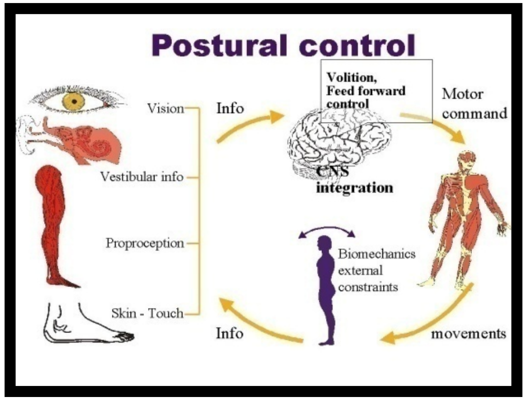
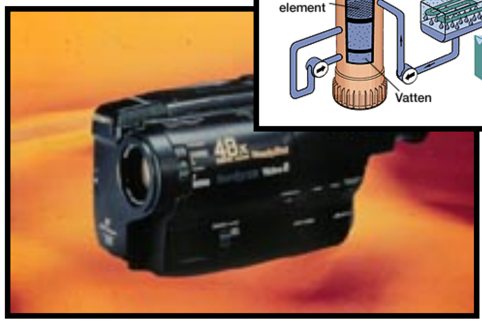
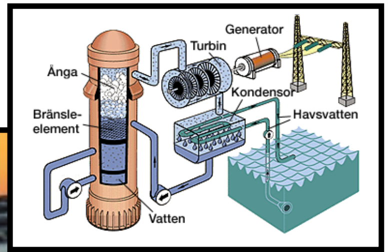


Introduction to Control

Bo Bernhardsson





thanks to Karl-Erik Årzen, Karl Johan Åström, Erik Johannesson

Nationalencyklopedin

regle´rteknik, läran om styrda system, ett grundläggande ämne inom ingenjörsvetenskapen.

The Idea of Feedback

Compare the actual result with desired result
Take actions based on the difference

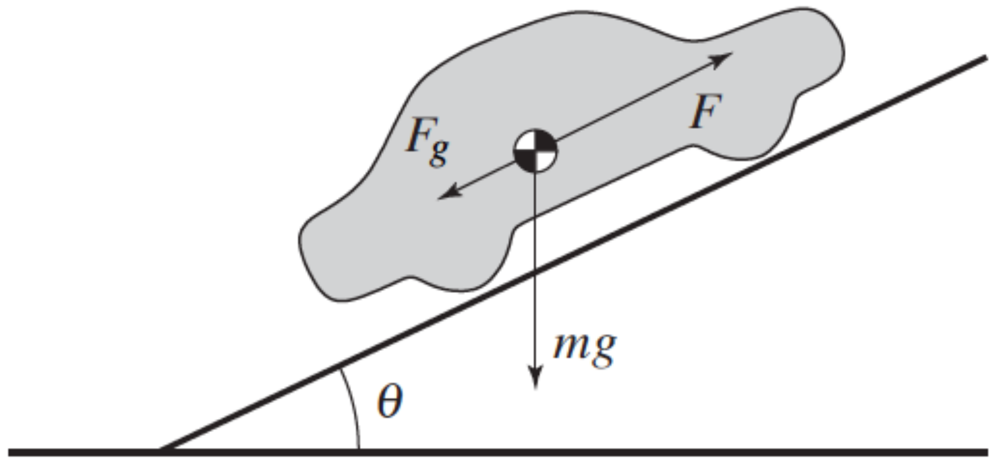
This seemingly simple idea is tremendously powerful in many different context: science, engineering, management…

Use of feedback has often been revolutionary

Feedback is also called **closed loop control.** The opposite is **feedforward** or **open loop control**: make a plan and execute it

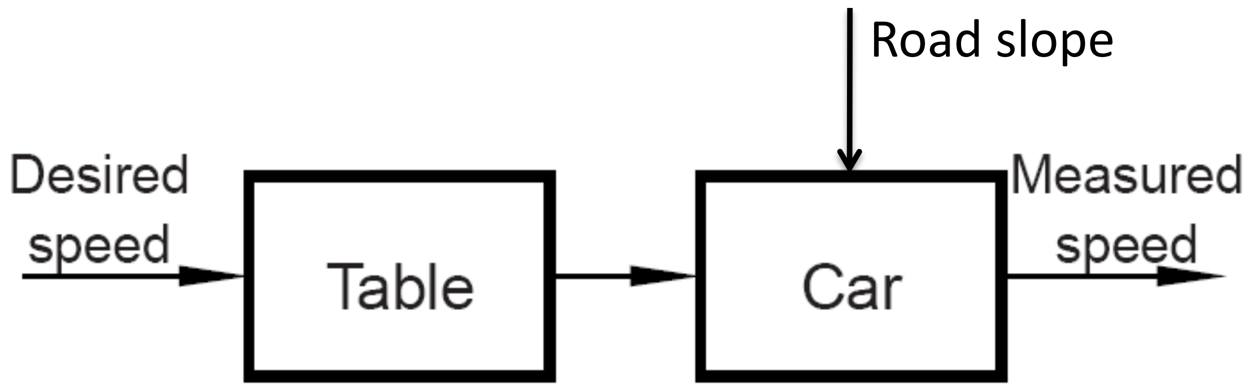
Example: Cruise Control

Typical regulation problem – keep velocity constant



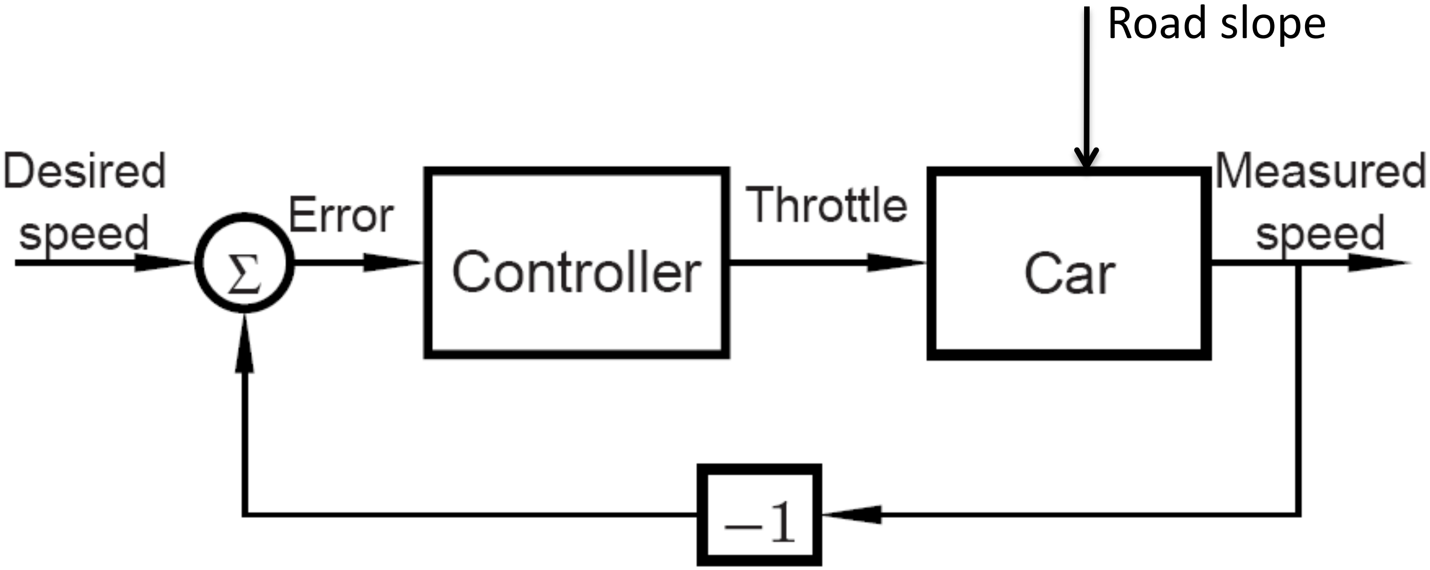
- Process input or control variable: gas pedal (throttle) u
- Process output : car speed v
- Desired output or reference signal: desired car speed r
- Main disturbance: slope Θ

Cruise Control: Open loop



- Open loop
- Problems?

Cruise Control: Feedback



- Closed loop
- Simple controller:
  - Error > 0: increase throttle
  - Error < 0: decrease throttle

Will this simple controller work ?

Feedback (återkoppling)

Feedback has some amazing properties, it can

+ make good systems out of bad components
+ reduce impact of disturbances and sensitivity to component variations
+ create desired behavior, for example linear behavior from nonlinear components or stable system from unstable

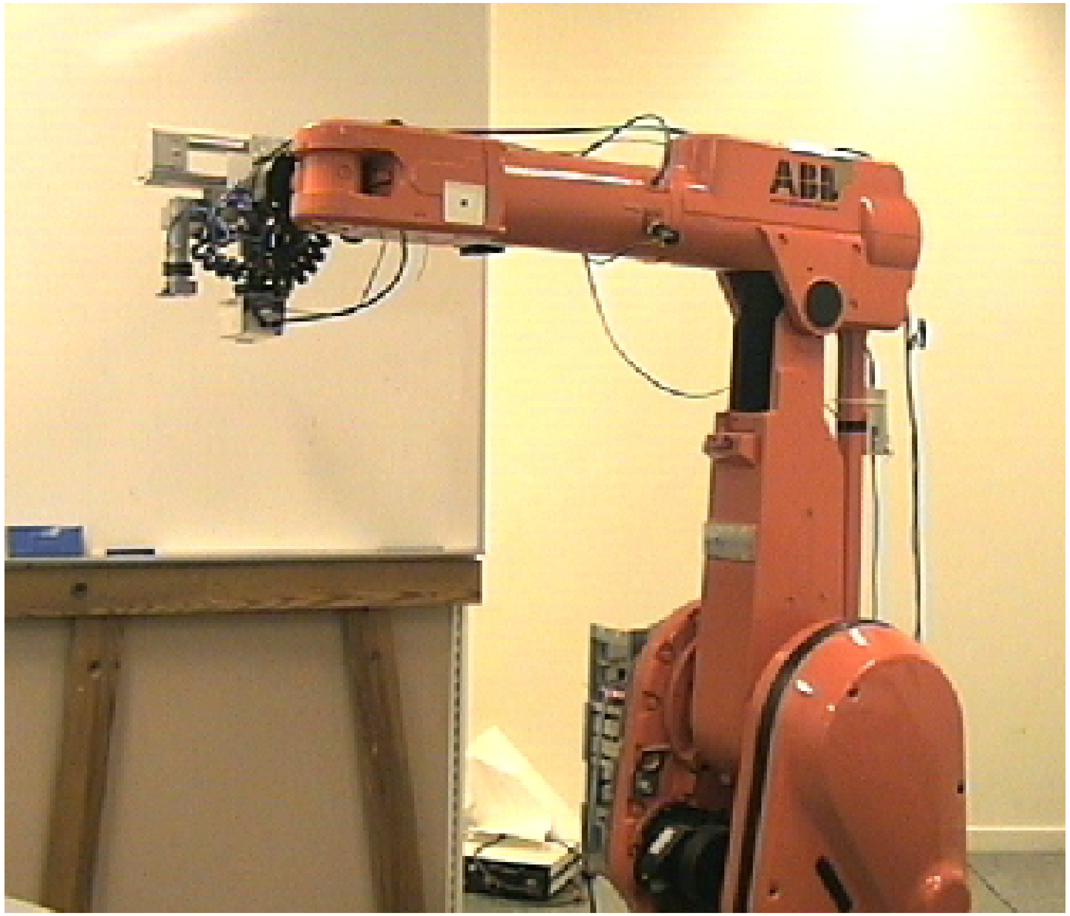
The major drawbacks are that

- Feedback can cause instabilities
- Sensor noise is fed into the system

Open loop, feedforward (öppen loop, framkoppling)

+ Reduces impact of measurable disturbances
+ Allows fast reference changes (look-ahead)
- Good process models needed
- Stable system needed

