Control Systems ELEN90055

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Partly based on material by Profs D. Nesic and M. Cantoni

Lectures

- 3 zoom lectures/week x 12 weeks in Wright Theatre, Medical Building
  - Mon & Wed 12-1pm, Thurs 10-11am (Melbourne time)

- Lectures will also be live-streamed over zoom, with recordings made available afterwards (see Zoom tab in subject LMS website)

- When possible, every alternate Thurs lecture slot will be used as a tutorial-style class, in which I'll work through selected problems from a worksheet.

- Lecturer consultation:

  Week 1 only: Fri 11am-12pm, room 214, level 2, EEE

  Weeks 2-12: Monday 2.45 – 3.45pm , room 214, level 2, EEE

Other Resources on Subject Website

- Worksheets - will be made available a few days before each tutorial-style lecture. Solutions will be released after each tutorial.
- Supplementary Notes and Problem Sets by M. Cantoni - useful resources that you should read and attempt on your own

Books

- I'll loosely follow *Control System Design* by Goodwin, Graebe and Salgado (Prentice Hall)
- Other texts I'll refer to:
  - *Modern Control Engineering* by Ogata (Prentice Hall, 5th ed)
  - *Feedback Control of Dynamic Systems* by Franklin, Powell & Emami-Naeini (Pearson)

Workshop Classes

- MATLAB/Simulink-based. Classes commence Week 3 (Mon Aug 9). Zoom meeting ID’s for each class will released in Week 2, on Canvas.
- There are currently 9 workshop slots/week. Enrol in one fixed slot/week via the student system – some may be full and not accepting new enrolments.
- 7 of the workshops will be conducted in-person in EDS8, while 2 are online-only, via zoom.
- Email me if all the workshop classes currently listed as available clash with other **core** subjects you’re doing.

Assessment

- **Mid-term written test** (around week 7) - 10%
- **Final written exam** (3 hours at end of semester; hurdle) - 70%
- **Two workshop reports** each worth 10%, including up to 2% in-class individual assessment each.
- The first report is due in Week 10, the second due date will be advised.
- Reports to be written in groups of max. 2, with others in the same class. Don’t miss your first few classes, which are when most groups are formed. Your demonstrator can help you form a group if you don’t know anyone else in the class.

Lecture 1

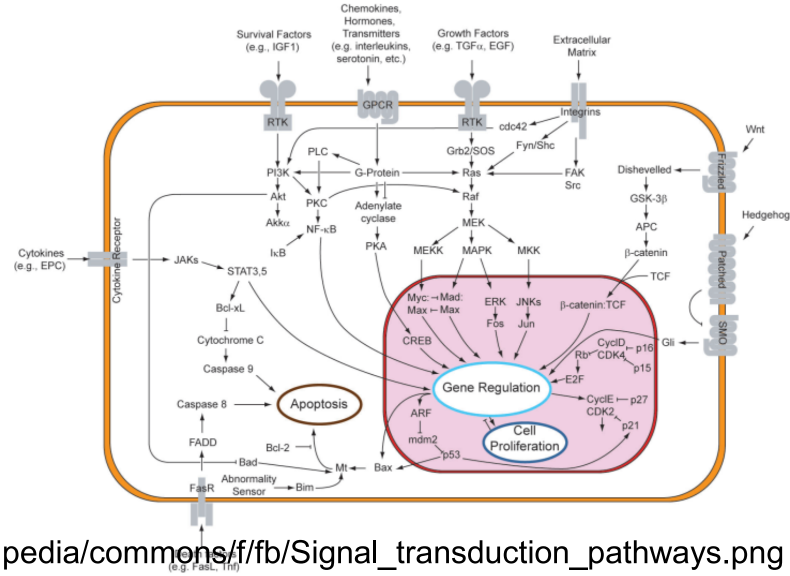
Introduction to Control

Dynamical Systems Revisited

- Any colelction of things that can change with time is a *dynamical system*
- Defined by
  - Variables that can change with time, i.e. *signals*. E.g. inputs (*u)* that can be freely adjusted, external disturbances (*d)* or *references (r);* outputs (*y)* that are measured and/or have special relevance for the application.
  - A law or rule that describes how these signals interact and evolve over time for any input (and initial condition). E.g. differential equations, difference equations.

A few examples

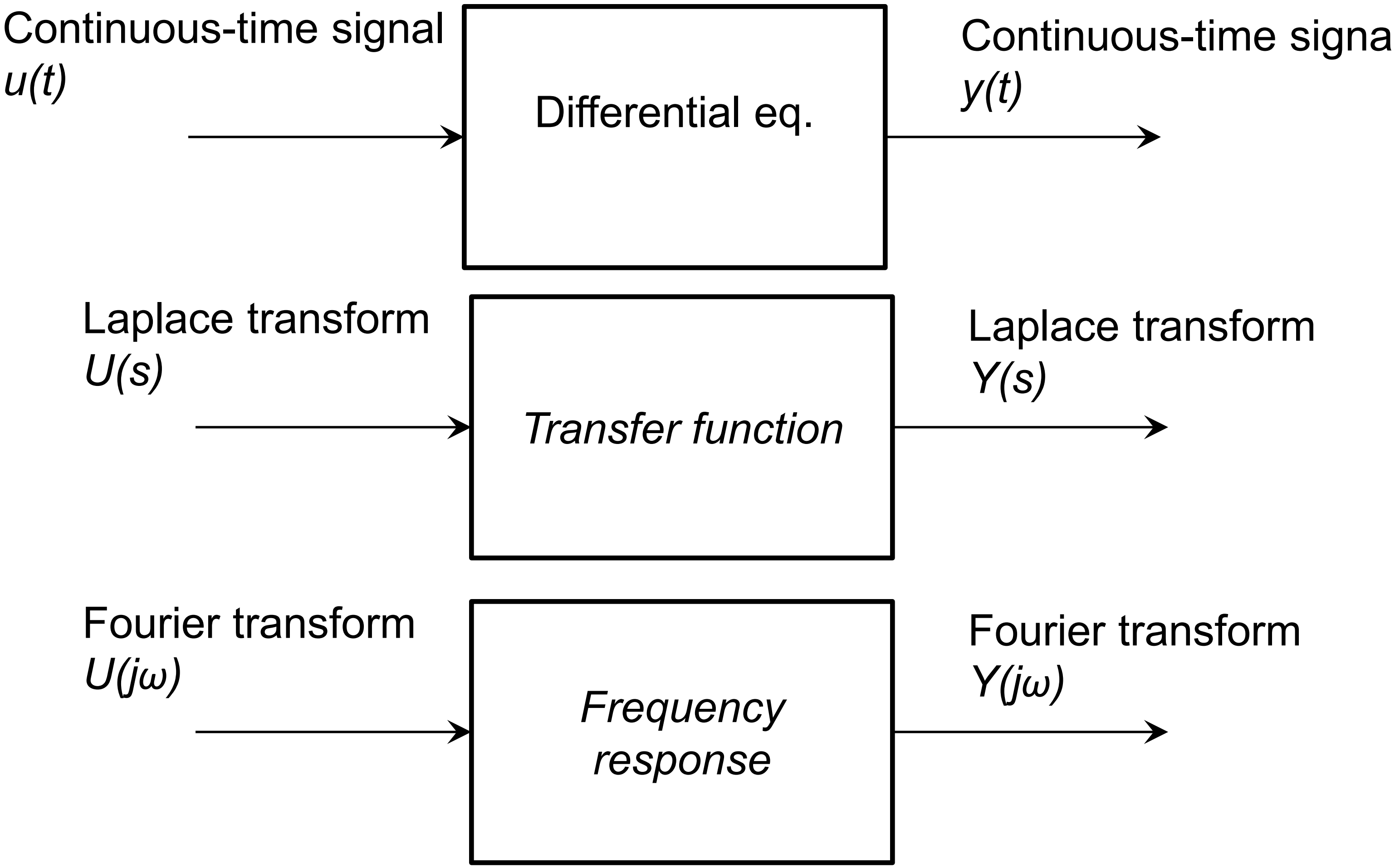
https://msd.unimelb.edu.au/research/projects/completed/building-with-drones



https://upload.wikimedia.org/wikipedia/commons/f/fb/Signal_transduction_pathways.png

http://www.enhar.com.au/templates/images/wind_turbine.jpg

Modelling Dynamical Systems



Control Systems

- In a *control system*, an input signal *u* is chosen specially to try to make output signal *y* behave in a specified way – e.g. to quickly approach and remain close to close to some desired set-point.
- If there are no disturbances and the input-output dynamics are "nice" (e.g. static or *stably invertible*), easy: just invert to find *u* that yields the desired *y*.
- But the real world has unmeasured disturbances, parameter deviations, or unstable/oscillatory dynamics.

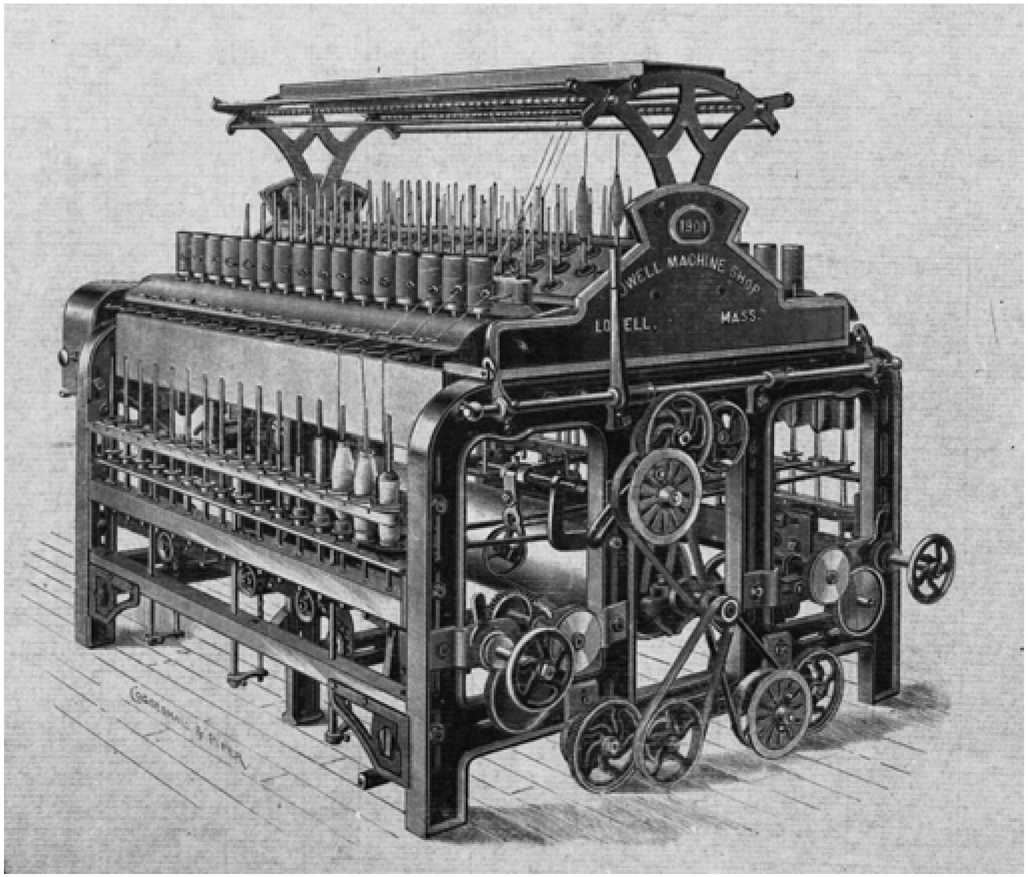
➔ **Feedback Control.** Measure *y*, then design a *feedback controller* that changes *u* to automatically compensate for these issues

Prevalence of control systems

- Control systems are ubiquitous in our world
- An enabling technology: essential for the reliable operation of most engineered and natural systems.
- The success of control means it is often invisible to non-experts…till something goes wrong!

Transportation systems, cars, planes, drones, agriculture, irrigation, food processing,Household appliances, HVAC, TVs, phones, internet, telecommunication systems, manufacturing industry, chemical processes, digital technology, electrical power systems, medical technology…

Control and the Industrial Revolution

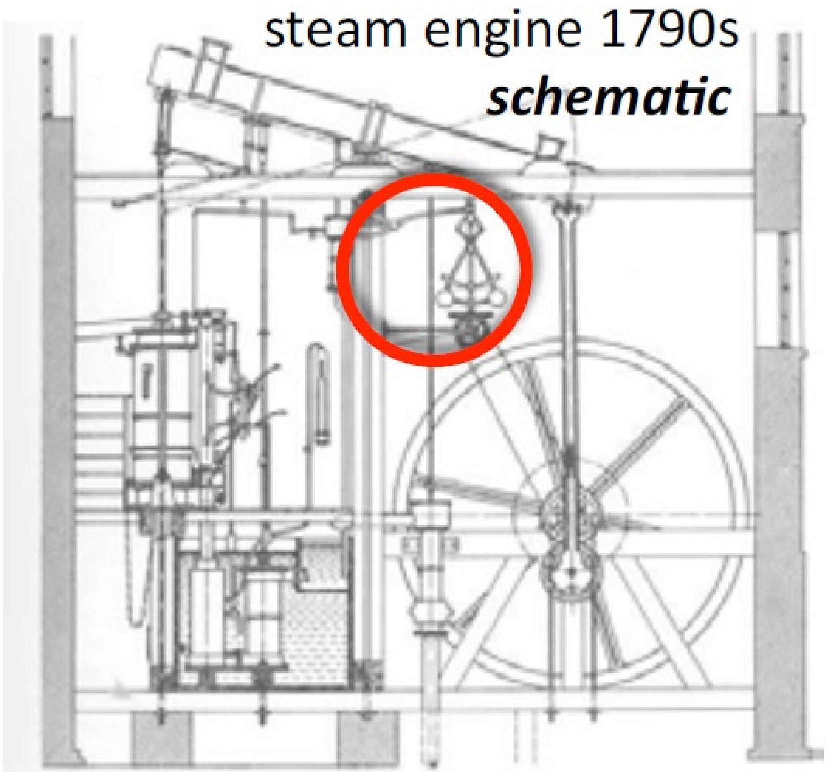


Industrial revolution was largely driven by the mass production, e.g. in textiles industry.

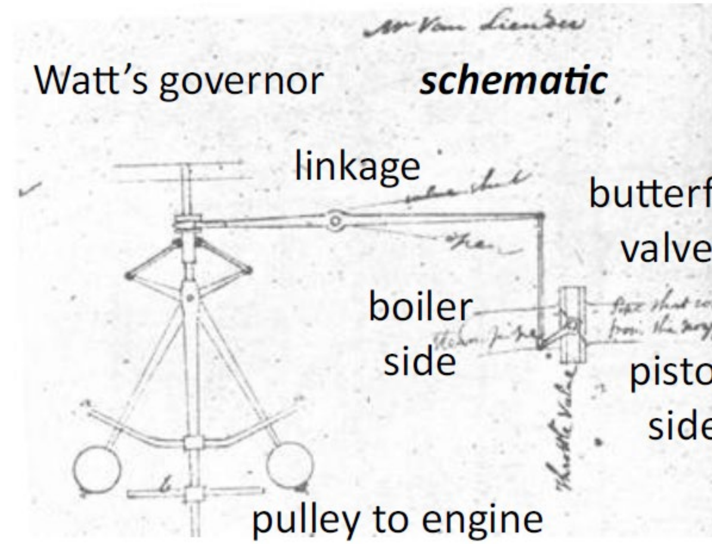
A control system was at the heart of machines that fuelled the industrial revolution.

Taken from http://boivieapedia.pbworks.com/f/1270415464/spinning_frame.gif

Watt's fly-ball governor



http://www-g.eng.cam.ac.uk/125/1950-1975/control_wattengine.html



http://www-g.eng.cam.ac.uk/125/1950-1975/control_governor.html

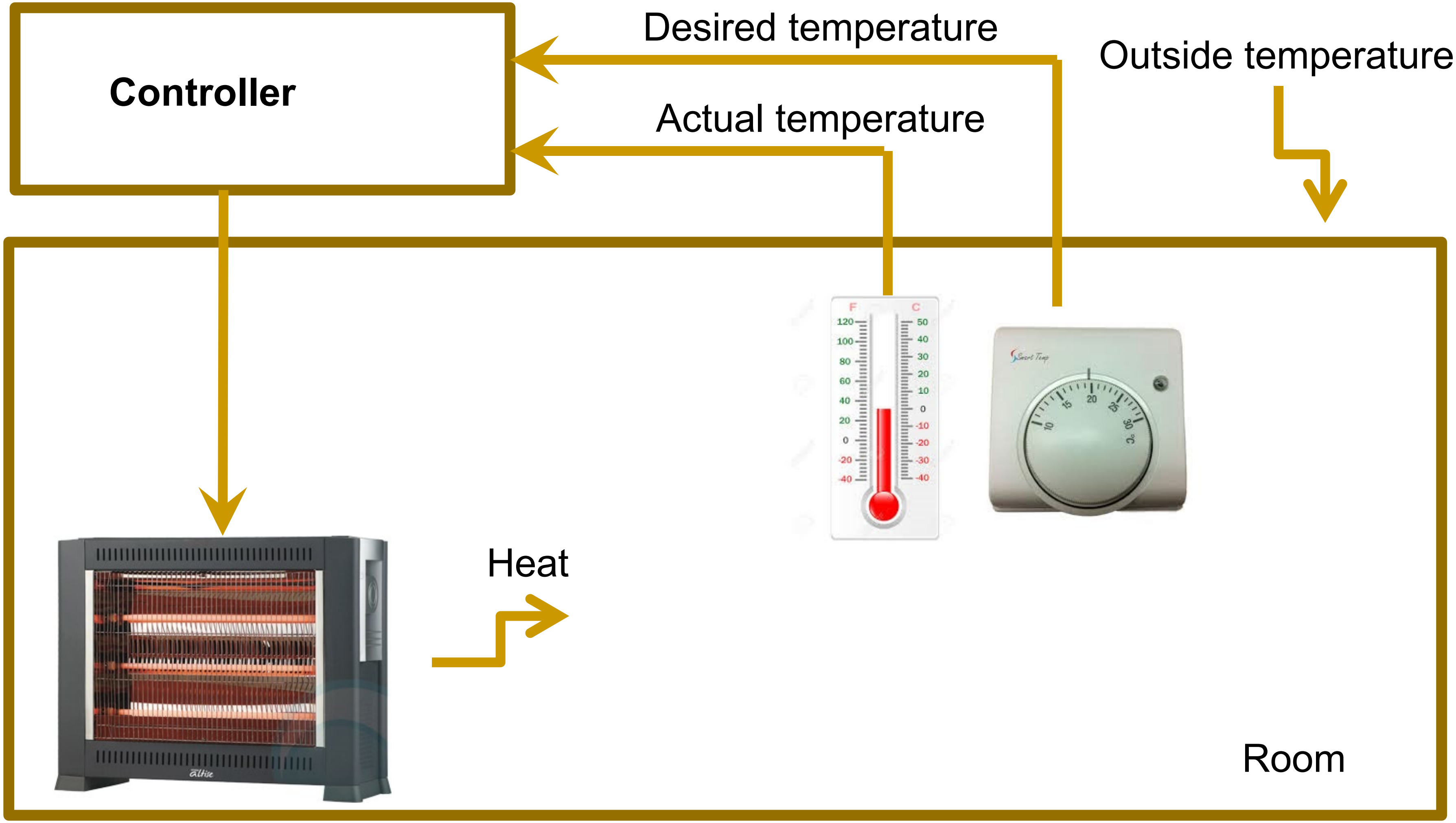
1778, Watt based his design on similar governors in windmills.

1868, Maxwell analysed it and posed a control problem for Adams Prize.

1877, E.J. Routh won the Adams Prize.

See animation on http://www.mekanizmalar.com/flyball_governor.html

Room temperature control



Components of Control System

- Plant (room) – given dynamical system we want to control;
- Sensor (thermometer) – measurement device
- Actuator (heater) – device that enables us to affect the sensor

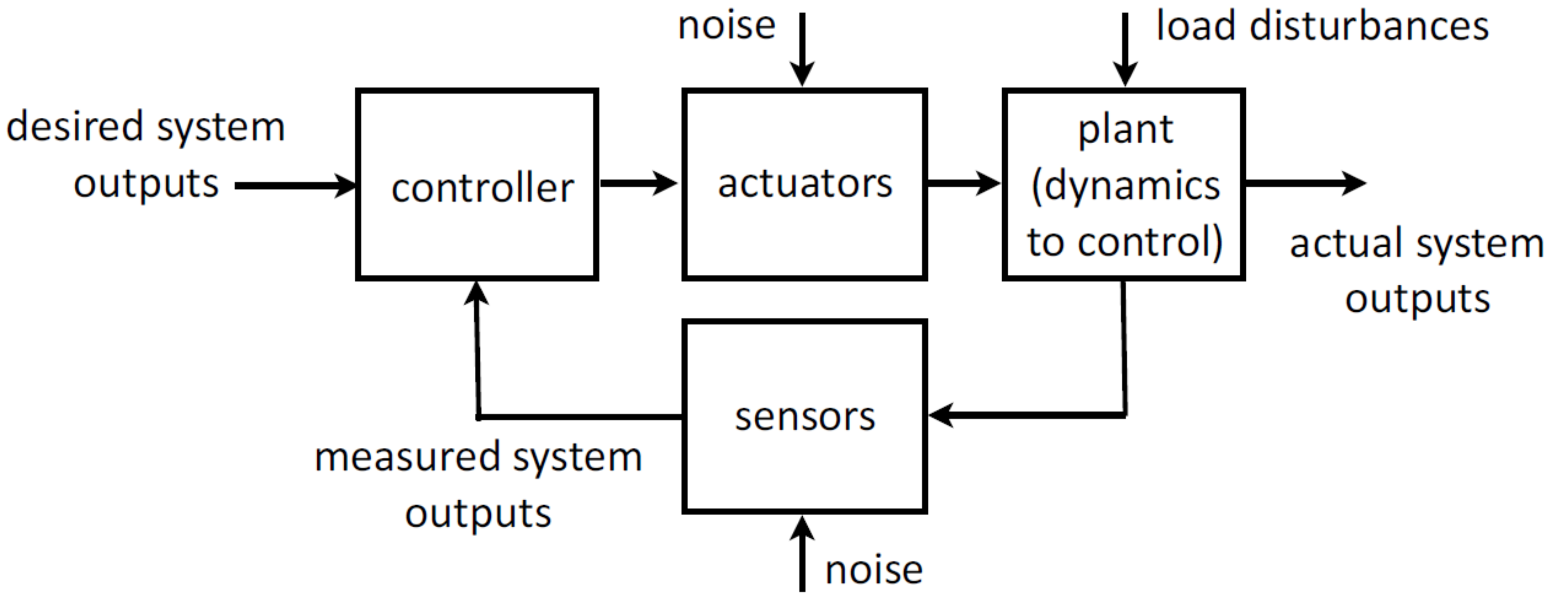
Note: if the sensor and actuator have their own dynamics, these are often combined with the plant to form a larger virtual plant

- Controller – device that takes sensor measurements and sends control inputs to the actuator

Main Signals in a Control System

- Output (actual temperature) – physical variable we are interested in controlling
- Input (voltage signal to heater) – signal produced by controller to be fed to the actuator
- Disturbance (outside temperature) – physical variable that affects the system dynamics; can't be controlled
- Noise – high frequency disturbances

Block diagram of feedback control



Signals (physical variables) represented by arrows
Systems (devices) represented by boxes
NOTE THE FEEDBACK CONNECTION!

Tentative Schedule: weeks 1 – 4

- Fundamental tools for open-loop dynamical systems:
- Differential equation models; linearisation; step response; convolution; transfer functions; time-domain effects of poles and zeros; input-output stability; frequency response; Bode plots

- see Chapters 3 and 4 of GGS

Tentative Schedule: weeks 5 – 9

- Stability and performance of LTI feedback control systems
  - Closed-loop stability; closed-loop sensitivity functions; root-locus plots; Nyquist plots; relative stability; robustness to model uncertainty; fundamental limitations; the internal model principle; feedforward compensation
- see Chapters 5, 8 and 10 of GGS

Tentative Schedule: weeks 10-12

- Designing feedback controllers to meet stability and performance specifications:
  - Proportional (P), integral (I), lag and lead compensation; PID controllers and empirical tuning rules; classical loop-shaping; the polynomial approach to pole-placement;
- see Chapters 6 and 7 of GGS
- Time permitting: techniques for dealing with actuator constraints (Chapter 11 of GGS)

Conclusions

- Control systems are an enabling technology that are ubiquitous but hidden in the engineered and natural world
- An important feature of control systems is feedback
- Block diagrams are a useful abstraction for understanding the operation of control systems
- We introduced the basic elements of a control system via an example.