ENEL441
Control Systems I
Introduction
unit 1

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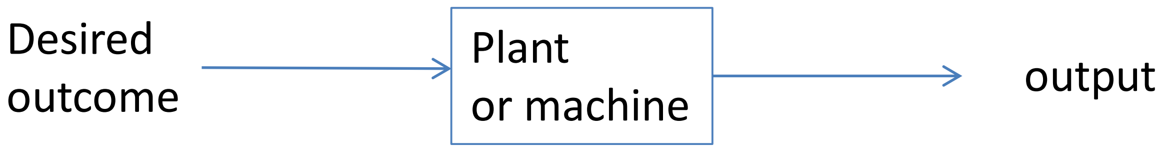
Office hours – anytime I'm in my office (afternoons are best)

What is a control system?

A system that:

- controls a machine or process
- ruled by some desired outcome

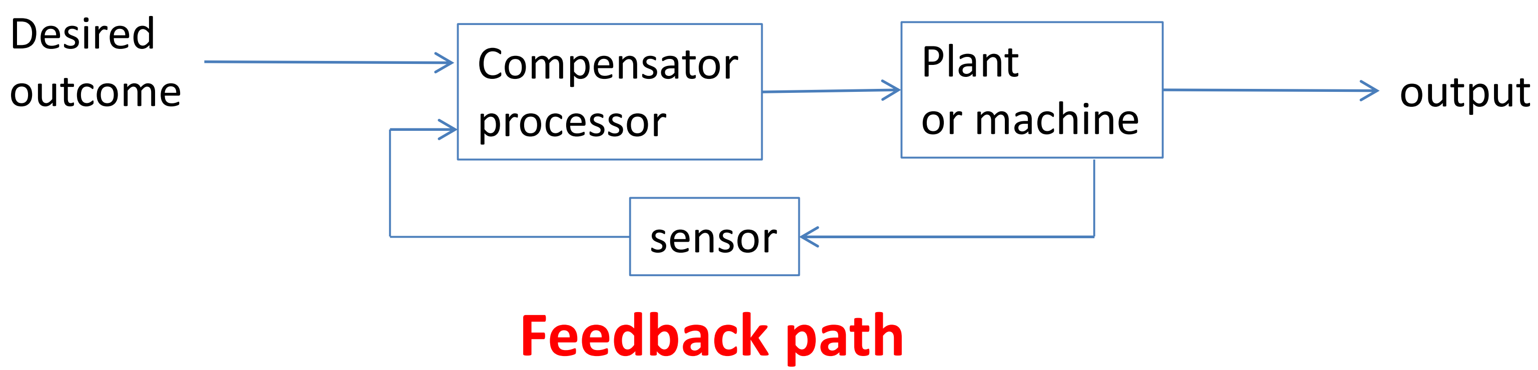


How do we know it is working?

Is the output in accordance with desired outcome?

Need to monitor what the system is doing

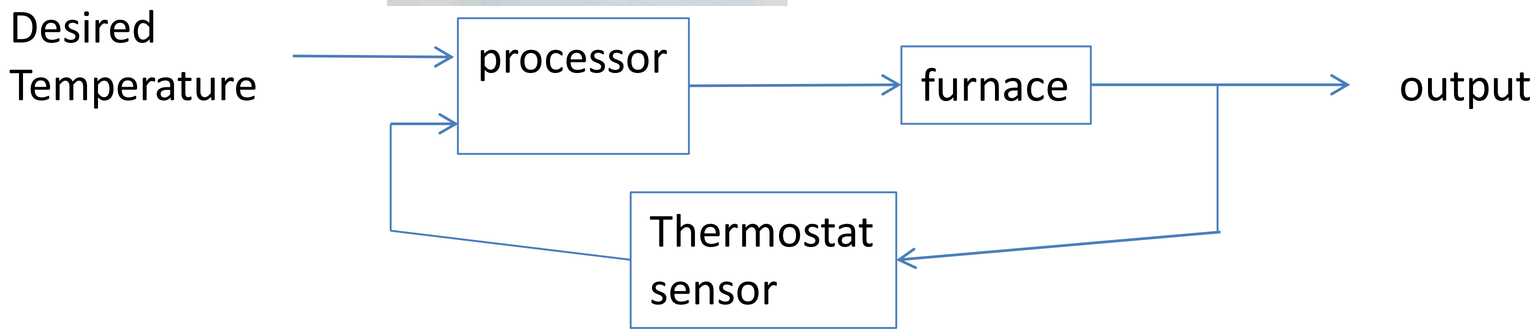
- Sensor feedback
- Compare with desired outcome



feedback control system

ENEL441 primarily about designing systems with feedback

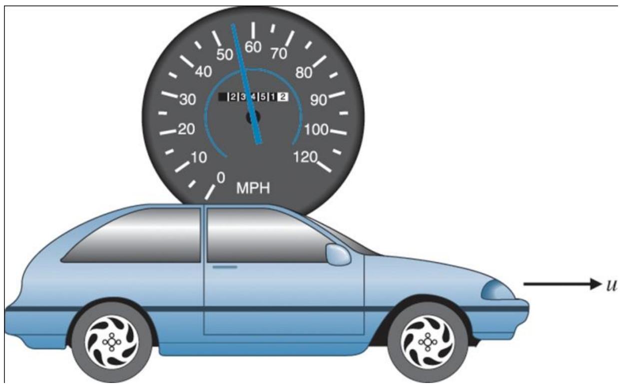
Simple example – heating system for a house

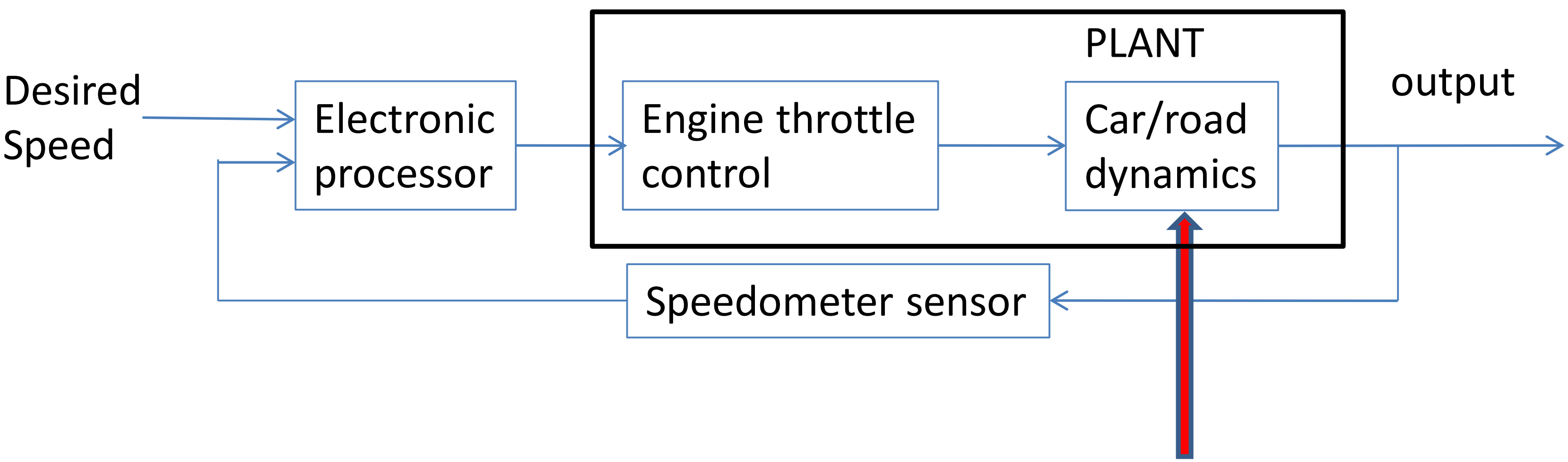


Feedback path

- Operator sets the desired temperature to 20^{o}C and goes away
- Processor controls when to best turn on/off the furnace (built-in rules)
- control loop simplifies the operation of furnace

Another example – car cruise control





Control loop compensates for random variable road conditions
-uphill/downhill, wind, road friction etc.

Control of a Drone quad rotor
control of four rotors difficult, need experienced pilot

Consider the problem of controlling the rotation rate of each of the four rotors directly

Control of a Drone quad rotor

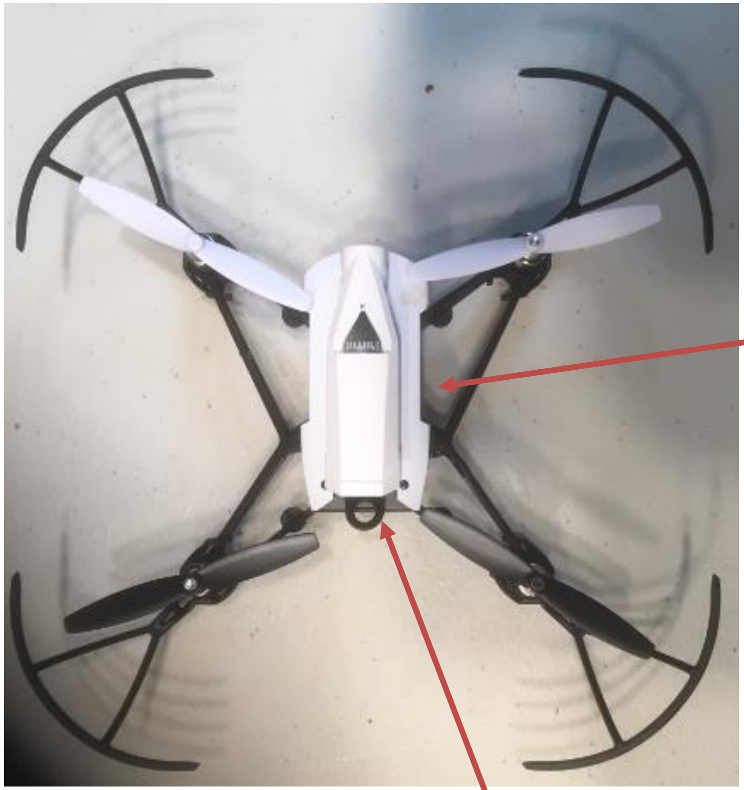
control of four rotors difficult, need experienced pilot

User input
up/down
Forward/backward
Left/right

Intelligent control
Maps simplified user commands to
complex rotor control

Untrained pilot
Point and fly

Drones



Wireless link

User input
up/down
Forward/backward
Left/right

Internal sensors
Camera, inertial, ultrasonic
Embedded controller with real time control algorithm

Simplified user control

Drones

Accelerometer
For tilt sense

Rate gyro for
Rotation sense

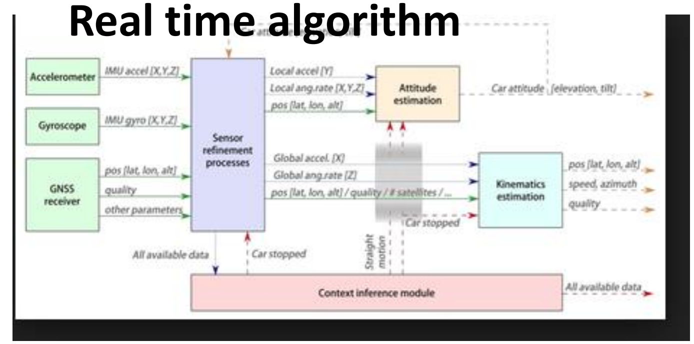
Camera

ultrasonic

Drones

Microcontroller with control

Real time algorithm



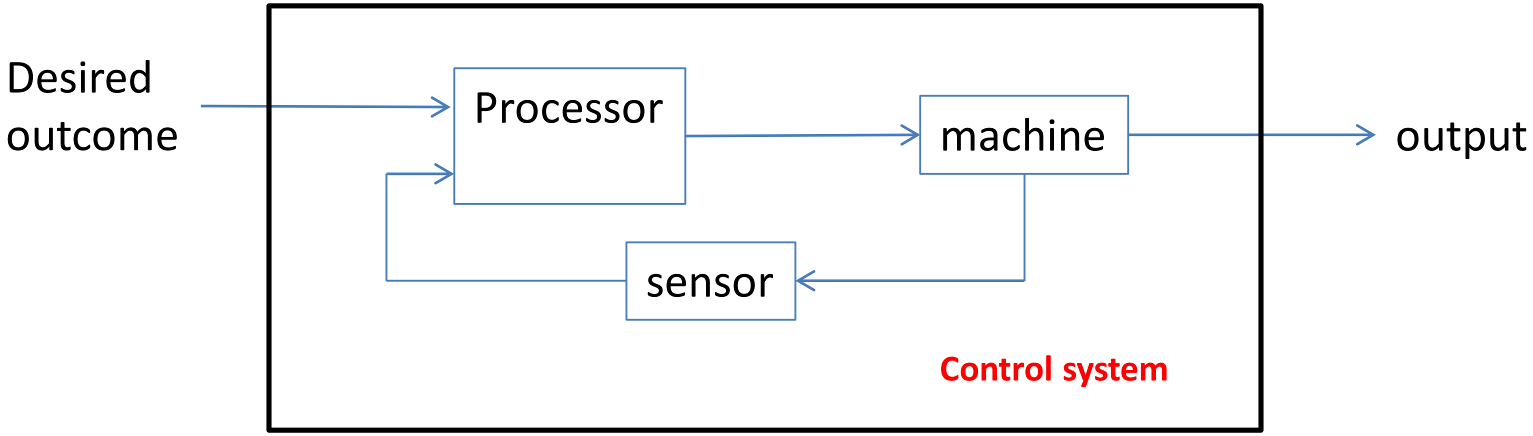
Rotor control

Camera

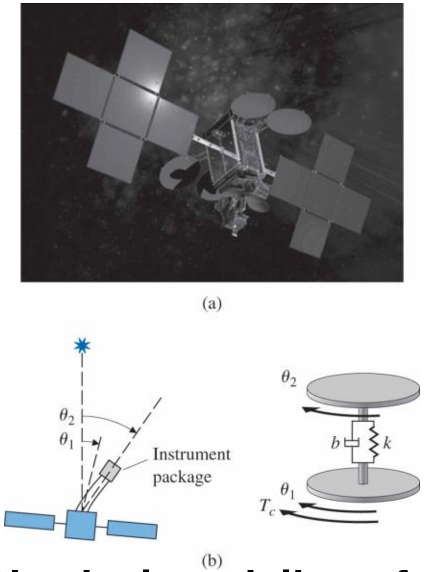
ultrasonic

Overall Objectives of ENEL441

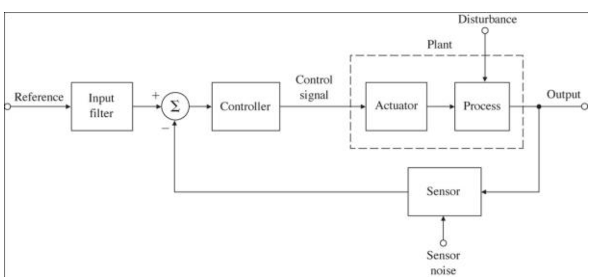
- Analyze and model the machine (plant)
- Design processor based on control performance specifications.
- Specify sensors required to complete loop
- processor implementation, analog and digital



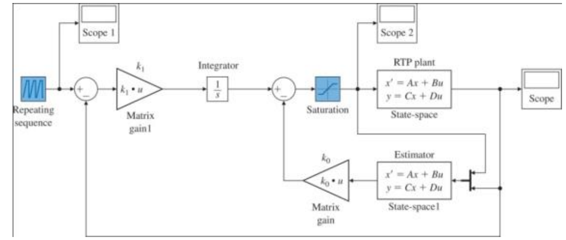
So what is 441 about?



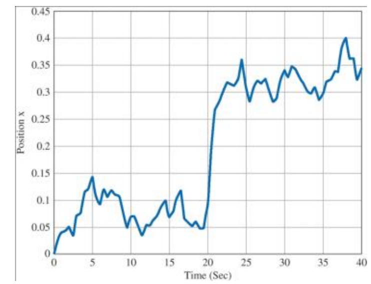
1. Physical modeling of machines and systems



2. Mapping model into a linear continuous time system



3. System simulation (Matlab/Simulink)



4. Analysis of system dynamics

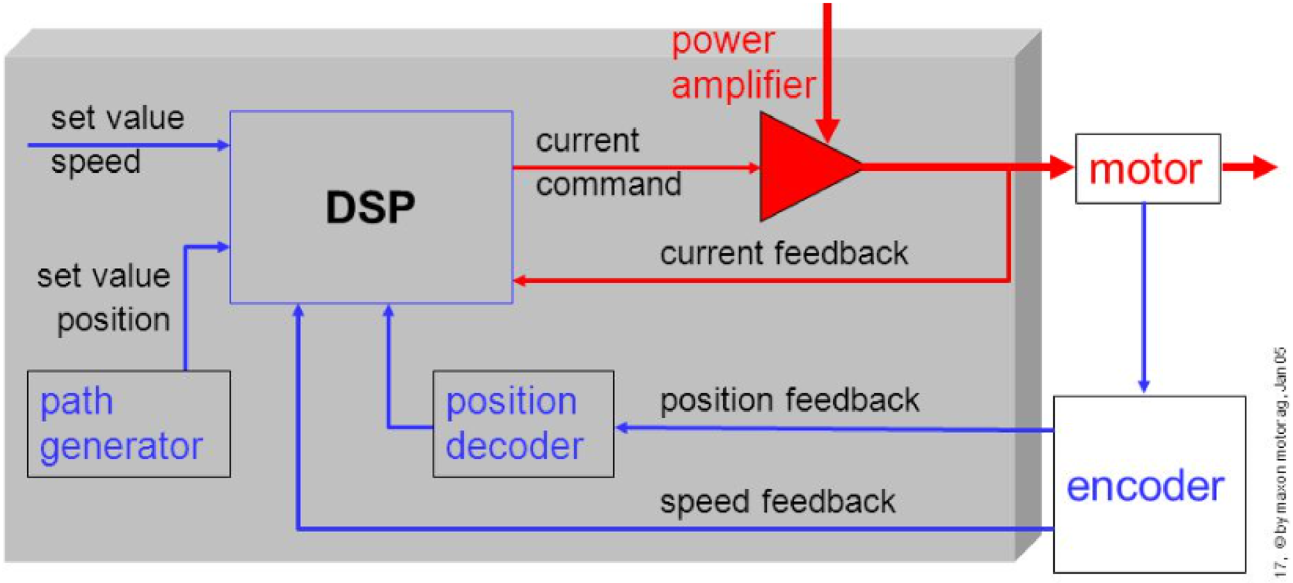
5. Optimizing of the overall control System dynamic behavior

6. Design of complex feed back control loops
- Digital and state space

End Goal

Get to the point where you can design a feedback loop to control some machine   eg. Servo motor,
design a compensator for it and map this into a digital implementation.

Fit compensator processing into general microcontroller such as those found in the Arduino or Raspberry Pi or other



Evaluation

Component	Weight
Quizzes	35 %
Laboratory	20 %
Final Examination	45 %
TOTAL	100 %

Quiz

30 minute quizzes during tutorial sessions

- First quiz, January 29
- 6 quizzes total
- **Best 5 out of 6**
- written response questions
- Closed book
- Calculators ok – cannot run matlab or communicate!
- Aid sheet that comes with the quiz will be posted prior to quiz
- Forces you to keep up with the lecture material

Final exam

- Standard 3 hrs
- Uniform coverage of material of course
- Closed book
- Any calculator ok – cannot run Matlab or communicate
- Written response problem questions

Problem sets (not marked)

Problems with solutions that are targeted for the quizzes are part of posted lecture notes. Make sure you know how to solve these, in preparation for the quizzes

Laboratory

- 4 labs based on Matlab/Simulink and digital hardware
- 3 hr Lab sessions Thursday afternoons
- Go at your own pace but there are deadlines for each lab report submission as posted on D2L
- Work individually/pairs/ groups - one lab report per one or two students
- Matlab/simulink available on network, can access anywhere and outside scheduled lab hours
- Use your own laptop with downloaded Matlab (much more convenient)
- Labs are drop in, not mandatory, TA will be available for tutorial help

What pre-requisitions are assumed?

That you remember the fundamentals of **ENEL327, Signals and systems** and **ENEL343 (circuits II)**

- Linear differential equations
- Frequency and time domain analysis
- What **S** means
- Linear time invariant systems
- Laplace transform
- Transfer functions
- Impulse response
- Basic circuits

ENEL441 builds on these foundations.
We will **briefly** review essential concepts

The content of ENEL441 is straightforward and intuitive if you know these fundamentals. **If your rusty…. Better review them.**

Lecture notes

6 units- Find in D2L contents area

Unit 1 review of Laplace, transfer functions

Unit 2 transfer functions of electrical and mechatronic systems

Unit 3 Time domain and frequency domain analysis of systems

Unit 4 Feedback loop analysis methods, root locus and Nyquist plots

Unit 5 Compensator design methods

Unit 6 Digital control and state space analysis

- Lots of problems with solutions, previous quizzes and final exam questions
- Practice problems focused for quizzes – make sure you understand how to solve them!

PROMISE

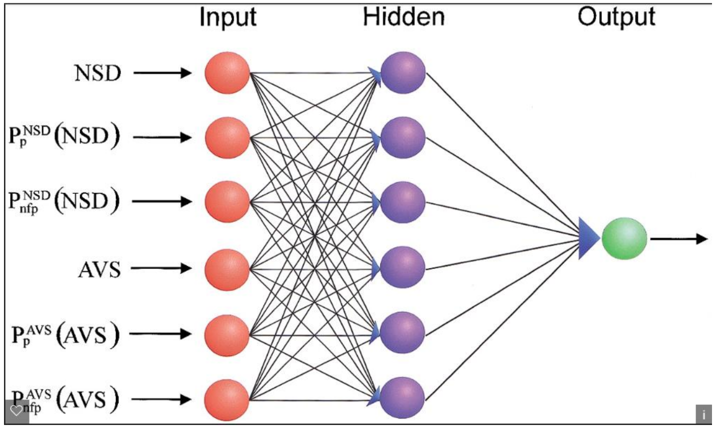
Questions and problems on quizzes or final exam will only be based on material that is included in the D2L posted unit notes or lab notes.

Beyond feedback control systems

How did you learn to walk or ride a bicycle?

Abstract versions of programming your biological neural network which resulted in a sort of control system and intelligence

Future control systems will involve artificial neural networks, a form of machine learning which is a start to artificial intelligence



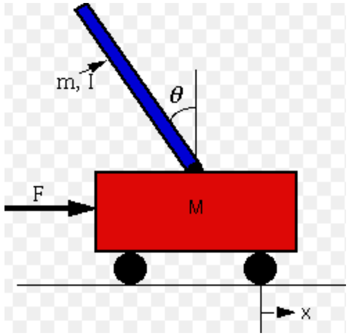
Much we can learn from biological control systems. Refined through an evolutionary process over many generations

Mystery of how a unicycle stays balanced

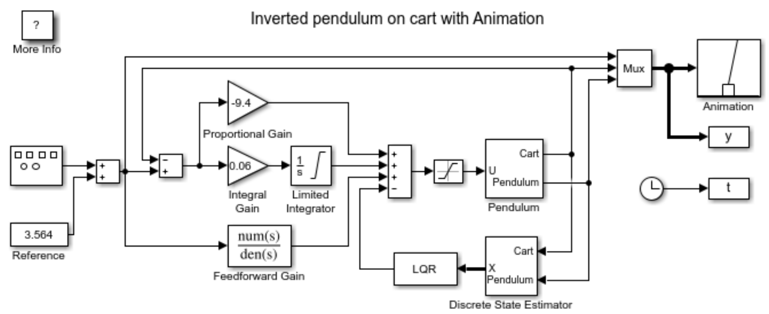
Processor at about 20 Hz clock rate but massively parallel

Neural network control

Consider stabilizing an inverted pendulum

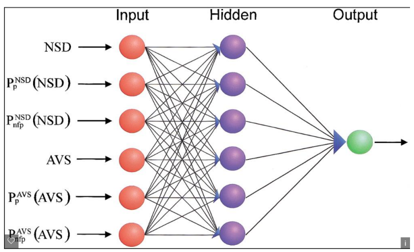


Instead of the conventional approach
Implement mathematical function



Train a neural network

Input State
{Position, angle, velocity, rotation rate}

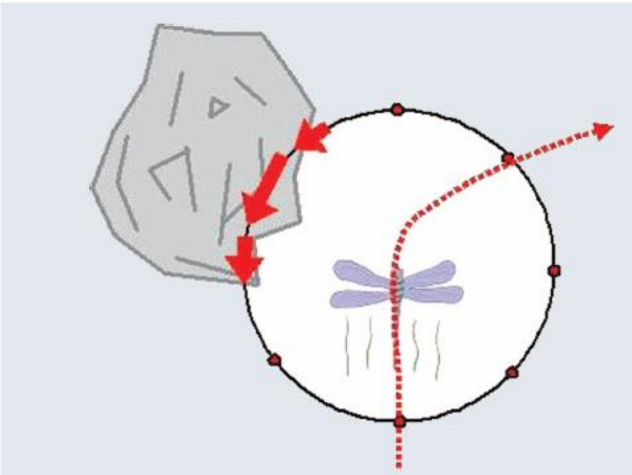


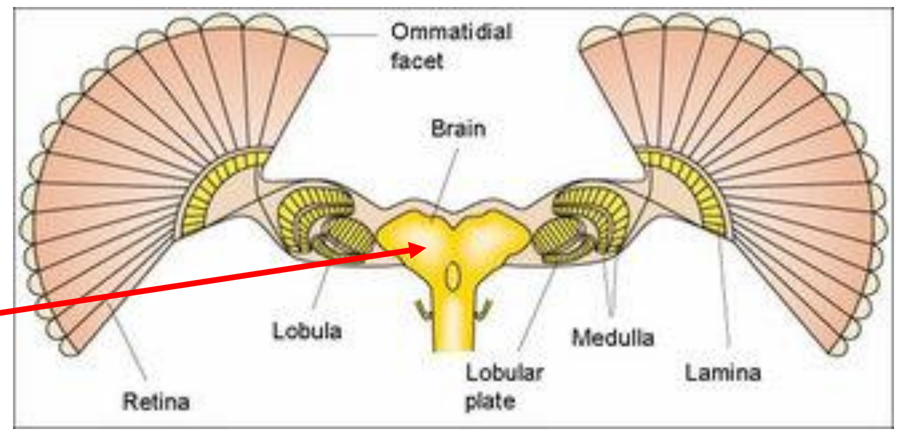
‘Best’ update response

What else can we learn from biological systems?

Lowly house fly with ~36,000 neurons and ~1000 sensor cells has far superior aerodynamic agility and control than the most advanced fighter with multiple gigaflop processors

How is a complex control system built into an insect work?





10,000 neurons
20 Hz clock rate

Low power compact vision processing for nanobots?