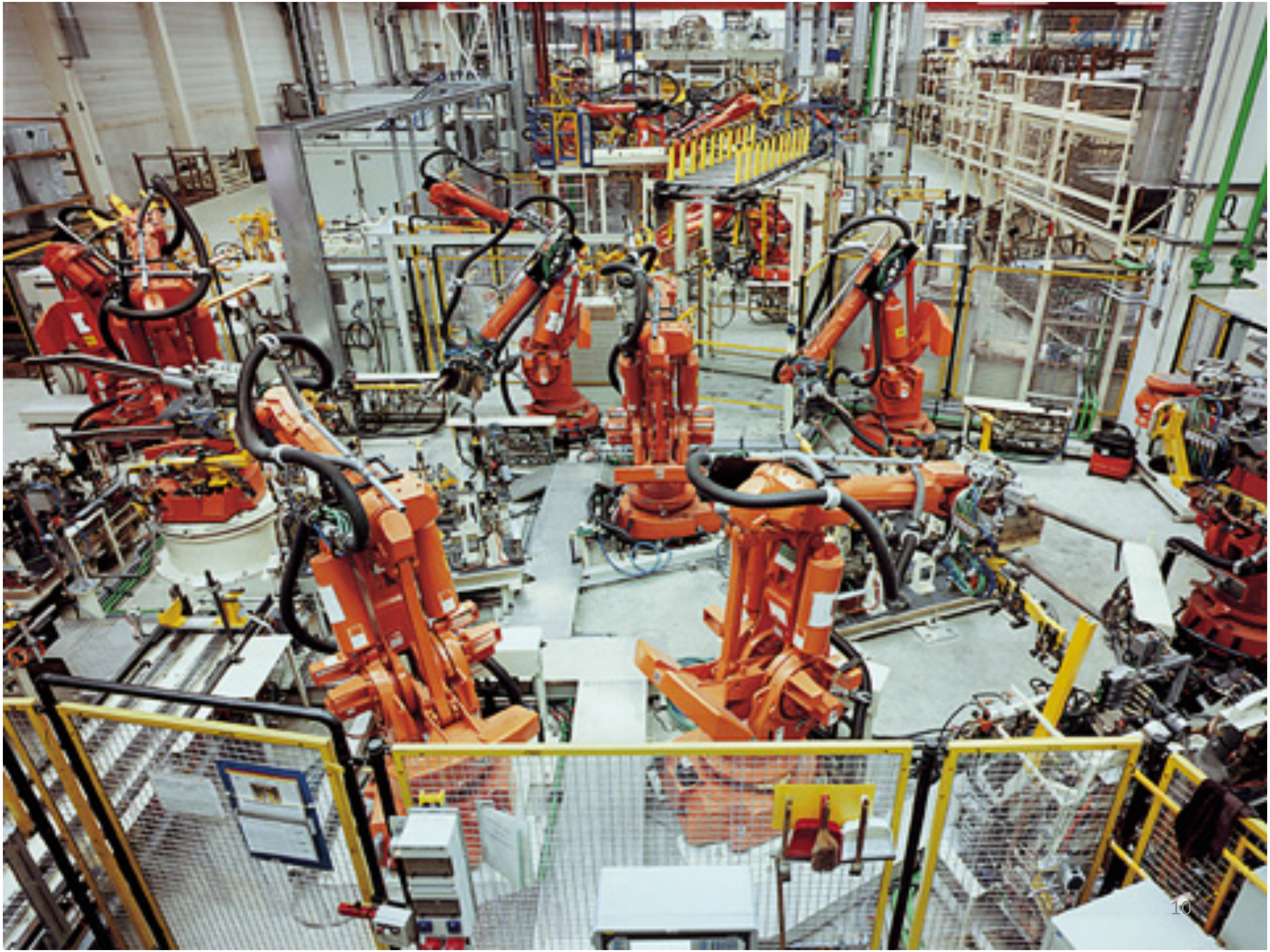
The ABB IRB 2000 Robot



- Axes: 6
- Payload: 10 kg
- H-Reach: 1542 mm
- Repeatability: ±0.1 mm
- Robot Mass: 350 kg

Design compromise:

Power (speed, force), stiffness (repeatability) **versus** cost, weight, power consumption

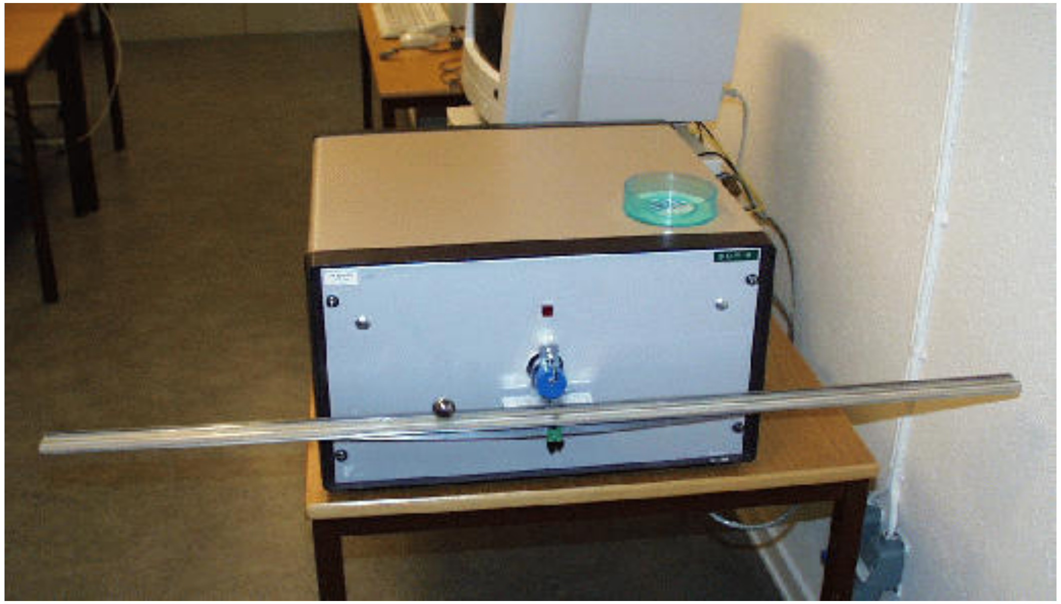


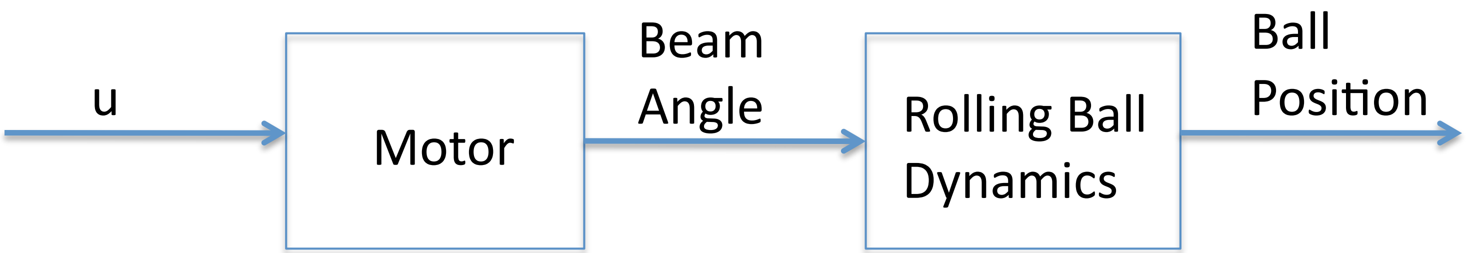
Robot Power and Speed

Robot Precision

Superior control is vital for market leadership

Ball and Beam Process (Lecture 14)





Good Systems from Bad Components

Example: The **feedback amplifier**

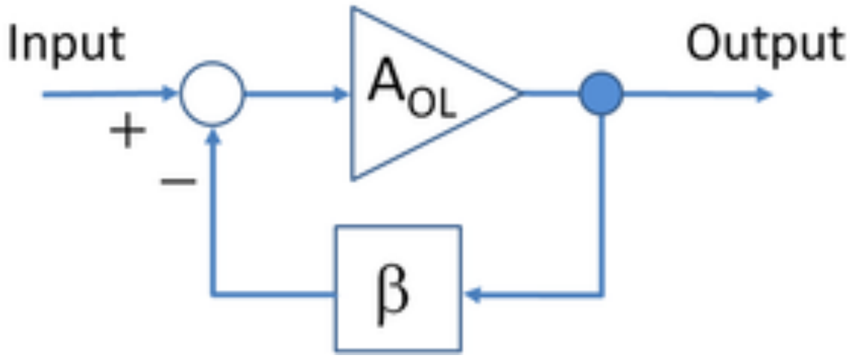
- Invented by H. Black at Bell labs in 1927
- Rapid increase in telephone communication in 1920s
- Carrier technology (many simultaneous connections on one line) is made possible 1917 by innovative filters

A Story: 1930s Phone Network Battle

- Long distance: need many amplifiers
- 1915 Transcontinental phone line built with 3 amplifiers
- 1921 Upgraded to 3-channel system with 12 amplifiers
- Tube amplifiers are nonlinear and distorts sound
- 1923 Bell company built 2nd line (4 channels and 20 amplifiers)
- Bell policy: technology leadership to keep monopoly. Invention of a working **repeater** was top priority

Idea by H. Black (1898-1983)

- Started to work on the problem 1923
- In August 1927 he got this idea:



$$A_{\text{fb}} = \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{A_{OL}}{1 + \beta \cdot A_{OL}}$$

If $\beta \cdot A_{OL} >> 1$ then $A_{fb} \approx 1/\beta$

- Patent filed in 1928 (with 126 claims)
- Finally awarded patent 9 years (!) later, believed ”too good to be true”.

