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

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University of Victoria

http://courses.seng.uvic.ca/courses/2013/summer/seng/480b
http://courses.seng.uvic.ca/courses/2013/summer/csc/485b
http://courses.seng.uvic.ca/courses/2013/summer/csc/586b

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## Quiz 4

- Are you sitting next to the same person you did on Wed?
- Did you look up any term or resource related to this course since Wed?

- This course involves a lot of reading! How much reading have you done so far?

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## Course Web Sites

- Course outline
  - Undergraduate students
    - http://courses.seng.engr.uvic.ca/courses/2010/spring/seng/480b
    - http://courses.seng.uvic.ca/courses/2013/summer/seng/480b
  - Graduate students
    - http://courses.seng.uvic.ca/courses/2013/summer/csc/586b
- Course websites
  - http://www.rigiresearch.com/courses/sas
  - Syllabus
  - Lecture slides (pdf)
  - Assignments
  - Materials for reading assignments
  - Everything else you need to know about the course

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## Course Website


http://www.rigiresearch.com/courses/sas

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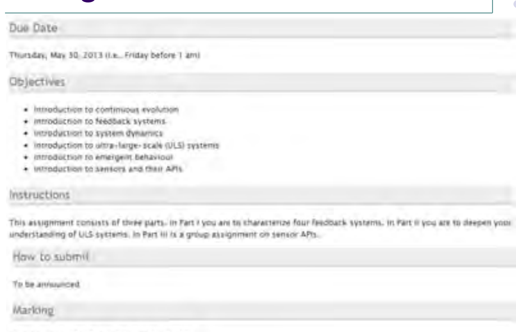
## Assignment 1— Instructions



Due Date

Thursday, May 30, 2013 (i.e., Friday before 1 am)

Objectives

- Introduction to continuous evolution
- Introduction to feedback systems
- Introduction to system dynamics
- Introduction to ultra-large-scale (ULS) systems
- Introduction to emergent behaviour
- Introduction to sensors and their APIs

Instructions

This assignment consists of three parts. In Part I you are to characterize four feedback systems. In Part II you are to deepen your understanding of ULS systems. In Part III is a group assignment on sensor APIs.

How to submit

To be announced

Marking

Part I is worth 35%, Part II 35%, and Part III 30%

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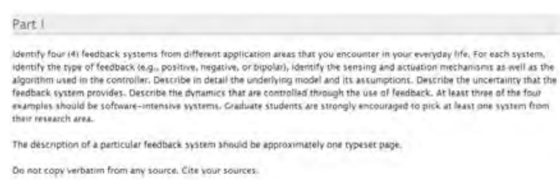
## Assignment 1 — Part I



Part I

Identify four (4) feedback systems from different application areas that you encounter in your everyday life. For each system, identify the type of feedback (e.g., positive, negative, or bipolar), identify the sensing and actuation mechanisms as well as the algorithm used in the controller. Describe in detail the underlying model and its assumptions. Describe the uncertainty that the feedback system provides. Describe the dynamics that are controlled through the use of feedback. At least three of the four examples should be software-intensive systems. Graduate students are strongly encouraged to pick at least one system from their research area.

The description of a particular feedback system should be approximately one typeset page.

Do not copy verbatim from any source. Cite your sources.

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## Assignment 1 — Part II

Part II

Study the ULS book:

- Northrop, L., Feiler, P., Gabriel, R., Goodenough, J., Linger, R., Longstaff, T., Kazman, R., Klein, M., Schmidt, D., Sullivan, K., Wallnau, K.: Ultra-Large-Scale Systems. The Software Challenge of the Future. Technical Report, Software Engineering Institute, Carnegie Mellon University, 134 pages ISBN 0-9786956-0-7 (2006)
- http://www.sei.cmu.edu/uls

1. What are the main characteristics of a ULS system?
2. Contrast centralized and decentralized control.
3. Describe three selected challenges for the design and evolution of ULS systems in detail.

The answers for this question should fit into approximately 2-3 typeset pages.

Do not copy verbatim from any source. Cite your sources.

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## Assignment 1 — Part III

Part III - Group Poject (3-4 people per group)

1. Identify and describe sensor APIs for different platforms (e.g., different operating systems). Pick an interesting category of sensors or sensor network and describe its API in detail.
2. Design, implement and document a simple application using this API.
3. Describe how this API and your application can be transitioned to a cloud computing environment.

All group members have to work on all three parts together. Learn from each other.

The answers for this question should fit into approximately 3-4 typeset pages.

Do not copy verbatim from any source. Cite your sources.

**Groups**

| | |
|---|---|
| G1 | Kelvin Lacy, Daniel Mow, Nina Taheri, Lorena Castaneda |
| G2 | Mohammed Alghamdi, Heng Wu, Andi Bergen, Carlos Gomez |
| G3 | Pratik Jain, Guy Evans, Meghan Reid, Curtis St. Pierre |
| G4 | Nitin Goyal, Angela Rook, Cordon Meyer, Pauline Redding |
| G5 | Marcelle Wheeler, Mehrdad Mansouri, Muhammad Azam, Gareth Johnson |
| G6 | Noe Hwang, Derek Roberts, Ali Alsarhany, Mustafa Abualsaud |
| G7 | David Clarke, Tom Gibson, Daniel Ennti, Alessia Knauss |
| G8 | Cale McNulty, Lee Myhre, Peter Bi, **one more** |

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## Self-Adaptive Systems (SAS)

- A SAS can alter its behaviour at runtime (on the fly) in response to its perception of
  - its environment
  - its own state

  by adapting itself


- SAS abilities
  - Assess its own behaviour
  - Observe its context or environment
  - Adapt without shut down


- Oreizy, et al.: An Architecture-Based Approach to Self-Adaptive Software, *IEEE Intelligent Systems,* pp. 54-62 (1999)
- MacManus: Why Software is More Important Than Sensors in the Internet of Things, ReadWriteWeb (2010)

## Situational Awareness (SA)

- SA is the perception of environmental and personal context with respect to time and space
- Comprehension of its meaning and its projection into the future
- Critical to decision-making in complex, dynamic situations

- Applications
  - Mars Curiosity
  - Aviation—UAV, drones
  - Military command and control
  - Emergency services
- Applications
  - Driving a car
  - Crossing a street
  - Playing basketball
  - Shopping

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Intuitively we know how critical and valuable context is.
But context is complicated.

"Context is the new battleground between Android, iOS, Windows, Symbian and Apple, Google, IBM, Microsoft, Nokia, Samsung."

**The Age of Context**

Simple can be harder than complex. You have to work hard to get your thinking clean to make it simple.

*Steve Jobs,* BusinessWeek, 1998

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Something profound is happening …
The Smart Systems Revolution

Instrumented + Interconnected + Intelligent

## Confluence of Sensors, Networks, Devices, Clouds, and Apps


## The Internet of Things (5 minutes)

IBM

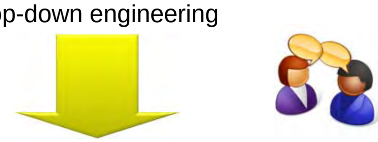
## Continuous Evolution

- **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

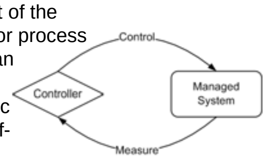


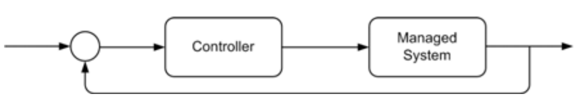
- To satisfaction of requirements by regulation of complex, decentralized systems

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

## 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)



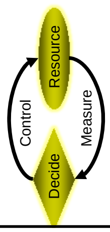


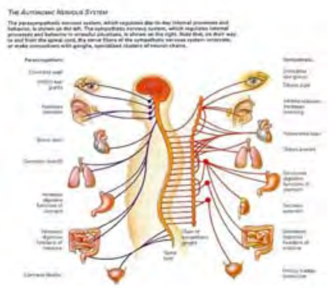

**Feedback is ubiquitous in natural and engineered systems**

## 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
mmune response



Monitor and Regulate

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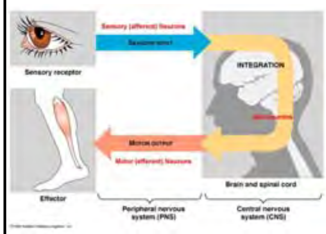
## ANS Reflex Control Loop Sensory and Motor Neurons




- 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.

