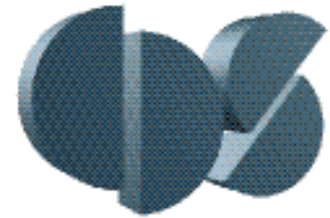# CDS 101/110a: Lecture 1.1
Introduction to Feedback & Control

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29 September 2008

Goals:

- Give an overview of CDS 101/110/210: 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]
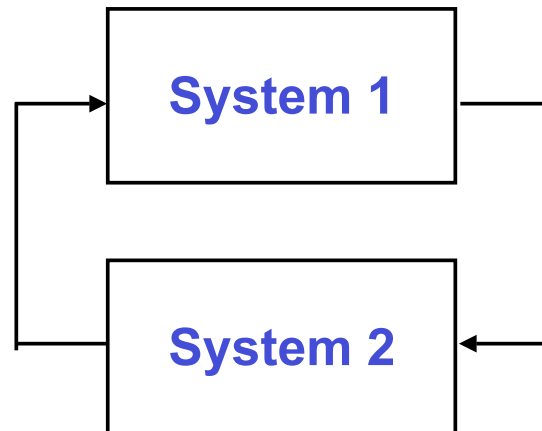
What is Feedback?

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]
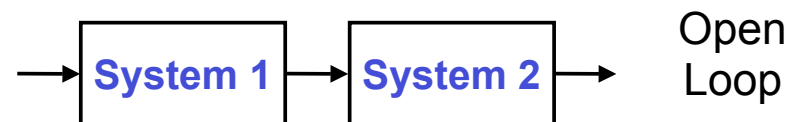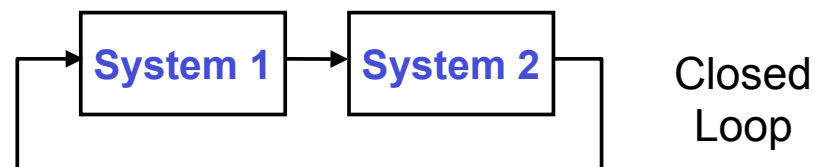
Feedback = mutual interconnection of two (or more) systems

- System 1 affects system 2
- System 2 affects system 1
- Cause and effect is tricky; systems are mutually dependent
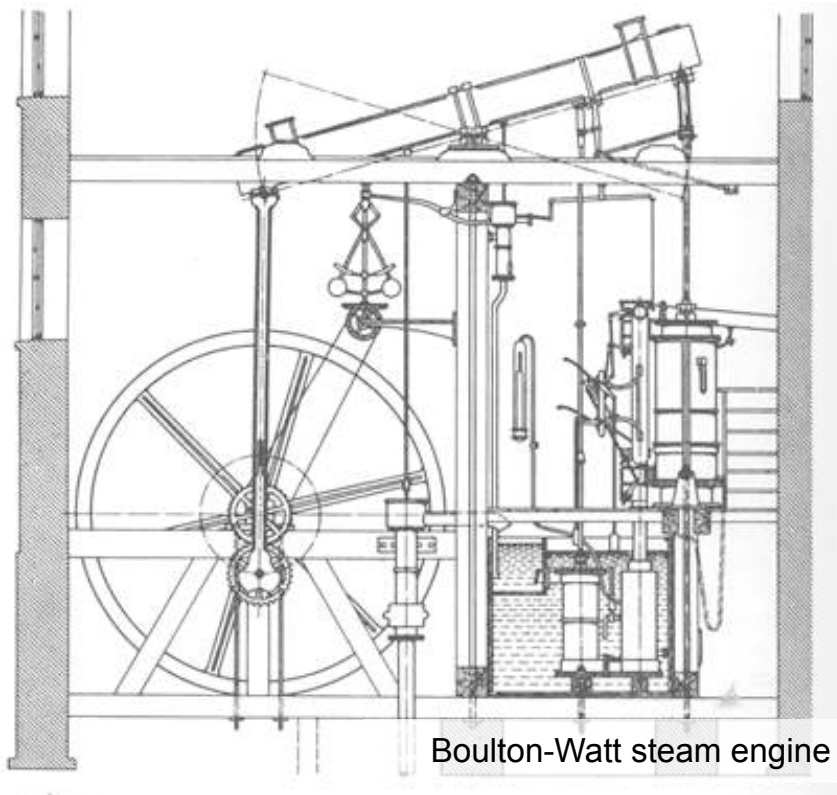
Feedback is ubiquitous in natural and engineered systems

System 1

System 2

Terminology

System 1 **System 2** Closed Loop

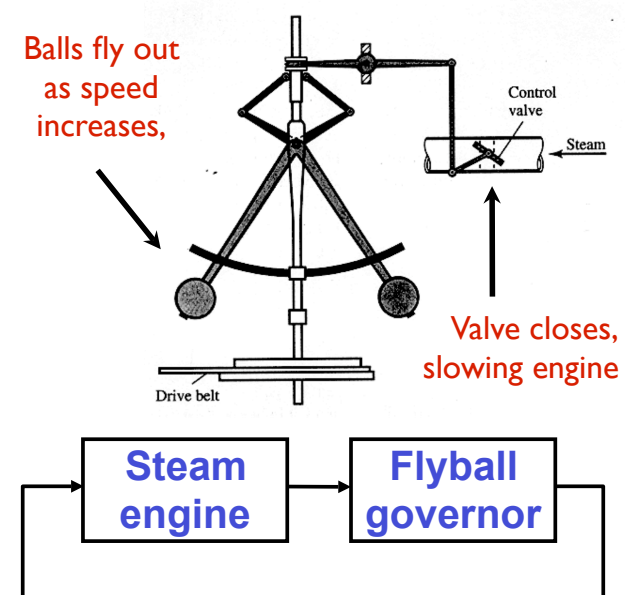**System 1** **System 2** Open Loop

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

Balls fly out as speed increases,

Control valve

Steam

Valve closes, slowing engine

Drive belt

Steam engine → Flyball governor

Boulton-Watt steam engine

Courtesy Eric Klavins, U. Washington (2008)
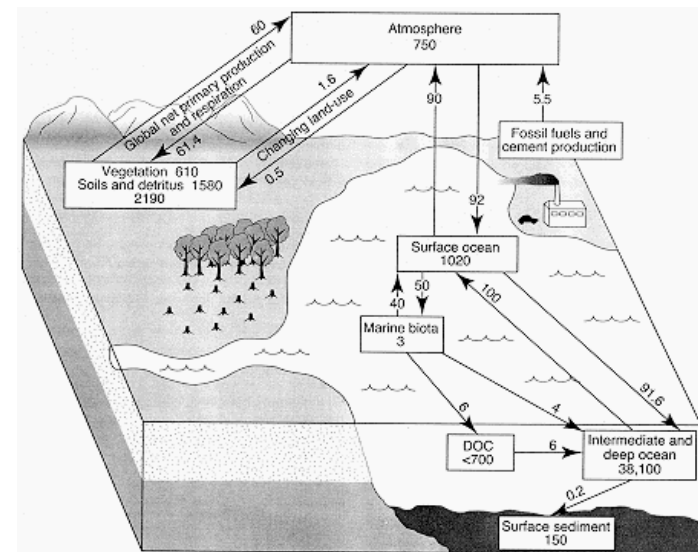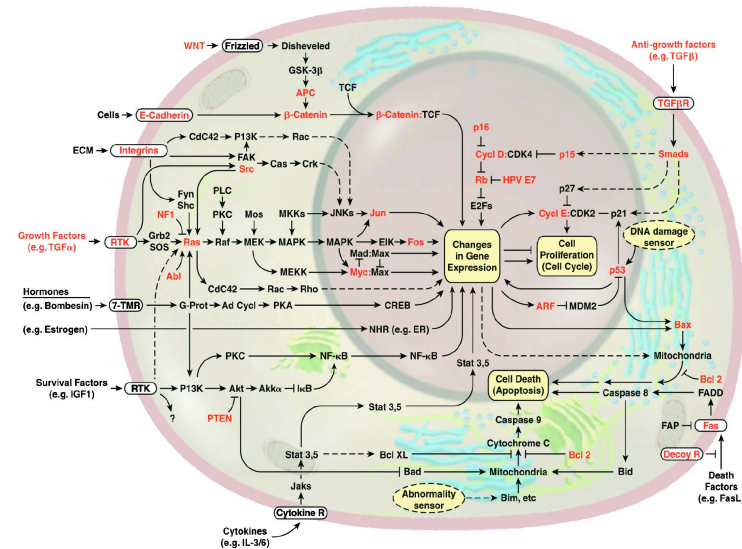
Other Examples of Feedback

Biological Systems

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

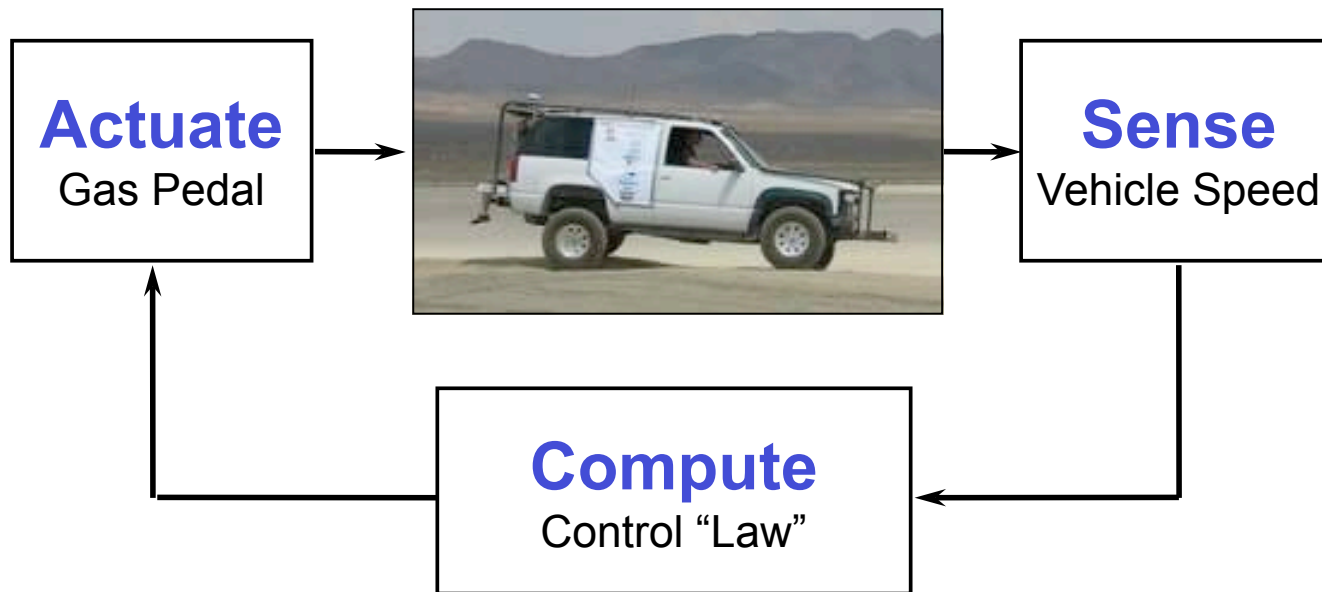**Environmental Systems**

- Microbial ecosystems
- Global carbon cycle

Financial Systems

- Markets and exchanges
- Supply and service chains

Control = Sensing + Computation + Actuation

In Feedback "Loop"

Actuate
Gas Pedal

Sense
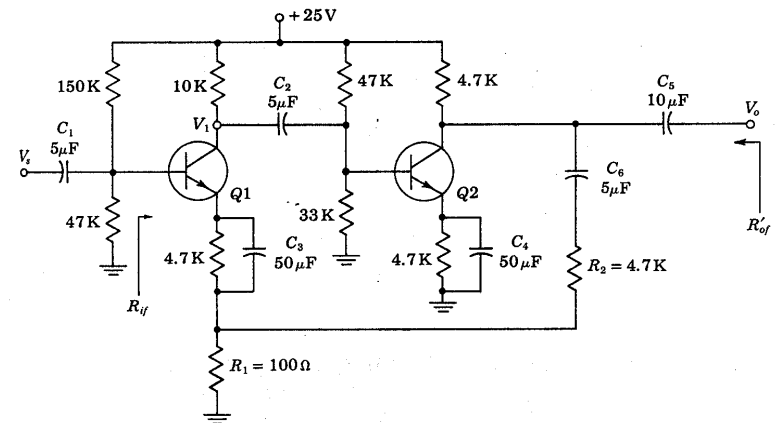Vehicle Speed

Compute
Control "Law"

Goals

- Stability: system maintains desired operating point (hold steady speed)
- Performance: system responds rapidly to changes (accelerate to 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
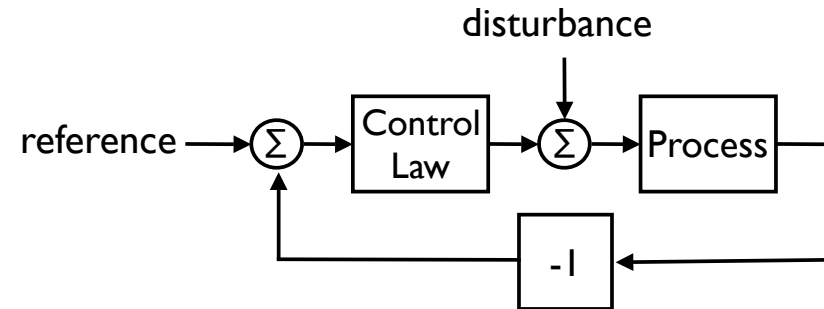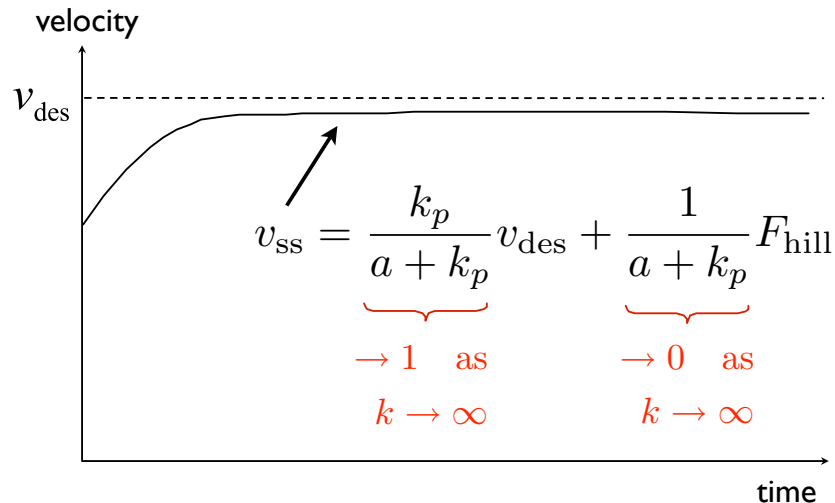
X-29 experimental aircraft (NASA)

Example #2: Speed Control

"Bob"

reference → Σ → Control Law → Σ → Process

disturbance

-1

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

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

velocity

v_{des}

$$v_{\text{ss}} = \underbrace{\frac{k_p}{a + k_p}}_{\substack{\to 1 \text{ as} \\ k \to \infty}} v_{\text{des}} + \underbrace{\frac{1}{a + k_p}}_{\substack{\to 0 \text{ as} \\ k \to \infty}} F_{\text{hill}}$$

time

Stability/performance

- Steady state velocity approaches desired velocity as $k \to \infty$

- Smooth response; no overshoot or oscillations

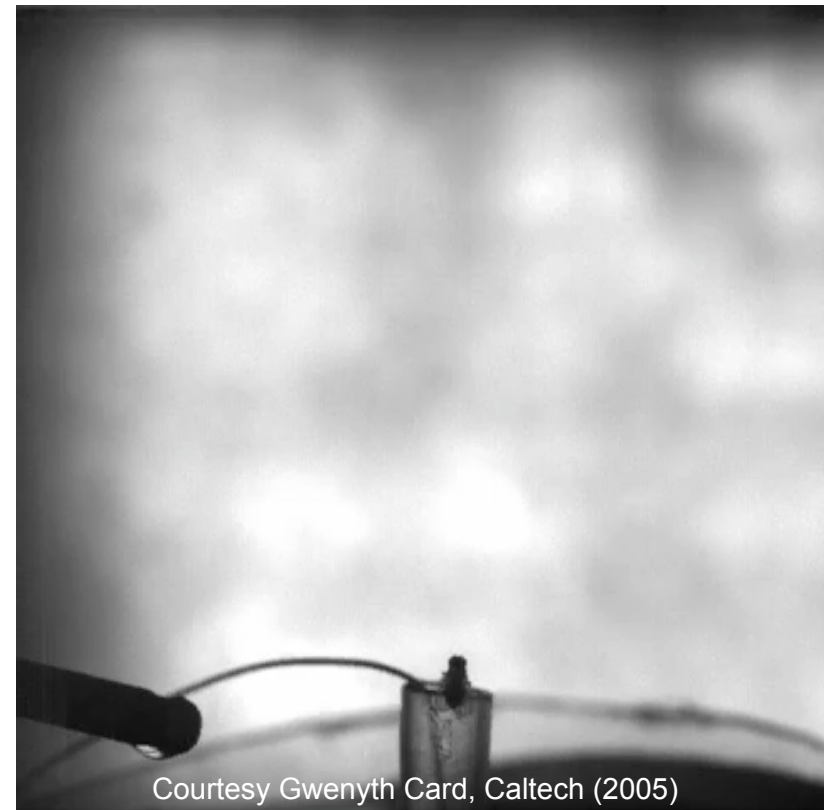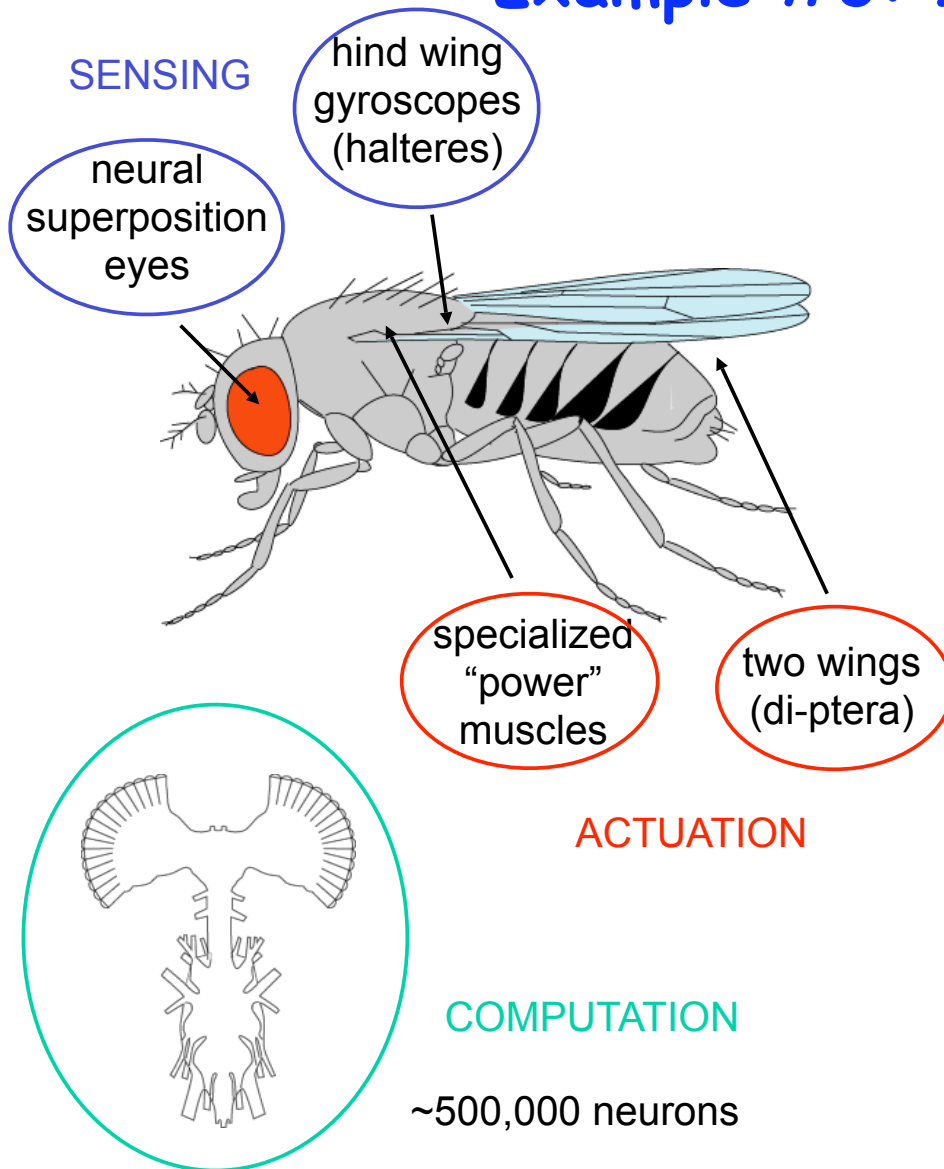**Disturbance rejection**