1934 Amazing Linearity Results achieved at Bell

Feedback can eliminate variations of the electronic tube
Results were spectacular

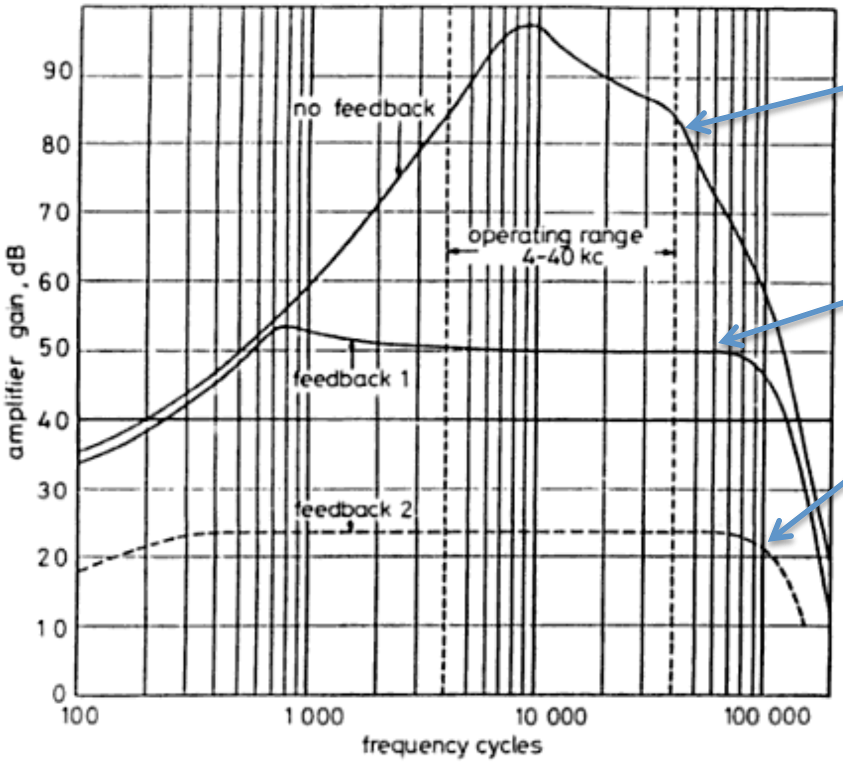


Figure 3.3 *Gain frequency characteristics with and without feedback*

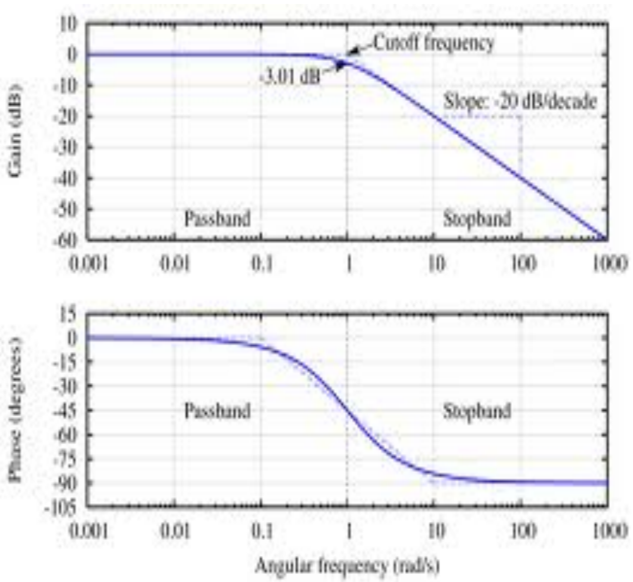
Reproduced (with partial redrawing) by permission of H.S. Black, from *Bell System Technical Journal*, 1934, **13**, p. 12

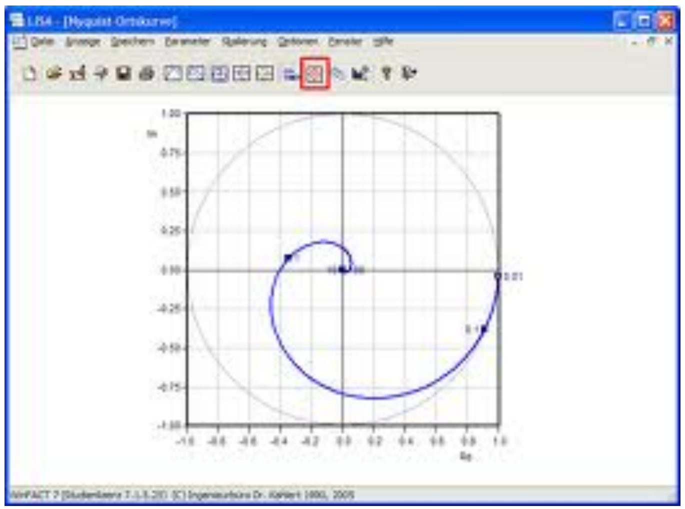
Distorted sound

Clear sound, also with many amplifiers in series

The Stability Problem

- Stability problems (”singing”)
- When can one use loop gains larger than 1?
- Fundamental results understanding stability by H. Nyquist and H. Bode (also Bell labs) etc in 1930-40s

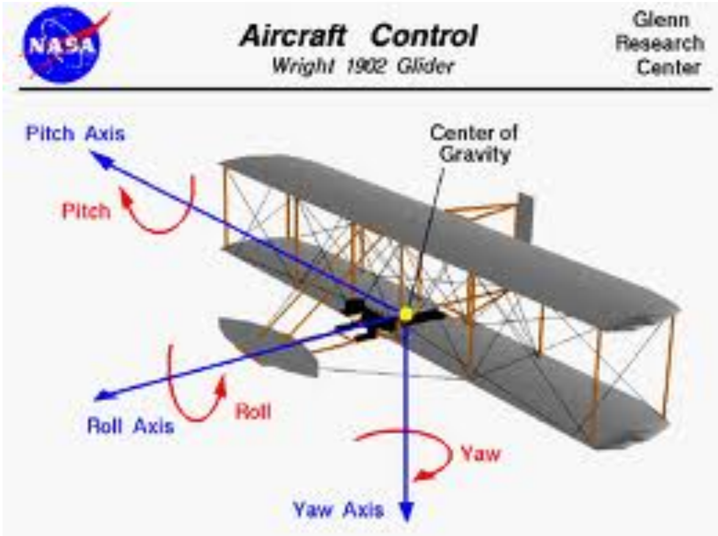




Stabilize and Shape Behavior

Many systems use feedback stabilization to operate

- Airplanes
- Bicycles
- Segway
- Missiles
- Exotherm reactors
- Nuclear reactors
- …

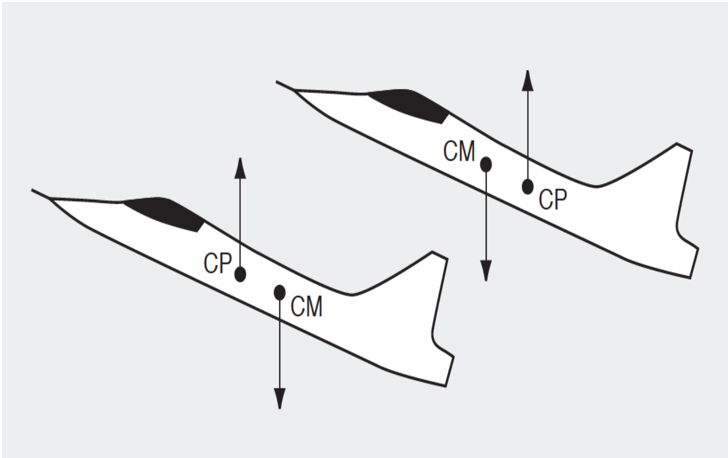


Shaping Behavior

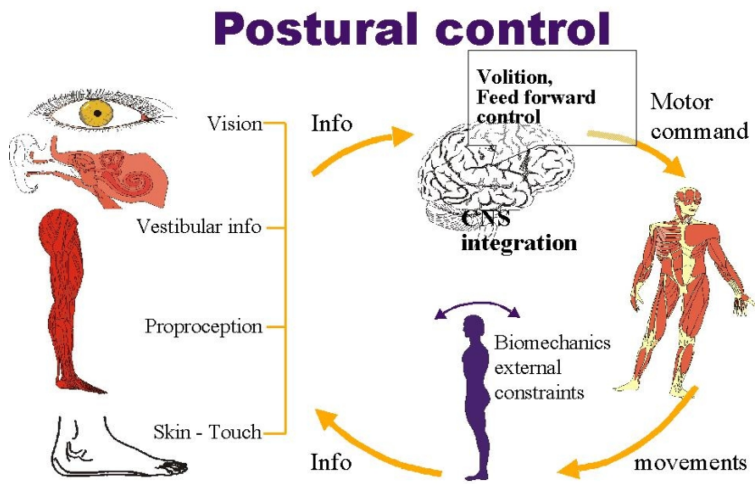
Lecture by Wilbur Wright 1901:

We know how to construct airplanes
We also know how to build engines
Inability to balance and steer still confronts students of the flying problem
When this one feature has been worked out, the age of flying will have arrived, for all other difficulties are of minor importance

The main stream idea at the time was to build stable airplanes. The Wright Brothers built an **unstable** airplane that was **manoevrable.**
Substantial advantages are obtained by designing an unstable aircraft and using a control system to stabilize the system



General Theory: Inverted Pendulums



Same underlying mathematics and control theory

The Segway Example

How should the controlled system behave?
”Keep balance and move by leaning”

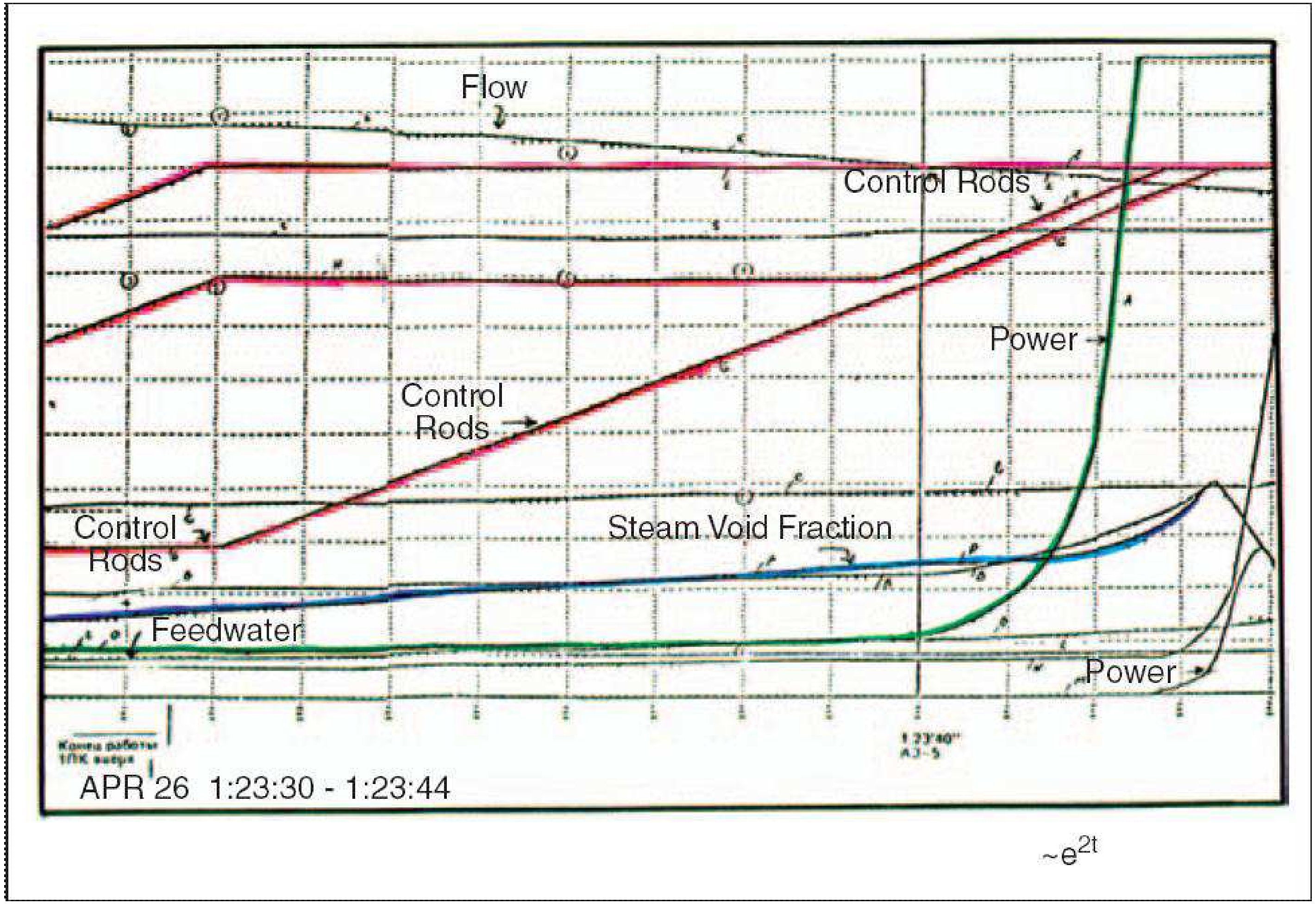
Segway Variants

Control is Everywhere – But Often a Hidden Technology

- Used everywhere and very successful
- Mission-critical for many products and systems
- Not very much attention
  - Except when failing

- Why?
  - Easier to market physical things than principles, methods and ideas

What process is (was) this?



Dont try this at home!

Chernobyl Nuclear Power Plant

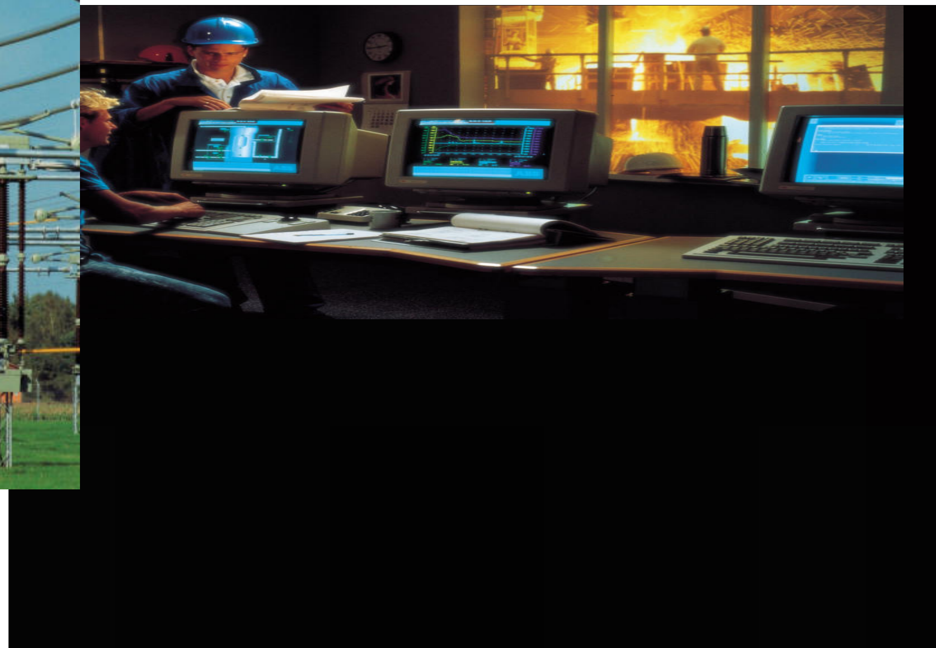
©AP/WIDE WORLD PHOTOS

Figure 2. *Chernobyl nuclear power plant shortly after the accident on 26 April 1986.*

A Swedish (Linköping) Example

On 2 February 1989, the first prototype JAS 39-1 crashed on its sixth flight, when attempting to land in Linköping. The accident was filmed in a now famous recording by a crew from Sveriges Television's Aktuellt. The pilot, Lars Rådeström, remained in the tumbling aircraft, and escaped with a fractured elbow and some minor injuries. The crash was the result of pilot-induced oscillation (PIO).

Power Generation and Distribution



Process Control

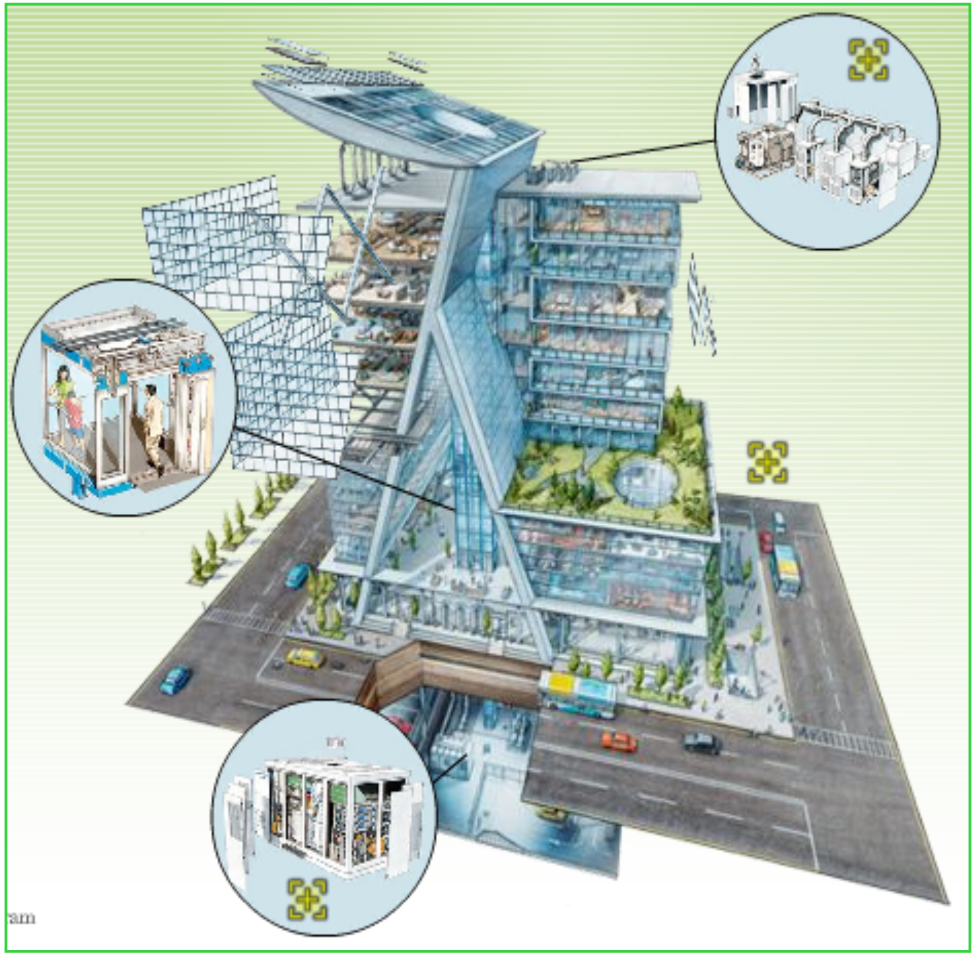
Buildings

Design &
Energy Analysis

Windows &
Lighting

Natural
Ventilation

Indoor
Environment



Elevators

Safety

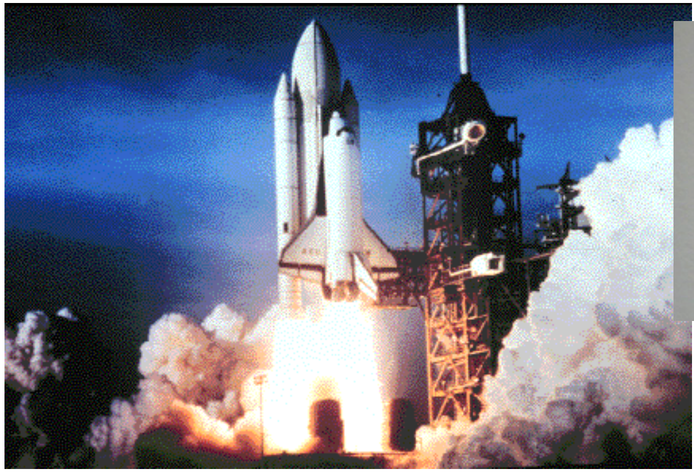
HVAC

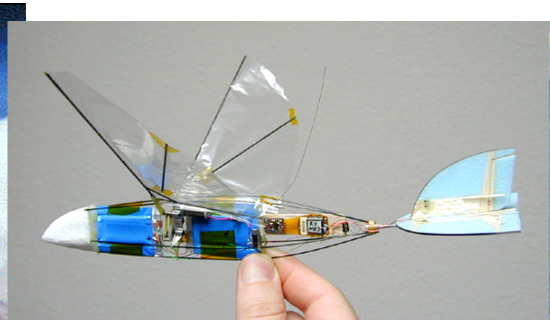
Vibration
damping

Sensors, Networks,Communications, Controls

Slide from UTRC

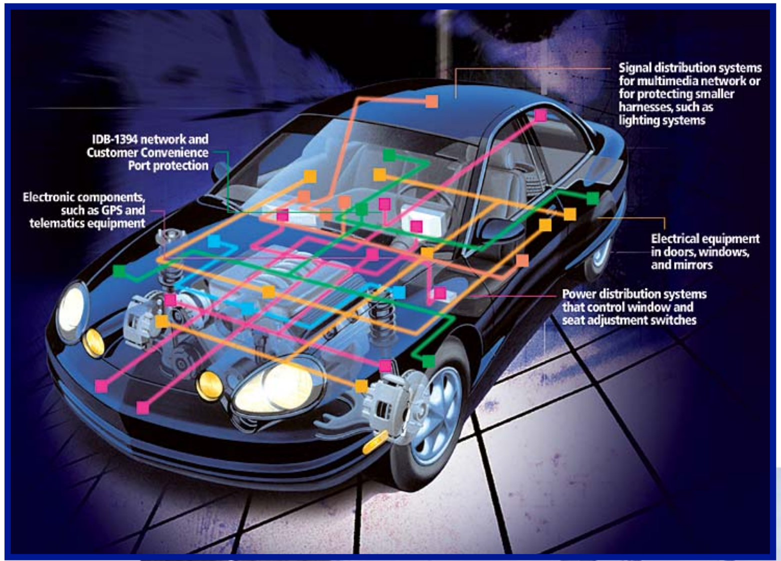
Vehicles



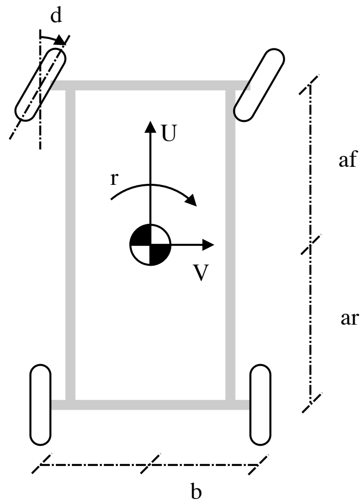


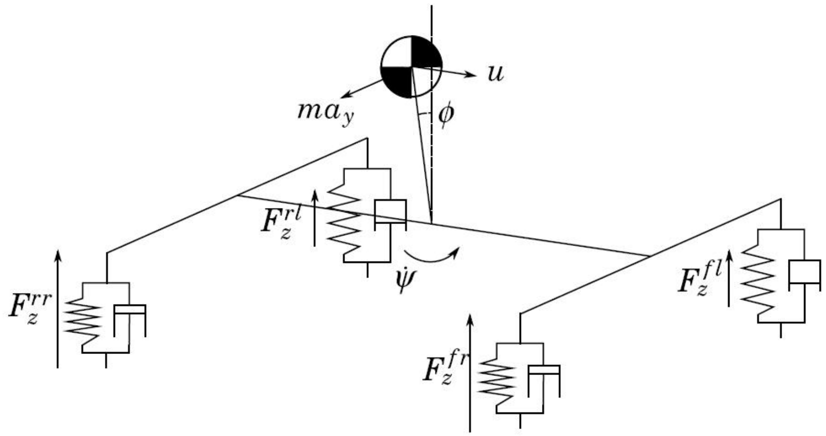
Automotive

- Strong technology driver
- Engine control
- Power trains
- Cruise control
- Adaptive cruise control
- Traction control
- Lane guidance assistance
- Traffic flow control



