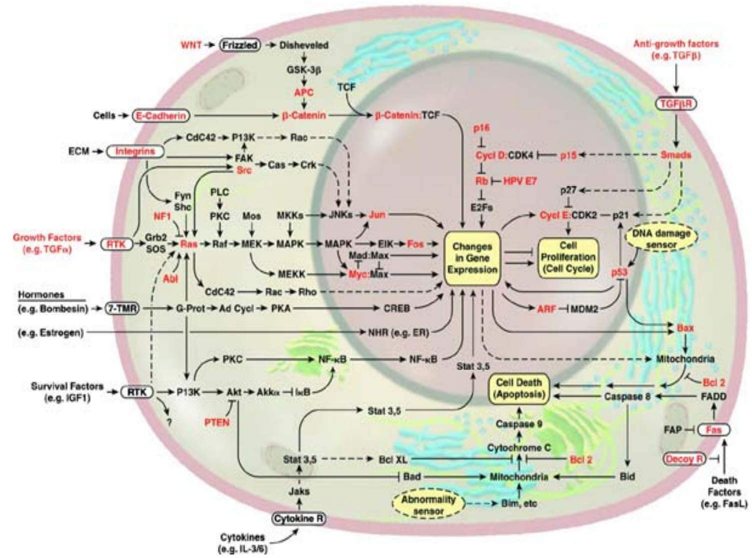
- Physiological regulation (homeostasis)
- Bio-molecular regulatory networks