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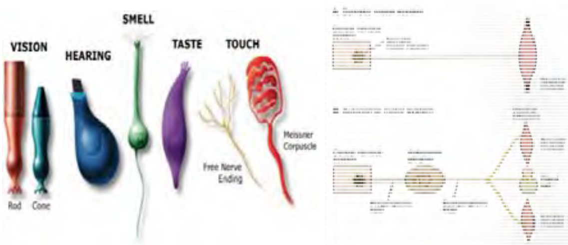
## ANS Reflex Control Loop




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

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## 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?

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## Sympathetic Nervous System


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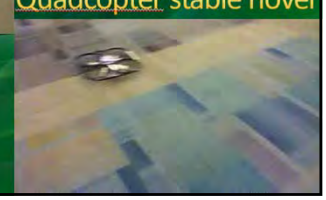
Wall-following blimp

Mantis Cheng
Computer
Science
UVic

Quadcopter stable hover



Autonomous
vehicles

## Raffaello D'Andrea, ETH Zürich & Kiva Systems

The Flying Machine Arena
Quadrocopter Ball Juggling

IDSC

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

## 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

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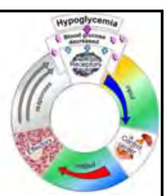
## Physiological Regulation *Homeostasis*




- ***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 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

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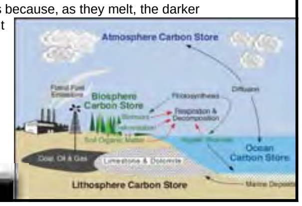
## Carbon-Water Climate Models

- 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




PhysicalGeography.net

## 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.

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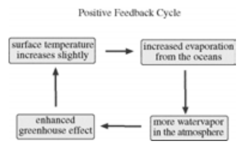
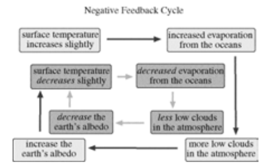
## Climate Feedback Examples

- The balance of incoming and outgoing energy in the earth's atmosphere system can be altered by feedbacks
- 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.

http://www.simoleonsense.com/benoit-mandelbrot-how-fractals-can-explain-whats-wrong-with-wall-street/

## Generating Ferns and Grasses

$$Fx(x) = ax + by + e$$
$$Fy(y) = cx + dy + f$$

| a | b | c | d | e | f | p |
|---|---|---|---|---|---|---|
| 0.0 | 0.0 | 0.0 | 0.16 | 0.0 | 0.0 | 0.10 |
| 0.2 | -0.26 | 0.23 | 0.22 | 0.0 | 1.6 | 0.08 |
| -0.15 | 0.28 | 0.26 | 0.24 | 0.0 | 0.44 | 0.08 |
| 0.75 | 0.04 | -0.04 | 0.85 | 0.0 | 1.6 | 0.74 |

p = probability with which the transformation is applied 34

## Fractal Generator

- Does the sequence approach a limit value?
- Will the sequence arrive at a cycle of repeated values?
- Will the sequence be completely erratic?
- C, $x_0$ = constants
- $x_n$, $x_{n+1}$ = subsequent values in sequence; feedback

$$x_{n+1} = f(x_n, c)$$

For example

$X_{n+1} = (x_n + c) \bmod 11$

How does this sequence behave?

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## Fractal Generator Example

- $x_{n+1} = (x_n + c) \bmod 11$
- c = 3 and $x_0 = 0$
  - → 0 3 6 9 1 4 7 10 2 5 8 0 3 …
- c = 2 and $x_0 = 0$
  - → 0 2 4 6 8 10 1 3 5 7 9 0 2 …
- c = 11 and $x_0 = 0$
  - → 0 0 0 …

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## 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
  - Julia-Fatou 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)

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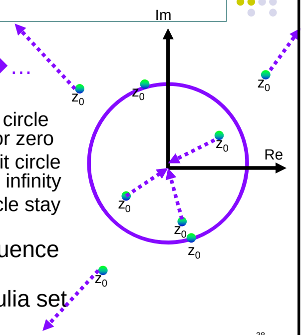
## Julia Set c = 0

- c = 0
- $z_0$ ➔ $z_0^2$ ➔ $z_0^4$ ➔ $z_0^8$ ➔ …
- Depending on $z_0$
  - Numbers inside the unit circle are drawn to the attractor zero
  - Numbers outside the unit circle are attracted to attractor infinity
  - Numbers on the unit circle stay there
- Thus, two zones of influence divide the plane
- The circle is called a Julia set

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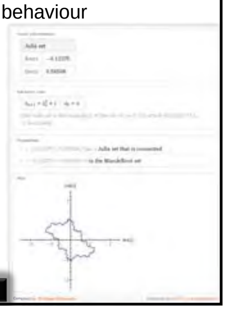
## What happens if c ≠ 0?

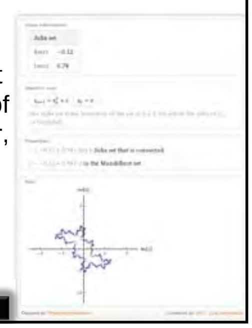
- C = -0.12375 + 0.56508i
- ➔ Degenerate circle, but the same behaviour
- The boundary (i.e., the degenerate circle is called a Julia set)
- Zoom in on curve
  - Self-similar
  - Fractal curve
- That is, depending on $z_0$
  - Numbers inside the degenerate circle are drawn to the attractor zero
  - Numbers outside the degenerate circle are attracted to attractor infinity
  - Numbers on the degenerate circle stay there



http://www.wolframalpha.com

## What happens if c ≠ 0?

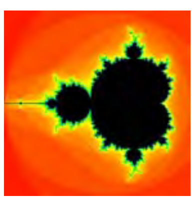
- C = -0.12 + 0.74i
- ➔ Julia set is no longer a single deformed circle, but rather an infinite number of deformed circles; however, it is still a connected set
- The beginning of chaos
  - 3 interior attractors
  - Infinity attractor



http://www.wolframalpha.com

## Mandelbrot Set

- The Mandelbrot set tells us which kind of Julia set we can expect
  - A given c either belongs to the black structure M or not
    - If c is inside M ➔ connected Julia set
    - If c is outside M ➔ disconnected Julia set
- Visualize all the Julia sets on a path from a point inside M to a point outside M
  - The Julia sets are exploding
  - Decompose into cloud of points
  - Chaos ensues



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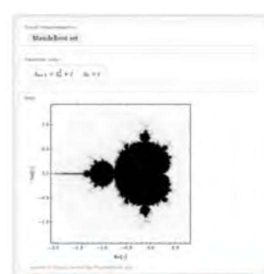
## Mandelbrot and Julia Sets

- Most famous fractal
  - $Z_{k+1} = z_k^2 + c$ where z, c are complex numbers
- Compute the Julia-Fatou sets for all possible values of c and colour each point in the complex plane
  - black if the Julia set is connected: made of one piece, not broken into disjoint islands
  - white if the set is not connected
- The result is the Mandelbrot set
- The Mandelbrot set is self-similar



Benoit Mandelbrot, IBM 1979

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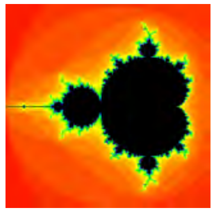
## Colouring Mandelbrot Sets

- $z_{k+1} = z_k^2 + c$ where z, c are complex numbers
- If sequence diverges, colour point white otherwise black
- Further, if the sequence diverges, assign different colours according to how quickly one can decide that the sequence diverges



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

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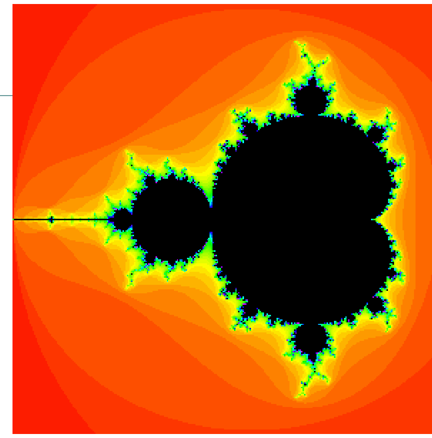

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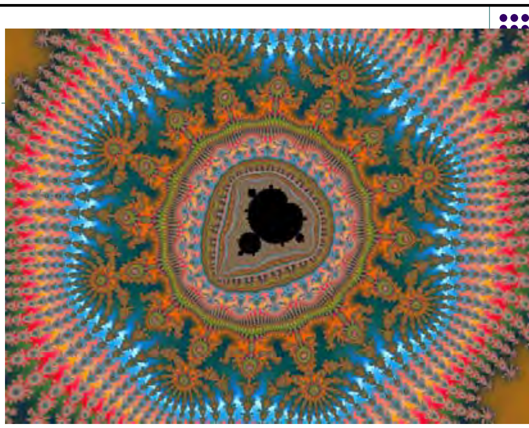

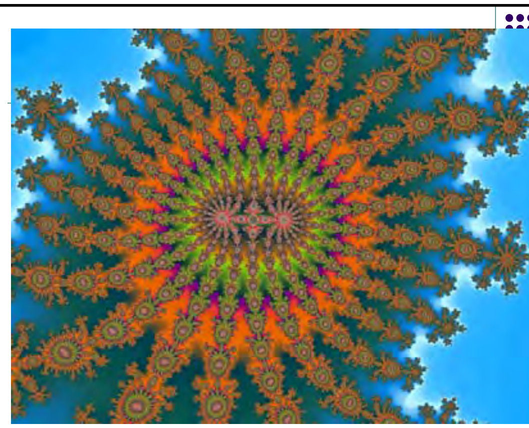

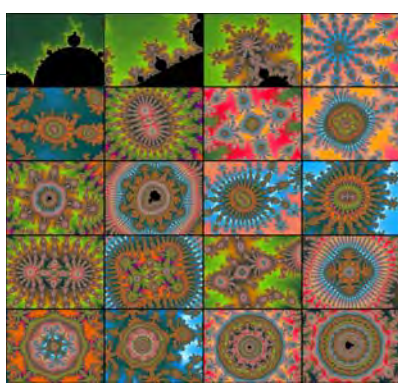

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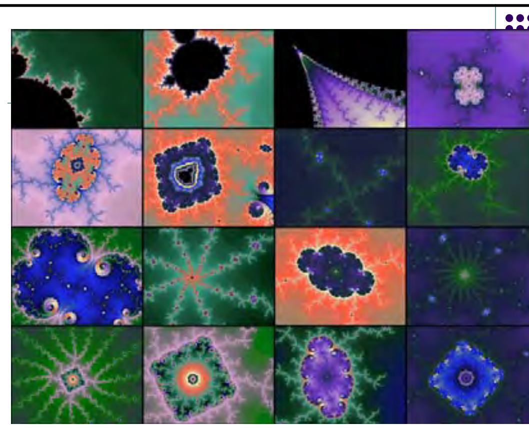

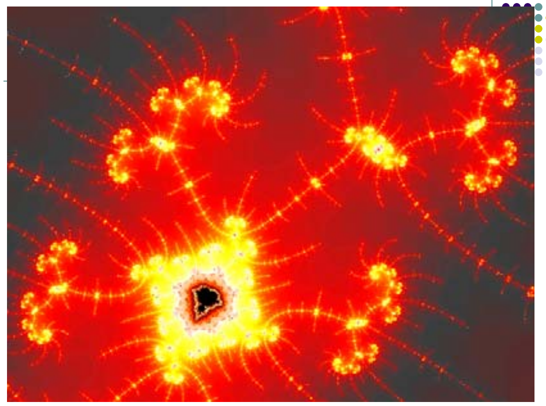

## 3-D Mandelbrot Set—Mandelbulb

http://www.skytopia.com/project/fractal/mandelbulb.html

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