Example: Stabilization of Vehicle Dynamics



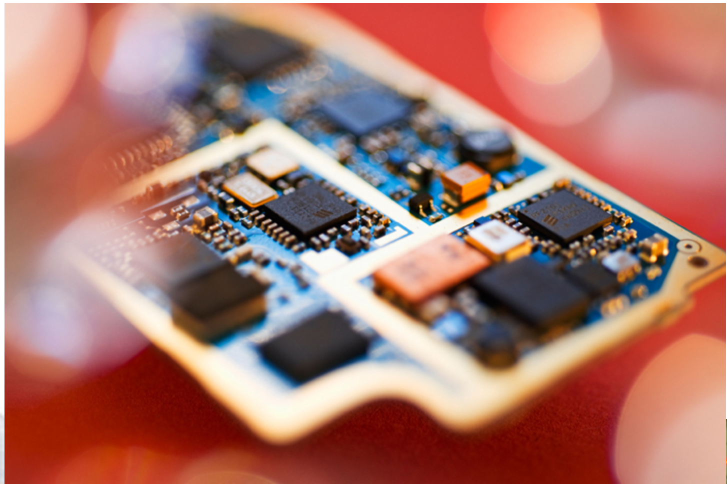


Brad Schofield Automatic Control LTH 2006

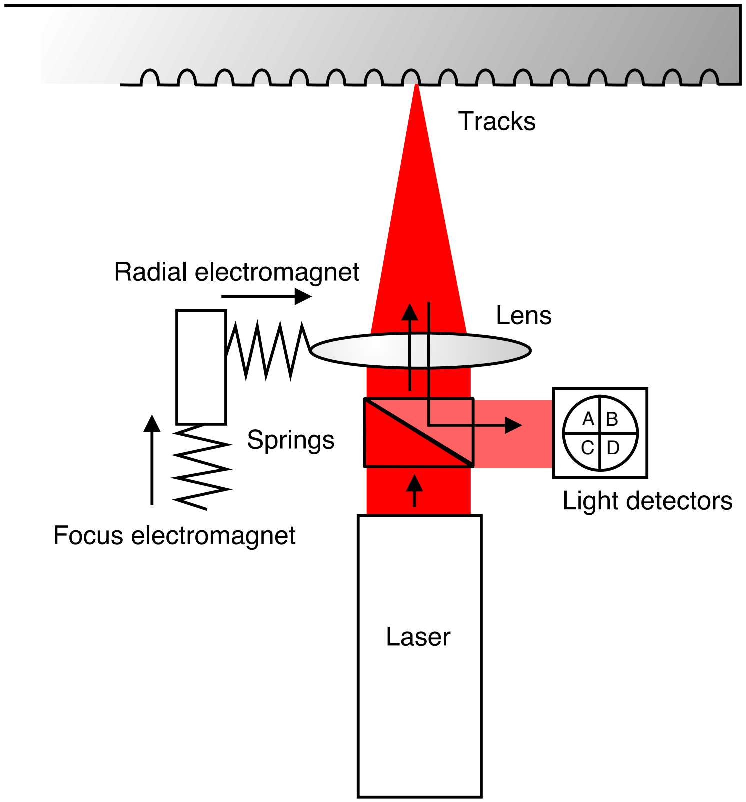
Unmanned Aerial Vehicles

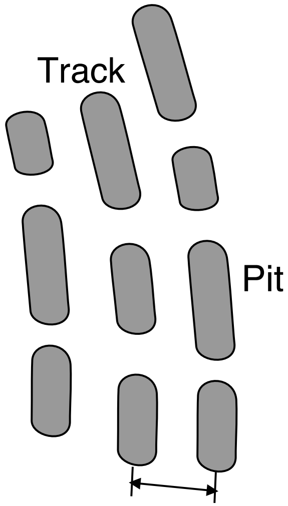
The QuadRotor

Consumer Electronics



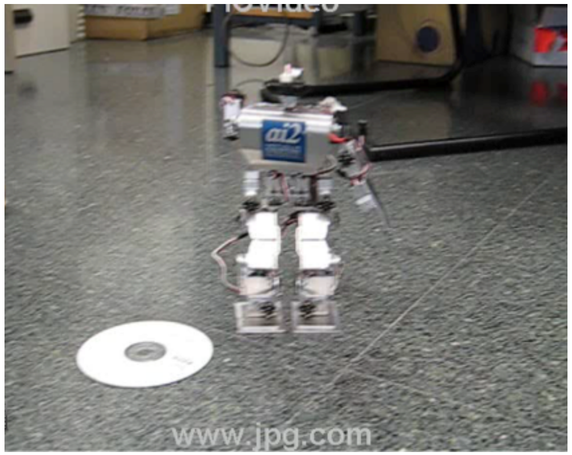
Track following in DVD players

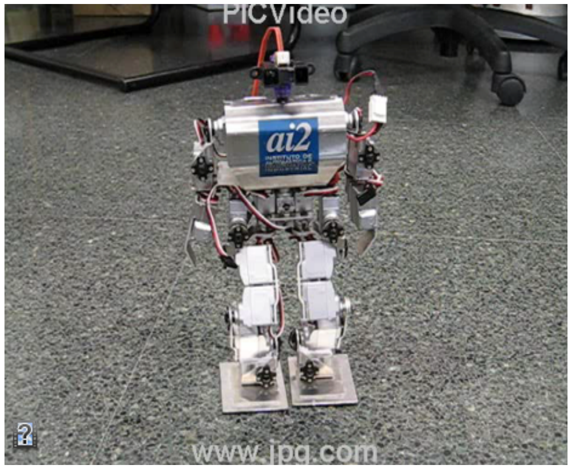




Bo Lincoln, Automatic Control LTH 2000

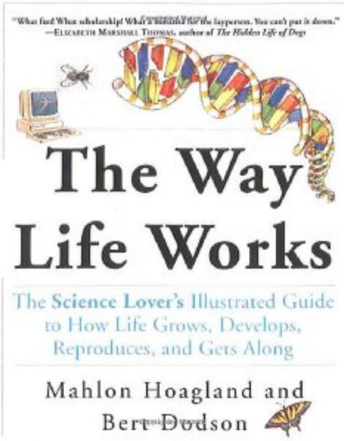
Big and Small Toys



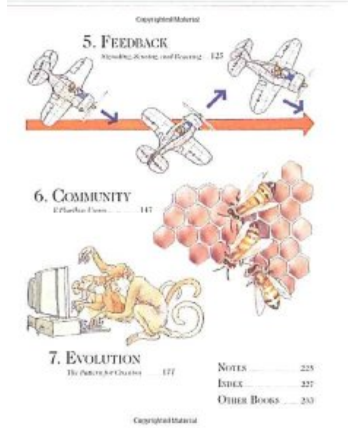


http://video.google.se/videoplay?docid=1210345008392050115&ei=tznoSrXwKqDQ2wLP1I2PDw&q=humanoid+robot&hl=sv

http://www.youtube.com/watch?v=W1czBcnX1Ww



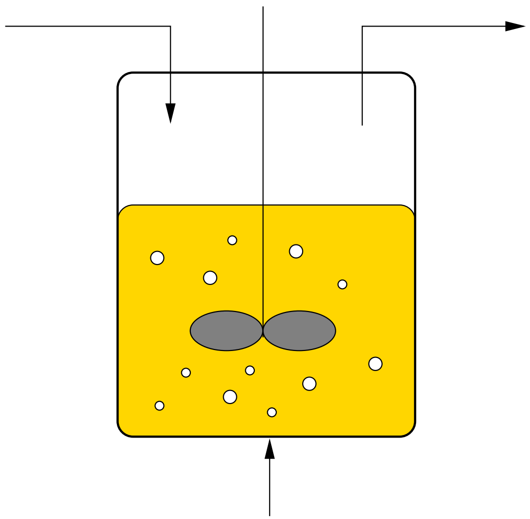
Biology



Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure, and cholesterol level. The mechanisms operate at every level, from the interaction of proteins in cells to the interaction of organisms in complex ecologies.

