YORK UNIVERSITÉ UNIVERSITY

ASRL
Adaptive Systems Research Lab

Adaptive Software Systems
GS/EECS 6432

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Syllabus Overview

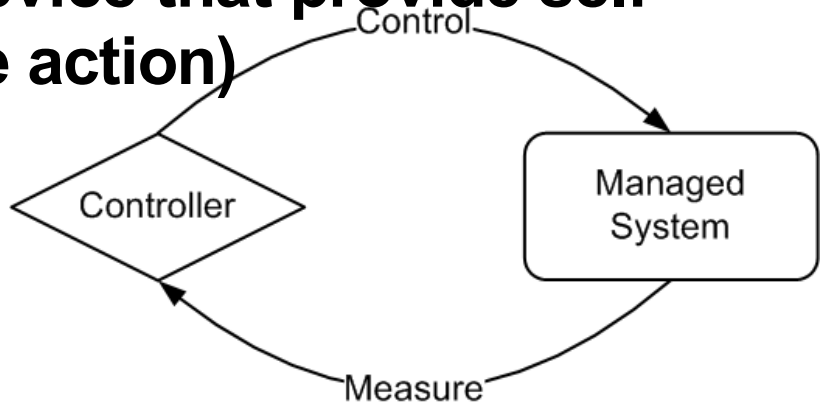
- Introduction to Adaptive Software
  - Requirements of Cyber-Physical Systems, Ultra Large Scale Systems, Internet of Things
- Adaptive Architectures
  - MAPE: Monitoring, Analysis, Planning, Execution
- Software Defined Infrastructures
  - Cloud Computing, Big Data, Containers
- Runtime Models for Elastic Applications
  - Machine Learning, Queuing, Control Theory Linear Models
- Analysis and Planning
  - Searched Based, Proportional, Integrative, Derivative Controllers, Control Theory
- Engineering Adaptive Applications
  - Policy Languages, Utility Functions
  - Case Studies

Feedback Systems

- **Definitions**
- **Principles**
- **Examples**

Feedback Systems

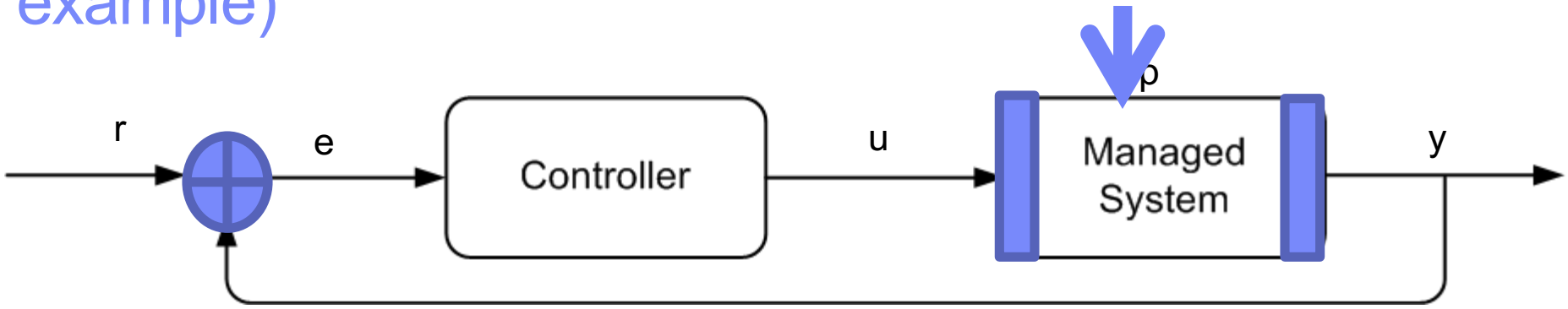
- **Merriam-Webster's Online Dictionary**
  the return to the input of a part of the output of a machine, system, or process (as for producing changes in an electronic circuit that improve performance or in an automatic control device that provide self-corrective action)



York turn

- **Draw a diagram of 1 of the following ubiquitous systems, by abstracting how do they perform their main functions(*italic*). Work in teams of 2-3.**
  - Cruise control: *maintain speed*
  - A plane on autopilot: *maintain direction*
  - A web site: *maintain quality through feedback (ratings, etc..)*
  - Amazon books recommender: *personalized recommendation*
- ***Identify***
  - *What is the goal of the system?*
  - *What does it measure?*
  - *What does it control?*
  - *What is the algorithm*

Feedback loop explained (on a cruise control example)



- **Managed system is car (cruise control)**
- **Set points (r): this is the speed of cruise control**
- **Measured value (y): this is actual speed**
- **Error (e)= r-y: this is difference between the measured and target speed:**
- **Controlled input (u): if e>0 the gas volume is increased; if e=0, the gas is kept constant**
- **Perturbations (p): hills, wind..**
- **Transducers (sensors): these measure the speed**
- **Effectors (actuators): those are devices that adjust the gas volume/activate the brake**
- **Comparator (compare the measured value with the set point)**
- **Controller: a device/program/service; its goal is to make the error close to zero..**

More in this on line tutorial

https://www.mathworks.com/videos/understanding-control-systems-part-3-components-of-a-feedback-control-system-123645.html

Quiz

- **Identify the sensors, the actuators, the perturbations in the following situations and explain how the feedback loop works**
  - Cruise control
  - Plane on auto-pilot
  - Web site personalization
  - Web site ratings
  - Google driverless car

Is there feedback in software systems?

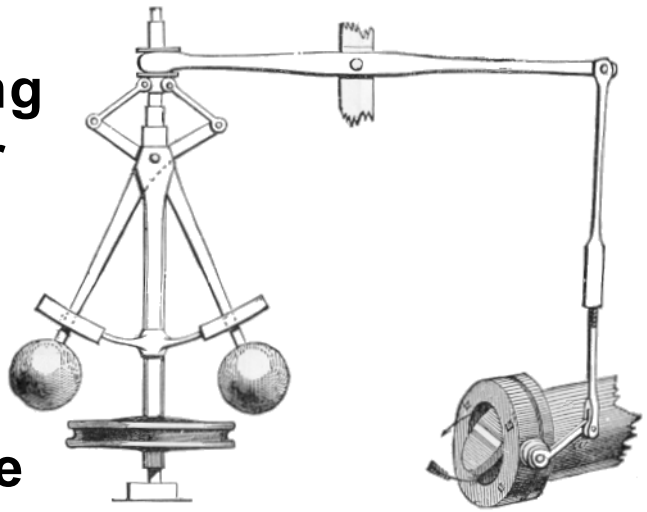
- **Network protocols**
- **Error correction algorithm (memory faults can be corrected)**
- **Social networks (users provide feedback)**
- **Personalized web sites**
- **Adaptive user interfaces...see MS Word menus that adapt based on the usage.**
- **Etc....**

Feedback is ubiquitous
in natural and
engineered systems

Early Engineered Feedback System

Steam Engine with Governor

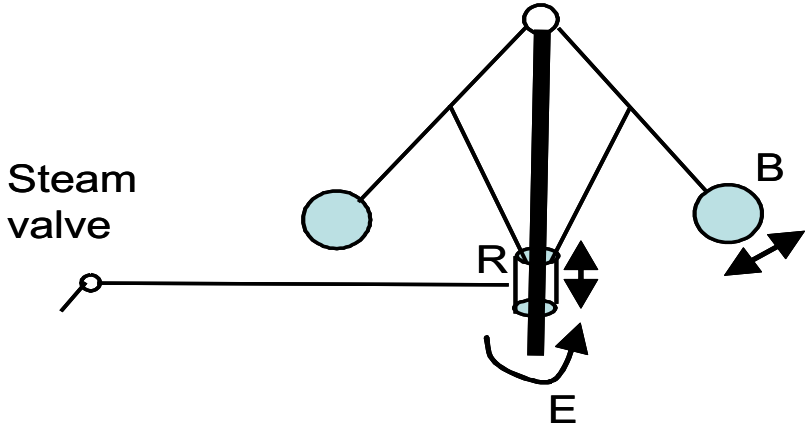
- **A centrifugal governor is a specific type of governor that controls the speed of an engine by regulating the amount of fuel (or working fluid) admitted, so as to maintain a near constant speed whatever the load or fuel supply conditions. It uses the principle of proportional control.**



- **It was invented for steam engines where it regulates the admission of steam into the cylinder. Also internal combustion engines and striking clocks.**
- **James Watt designed his first governor in 1788 for steam engines, but never claimed the centrifugal governor to be an invention of his own.**

The Governor: How Does it Work

- **A fly-ball governor (see figure below) is a sensor and an actuator at the same time: it has two balls B attached through arms at the end of a spindle. The spindle and the balls rotate with the engine's shaft, and as the shaft rotates faster (because of low workload), the balls are swung further away from the spindle by centrifugal force. The movement of the balls is transmitted to a sliding piece R attached loosely to the spindle. In the end, a throttle-valve closes, adjusting the steam in the engine and decreasing the rotation speed of the shaft.**



The Governor Evolution

- Watt's governor had many drawbacks: it could only be used for one type of engine, it could adjust the speed only for a small range of workloads, it overshot, oscillated, and it was unstable. It took about 100 years to improve the governor, and thousands of governor patents were granted throughout the world in the 19th Century.
- In 1878, Maxwell published his now-famous paper "On governors," in which he modeled the governor dynamics through differential equations. The paper was a milestone in the history of governors and in that of automatic control because it offered theoretical insights needed to find solutions to a wide range of control problems.
- Similar to the governor's history was the introduction of automation in other engineering fields: telephony (electronic negative feedback amplifier), anti-aircraft control (servomechanisms), and aviation (navigation and position control, automatic pilot, automated landing).

Natural Feedback Systems

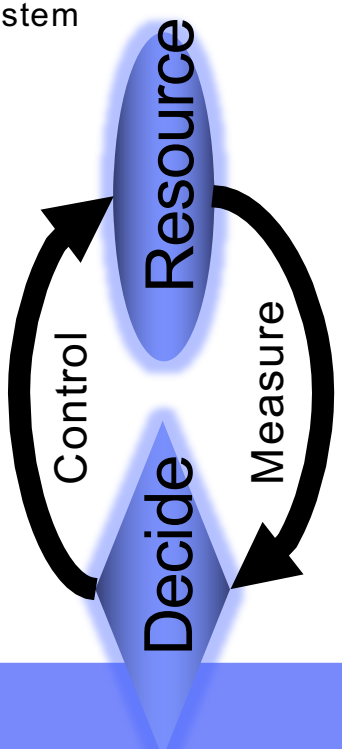
- **Biological Systems**
  - Physiological regulation (homeostasis)
  - Bio-molecular regulatory networks
- **Environmental Systems**
  - Microbial ecosystems
  - Pelagic and terrestrial ecosystems
  - Global carbon cycle
- **Financial Systems**
  - Markets and exchanges
  - Supply and service chains

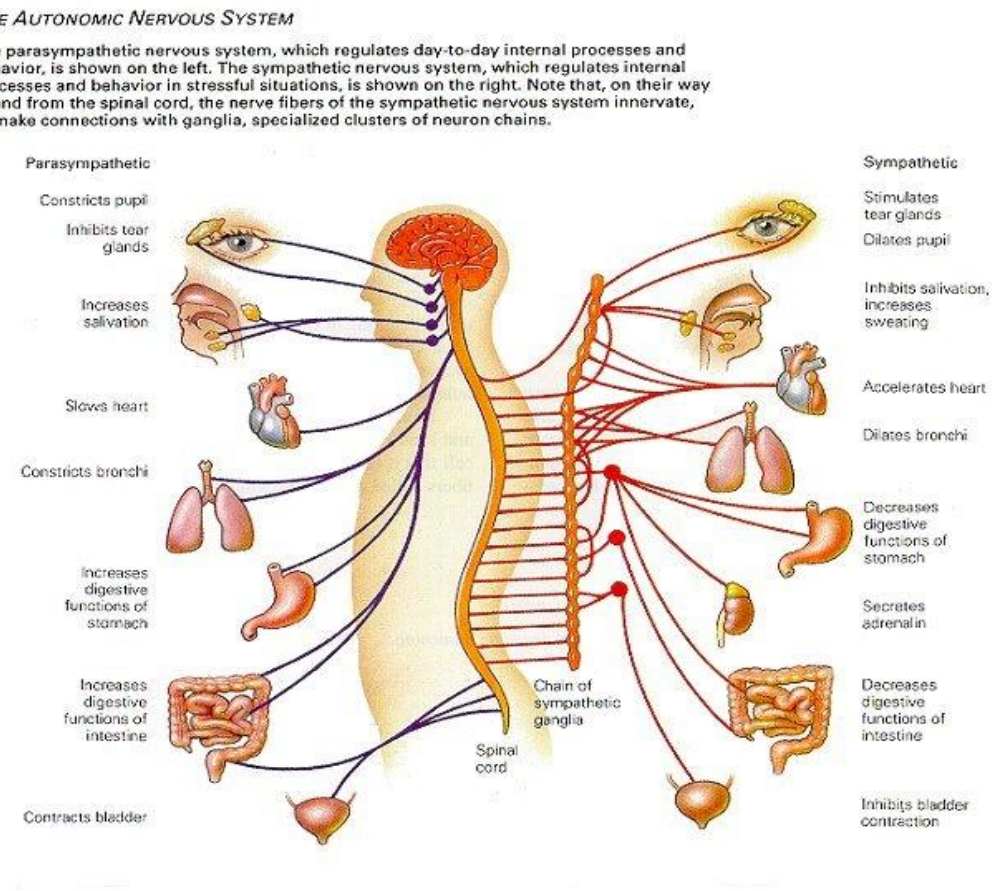
Most Famous Feedback System
Autonomic Nervous System (ANS)

Autonomic nervous system (ANS)

- Parasympathetic
  - Day-to-day internal processes
- Sympathetic
  - Stressful situation processes
  - "fight or flight" system

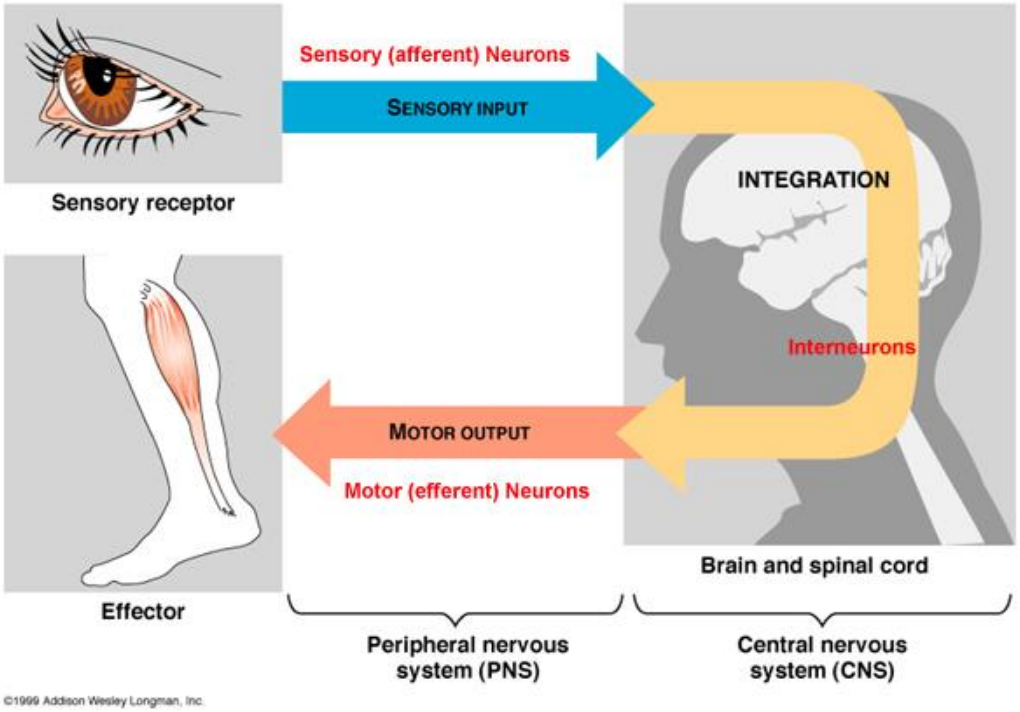
Temperature
Heart rate
Breathing rate
Blood pressure
Blood sugar
Pupil dilation
Tears
Digestion
Immune response





Monitor and Regulate

ANS Reflex Control Loop
Sensory and Motor Neurons



- A reflex is the neural pathway that mediates a reflex action.
- A stimulus causes sensory receptors to generate nerve impulses that travel in sensory axons to the spinal chord.
- Interneurons integrate data from sensory neurons and then relay signals to motor neurons.

Interesting Architectural Note

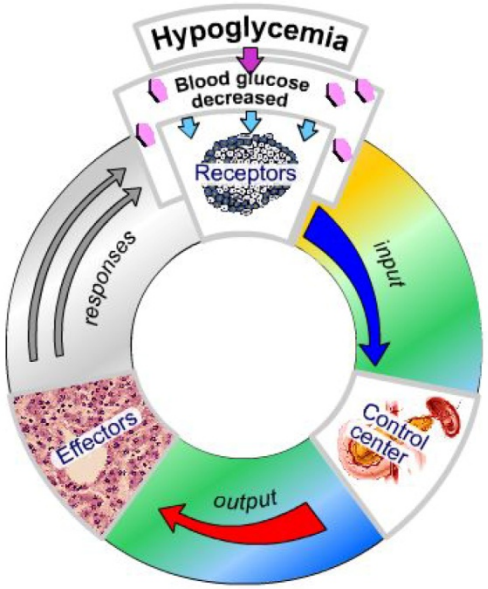
- **Architecturally the ANS seems to separate the normal day-to-day internal processes from the exceptional, stressful situation processes**
  - Parasympathetic
    - Day-to-day internal processes
  - Sympathetic
    - Stressful situation processes

- **Could we use this interesting architectural design decision for Autonomic software systems?**

Types of Feedback

- **Negative feedback**
  - Stabilizes operation; regulates within a set and narrow range
  - Classic examples
    - Thermostat control
    - Homeostasis
- **Positive feedback**
  - Increase, accelerate, or enhance output created by a stimulus that has already been activated
  - Classic example
    - Audio feedback—sound from loudspeakers enters a poorly placed microphone and gets amplified, and as a result the sound gets louder and louder
    - Blood platelet accumulation, which, in turn, causes blood clotting in response to a break or tear in the lining of blood vessels
    - Release of oxytocin to intensify the contractions that take place during childbirth
- **Bipolar feedback**
  - Either increase or decrease output
  - Bipolar feedback is present in many natural and human systems
  - Feedback is usually bipolar in natural environments producing synergic and antagonistic responses to the output of system

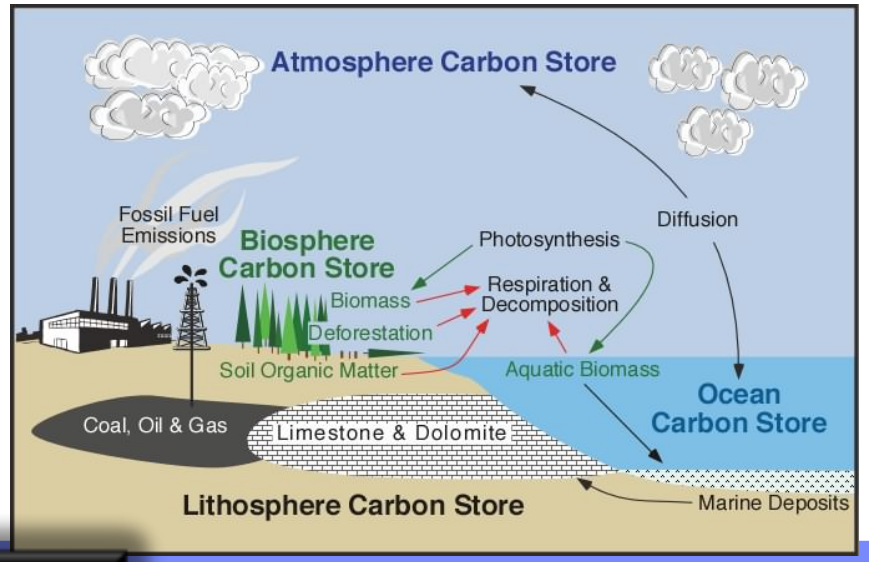
Physiological Regulation- is a negative feedback
Homeostasis



- ***Homeostasis* is the property of a system that regulates its internal environment and tends to maintain a stable, constant condition**
- **In animals the internal environment of our bodies must have certain conditions within tolerable limits to continue the healthy functioning.**
- **This is done by a process called negative feedback control, where various receptors and effectors bring about a reaction to ensure that such conditions remain favourable—the control of blood sugar concentrations, water concentrations, or temperature.**
- **Physiological homeostasis = Physical equilibrium**
  - Glucose level in the bloodstream drops
  - Person requires glucose in cells to meet the demand for ATP—Adenosine triphosphate
  - The body detects this with a particular receptor designed for this function
  - These receptors release hormones, chemical messages that initiate the start of the feedback mechanism
  - The hormones travel to their target tissue and initiate a corrective response
  - In this case, the response is the secretion of more glucose into the bloodstream

Carbon-Water Climate Models

- **Carbon-climate models all demonstrate a positive feedback between terrestrial carbon cycles and climate warming**
- **Air holds more water vapour (i.e., clouds) as temperature rises**
  - positive feedback magnifying the climate response
- **Changes of clouds, snow cover, and sea ice**
  - It is uncertain whether the cloud feedback is positive or negative
  - Snow and ice are positive feedbacks because, as they melt, the darker ocean and land absorb more sunlight
- **Field experiments suggest rich mechanisms driving ecosystem responses to climate warming**
  - Extended growing seasons
  - Enhanced nutrient availability
  - Shifted species composition
  - Altered ecosystem-water dynamics



Ice-Albedo Feedback

- **Albedo**
  - The amount of energy reflected by a surface; scale from zero to one
  - For dark colors albedo close to zero; light ones close to one
- **Arctic sea ice is covered with snow all winter.**
- **Bright white, the snow-covered ice has a high albedo so it absorbs very little of the solar energy that gets to it.**
- **Because Earth's temperature is climbing, the snow on top of the ice melts earlier in the spring**
- **There is more time during the summer for the compounding cycle of melting ice, lowering albedo, trapping of more solar energy, and more ice to melt.**
- **Albedo feedback is positive because the initial temperature change is amplified.**

Feedback in Financial Markets

- **The stock market has both positive and negative feedback mechanisms. This is due to cognitive and emotional factors belonging to the field of behavioural finance.**
  - When stocks are rising—a bull market, the belief that further rises are probable gives investors an incentive to buy—positive feedback; but the increased price of the shares, and the knowledge that there must be a peak after which the market will fall, ends up deterring buyers—negative feedback.
  - Once the market begins to fall regularly—a bear market, some investors may expect further losing days and refrain from buying—positive feedback, but others may buy because stocks become more and more of a bargain—negative feedback.

A special form of feedback: Fractals

- **A fractal is "a rough or fragmented geometric shape that can be split into parts, each of which is (at least approximately) a reduced-size copy of the whole," a property called self-similarity.**
- **A mathematical fractal is based on an equation that undergoes iterations, a form of feedback: the output becomes the input after each iteration and the process is continued...**

http://www.wolframalpha.com

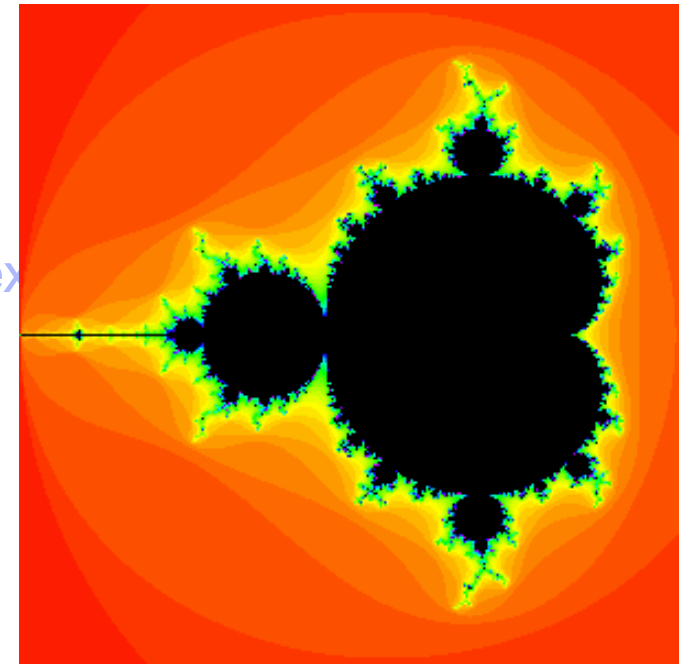
Mandelbrot and Julia Sets

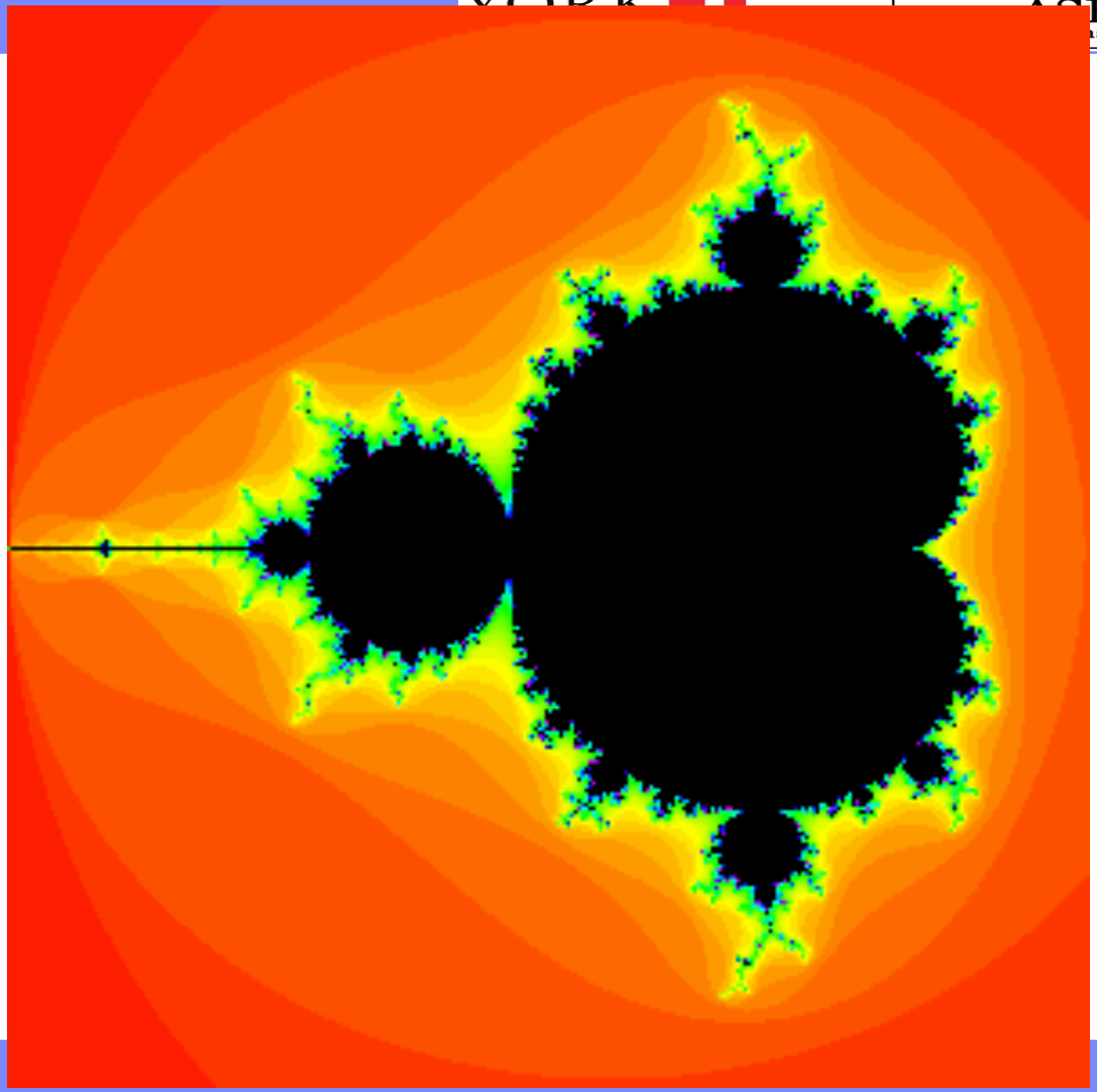
- **Most famous fractal**
  - $Z_{k+1} = z_k^2 + c$ where z, c are complex numbers
- **Suppose we fix c (not origin of complex plane) and let z vary over all complex numbers, what do we get?**
- **➔ Depending on c, we get completely different sets**
  - Some complex numbers attracted to
    - Infinity (i.e., the sequence diverges to infinity)
    - Finite numbers (i.e., the sequence drifts to a finite number)
    - Neither (i.e., the sequence oscillates between several numbers)

Colouring Mandelbrot Sets

- Mandelbrot sets: another type of fractals

- **Julia set and Mandelbrot set explorers**
  - http://www.wolframalpha.com
  - http://aleph0.clarku.edu/%7edjoyce/julia/ex





Conclusions

- **Feedback is the means to achieve adaptive systems**
  - Is ubiquitous
    - Physical systems
    - Ecosystems
    - Economy
    - Mathematical modeling (fractals)
    - Software systems
- **In software, feedback is sporadic and not systematically applied**
- **Adaptive computing tries to make feedback loops more prevalent in computing systems**