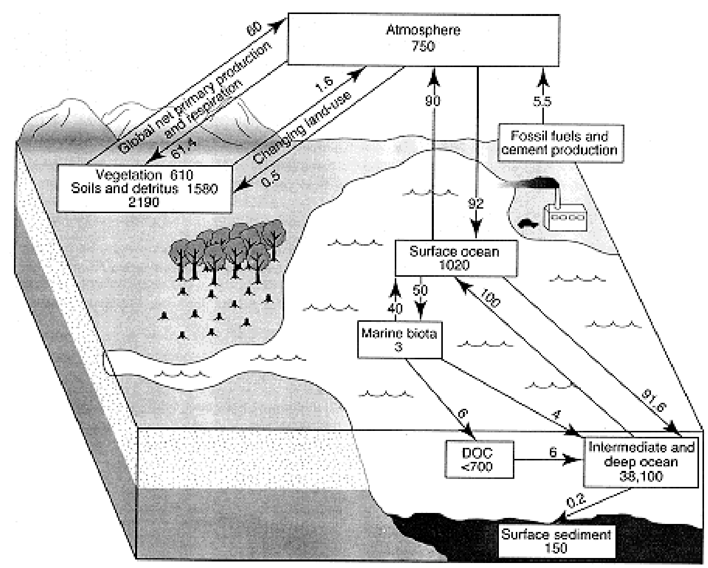
Environmental Systems

- Microbial ecosystems
- Global carbon cycle

Financial Systems

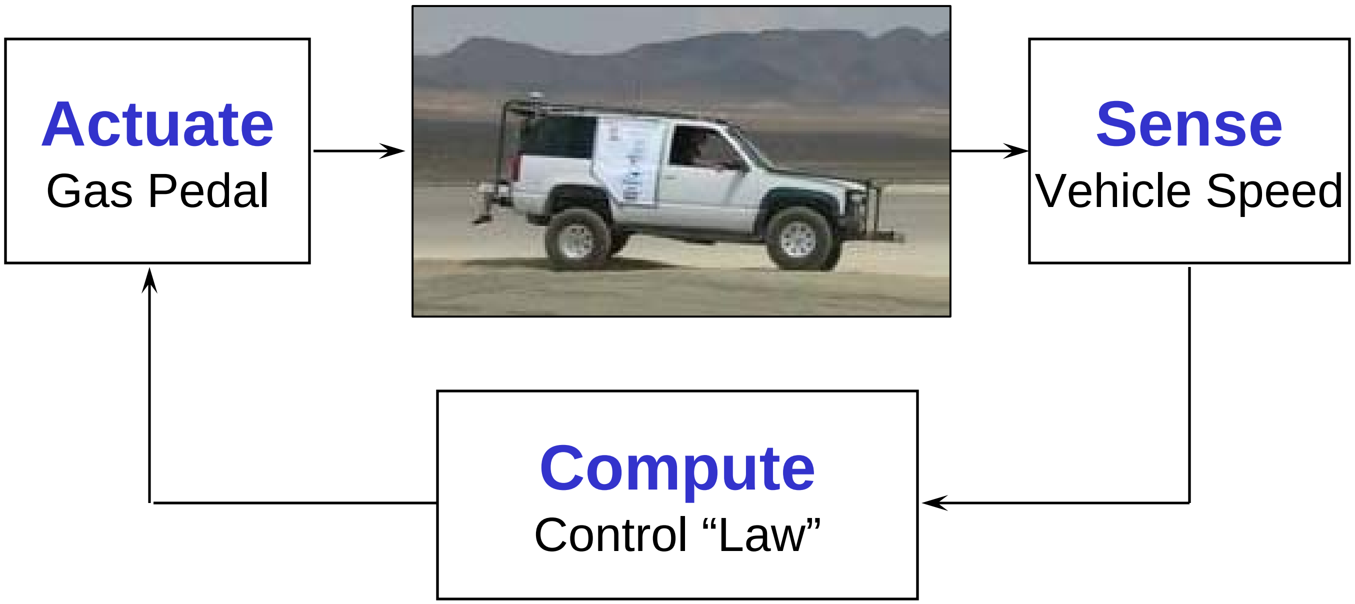
- Markets and exchanges
- Supply and service chains





Control = Sensing + Computation + Actuation

In Feedback “Loop”



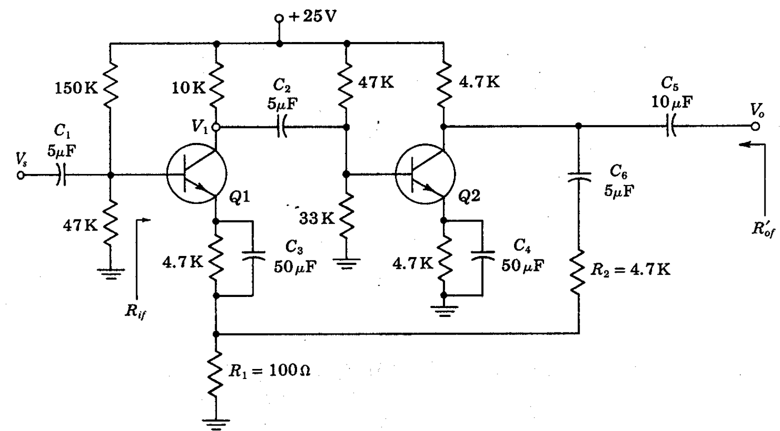
Goals

- 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

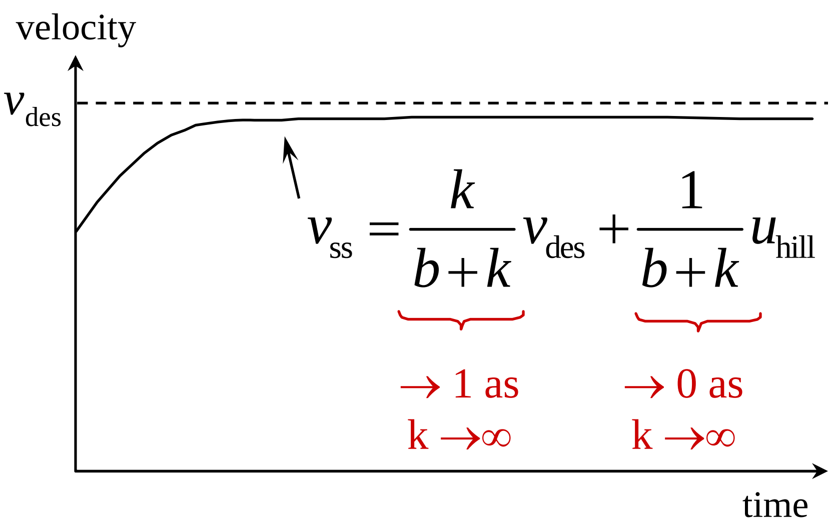
- Feedback allows the dynamics (behavior) of a system to be modified
- Example: stability augmentation for highly agile, unstable aircraft
- Key idea: interconnection gives *closed loop* that modifies natural behavior