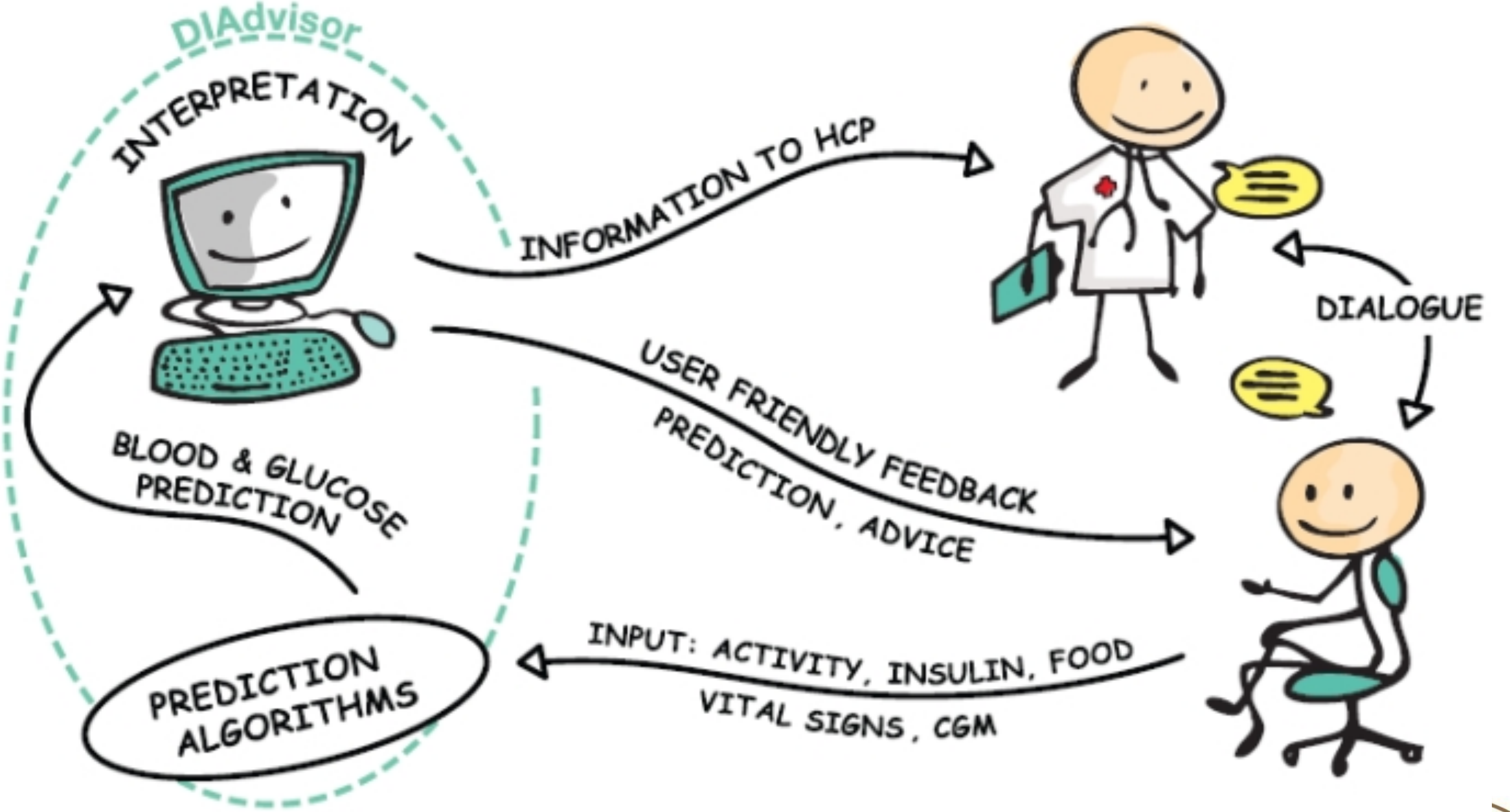
Mahlon B Hoagland and B Dodson The Way Life Works Times Books 1995

Optimal Growth of Bacteria



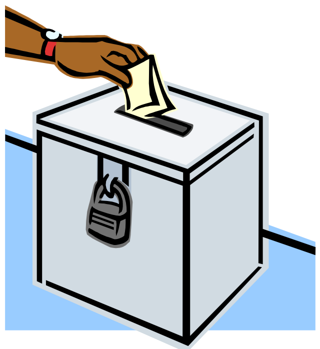
Lena de Mare, Automatic Control LTH 2006

The Diabetese Advisor Project



Other Sciences

- Economy
  - “Controller”
  - Stocks and options
- Politics
  - Democracy = feedback
- Organization theory
  - Educational system
- …..
- …..



Why Work With Control?

- Can work in many different areas – no need to commit to specific field. Courses for F, E, D, C, M, I, Pi, K, B, W, N

- Fun mixture between theory and practice

- Holistic view of systems, get the complete picture, not only different small parts (future is in complex systems)

- Working with many different sort of people

- Broad job market. Future-proof. Flexible. Fun.

So Follow Master Yoda's Advice: