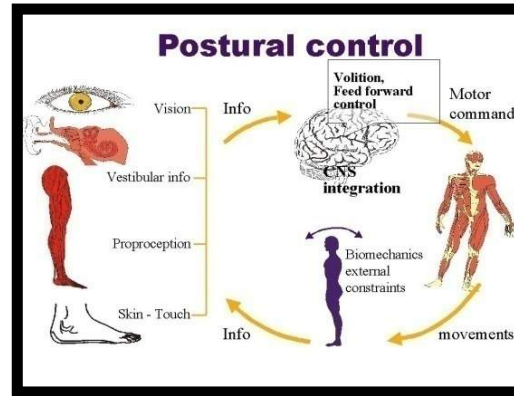
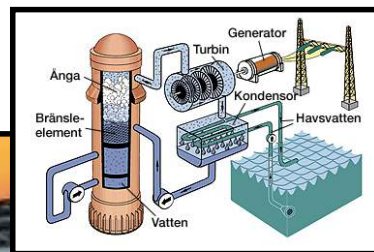




Introduction to Control

Bo Bernhardsson



thanks to Karl-Erik Årzen, Karl Johan Åström, Erik Johannessson 1

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

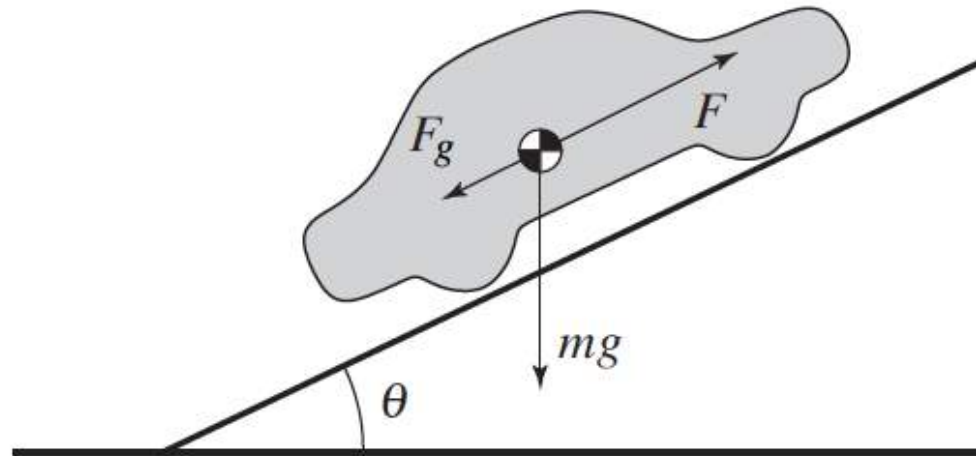
This seemingly simple idea is tremendously powerful in many different context: science, engineering, management...

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

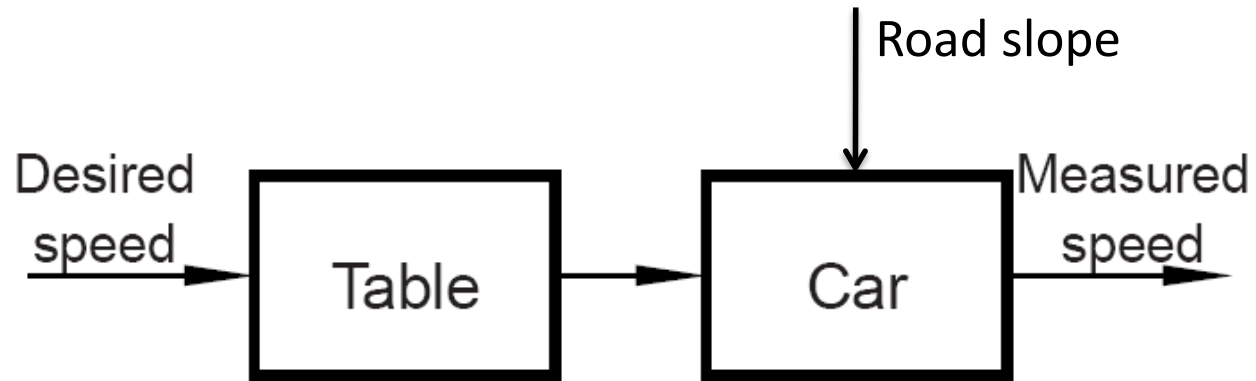
Example: Cruise Control

Typical regulation problem – keep velocity constant



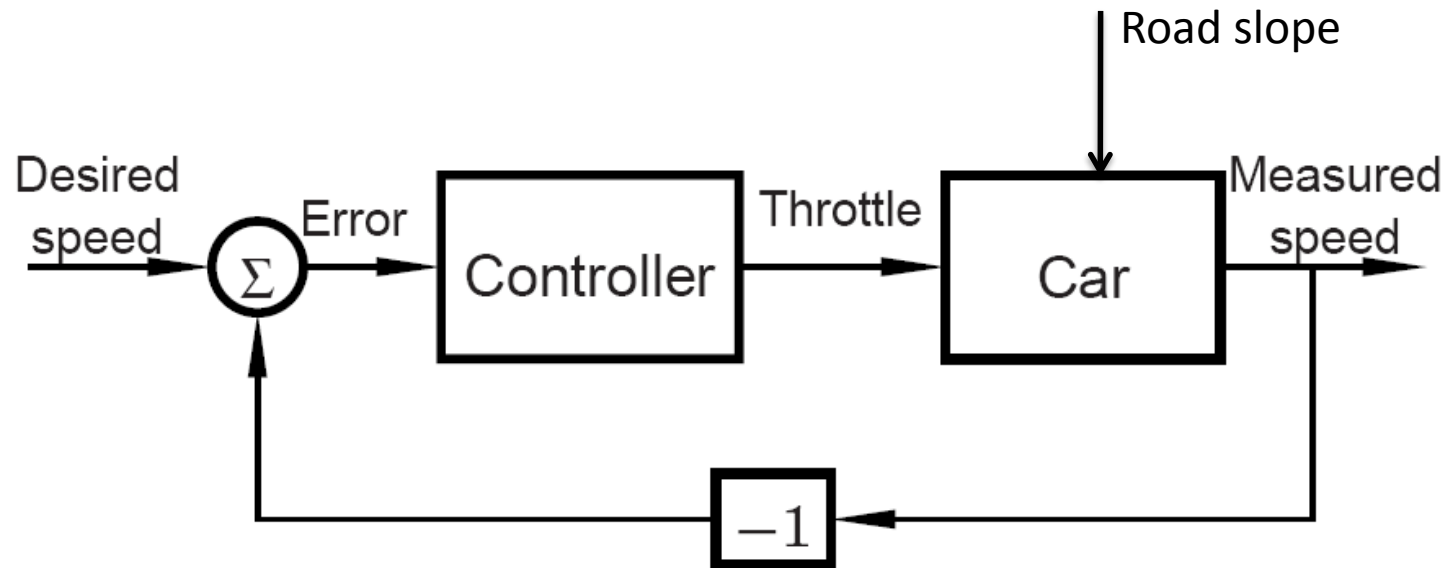
- Process input or control variable: gas pedal (throttle) u
- Process output : car speed v
- Desired output or reference signal: desired car speed r
- Main disturbance: slope Θ

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

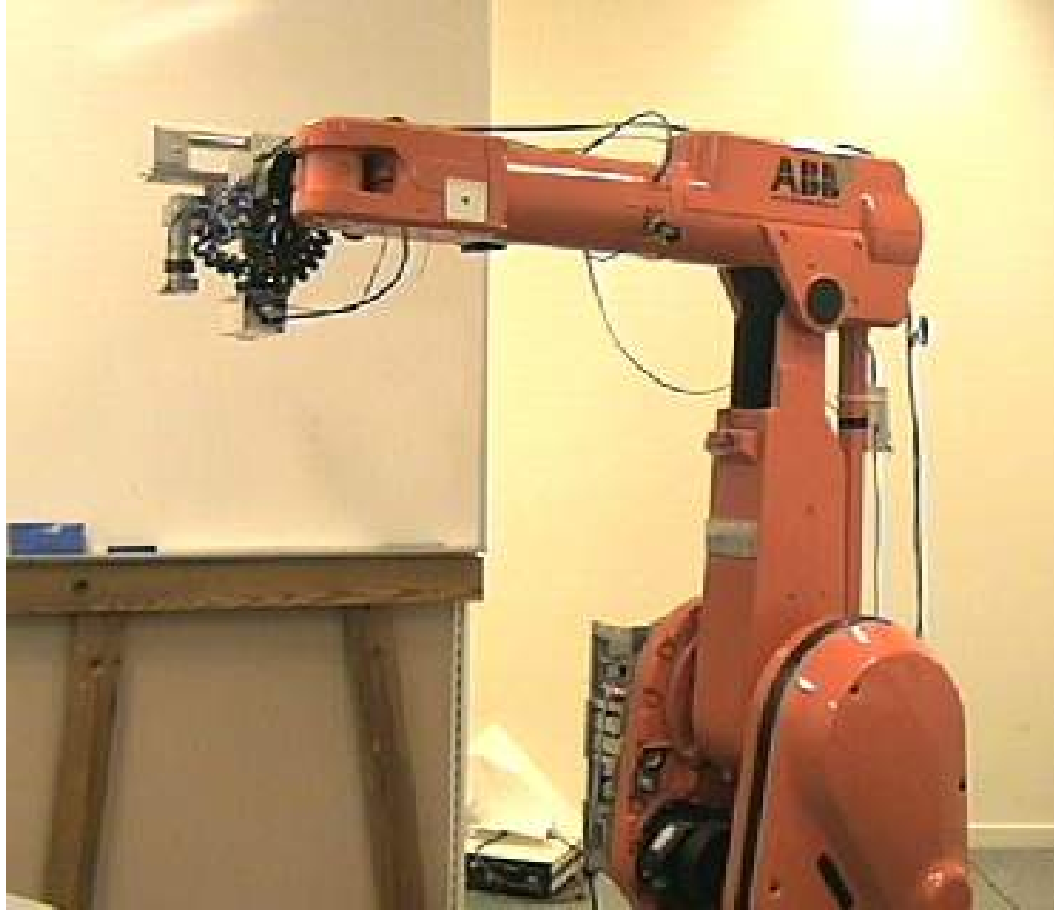
The major drawbacks are that

- 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

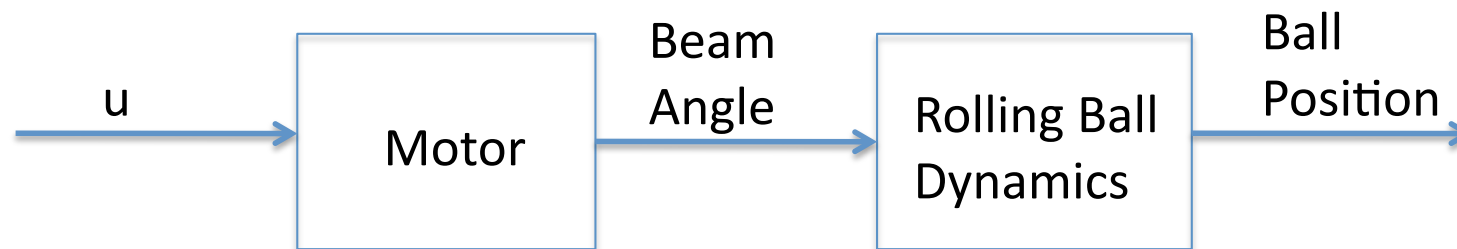


Robot Precision



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

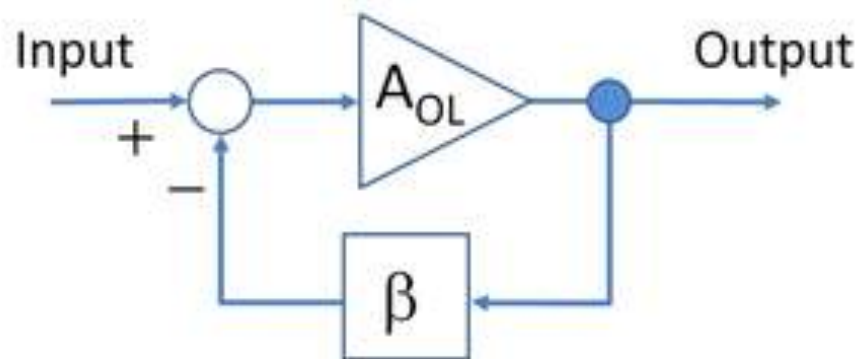


A Story: 1930s Phone Network Battle

- 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:



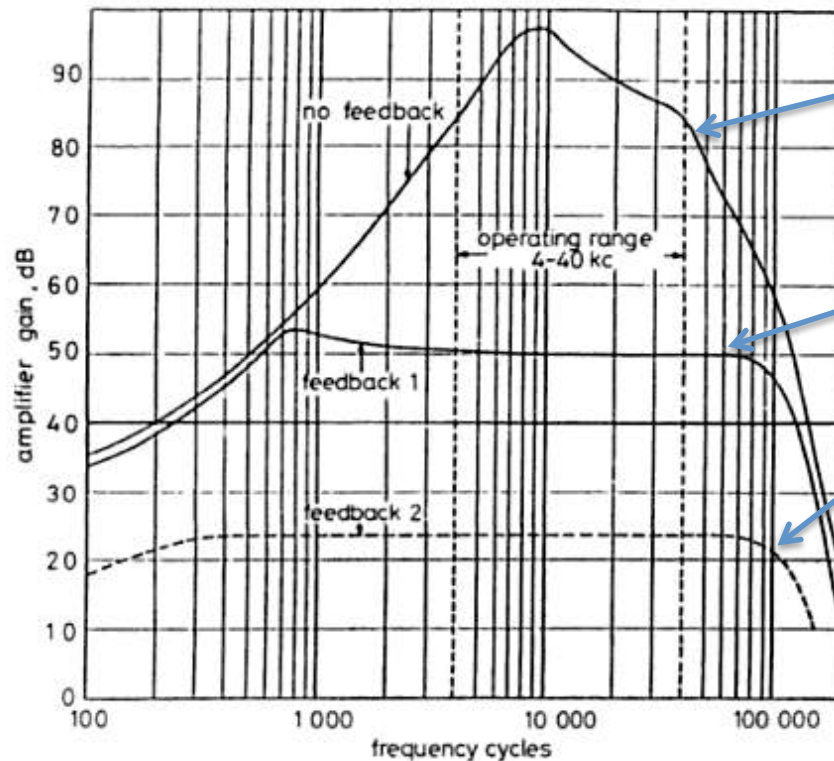
$$A_{fb} = \frac{V_{out}}{V_{in}} = \frac{A_{OL}}{1 + \beta \cdot A_{OL}}$$

If $\beta \cdot A_{OL} \gg 1$ 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



Distorted sound

Clear sound, also with
many amplifiers in series

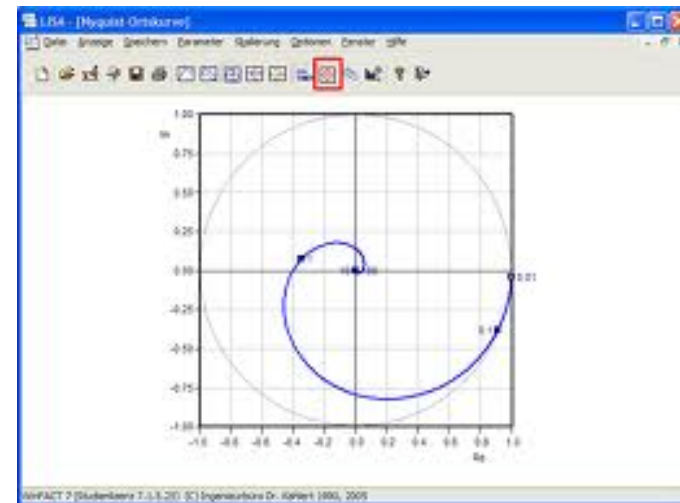
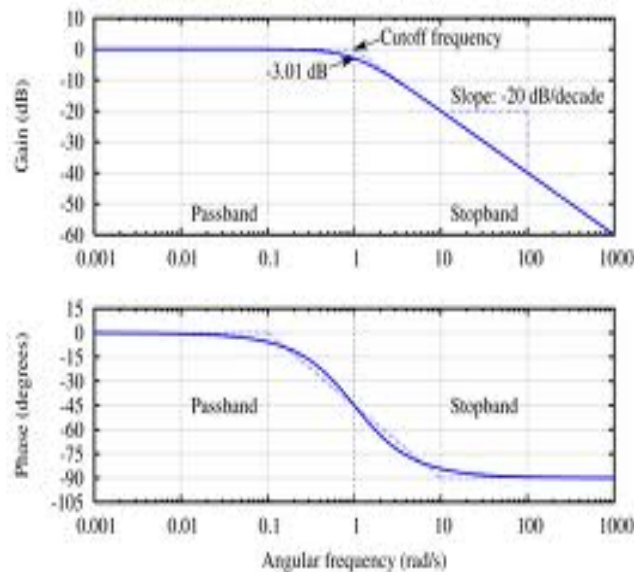


Figure 3.3 Gain frequency characteristics with and without feedback

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

The Stability Problem

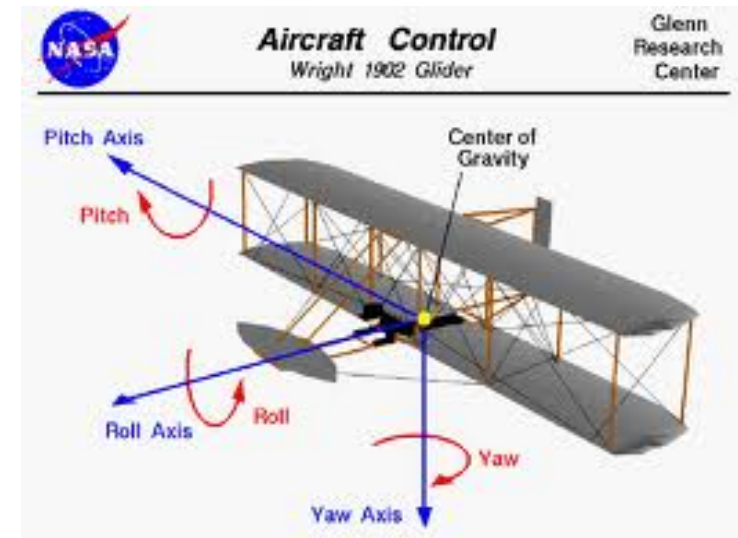
- Stability problems ("singing")
- When can one use loop gains larger than 1?
- Fundamental results understanding stability by H. Nyquist and H. Bode (also Bell labs) etc in 1930-40s



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

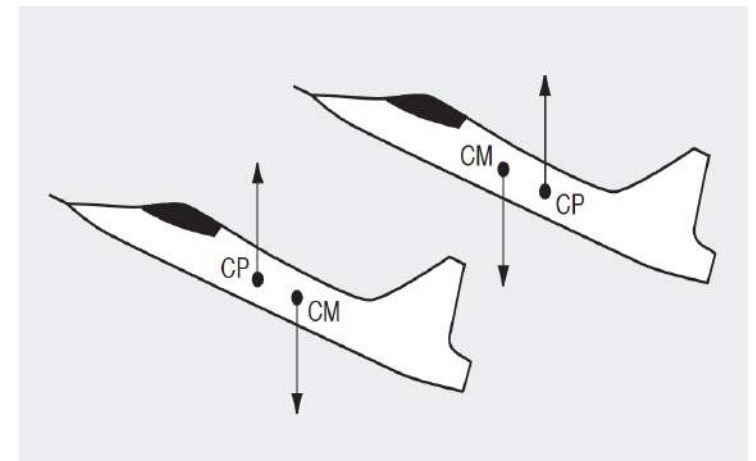
*Inability to balance and steer still confronts
students of the flying problem*

*When this one feature has been worked out,
the age of flying will have arrived, for all other
difficulties are of minor importance*

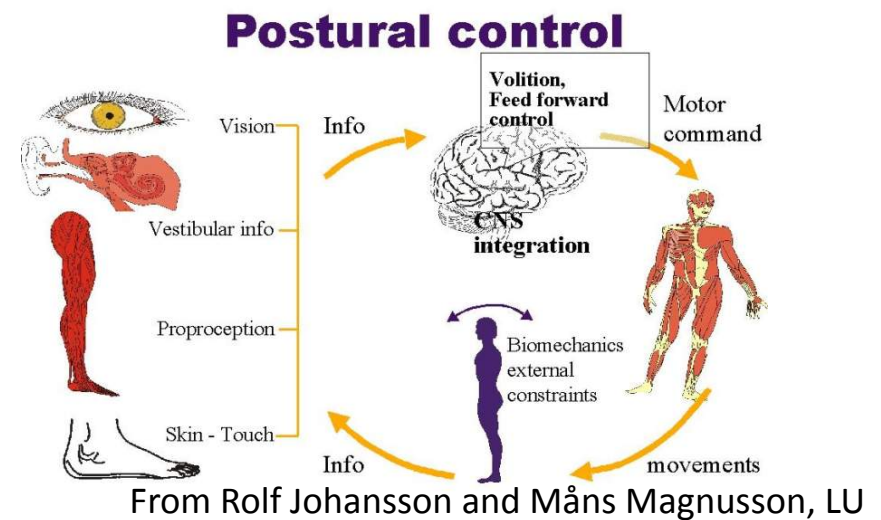


The main stream idea at the time was to build stable airplanes. The Wright Brothers built an **unstable** airplane that was **manoevrable**.

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"

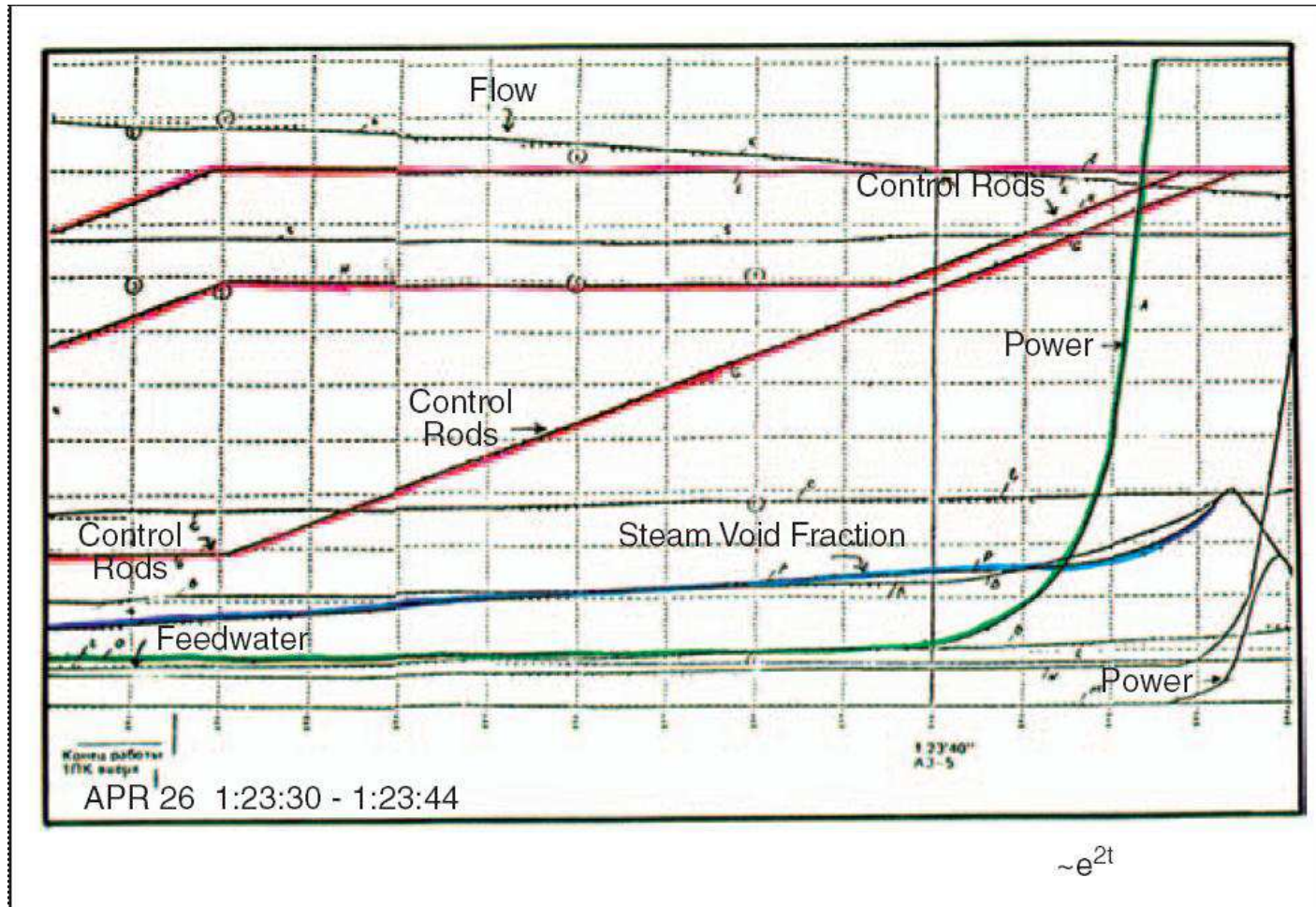
Segway Variants



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

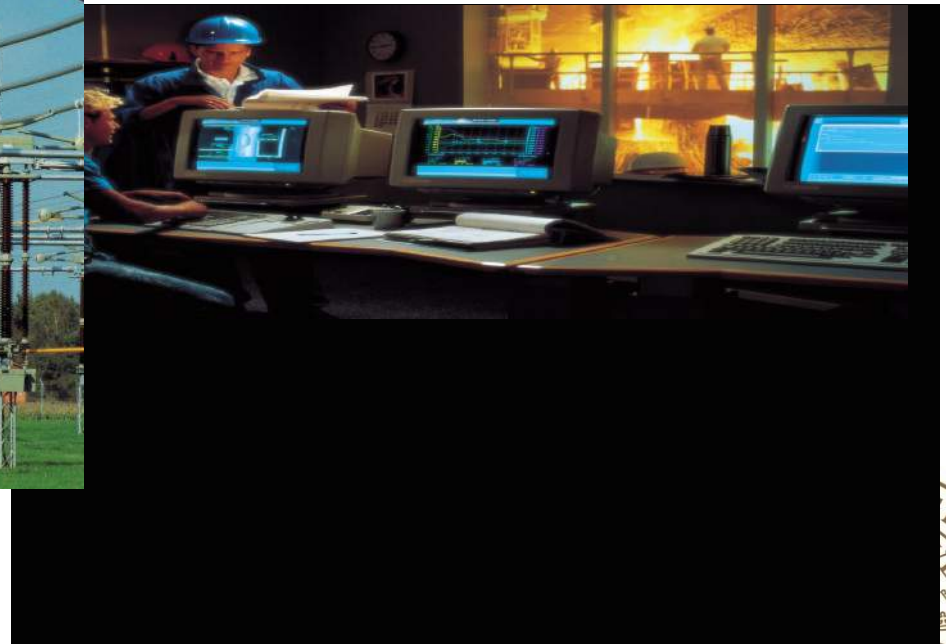
Figure 2. *Chernobyl nuclear power plant shortly after the accident on 26 April 1986.*

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

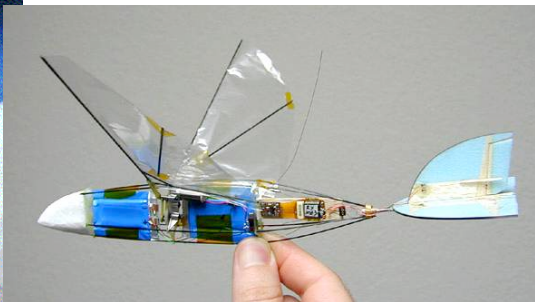
HVAC

Vibration
damping

Sensors, Networks, Communications, Controls
Slide from UTRC



Vehicles



Automotive

Strong technology driver

Engine control

Power trains

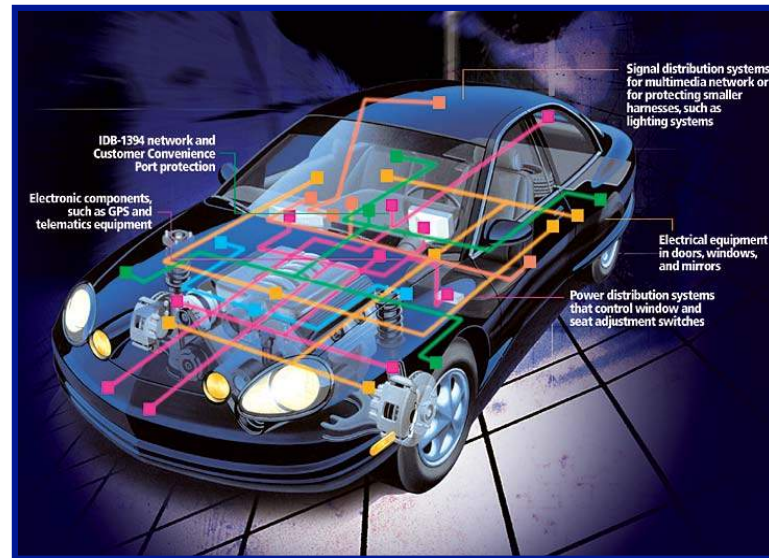
Cruise control

Adaptive cruise control

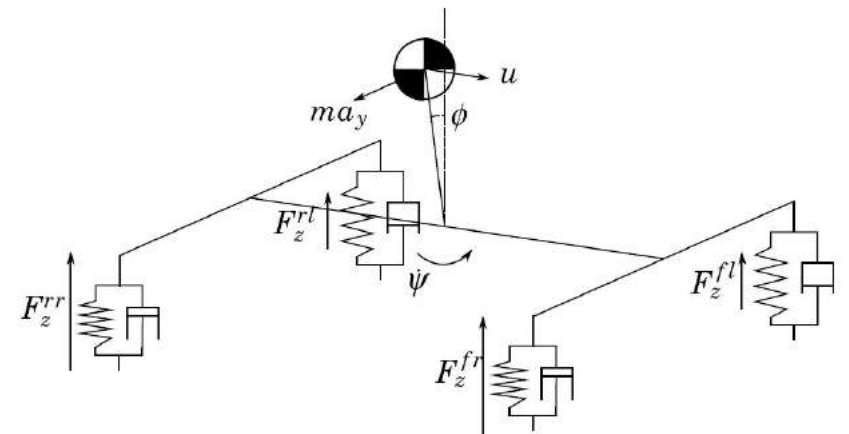
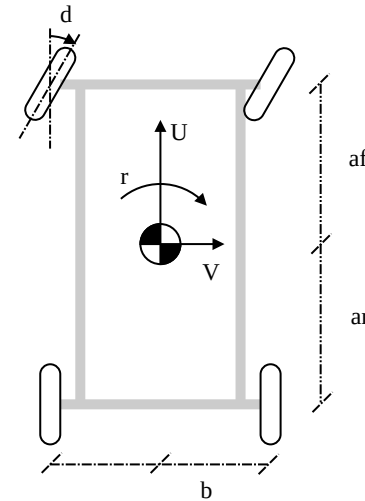
Traction control

Lane guidance assistance

Traffic flow control



Example: Stabilization of Vehicle Dynamics



Brad Schofield Automatic Control LTH 2006

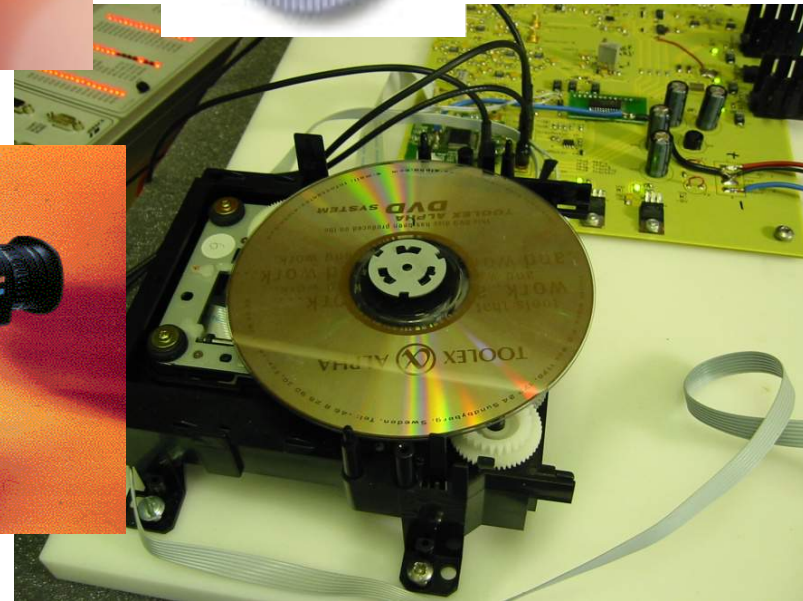
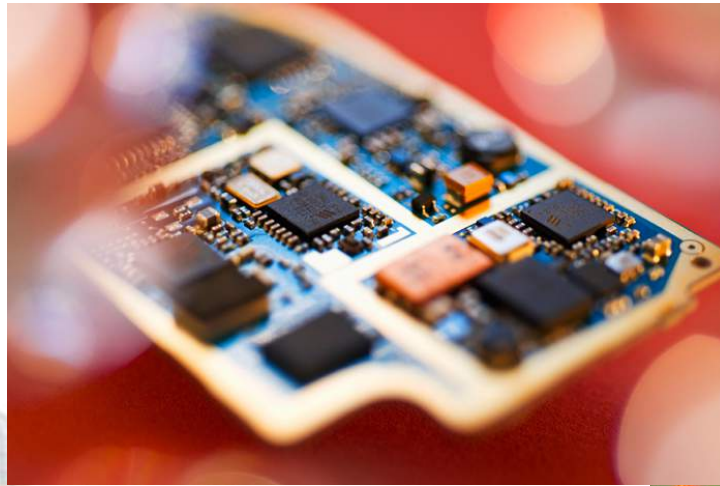


Unmanned Aerial Vehicles

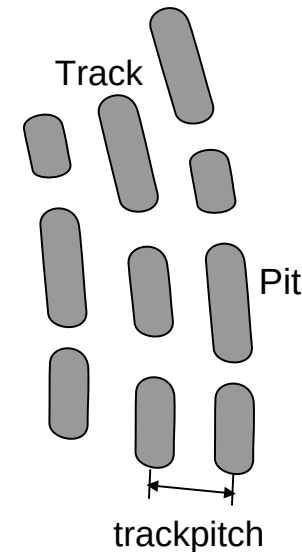
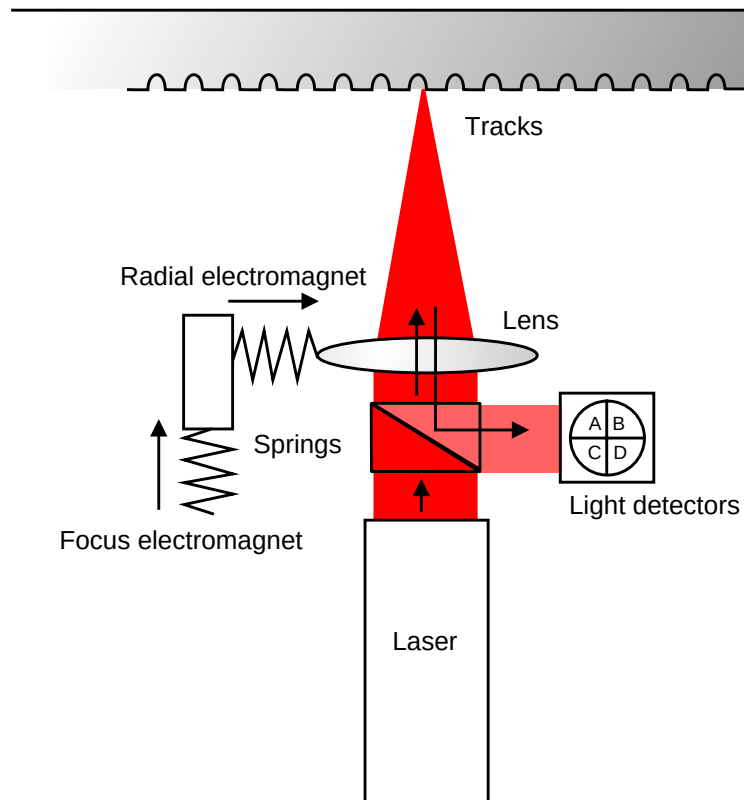
The QuadRotor



Consumer Electronics



Track following in DVD players



Bo Lincoln, Automatic Control LTH 2000

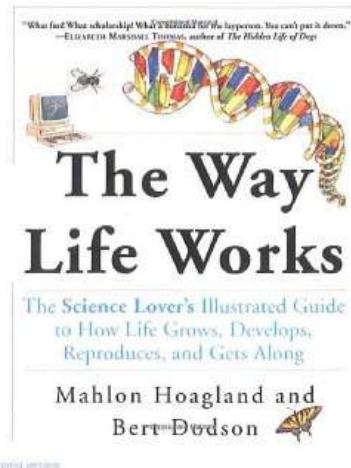


Big and Small Toys



[http://video.google.se/
videoplay?
docid=12103450083920501
15&ei=tznoSrXwKqDQ2wLP
1I2PDw&q=humanoid
+robot&hl=sv](http://video.google.se/videoplay?docid=1210345008392050115&ei=tznoSrXwKqDQ2wLP1I2PDw&q=humanoid+robot&hl=sv)

[http://www.youtube.com/
watch?v=W1czBcnX1Ww](http://www.youtube.com/watch?v=W1czBcnX1Ww)



Biology

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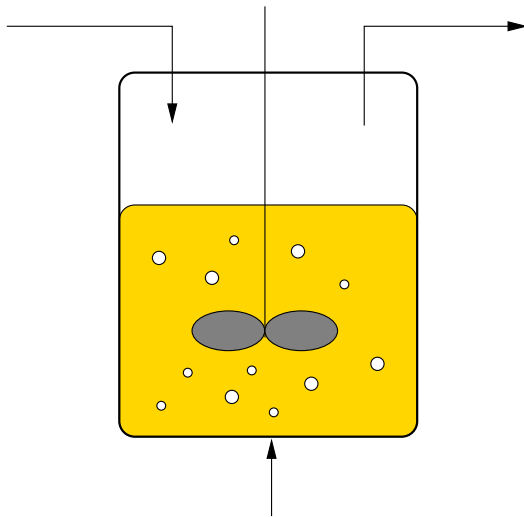
Feedback is a central feature of life. The process of feedback governs how we grow, respond to stress and challenge, and regulate factors such as body temperature, blood pressure, and cholesterol level.

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

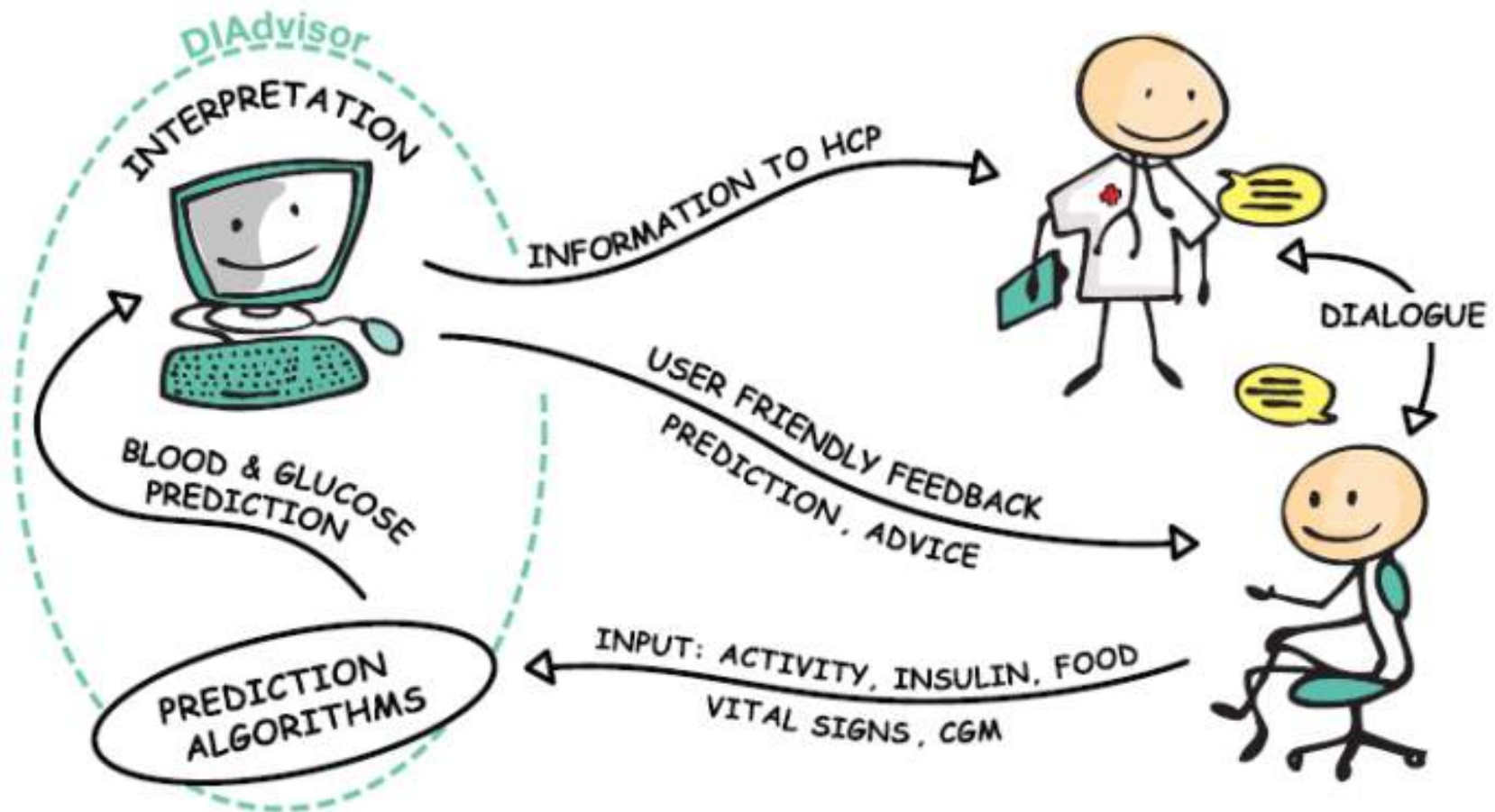


Optimal Growth of Bacteria



Lena de Mare, Automatic Control LTH 2006

The Diabetes Advisor Project

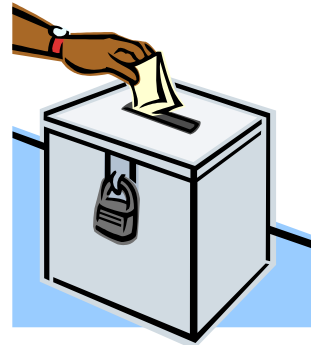
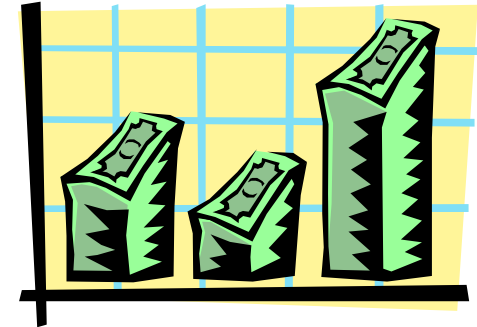


From www.diadvisor.eu



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:



References

The presentation in large parts originates from similar material collected by KarlErik Årzen, KarlJohan Åström, Anders Robertsson, Lund University. Thanks !

The Robotics images are taken from ABB home page and video clips are from Youtube

The description of Postural dynamics originates from Rolf Johansson and Måns Magnusson
Lund University

The DiAdvisor description is taken from the EU FP7 project page <http://www.diadvisor.eu>

Rocket and aircraft image originate from NASA image gallery

Image of a Mobile Platform is taken from ST Ericsson home page

Other images and video clips where source is not mentioned originate from publicly available material on Internet and are of unknown origin.

(video clips arenot included in this version of the presentation)