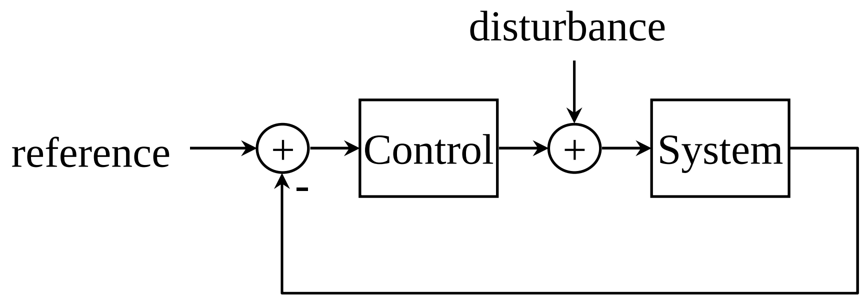

X-29 experimental aircraft

Example #2: Speed Control

$$m\dot{v} = -bv + f_{\text{engine}} + f_{\text{hill}}$$

$$f_{\text{engine}} = k(v_{\text{desired}} - v)$$





Stability/performance

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

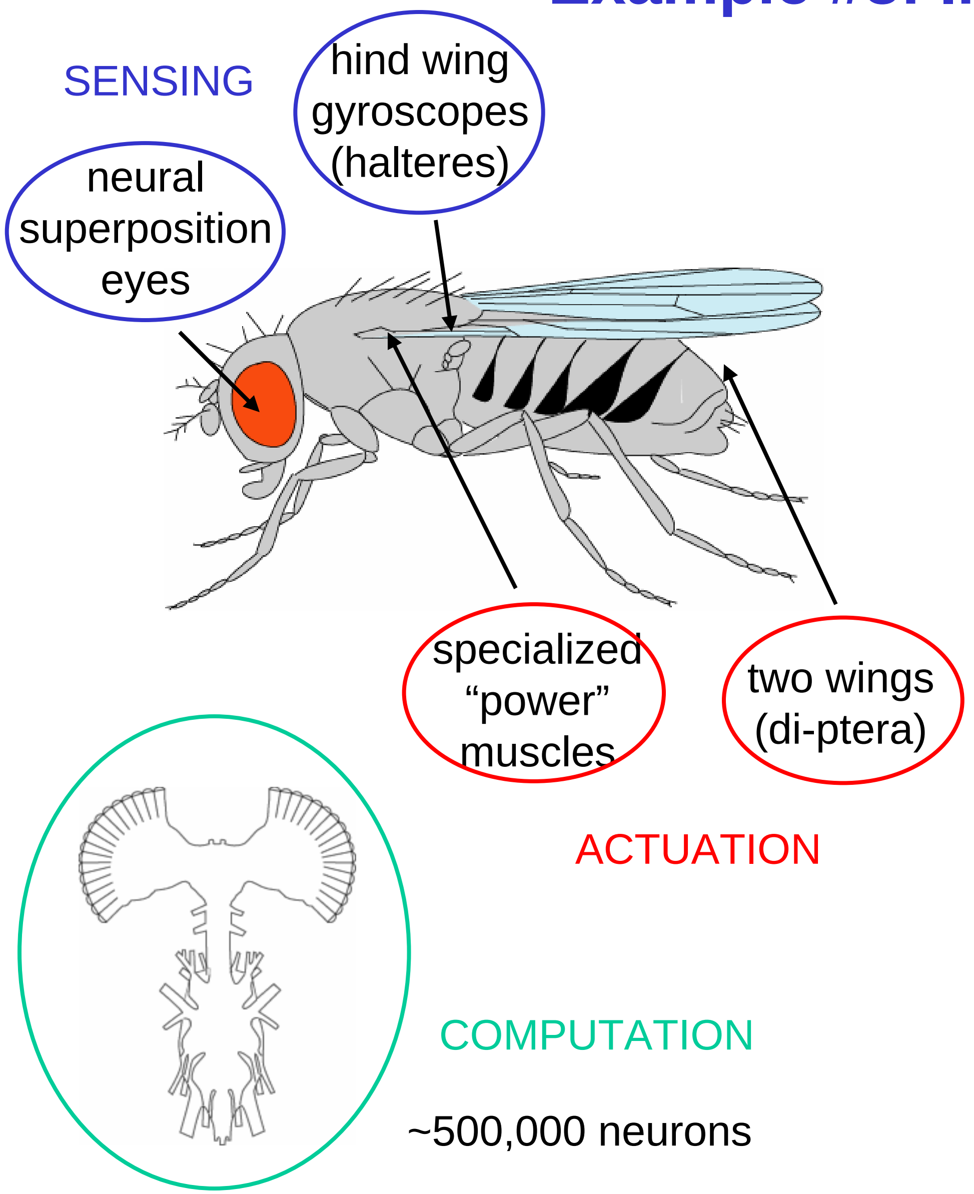
Disturbance rejection

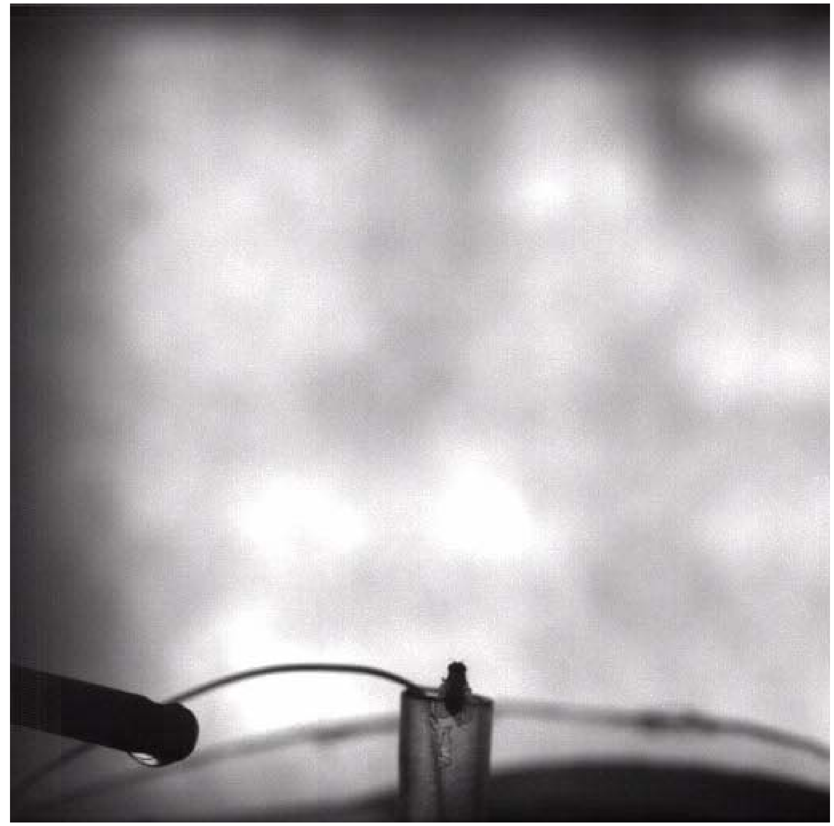
- Effect of disturbances (eg, hills) approaches zero as $k \to \infty$

Robustness

- Results don't depend on the specific values of *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)

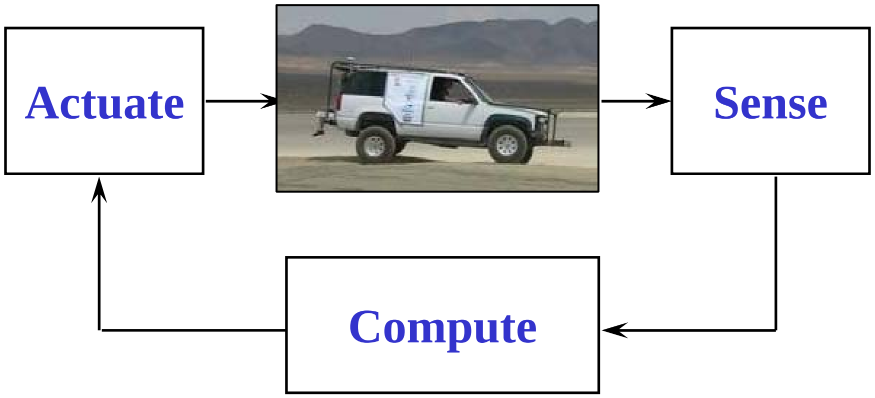
MATLAB Toolboxes

- 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

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

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: