Emergent Behavior and Boid Swarms

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October 20–22, 2011

Overview

- Fractals
- Complex Systems and Chaos
- Emergent Behavior
- Natural Phenomenon
- Cellular Automata: Demonstration
- Boids & Flocking: Demonstration

Fractals in Nature: *chou Romanesco*

Fractal forms are complex shapes which look more or less the same at a wide variety of scale factors, and are everywhere in nature.

Fractal

a geometric figure consisting of an identical motif
which repeats on an ever–reducing scale.

Diving in to Veggies

Look Closely — The Pattern Repeats!






Julia Sets

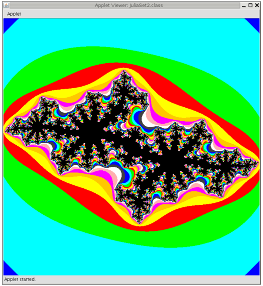
- A **fractal** may be a function that maps coordinates to values which we may then use to represent various colors, as in Julia Sets.

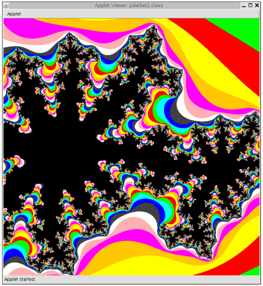
- **Julia Set** — To every real–valued pair, (a, b), we can associate a function of two variables referred to as the Julia map for (a, b), denoted by $F_{a,b}$, and described by the formula

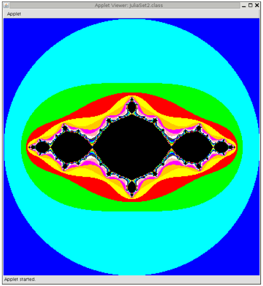
$$F_{a,b}(x, y) = (x^2 - y^2 + a, 2xy + b).$$

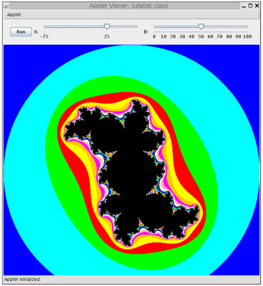
- The Julia set for (a, b), denoted by $J_{a,b}$, is the collection of all points in the plane from which you can start and never get too far away from the origin by repeated iterations of $F_{a,b}$.

Julia Set Examples — from CS I

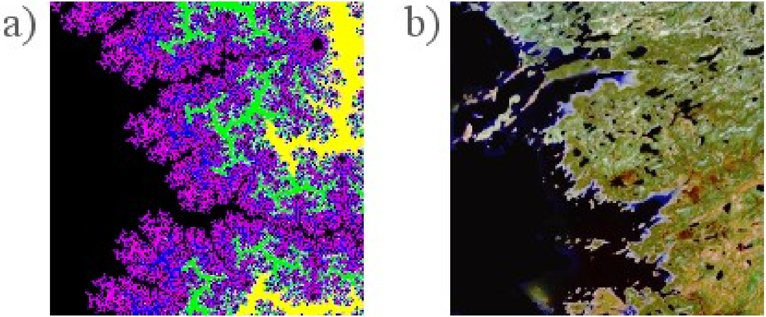








Synthesizing Nature: Coastlines



a) Part of the Mandelbrot set.

b) Part of the North American coastline near Hudson Bay.

Ferns

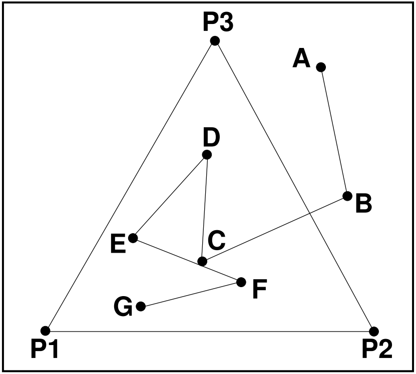
Complex Systems and Chaos

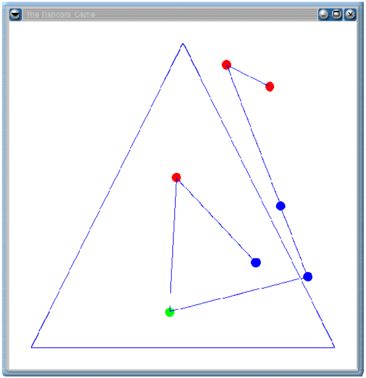
- A **complex system** is composed of **interconnected parts** that **as a whole** exhibit one or more properties not obvious from the properties of the **individual parts**.
- One type of complex, dynamical system is a **chaotic** system: from chaos sometimes comes order!
- Simple Rule(s) $\Rightarrow$ Complex Result.

