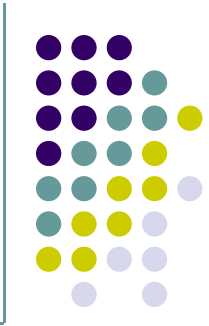
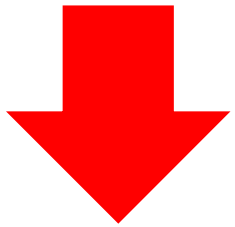


Welcome to SENG 480B / CSC 485A / CSC 586A Self-Adaptive and Self-Managing Systems

Dr. Hausi A. Müller
Department of Computer Science
University of Victoria



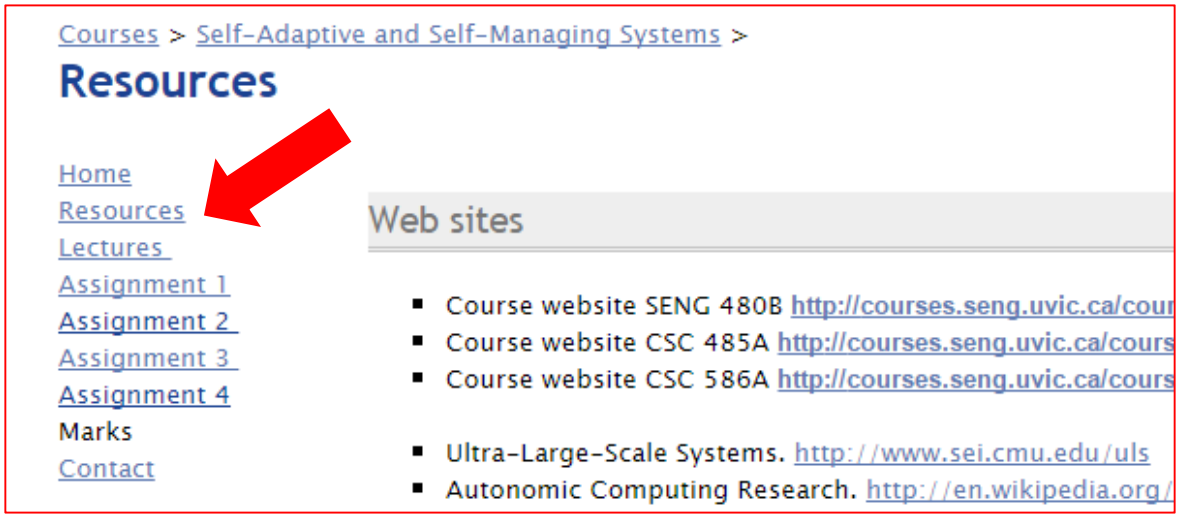
http://courses.seng.uvic.ca/courses/2015/summer/seng/480a
http://courses.seng.uvic.ca/courses/2015/summer/csc/485a
http://courses.seng.uvic.ca/courses/2015/summer/csc/586a

Announcements

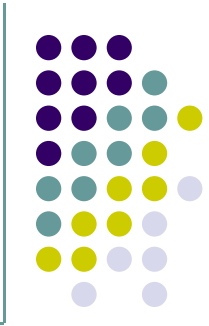
- Friday, May 29
  - A1 due
- Monday, June 1
  - Ron Desmarais—Control theory, PID controllers
- Thursday, June 4
  - Midterm I
  - In class
  - Closed books, closed notes
- TA Office hours
  - Refer to website

Midterm I

- Format
  - Closed books, closed notes
  - Leave books and gadgets at home
  - Essay style
- Topics
  - Definitions
  - ULS
  - PID controllers
  - Feedback loops
  - Assignment 1 topics
- Reading materials
  - All lectures notes
  - See next slide

