ENEL 441

Control Systems I

Arne Dankers

10-01-2023

Course Outline – Learning Outcomes

- System Modelling and Representations
  - Construct mathematical models of electrical, mechanical and mechatronic systems,
  - Represent and analyze a system using transfer function and state-space representations,
  - Determine properties of the transient response of a given system (rise-time, overshoot, settling time) using s-plane plots.
- Introduction to Control
  - List 4 common objectives of feedback and how to implement controllers to achieve those objectives by analyzing sensitivity functions and loop shaping,
  - Determine the stability and robustness of a feedback system using Nyquist and Bode plots.
- PID control
  - Design P controllers using Root Locus plots. Design PD, PI and PID controllers to meet design requirements.
- Lead/Lag Compensators
  - Design lead/lag compensators to meet design requirements
- Control Design Using State Feedback
  - Design controllers using state feedback (pole placement) to meet design requirements.

Controls is when mathematics comes alive!

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- I will attempt to connect theory to practice. Show how the mathematical world view of an engineer is implemented in practice.
- Many of the tools you have learned so far will be used in this course
- You will develop skills along the way that you will need in the workplace (Python, modelling, systems viewpoint).

Timetable

Section	Day(s) of the Week	Time	Location
LEC 01	TR	11:00-12:15	ENE 243
LAB B01	R	14:00-16:50	ENG 203
LAB B02	R	14:00-16:50	ENG 203
TUT T01	T	08:30-09:20	ENE 243

The first lab will start on Feb 9 (B01) and Feb 16 (B02)

Course Instructors

Course Coordinator

Section	First Name	Family Name	Phone	Office	Email
1	Arne	Dankers	403 220 8196	ICT413	arne.dankers2@ucalgary.ca

Feel free to email me with questions/concerns/comments. I will try to respond in a reasonable time. Please put ENEL441 in the subject line of the email.

I am usually in my office. Feel free to drop by and ask questions in person.

Teaching Assistants

Section	First Name	Family Name	Phone	Office	Email
	Mahmood	Khalgollah			mahmood.khalghollah@ucalgary.ca
	Amirhossein	Ahmadi			amirhossein.ahmadi@ucalgary.ca
	Shirin	Maneshkarimi			shirin.maneshkarimi@ucalgary.ca
	Gregory	Wong			gregory.wong@ucalgary.ca
	Arefeh	Kouhi			arefeh.kouhi99@gmail.com

Assessments

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Note: If students miss a required component of the course with a valid reason, they must contact the instructor in writing within 24 hours to discuss the reasoning and options to submit and/or make-up for that component.

Final Exam: There will be a 3 hour final exam scheduled by the registrar.

Quizzes: There will be 5 scheduled quizzes that will take place during scheduled tutorial sessions. Each quiz will be 50min duration and will cover the material of one unit. The best 4 out of 5 quizzes will be used to calculate the final grade.
Quiz 1 - Unit 1 (System Modelling and Representations) - Tues. Feb 7
Quiz 2 - Unit 2 (Introduction to Control) - Tues. Feb 28
Quiz 3 - Unit 3 (PID Control) - Tues. March 14
Quiz 4 - Unit 4 (Lead/Lag Compensators) - Tues. March 28
Quiz 5 - Unit 5 (Control Design using State Feedback) - Tues April 11

Assignments - There will be 5 take home assignments. Each assignment will cover the material of one unit. Assignments will be due by 5pm and must be submitted electronically via D2L.
Assignment 1 - Unit 1 (System Modelling and Representations) - Tues. Jan 31
Assignment 2 - Unit 2 (Introduction to Control) - Tues. Feb. 14.
Assignment 3 - Unit 3 (PID Control) - Tues. March 7
Assignment 4 - Unit 4 (Lead/Lag Compensators) - Tues. March 21
Assignment 5 - Unit 5 (Control Design using State Feedback) - Tues. April 3

Labs - There will be four labs that will be held during lab sessions. Each lab must be completed during the scheduled time. The first lab will start on Feb. 9 (B01) and Feb 16 (B02).

Final Grade Determination

Component	Learning Outcome(s) Evaluated	Weight
Quizzes	1-8	25%
Assignments	1-8	25%
Labs	1-8	25%
Final Exam	1-8	25%

Total:	100%

Textbook

Title	Modern Control Engineering
Author(s)	Katsuhiko Ogata
Edition, Year	5'th Edition, 2010
Publisher	Prentice Hall

Course Delivery - Lectures

- Mix between lecturing and tutorial style
- Technical content will be posted in videos on D2L. Watch the assigned videos before class.
- In class activities will consist of
  - Pencil and paper exercises (please come prepared).
  - Python exercises (focused on exploration not coding). Please bring a laptop, sit together around someone with a laptop, or contact me to borrow a laptop.
  - Mentimeter question and answer sessions.

Course Delivery - Tutorials

- Will focus on in class activities:
  - Pencil and paper exercises
  - Python exercises

Quizzes will be held during tutorials.

Course Delivery - Labs

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- 4 labs
- Simulation based (Python)
- Completed and handed in during the scheduled sessions

Test Mentimeter

Objectives

- Help you learn!
- Help me see how it is going

Notes:

- Private – no identifiers associated with answers, only final tally of answers can be accessed.
- Not for grades

Test - Running Python Jupyter Notebooks using Binder

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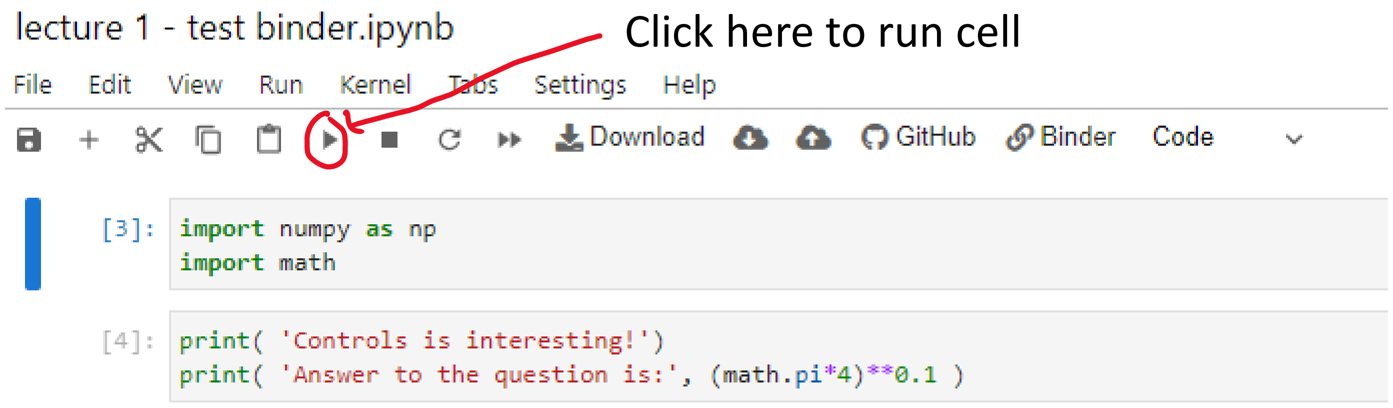
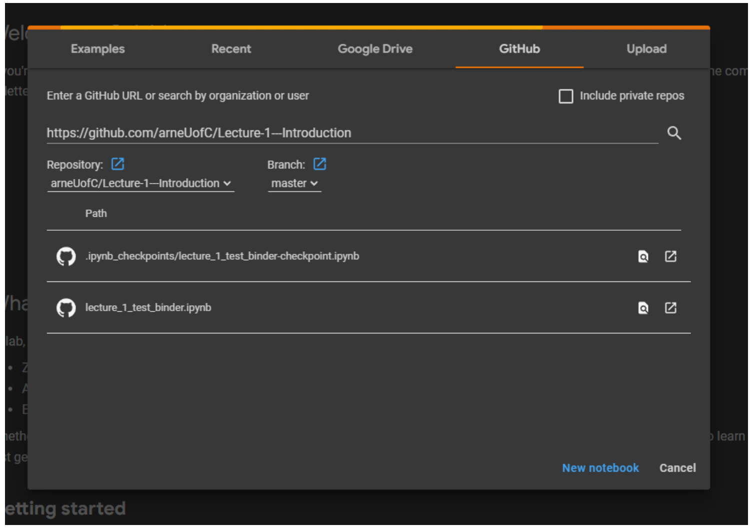
- Click on the link: https://mybinder.org/v2/gh/arneUofC/Lecture-1---Introduction/HEAD?labpath=lecture_1_test_binder.ipynb
- This should launch a Jupyter Notebook (although it may take a little while).
- Should see something like:



- Once the notebook launches, click on the "run" button and run all the cell in the notebook. You can also run cells by pressing Shift+Enter while the cell is active.

Test - Colab

- Go to: https://colab.research.google.com/
- Click on GitHub tab
- In the GitHub URL enter https://github.com/arneUofC/Lecture-1---Introduction
- You should see a .ipynb file called 'lecture_1_test_bind.ipynb. Open it.



Installing Jupyter Notebooks

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- Instead of using Binder, you can install a local version of Jupyter Notebooks and run the code locally on your machine. The advantage of this method is that any changes you make to the code will be saved on your machine.
- On D2L I have provided instructions on how to download and install Jupyter Notebooks.
- I showed 3 different way:
  - Miniconda
  - Anaconda
  - Colab
  - There are many other ways. Feel free to choose your own favorite version if you prefer.

Introduction – Arne Dankers

My research is in data driven modelling aka system identification

What is System Identification

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System Identification is a class of machine learning (ML) that uses data to learn the differential equations that govern a system. For example, the equations governing a chemical reaction can be learned using data. The result is a model of a system.

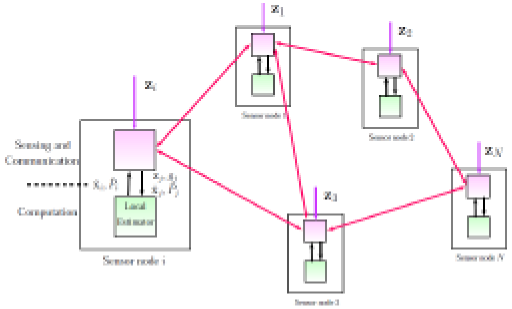
Think of it as ML tailored to engineering systems

What is System Identification Used For?

1. The resulting models can be used in order to design better controllers. Through better control the system can be made more energy efficient, or the purity of an end-product can be increased.
2. The resulting models can also be used to monitor the process for anomalies, changes or faults. The models can be used for predictive maintenance.

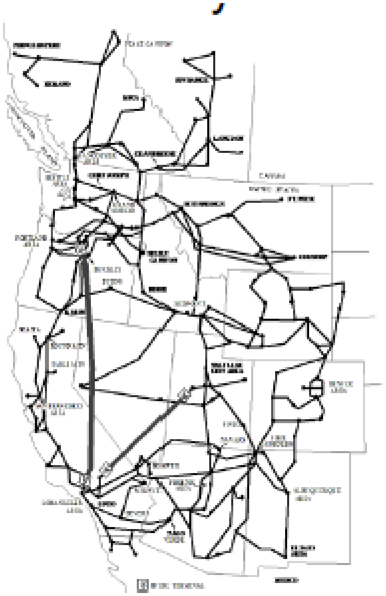
Network System Identification

Distributed control



source: Simonetto 2012

Power systems



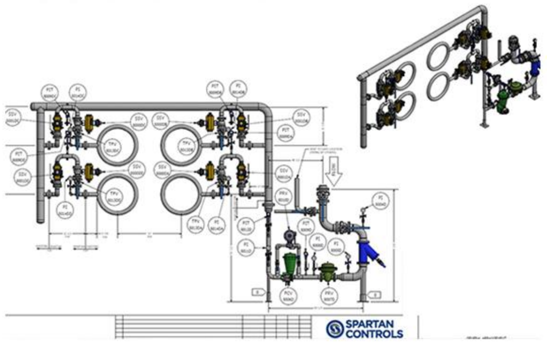
source: Pierre et al. 2012

Mechatronic Systems

Source: https://www.howtorobot.com/expert-insight/robotic-arms

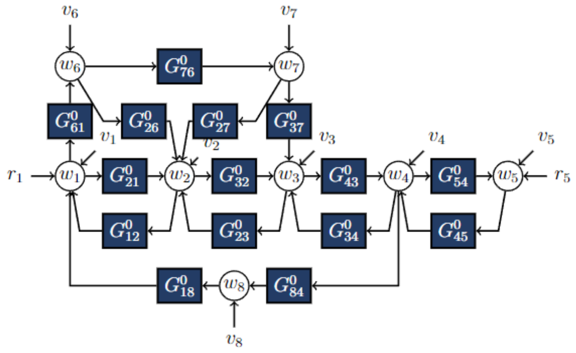
Unleash the Potential of Sensor Data!

Process



Source:
https://www.spartancontrols.com/solutions/combustion-management/boilers/water-tube-boilers/

Model



Sensor data

Optimization

Monitoring

Acoustic Pipeline Monitoring

hifi

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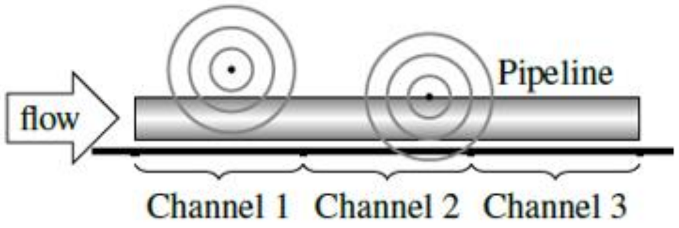
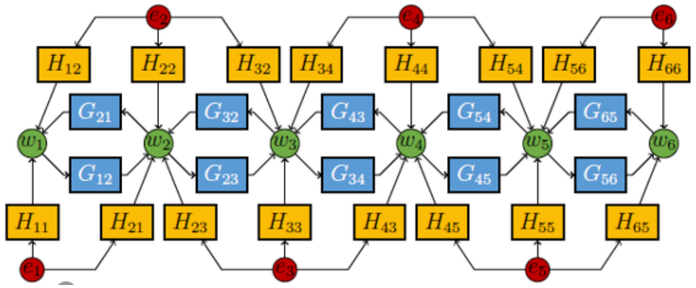
System

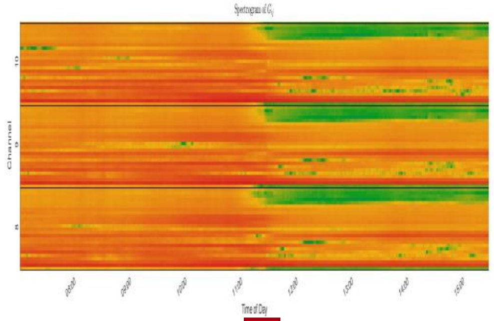


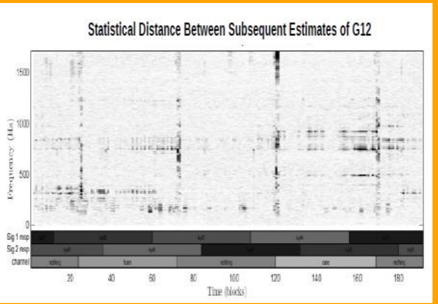
Acoustic sensors placed along pipeline

Model

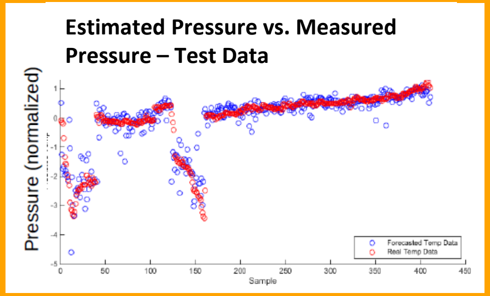


Using sensor data, estimate frequency response of pipeline dynamics every minute





Monitor for statistically significant changes



Use ML to classify/diagnose estimated transfer function

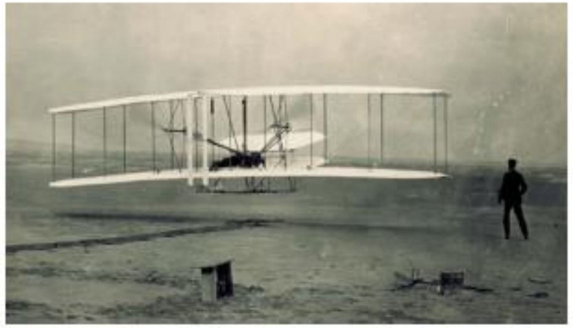
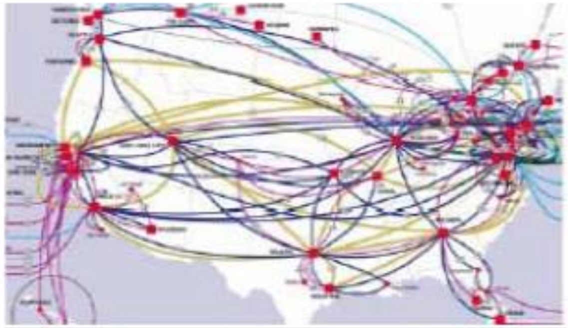
Attabotics

https://www.google.com/search?q=attabotics&rlz=1C1GCEA_enCA1019CA1019&source=lnms&tbm=vid&sa=X&ved=2ahUKEwjnocj2la38AhX1JTQIHRJ_ByQQ_AUoA3oECAEQBQ&biw=1280&bih=552&dpr=1.5#fpstate=ive&vld=cid:ef69d7d2,vid:WLtEBaHkNJc

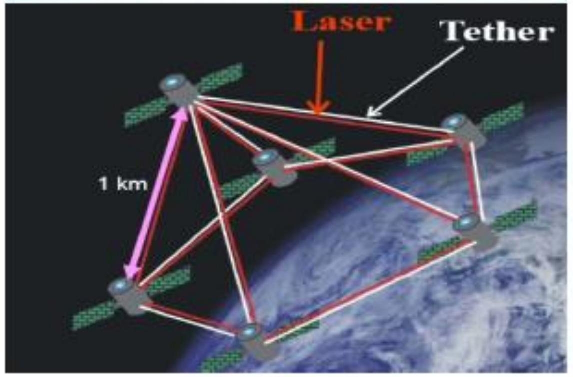
Want a Summer Job?

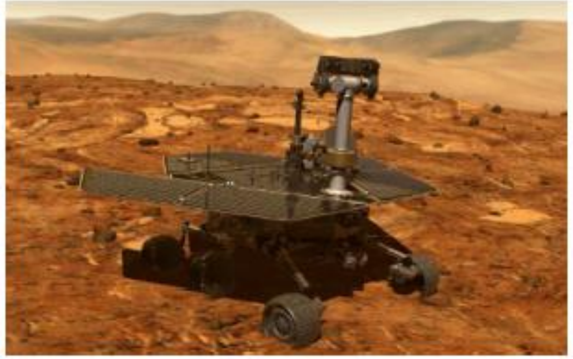
- Looking for summer students to 3D print a robotic arm and design/build a mini pipeline for acoustic monitoring.

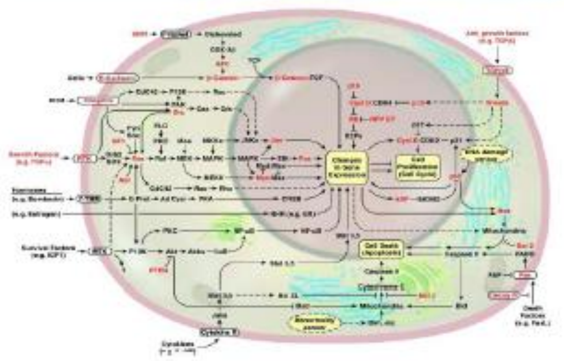
Introduction to Feedback and Control



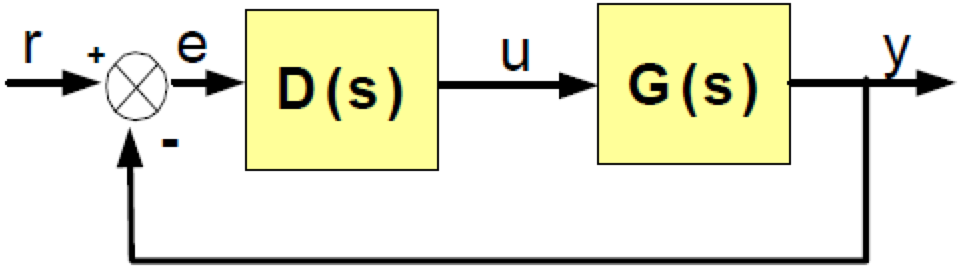






Feedback

The important principle of feedback:



"Measure and (re)act"

Examples of Control Systems

ASML:

https://www.youtube.com/watch?v=wI6nCmG-PpI

Future traffic intersection?:

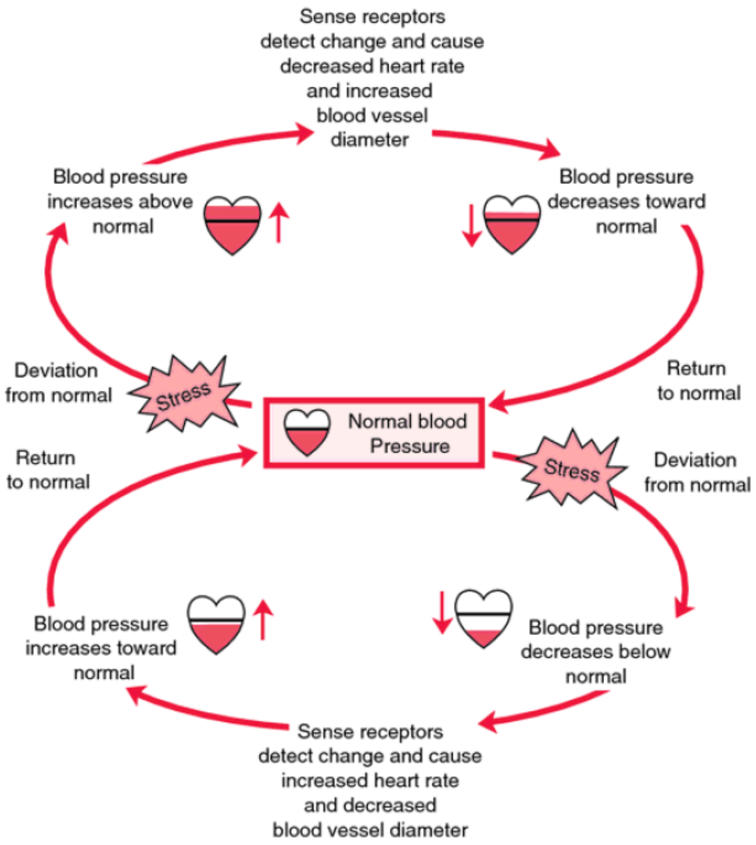
https://vimeo.com/106226560

In nature, feedback is everywhere:

https://www.google.com/search?q=feedback+in+nature&rlz=1C1GCEA_enCA1019CA1019&source=lnms&tbm=vid&sa=X&ved=2ahUKEwivof7Jjq38AhWbMDQIHbgwBrcQ_AUoAnoECAIQBA&biw=1280&bih=552&dpr=1.5#fpstate=ive&vld=cid:4d29c0bd,vid:inVZoI1AkC8

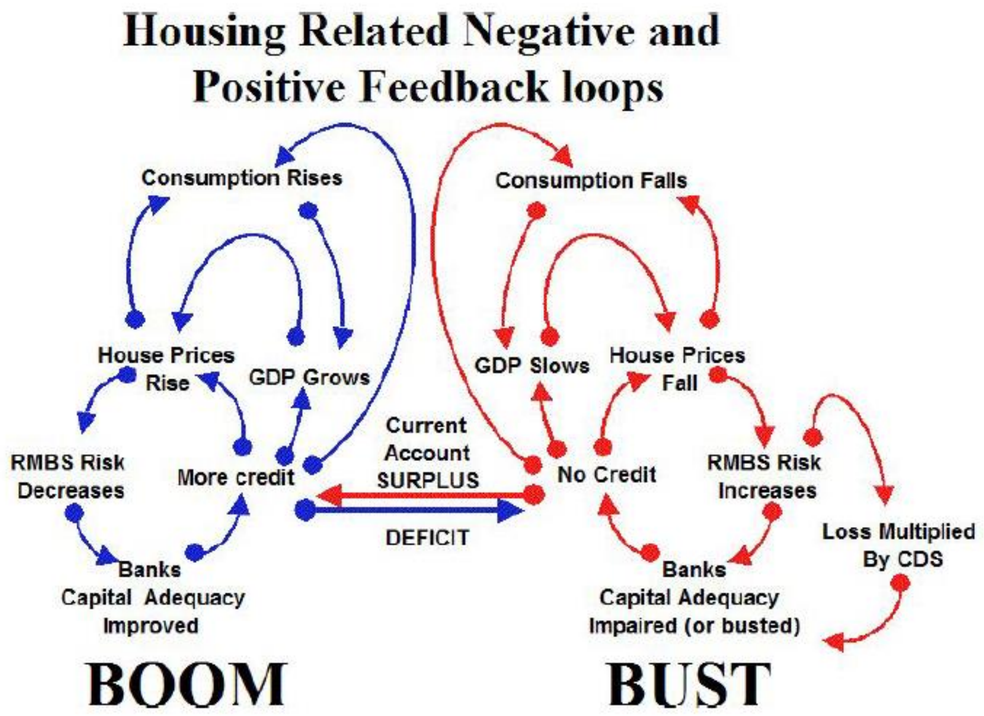
Cannot have intelligence without feedback.

Feedback



Sense receptors detect change and cause decreased heart rate and increased blood vessel diameter
Blood pressure increases above normal
Blood pressure decreases toward normal
Deviation from normal
Stress
Normal blood Pressure
Return to normal
Return to normal
Stress
Deviation from normal
Blood pressure increases toward normal
Blood pressure decreases below normal
Sense receptors detect change and cause increased heart rate and decreased blood vessel diameter

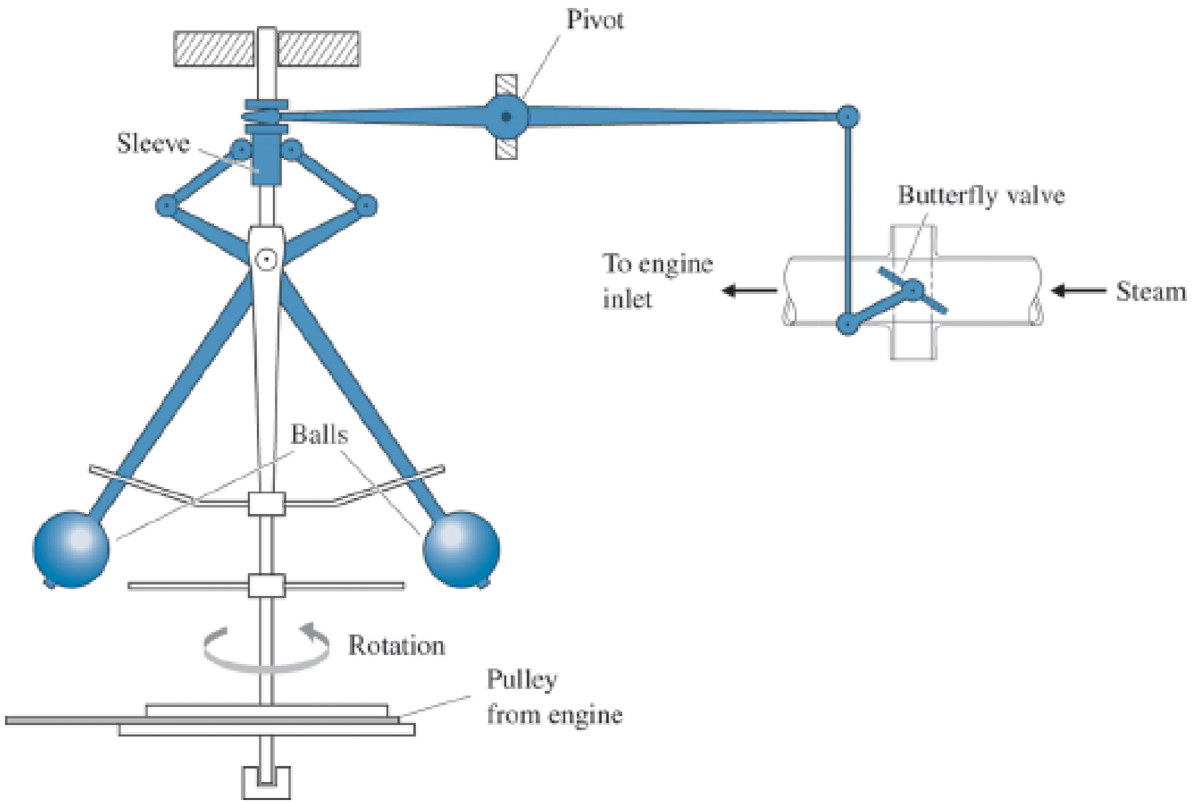
Feedback


Housing Related Negative and Positive Feedback loops
Consumption Rises
House Prices Rise
GDP Grows
RMBS Risk Decreases
More credit
Banks Capital Adequacy Improved
Current Account SURPLUS
DEFICIT
Consumption Falls
GDP Slows
House Prices Fall
No Credit
RMBS Risk Increases
Loss Multiplied By CDS
Banks Capital Adequacy Impaired (or busted)
BOOM
BUST

Feedback

Which other examples can you think of?

Historical Notes – Centrifugal Governor



- Keeps rotational speed constant
- Speed is largely independent from engine load
- Principle attributed to Watt and Boulton in 1788
- Stability analysis: Maxwell (1868) and Hurwitz (1895)

Electronic Feedback Amplifier (Black 1928)

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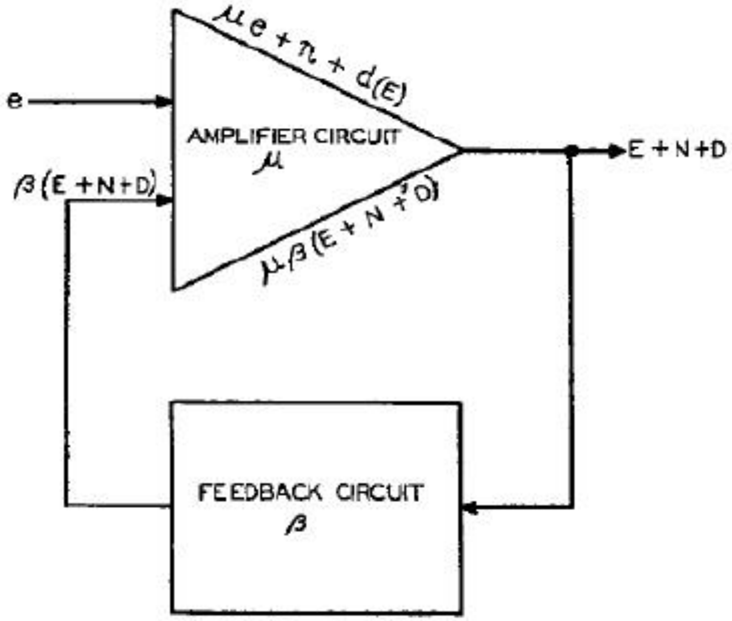
One of the most important inventions of the 20th century.



- Reliable amplifier by applying negative feedback,
- Linearization and disturbance rejection, but also risk for instability (ringing)

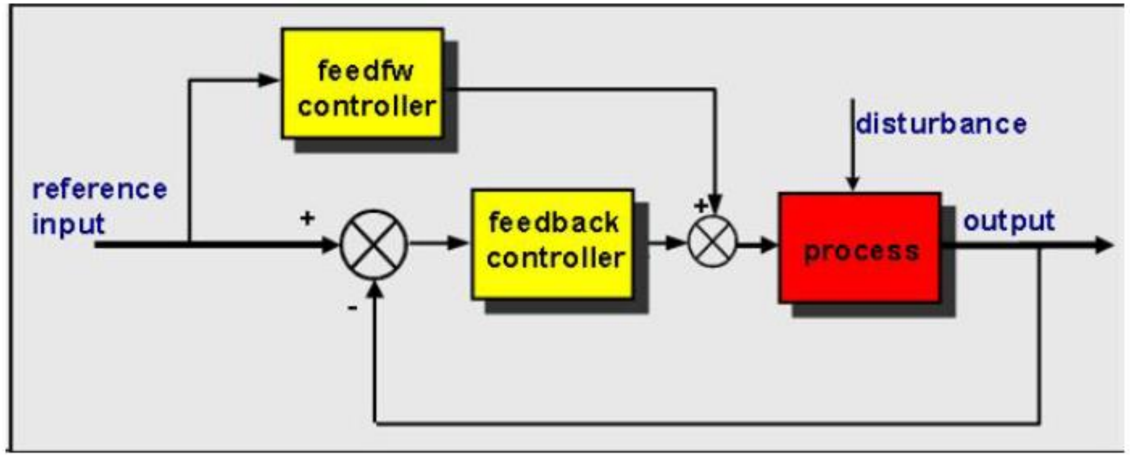
Feedback - Question

When you ride you bike, which control mechanisms do you apply?

Is this only feedback control?

Feedforward Control

Feed-forward can be an important control (steering) mechanism:



If you know where you should be going: steer upfront (and choose the right trajectory) by looking ahead

Control Systems

Combine:

- Models (to predict the ‘correct’ action),
- Sensors (to interact with/sense the environment),
- Actuators (to exert an action),
- Controllers (to decide what action to do)

In this Course

- Basic modelling (this is not a modelling course)
- Understand advantages of feedback
- Learn how to design 3 types of controllers (PID, lead/lag, pole-placement)

This is a great course!

- Control systems arise whenever you attempt to implement a system that needs to operate in the real world. By definition control systems live at the interface between theory and reality. To me this is fascinating!
- Control system design can be creative

Goals:

- https://www.youtube.com/watch?v=XWhGjxdug0o
- https://www.youtube.com/watch?v=jQXaMMotblE