- 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

neural superposition eyes

hind wing gyroscopes (halteres)

specialized "power" muscles

two wings (di-ptera)

ACTUATION

COMPUTATION

~500,000 neurons

Courtesy Gwenyth Card, Caltech (2005)

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"
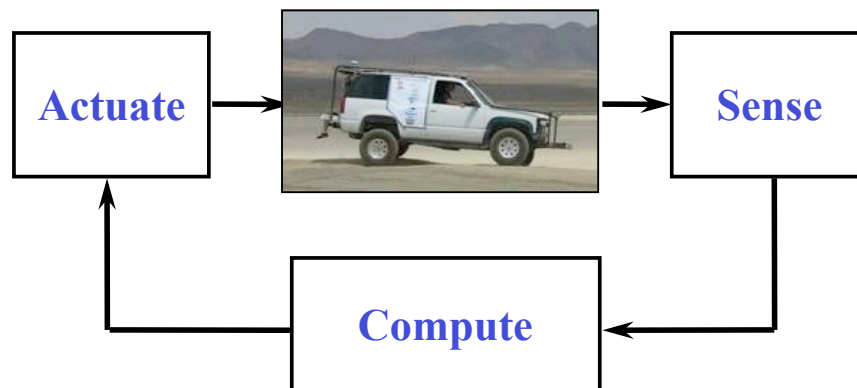- Performance of input/output systems (disturbance rejection, robustness)

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)

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:

BIO

ESE

CS