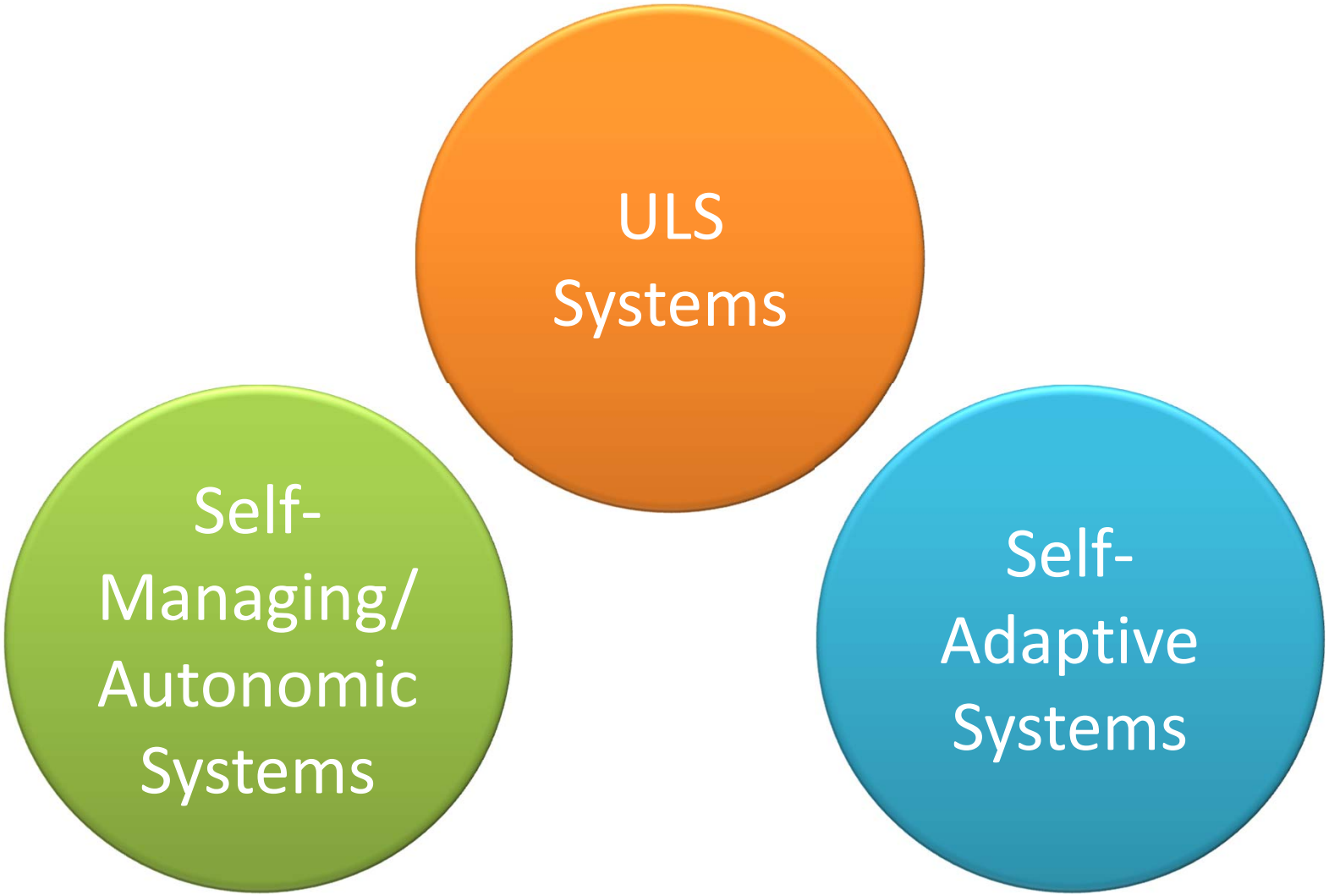


Midterm I Reading

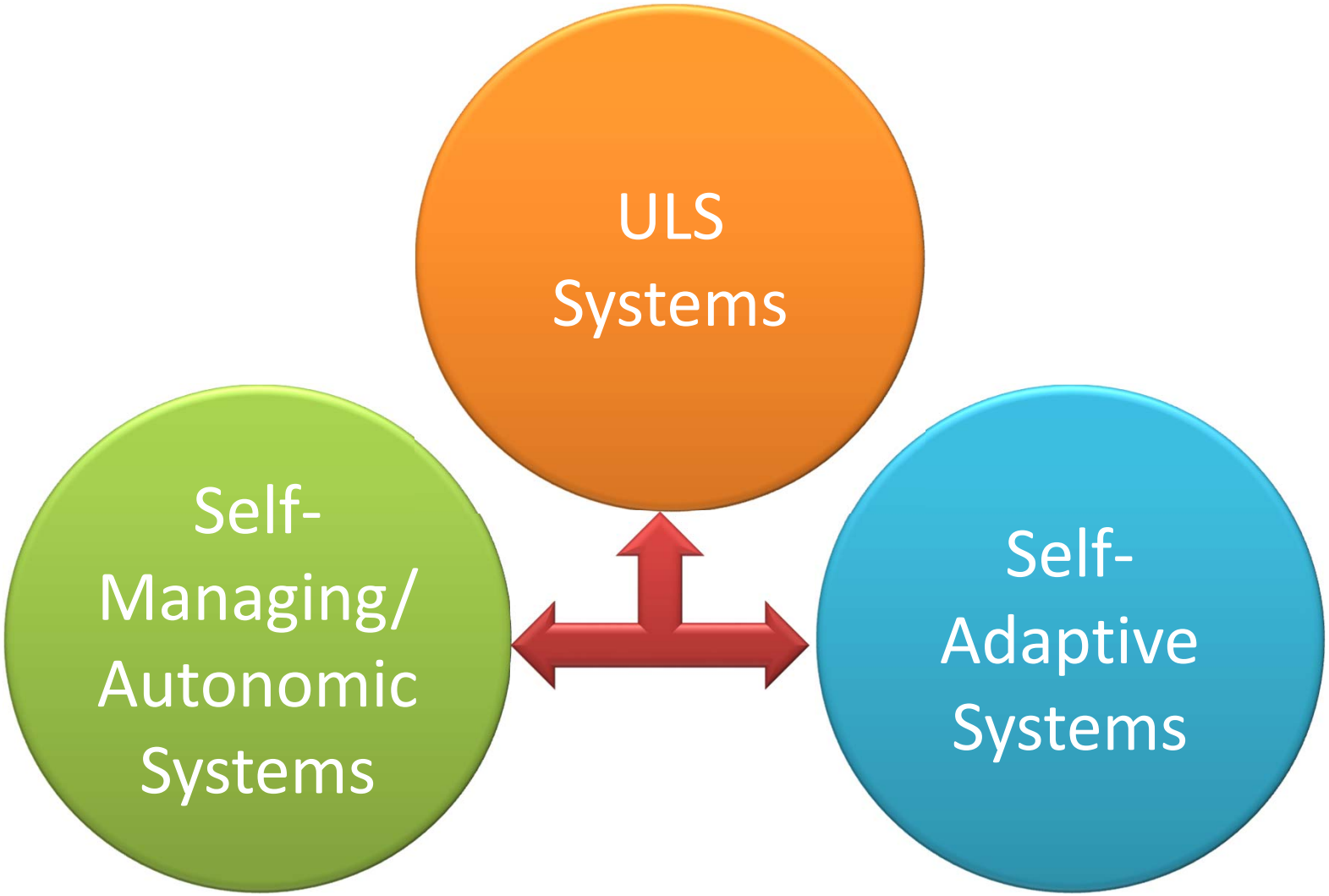


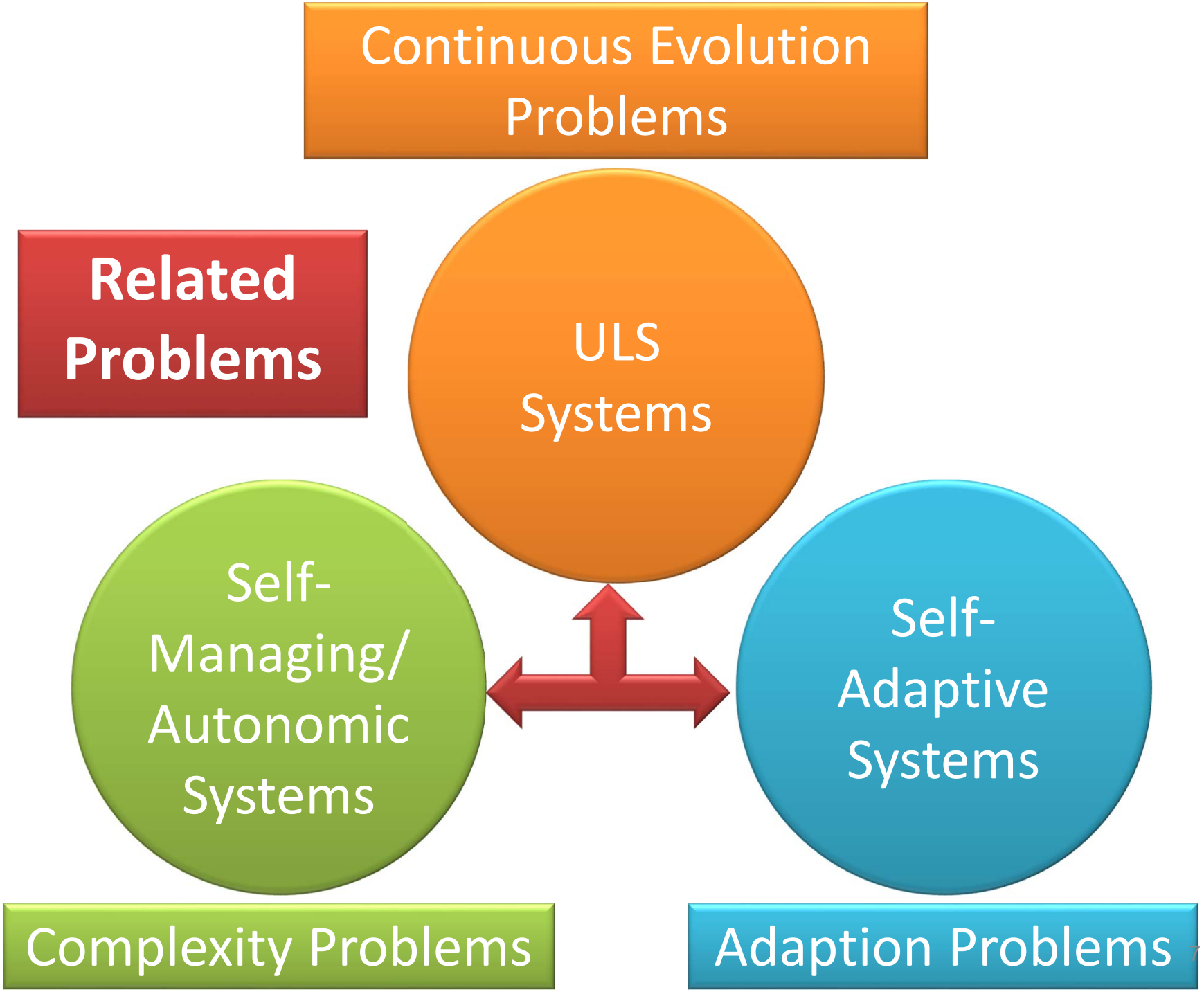
- Definitions
  - Ultra-Large-Scale Systems www.sei.cmu.edu/uls
  - Autonomic Computing en.wikipedia.org/wiki/Autonomic_computing
  - Cyber-physical systems. en.wikipedia.org/wiki/Cyber-physical_system
  - Complex Systems en.wikipedia.org/wiki/Complex_systems
  - Feedback en.wikipedia.org/wiki/Feedback
- Northrop et al.: Ultra-Large-Scale Systems. CMU Software Engineering Institute (2006) www.sei.cmu.edu/uls
- Murray: Control in an Information Rich World, Chap. 1&2, SIAM (2003) www.cds.caltech.edu/~murray/cdspanel/report/cdspanel-15aug02.pdf
- Kephart, J.O., Chess, D.M.: The Vision of Autonomic Computing. IEEE Computer 36(1):41-50 (2003) ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1160055
- IBM: An Architectural Blueprint for Autonomic Computing, 4th Ed. (2006) citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.150.1011&rep=rep1&type=pdf

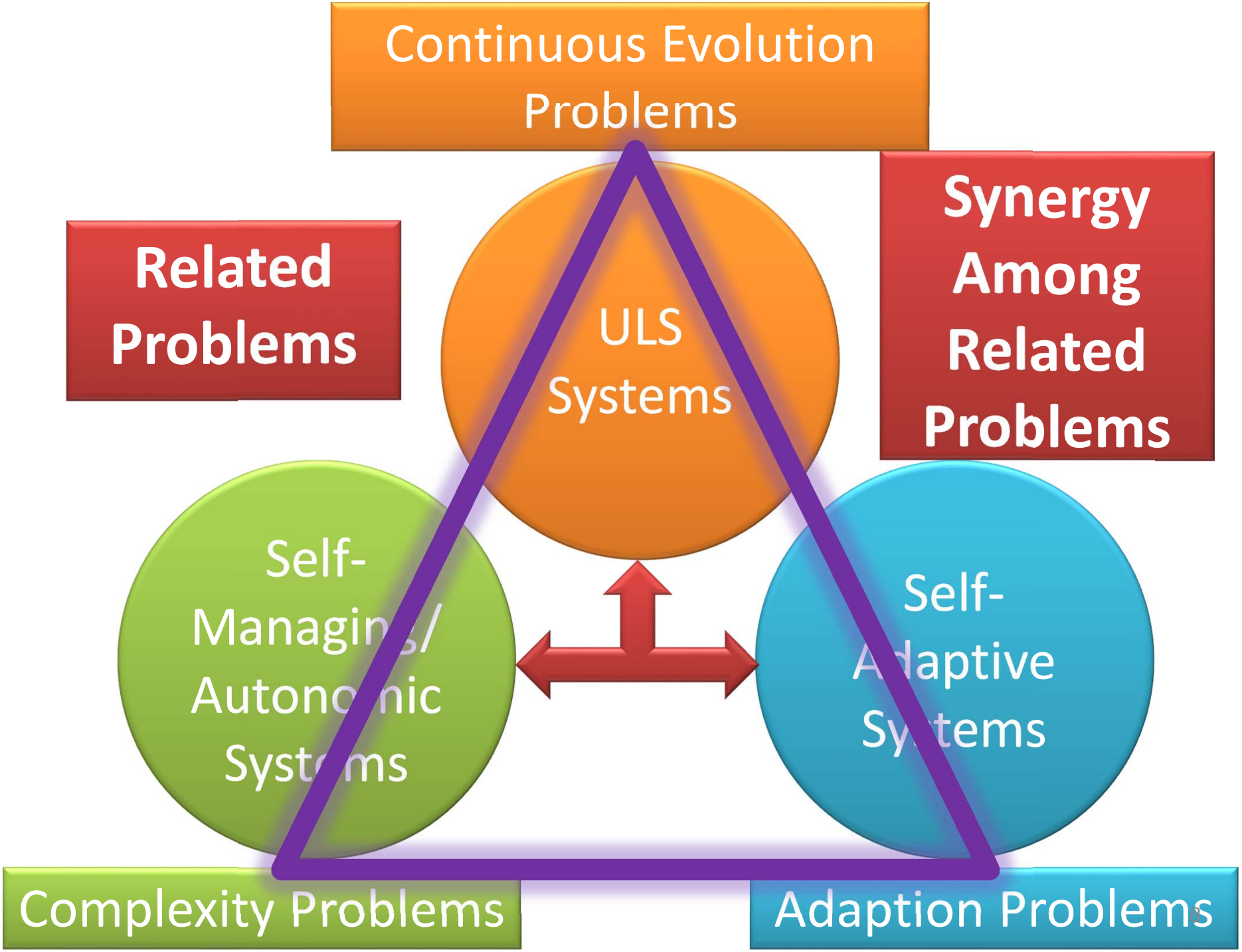
Related Systems



Synergy Among Related Systems




Continuous Evolution Problems
Related Problems
ULS Systems
Self-Managing/ Autonomic Systems
Self-Adaptive Systems
Complexity Problems
Adaption Problems


Continuous Evolution Problems
Related Problems
Synergy Among Related Problems
ULS Systems
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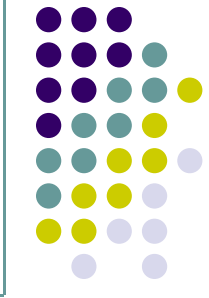
Complexity Problems
Adaption Problems

The Continuous Evolution Problem

Devices, environments, infrastructure, web, services, business goals, user expectations, …

all evolve over time

Continuous Evolution

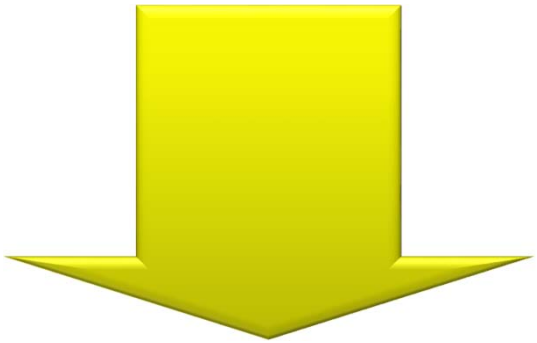


- Traditional (flawed) assumption: software systems should
  - support organizational stability and structure
  - be low maintenance
  - strive for high degrees of user acceptance
- Continuous evolution: software systems
  - should be under constant development
  - can never be fully specified
  - are subject to constant adjustment and adaptation [Truex99]
- Good news
  - for the software engineering community (adaptive, autonomic, reverse engineering in particular) since this view guarantees research problems for years to come
- Bad news
  - most software engineering textbooks will have to be rewritten

Truex et al., Growing Systems in Emergent Organizations, CACM, 1999

Managing Tradeoffs

- From satisfaction of requirements through traditional, top-down engineering



- To satisfaction of requirements by regulation of complex, decentralized systems

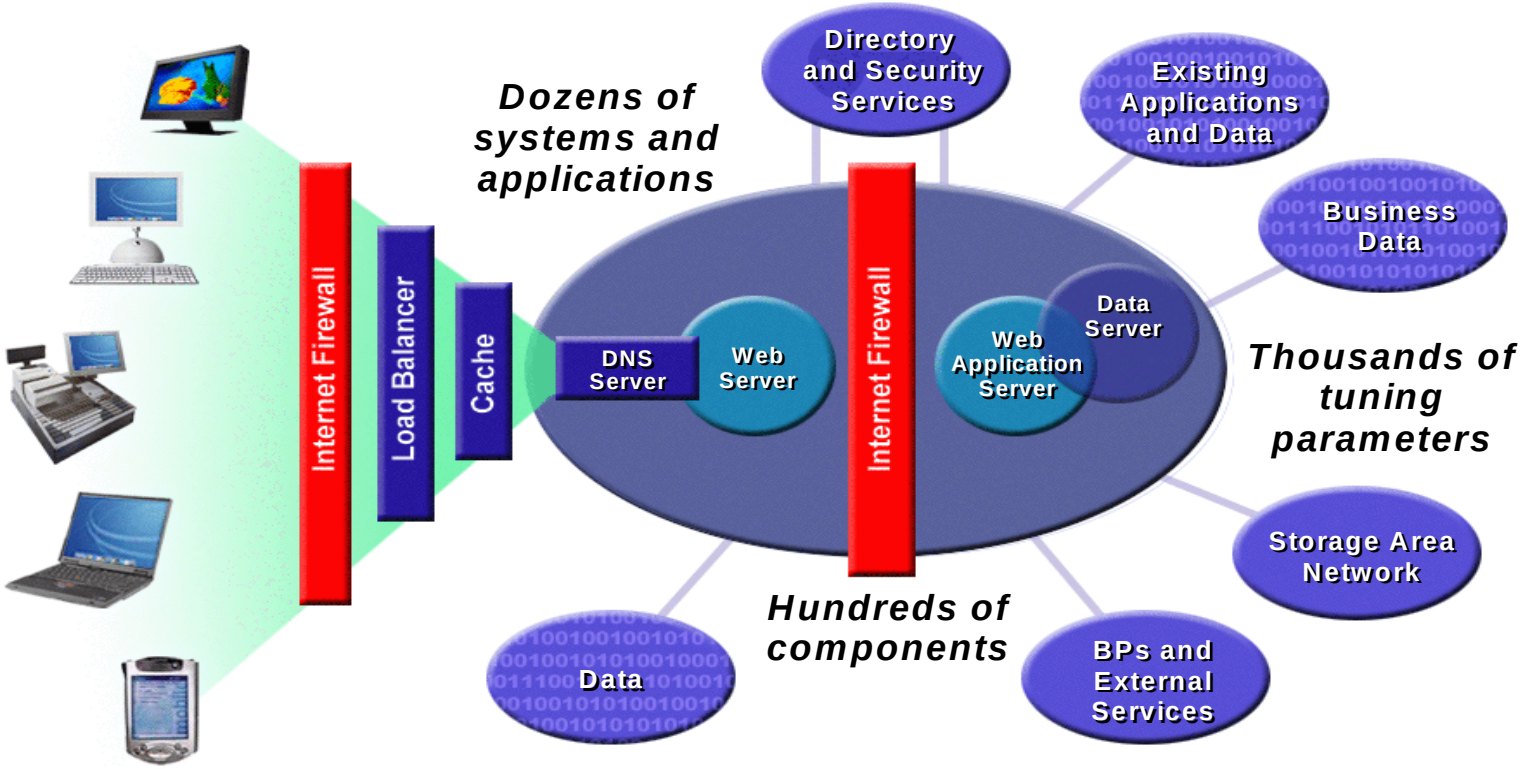
How much environment uncertainty can we afford? What's the cost?
What benefits do we accrue by accommodating context uncertainty?

The Complexity Problem

Build a system used by millions of people each day administered and managed by a half-time person

— Jim Gray, Microsoft Research

Complex Heterogeneous Infrastructure



Alan Ganek, VP IBM Autonomic Computing, 2003

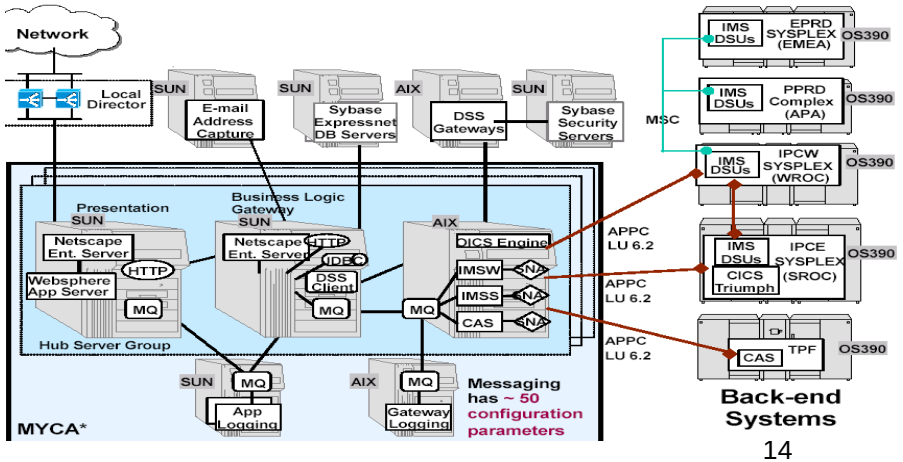
Complexity of Configurations

- Application Server
  - ~100 configuration parameters
  - Several applications
  - Hundreds of servlets
  - Tens of EJBs
- Web Server
  - ~20 configuration parameters
  - Serves thousands of web artifacts
- Messaging
  - ~30 configuration parameters
- DBMS, TCP/IP, OS …

Information systems are very complex for humans and costly to install an maintain

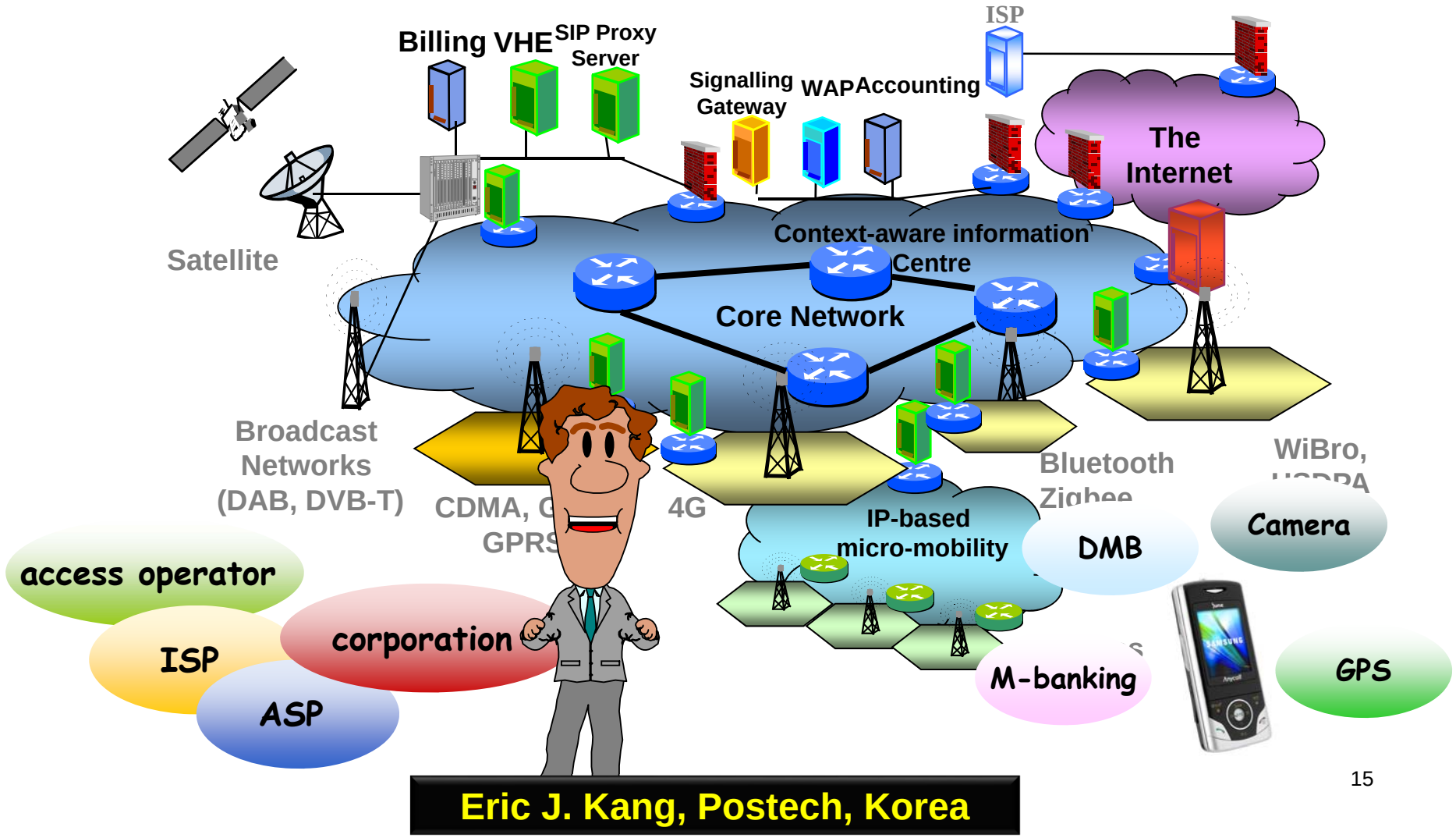
x 2-5 parameters

2^{150} settings



Marin Litoiu, IBM CAS, 2005

Complexity of Network Environment



The Complexity Problem

- The increasing **complexity of computing systems** is overwhelming the capabilities of software developers and system administrators to design, evaluate, integrate, and manage these systems
- Major software and system vendors have concluded that the only viable **long-term solution is to create computing systems that manage themselves**

… an elusive goal?!?

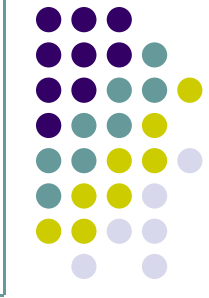
The Automation Conundrum

- Over the past 50 years, computer systems have had a huge capacity to automate
  - Enormous variety of tasks
  - Cost per task greatly reduced
  - Incalculable benefits
  - Unprecedented success

- Key challenges
  - Further declines in task costs by traditional methods are subject to the law of **diminishing returns**
  - The **complexity** of infrastructure management threatens to outweigh the benefits of further automation

A. Spector, VP IBM Services and Software Research, 2003

The Complexity Problem



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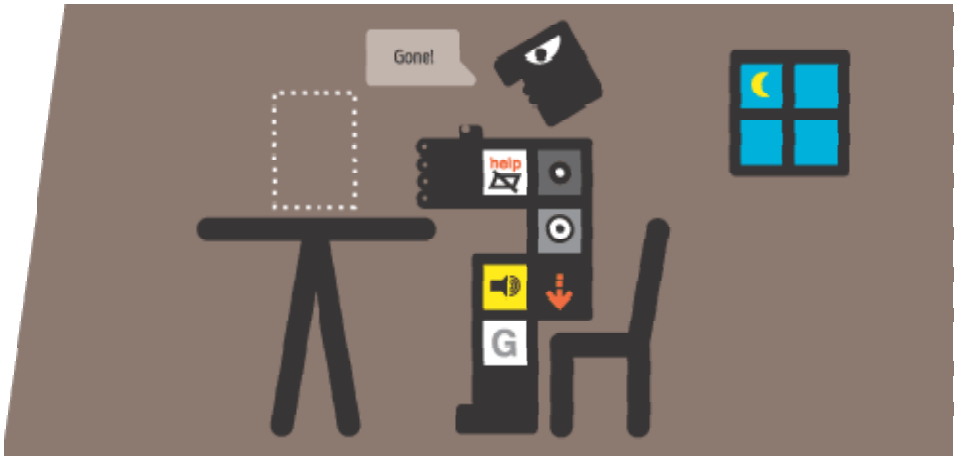
The Conquest of Complexity

- There has never been anything quite like information technology before, but there have certainly been other complex technologies that needed simplifying
- To be truly successful, a complex technology needs to “disappear”



Source: A. Kluth: Information Technology. The Economist, Oct 28, 2004

19th Century Technology

- Mechanical Clocks and Sewing machines
  - 1820's Long 40 page manuals of usage
  - 1880's Are simple and widely used
- Phonograph
  - Edison's 1877 cylinder version was unusable
  - Berliner's simplified disc version became gramophones, Victrolas, and record players

19th Century Technology

- Automobile
  - 1900s: mostly burden and challenge
    - Required skill in lubricating moving parts
    - Sending oil manually to the transmission
    - Frequent breakdowns
    - Mechanic hired as chauffeur
  - 1930s: usable and ready for mass market
    - Infrastucture: roads, gas stations, repair shops
    - Hiding technology from drivers
    - Highly more complex on the inside, because most of the tasks that had previously been carried out by drivers now had to be done automatically
    - Greatly simplified interface, more reliable

Model T Ford

20th Century Technology

- Electricity and power distribution
  - First generation
    - Households and firms have own generators
    - Full time job to keep the generators going
    - Vice President of Electricity (VPE)
      - like CIO or CTO today
  - Only one generation later
    - Power grid
    - Simplified, ubiquitous power plug
    - VPE disappeared
      - will CIOs or CTOs disappear?

Predictable Path of Technology

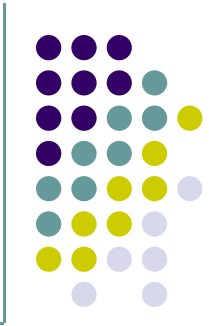
- Early stages
  - Technology needs lots of human involvment
  - New inventions are typically “geeky”, requiring significant expertise to install and maintain
  - In general, the “default” seems to be human work, due to its flexibility and adaptivity
  - At an early stage human involvement is always superior to alternatives
  - Culling of features is futile
- Push the complexity to the back end to make the front end very simple
  - Consumers don’t know when the Power Company upgrades its technology

Predictable Path of Technology

- Mature stage
  - Need for human expertise is greatly reduced due to technology becoming simple and standardized
  - To increase adoption and sales (electricity, cars)
  - To decrease cost (industrial revolution, agriculture)
  - To allow super-human performance (space aviation)
- Simplicity of usage often means increased overall system complexity
  - For every mouse click we take out of the user experience, 20 things have to happen in the software behind the scenes

Given this historical perspective, maybe there is hope for the information technology sector?!

Grand Challenge



- Today's computing systems are amazingly complex, and require daunting expertise and patience just to get them running and keep them running
- The increasing system administration will become a major barrier to deploying and maintaining large computing systems

Autonomic Computing Vision

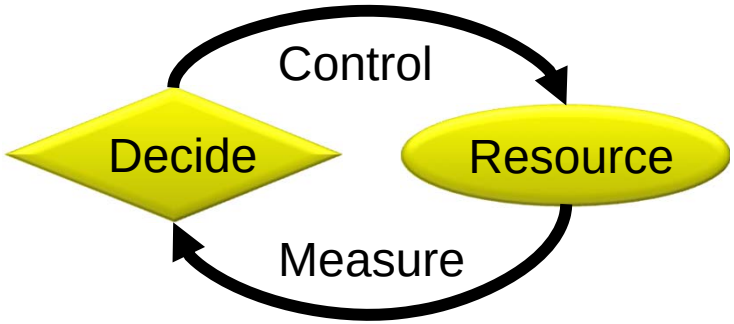
Autonomic Computing is really about making systems self-managing …

—Paul Horn, IBM Research, 2001

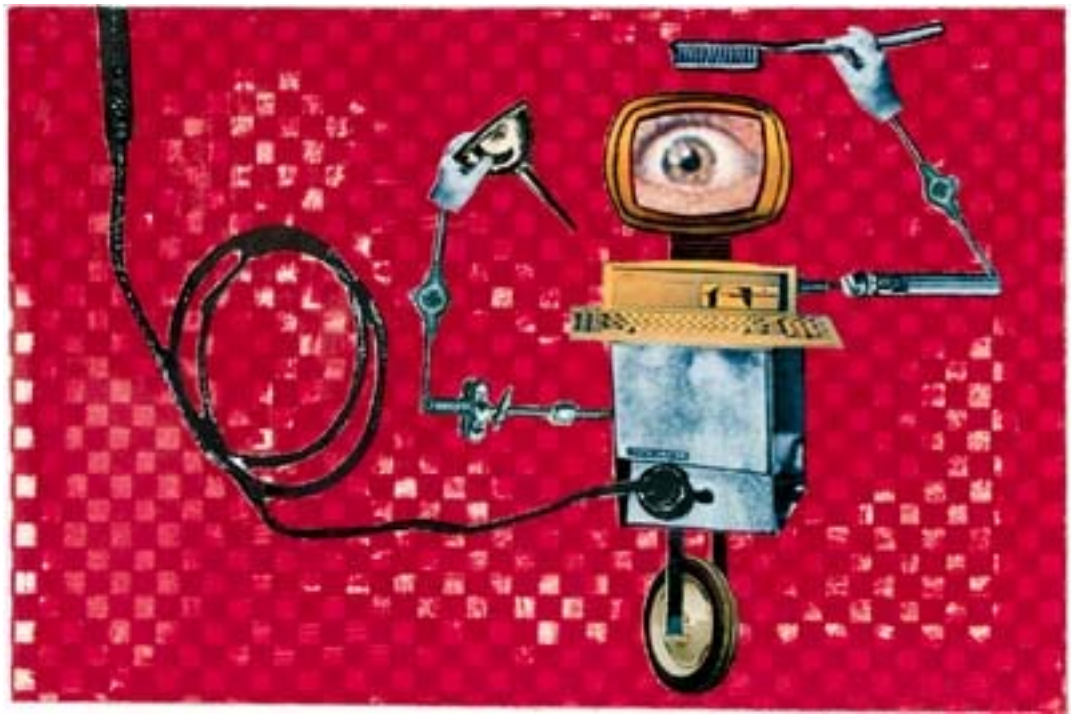
What is Autonomic Computing?

- Webster's definition
  - Acting or occurring involuntarily; automatic: an autonomic reflex
  - Relating to, affecting, or controlled by the autonomic nervous system or its effects or activity
  - Autonomic nervous system: that part of the nervous system that governs involuntary body functions like respiration and heart rate

- IBM's definition
  - An approach to self-managed computing systems with a minimum of human interference
  - The term derives from the body's autonomic nervous system, which controls key functions without conscious awareness or involvement



A First Look at an Autonomic System

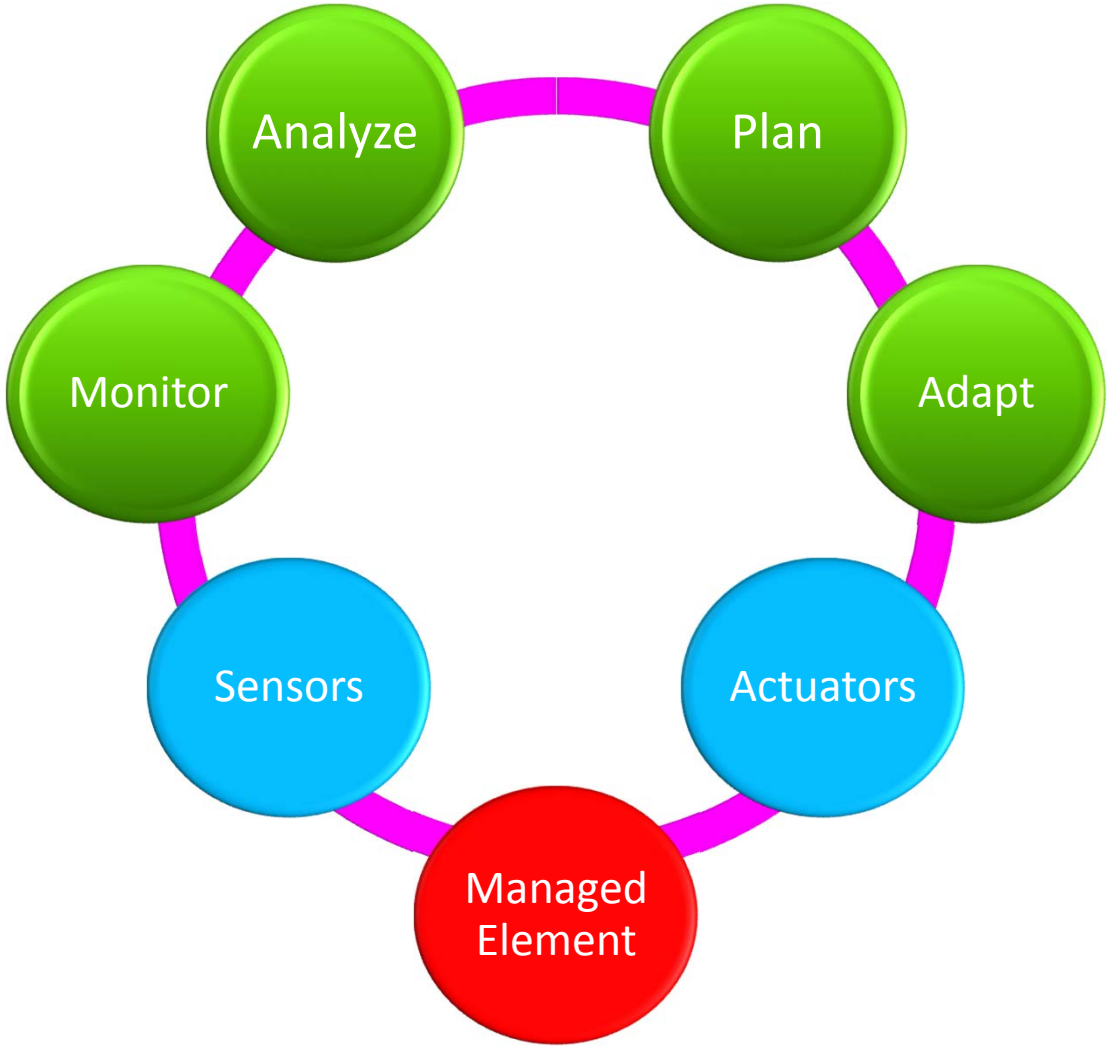


Autonomic System = Self-Managing System

Reading Assignment

- Kephart, J.O., Chess, D.M.: The Vision of Autonomic Computing. IEEE Computer 36(1):41-50 (2003)
  ieeexplore.ieee.org/stamp/stamp.jsp?tp=&arnumber=1160055
- IBM: An Architectural Blueprint for Autonomic Computing, 4th Ed. (2006)
  citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.150.1011&rep=rep1&type=pdf

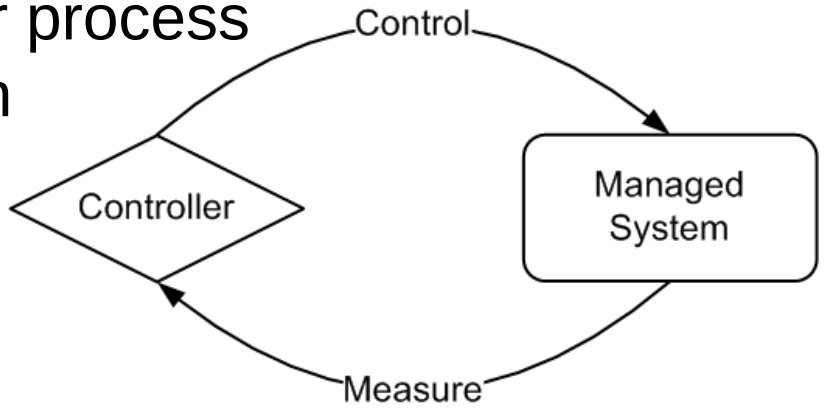
A Second Look at an Autonomic System

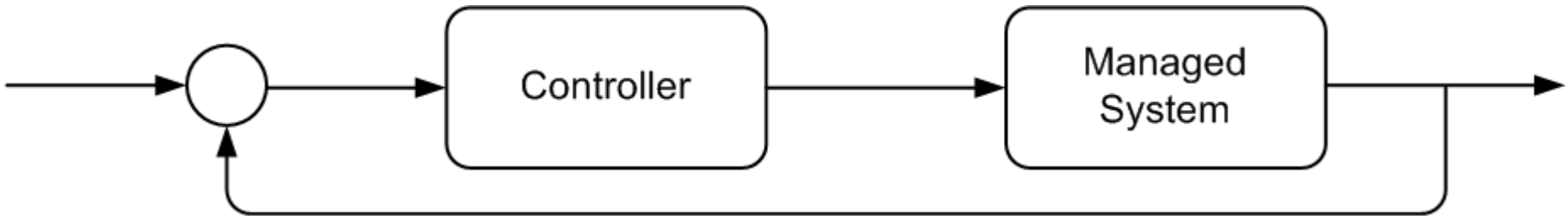


Feedback is ubiquitous in natural and engineered systems

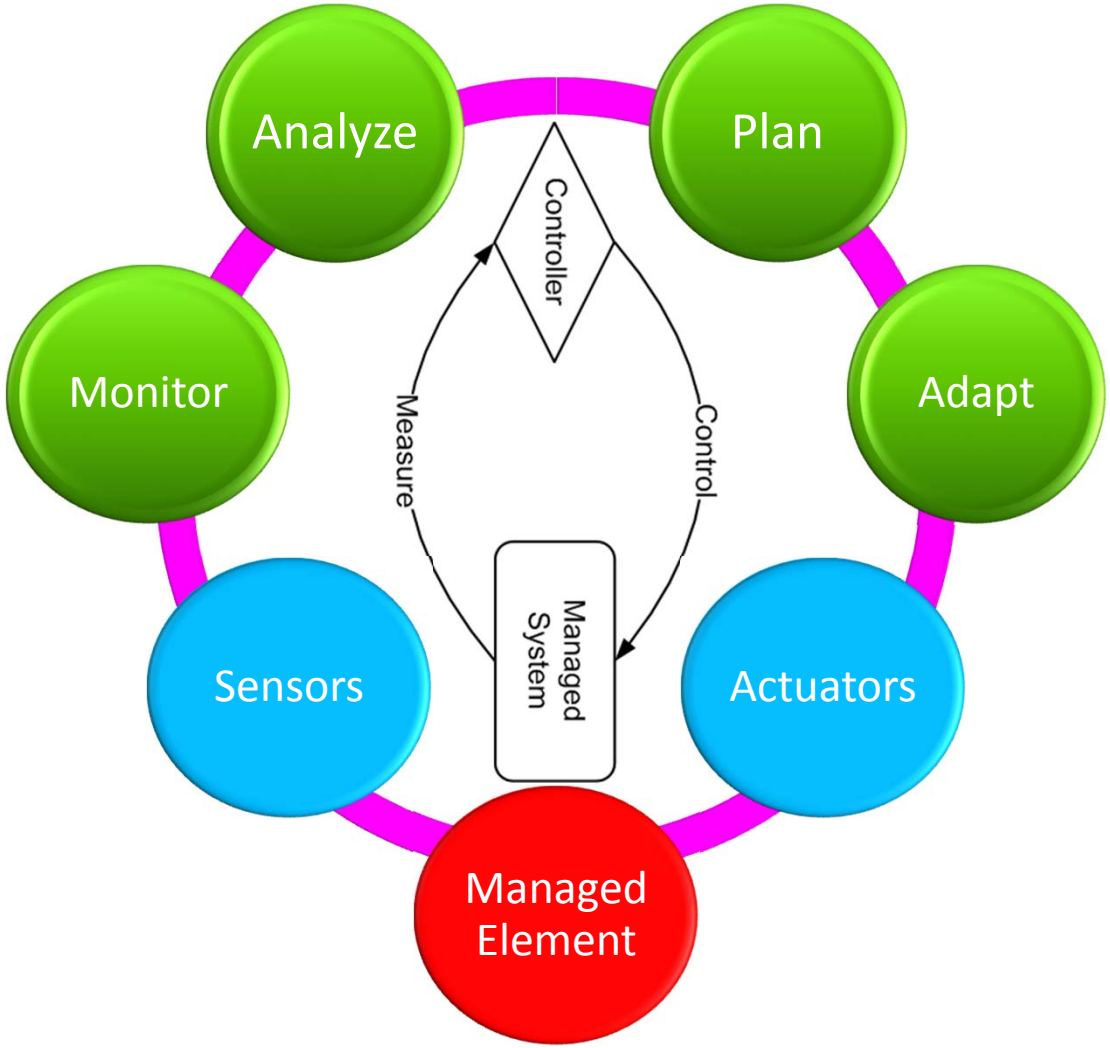
Feedback Systems

- **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)

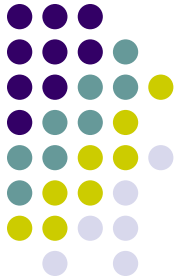




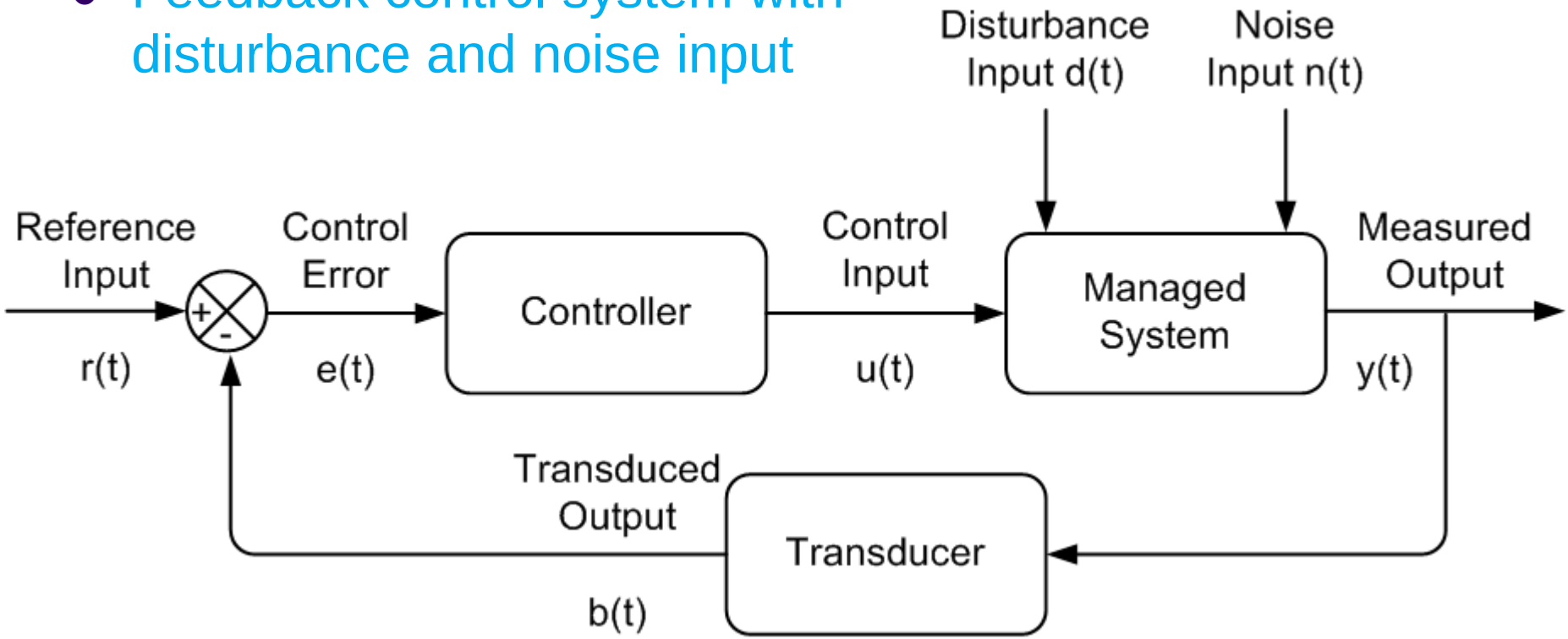
A Third Look at an Autonomic System



Realization of a Dynamic Architecture



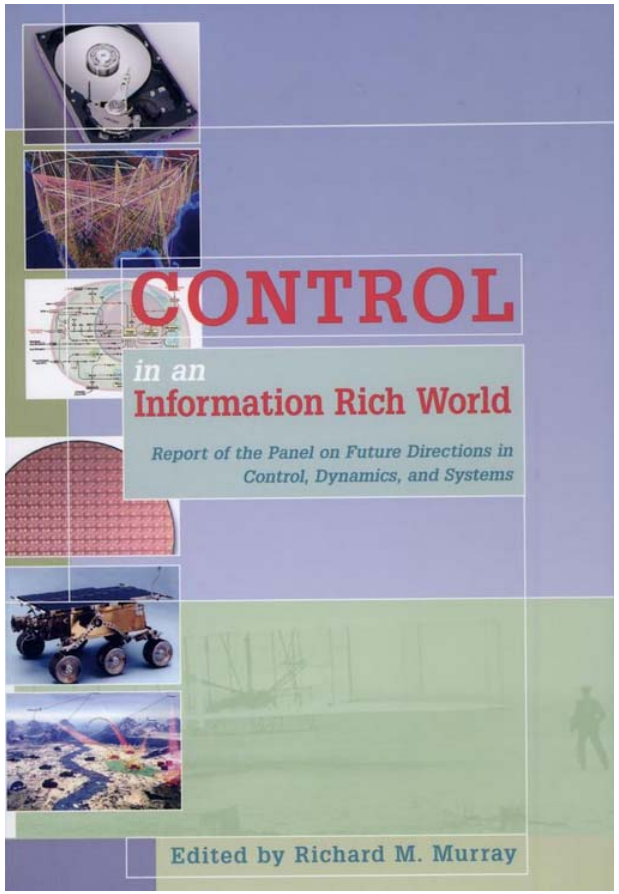
- Feedback control system with disturbance and noise input



Hellerstein, Diao, Parekh, Tilbury: Feedback Control of Computing Systems. John Wiley & Sons (2004)

Control in an Information Rich World

- Control in an Information Rich World
  Report of the Panel on Future Directions in Control, Dynamics, and Systems
  Edited by Richard Murray
  - Chapters 1 & 2
  - http://www.cds.caltech.edu/~murray/cdspanel/report/cdspanel-15aug02.pdf
- Quadcopters
  - http://www.bestquadcopterreviews.org/
  - http://www.droneflyers.com/2014/11/best-quadcopters-for-2015/
  - https://www.youtube.com/watch?v=CKMp29nC_34
  - http://www.geekosystem.com/quadcopters-james-bond-theme/



Feedback loops in natural and engineering systems

- Autonomous vehicles
  - Quadcopters, blimps, drones, robots, driverless cars
- Controllers in engineering
  - Centrifugal governor, cruise control, ABS, guidance and flight control, Mars Curiosity, industrial process control, printing press, NC machines, computer networks
- Autonomic Nervous System (ANS)
  - Separates normal day-to-day internal processes from exceptional, stressful situation processes
- Homeostasis
  - Property of a system that regulates its internal environment to maintain a stable condition (equilibrium)
  - Carbon-water, ice-albedo, climate, financial markets
- Feedback equations
  - Fractal generators—ferns and grasses
  - Julia and Mandelbrot sets

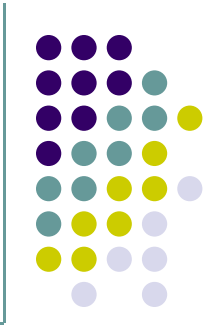
Types of Feedback

- **Negative feedback**
  - Stabilizes operation; regulates within a set and narrow range
  - Classic examples
    - Thermostat control
    - Homeostasis

www.youtube.com/watch?v=CLv3SkF_Eag

- **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

Types of Feedback



Negative feedback loop

Decreases effects

- Stimulus produces a response which reduces the original stimulus
- Examples
  - Sweating—reduces being hot
  - Shivering—reduces being cold
  - Blood Sugar—reduces sugar in blood
  - Stomata's and guard cells in plants—reduce water loss in transpiration

Positive feedback loop

Increases effects

- Stimulus produces a response which increases the stimulus
- Examples
  - Drug addict—needs more drugs
  - Apple ripening—ethylene is increased
  - Hormone produced to speed up contractions in childbirth—increases faster birth

Wall-following blimp

Mantis Cheng
Computer
Science
UVic

Quadcopter stable hover

Autonomous
vehicles

James Bond Theme Played by Quadcopters — 1:38 mins

http://www.geekosystem.com/quadcopters-james-bond-theme/

Raffaello D'Andrea, ETH Zürich & Kiva Systems

The Flying Machine Arena

Quadrocopter Ball Juggling

ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Raffaello D'Andrea
ETH Zürich & Technical Co-Founder Kiva Systems

DYNAMIC WORKS
HIGHLIGHTS

Raffaello D'Andrea
December 2011

Amazon Acquires Kiva Systems

March 19, 2012

Amazon.com Inc. is agreeing to pay **$775 million** for Kiva Systems Inc.

June 4, 2012

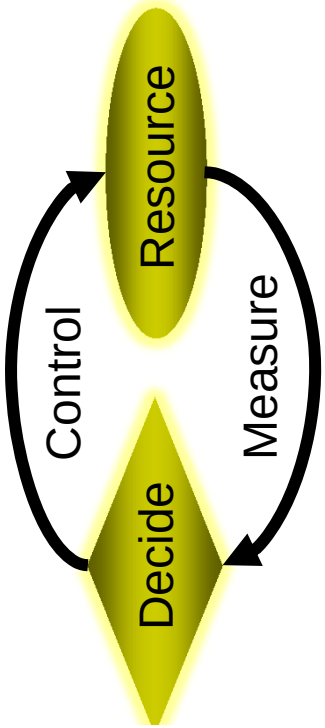
Keynote at SEAMS 2012 in Zürich

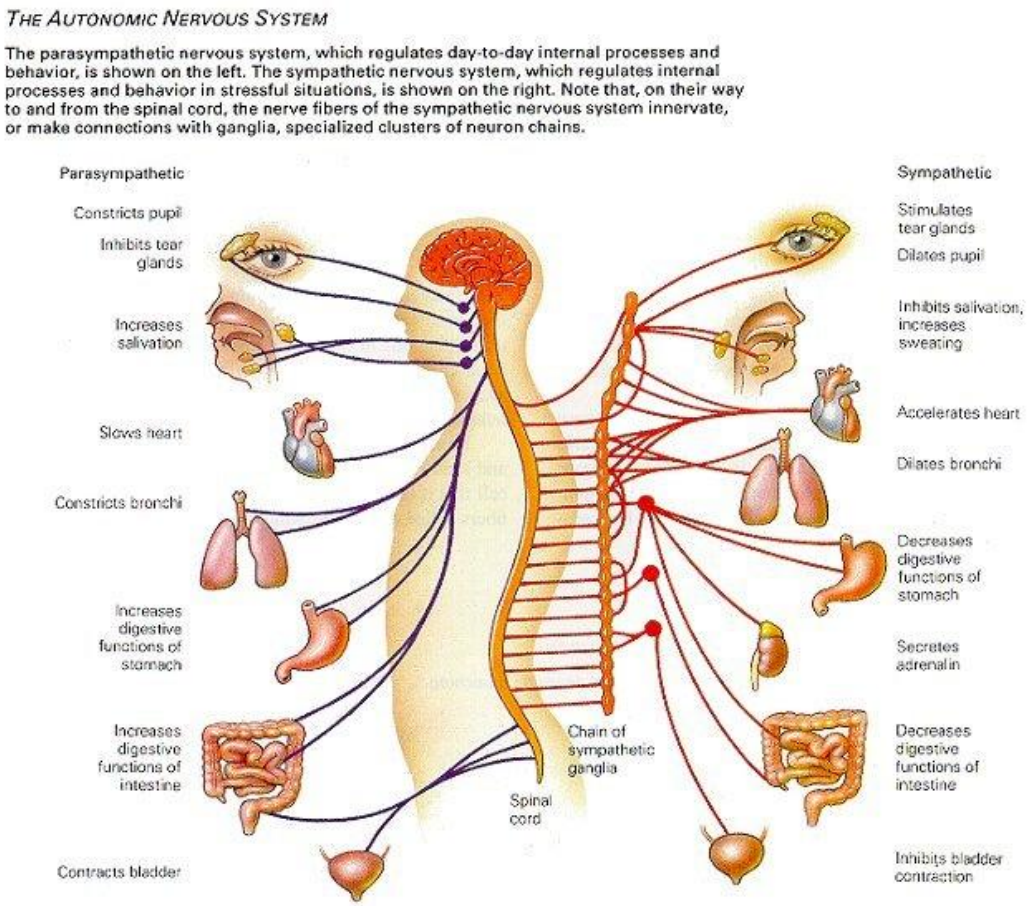
Most Famous Feedback System
Autonomic Nervous System (ANS)

Autonomic nervous system (ANS)

- Parasympathetic
  - Day-to-day internal processes
- Sympathetic
  - Stressful situation processes

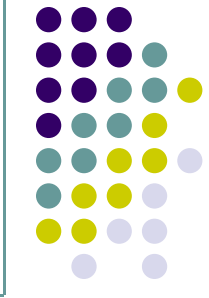
Temperature
Heart rate
Breathing rate
Blood pressure
Blood sugar
Pupil dilation
Tears
Digestion
Immune response





Monitor and Regulate

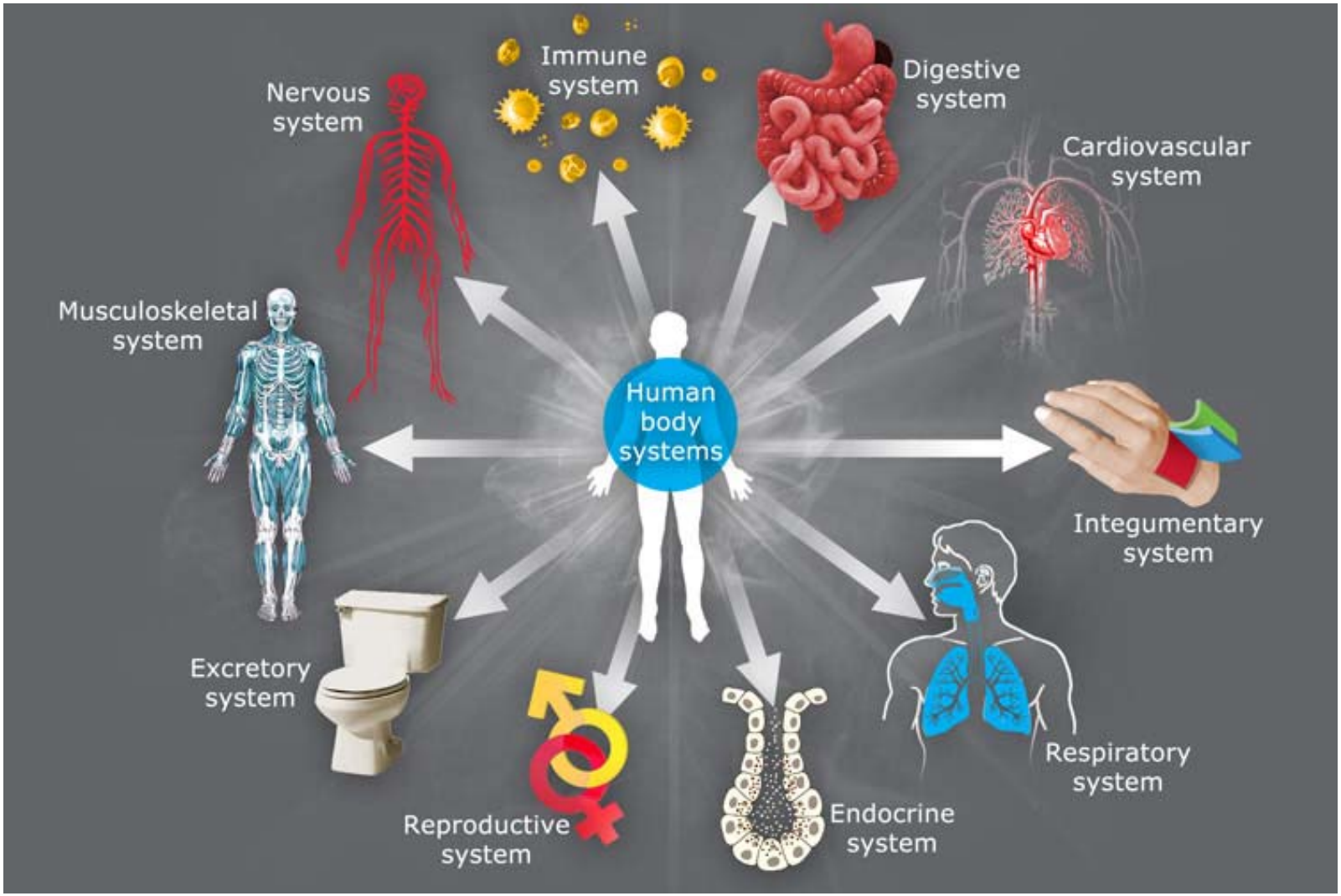
Interesting Architectural Note



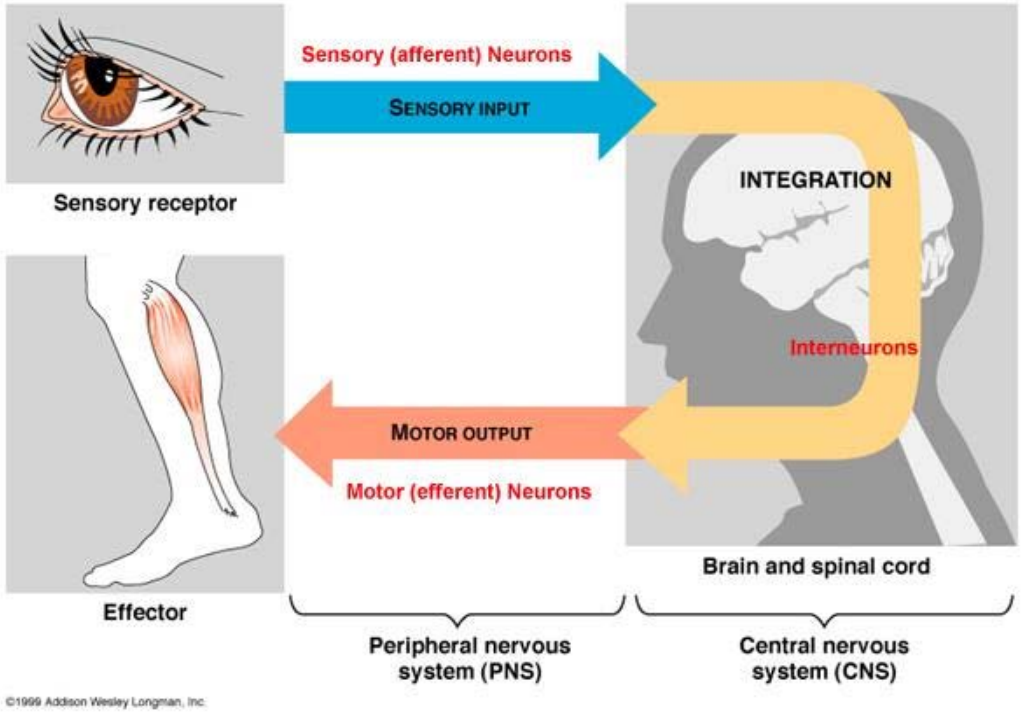
- Architecturally the ANS seems to separate the normal day-to-day internal processes from the exceptional, stressful situation processes
  - Parasympathetic
    - Day-to-day internal processes
  - Sympathetic
    - Stressful situation processes

- Could we use this interesting architectural design decision for self-managing and self-adaptive systems?

Human Body Systems

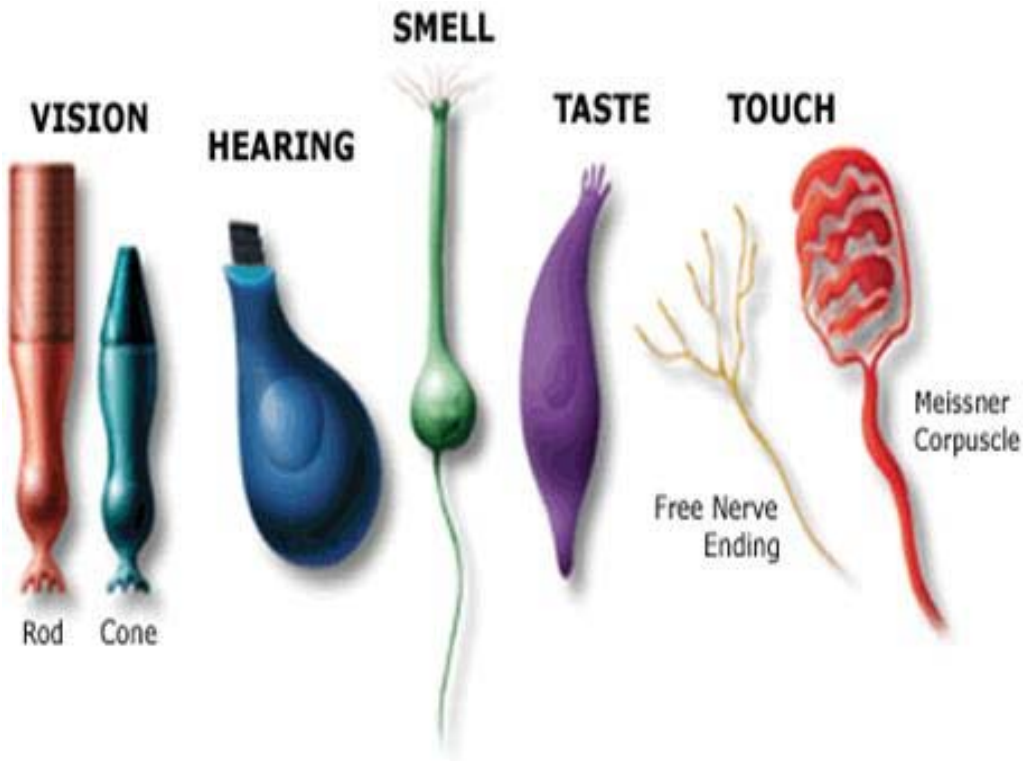


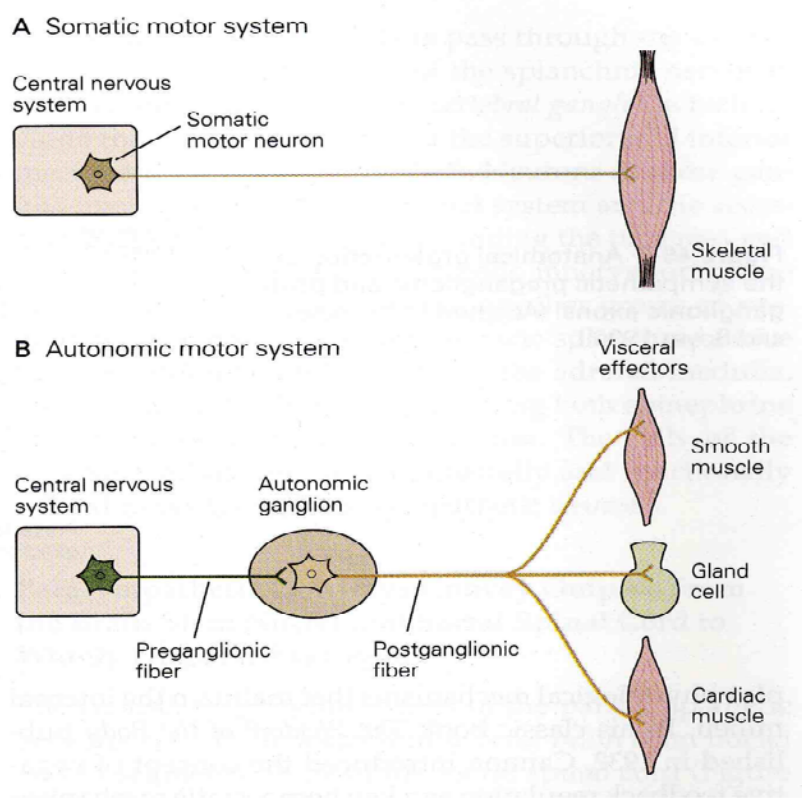
ANS Reflex Control Loop Sensory and Motor Neurons



- 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

ANS Reflex Control Loop

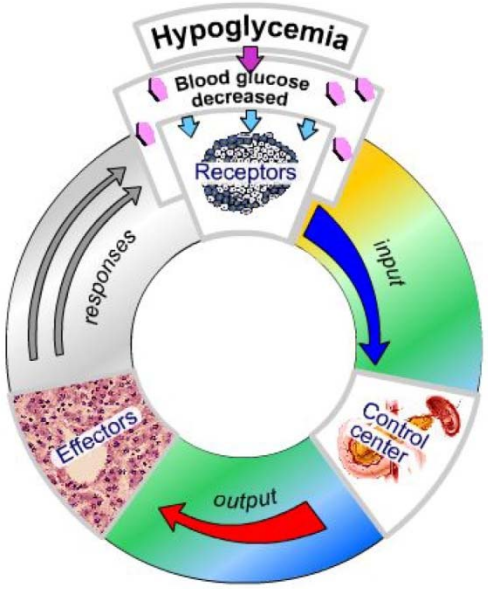




- Mechanical and chemical sensory receptors
- Motor neurons act on smooth muscle, cardiac muscle, and exocrine glands

Sympathetic Nervous System —1:50 mins

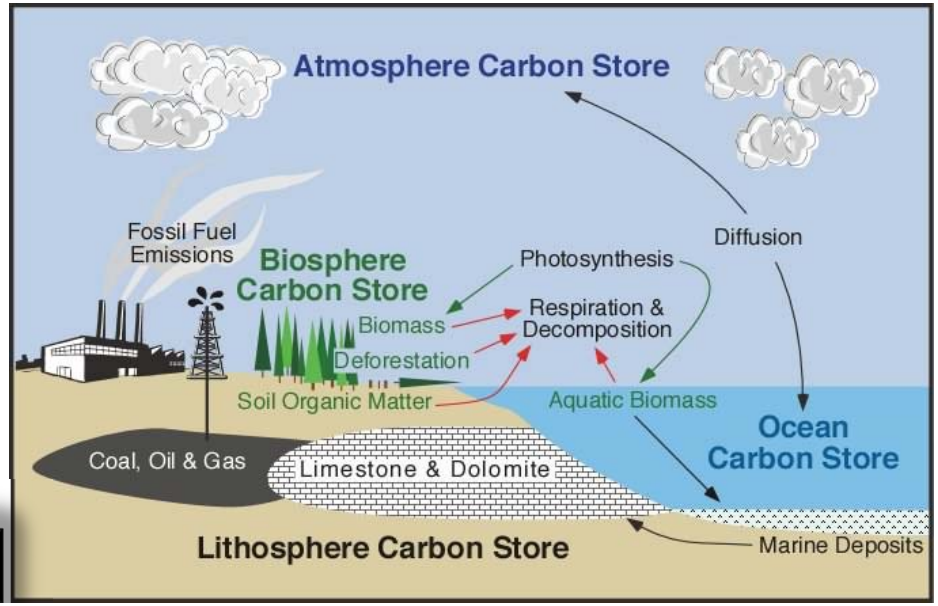
Physiological Regulation
Homeostasis



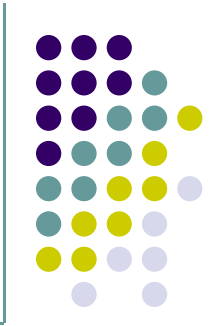
- ***Homeostasis*** is the property of a system that regulates its internal environment and tends to maintain a stable, constant condition
- In animals the internal environment of our bodies must have certain conditions within tolerable limits to continue the healthy functioning.
- This is done by negative 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



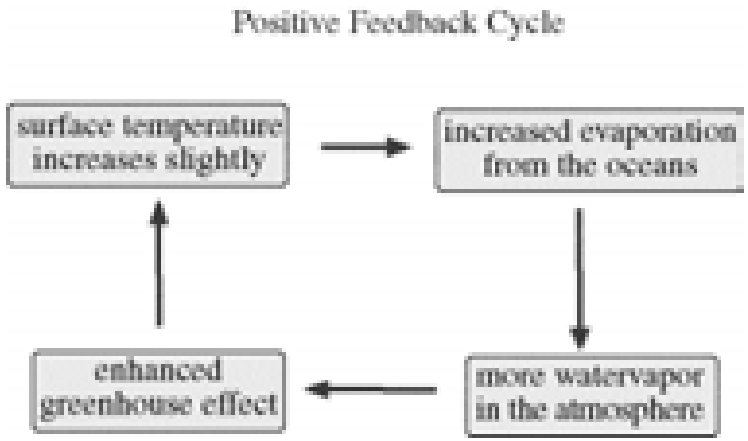
Ice-Albedo Feedback

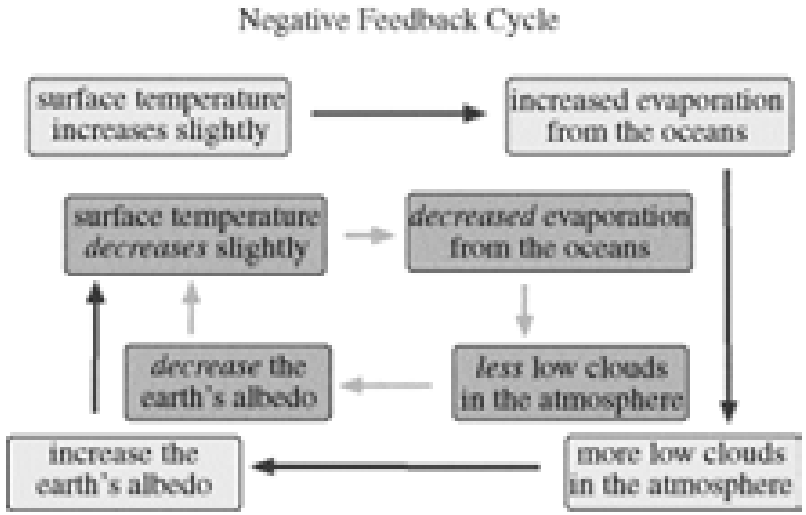


- Albedo
  - The amount of energy reflected by a surface; scale from zero to one
  - For dark colors albedo close to zero; light ones close to one
- Arctic sea ice is covered with snow all winter.
- Bright white, the snow-covered ice has a high albedo so it absorbs very little of the solar energy that gets to it.
- If 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.

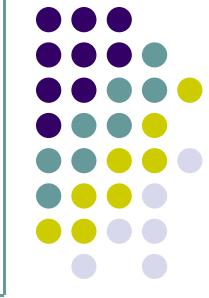
Climate Feedback Examples

- The balance of incoming and outgoing energy in the earth's atmosphere system can be altered by feedback loops
- Positive feedback mechanisms reinforce initial changes; negative feedback mechanisms weaken initial changes.





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.

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