Sierpinski Gasket – also from CS I

The Chaos Game

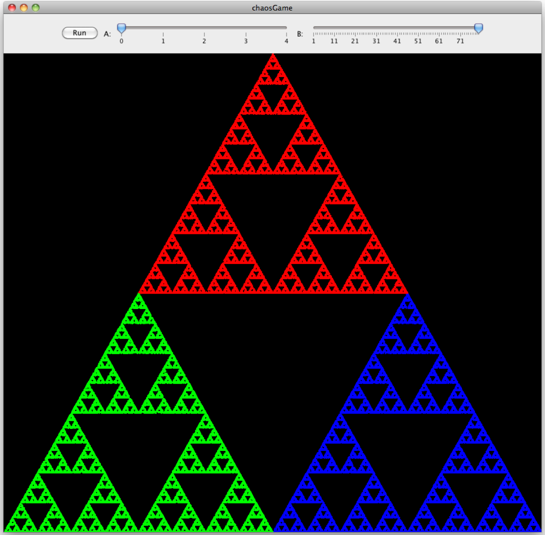
Rule: Randomly pick a vertex and move halfway toward it.



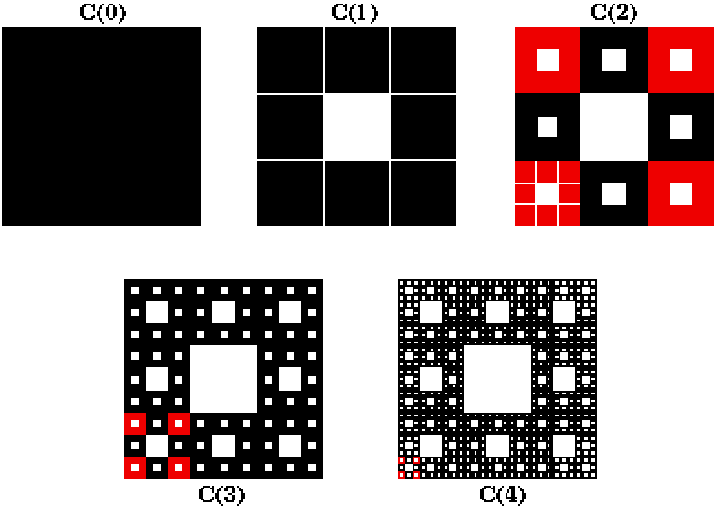


Color the new point according to which vertex was chosen.

The Result:

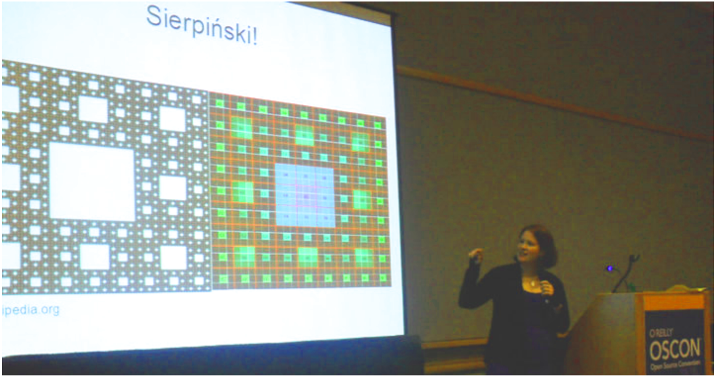


Sierpinski Carpet

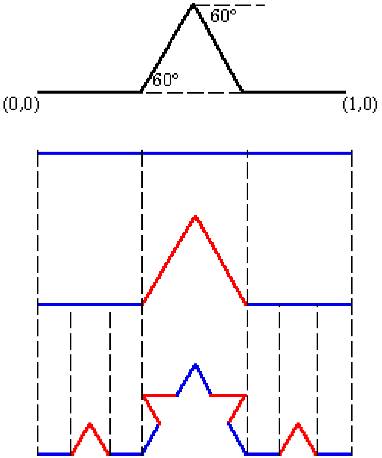


Rule: Subdivide square into 3×3 squares, remove middle; Repeat.

Sierpinski Carpet — and Quilt (OSCON, Australia)

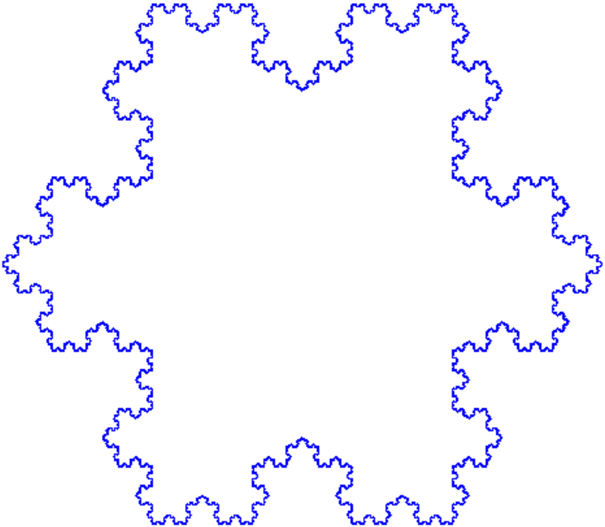


The Koch Snowflake

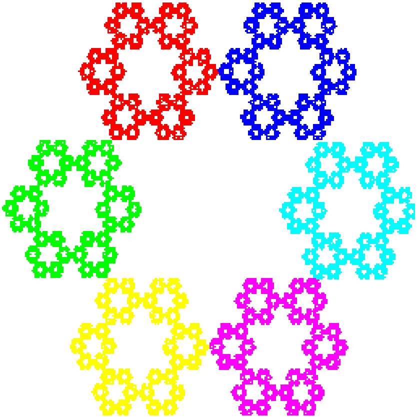


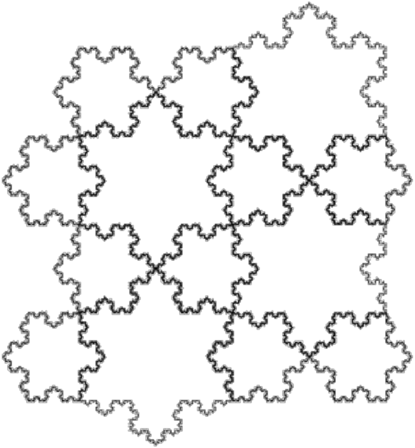
Rule: Replace the middle third of each line segment with 2 sides of an equilateral triangle.

The Koch Snowflake – Starting from a Triangle

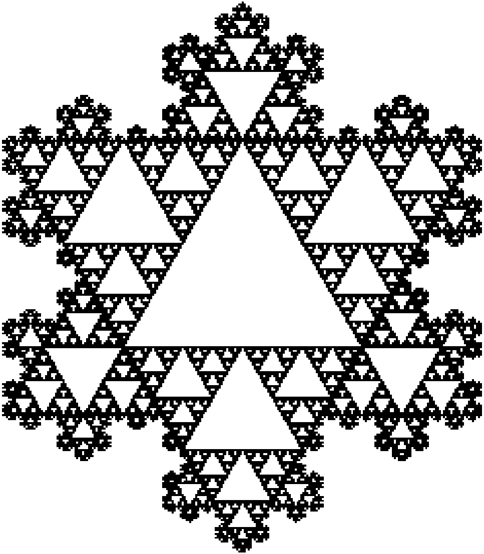


Tilings. . .





Back to the Sierpinski Triangle!



Emergent Behavior

- A complex system is a network of heterogeneous components that interact non-linearly, to give rise to **emergent behavior**.
- The number of interactions between components of a system increases combinatorially with the number of components — (potentially) allowing for many new and subtle types of behavior to emerge.

Complex Behavior

- **Emergence** is the way complex systems and **patterns** arise out of a multiplicity of relatively simple interactions.

- An **emergent behavior** or **emergent property** can appear when a number of simple entities (agents) operate in an environment, forming more **complex behaviors** as a **collective**.

Natural Phenomenon: Ice Crystals

Water crystals forming on glass

is an emergent natural process — a

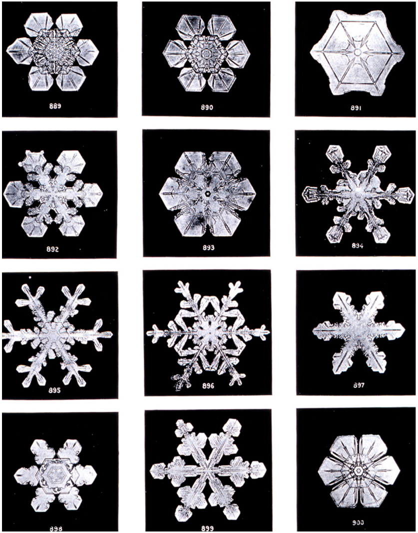
high level of organizational structure

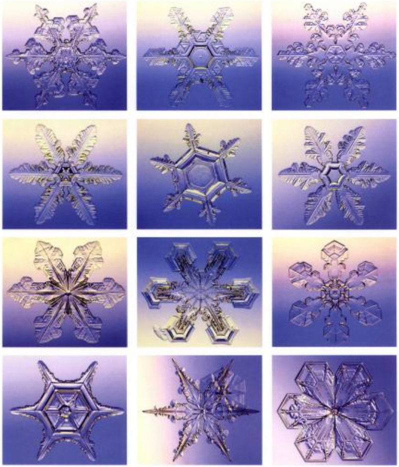
crafted directly by the

random motion

of water molecules.

Nature: Snowflakes





Fractal: Frost

Nature: Frost

Chaos and Hexagons

The most interesting stable patterns appear

right at the edge of chaos...

...a honeycomb arrangement of **hexagons**.

John Gribbin
Deep Simplicity

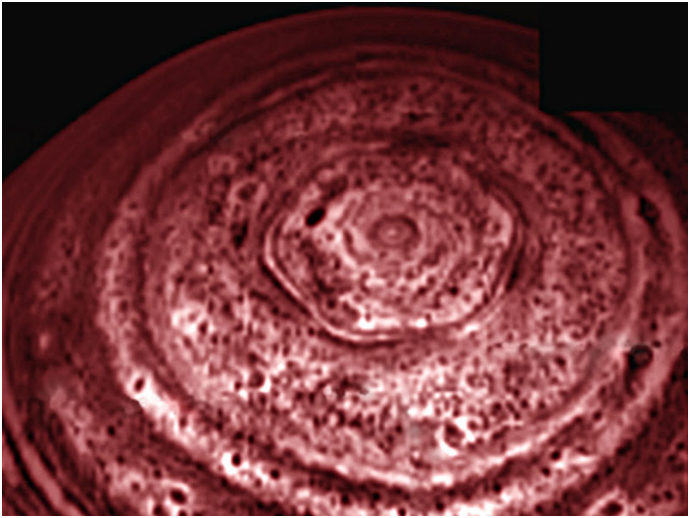
Hexagons Appear in Unexpected Places

Giant's Causeway, Ireland

About 40,000 interlocking basalt columns, the result of an ancient volcanic eruption.

Fingal's Cave, Scotland

Even in Space!



A hexagonal "feature" around Saturn's North Pole

Creating a Hexagon in Fluid (Aliens Not Included)

Similar effect with buckets of water

A pentagonal "hole" in the center of water swirling against the edge of a rotating bucket.

A **hexagon** appears when the bucket is spun at a higher speed.

Hexagons Are Everywhere!

Hexagons Occur in Nature

Some of Us Sport Our Own!

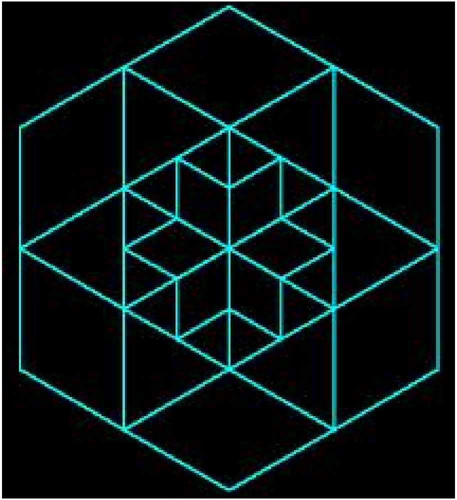
Hexagons in the Home

Crochet Pattern

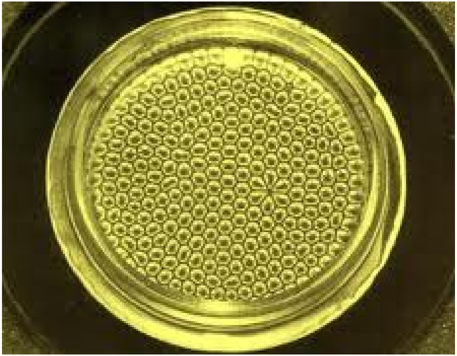
Crochet Colorfully Combined,
Tiling the Plane

Crochet: Sierpinski Pattern

Quilt Block Patterns



Hexagons in the Kitchen



Bénard Convection

One can observe the formation of Bénard cells
by heating a thin layer of oil in a pan.

Termites

- Complex social systems may exhibit behaviors that are **emergent**.
- The mound building of termites is a property that emerges from the collection of termites.

Termite Mounds

Classic examples of emergence in nature.

And Then There Are the Ants...

First you see one...

Then a few more...

Then the deluge!

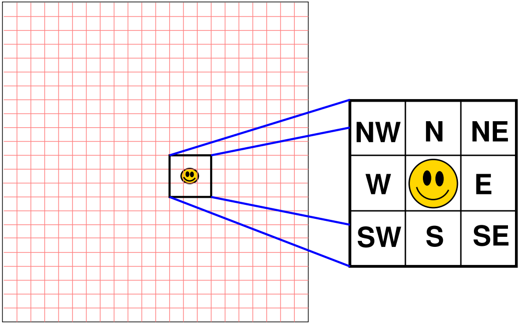
10 Tons of Concrete and 40 Tons of Dirt Later. . .

Simulating Complex Systems: Cellular Automata

- A **cellular automaton** consists of a regular grid of **cells**, each in a finite number of **states**.
- The **neighborhood** of a cell is a set of cells defined relative to the specified cell.
- An **initial state** (time $t = 0$) is created by assigning a state to each cell.
- A new **generation** is created (advancing t by 1), according to some fixed rule(s) that determines the new state of each cell in terms of the current states of the cell and its neighbors.

Conway's Game of Life

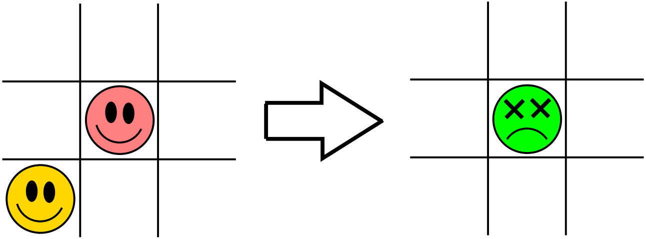
- A zero–player game (cellular automaton) devised by British mathematician John Horton Conway in 1970.
- Each cell on a grid has eight neighbors:



- There are four simple rules...

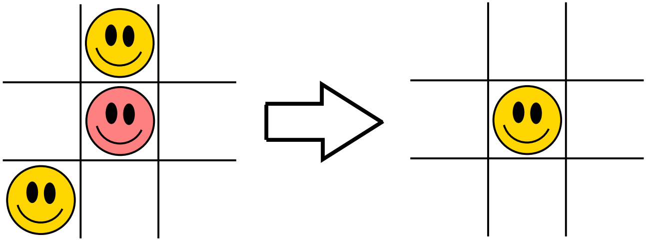
Rule No. 1 — Loneliness

Any live cell with **fewer than two** live neighbors **dies**



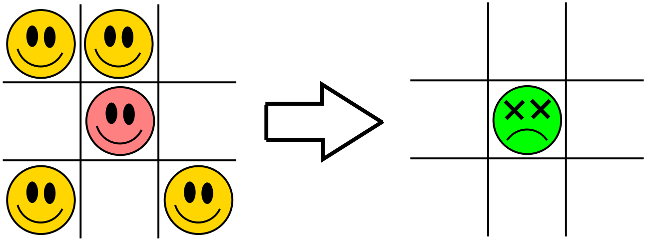
Rule No. 2 — Balanced Life

Any live cell with **two or three** live neighbors
lives on to the next generation



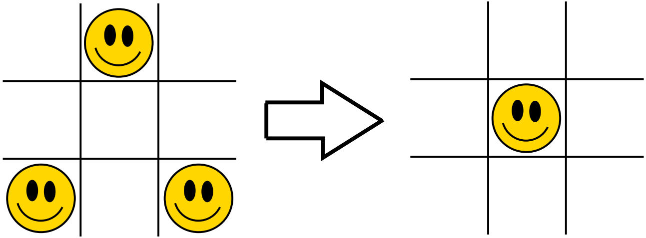
Rule No. 3 — Overcrowding

Any live cell with **more than three** live neighbors **dies**



Rule No. 4 — Reproduction

Any **dead** cell with **exactly three** live neighbors becomes a **live** cell

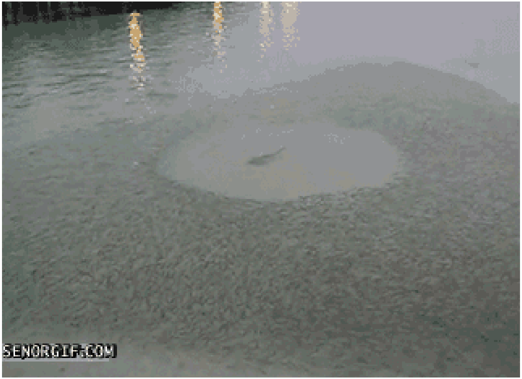


The Game Of Life

Complex Behavior

- As seen in the Game of Life, systems with **emergent properties or structures** may appear to defy entropic principles because they form and increase **order** despite the **lack** of **command** and **central control**.
- Open systems can extract information and order out of the environment.
- Another animation example is **boids**, which create swarming behavior in a simulated flock.

Feeding Fail

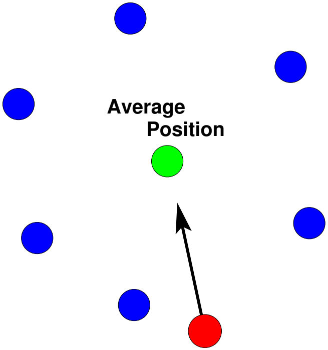


http://chzgifs.files.wordpress.com/2011/03/fishmagnetsarerepulsedp1.gif

Boids and Flocking

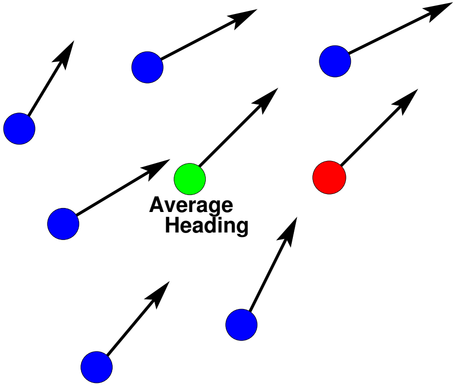
- There was a screen saver in UNIX some time ago, consisting of a **swarm** of short white lines which followed a red line around the screen much like a **school of fish** or **flock of birds**.
- In his 1987 SIGGRAPH paper "*Flocks, Herds, and Schools: A Distributed Behavioral Model*," Craig Reynolds coined the term **boids** to refer to this type of simulated flock.
- Boid flocks move in an extremely realistic way, creating complex motion and interaction.
- The behavior of boids is governed by simple rules. . .

Boid Rule: Cohesion



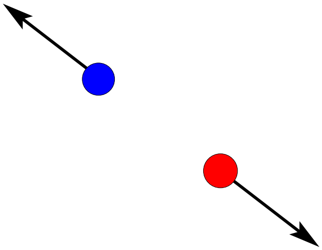
Cohesion: each unit steers toward the average position of its neighbors (stay with the group)

Boid Rule: Alignment



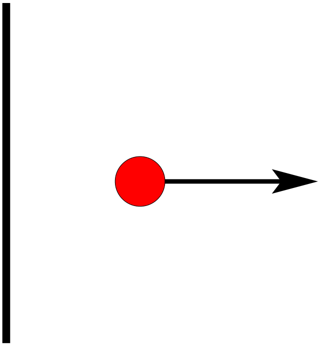
Alignment: each unit seeks to align itself to the average heading of its neighbors (move in the same direction)

Boid Rule: Separation



Separation: each unit attempts to avoid hitting its neighbors (maintain some "personal" space)

Boid Rule: Avoidance



Obstacle Avoidance: each unit attempts to avoid hitting obstacles (such as a wall or the mouse)

Boid Program Controls

- The **separation**: how hard the boids try to maintain some "personal" space
- The **separation distance**: the ideal amount of personal space (in pixels).
- **Alignment**: how hard boids try to move in the same direction.
- **Cohesion**: how hard boids try to stay in a group.
- **Avoidance**: how hard the boids try to stay away from the walls and mouse.
- **Visible range**: how far each boid can "see."

Flocking Program: Demonstration

http://www.zemows.org/~mertz/flock/launch.jnlp

Control Settings with Interesting Results

Simulates	Sep	Sep Dist	Align	Avoid	Cohesion	Vis	Boids
bird flock	1	10	1	1	0.2	100	600
gnats	2	20	0.1	1	0.5	100	600
fish tank	3.0	20	1	3.0	0.5	100	12
gas	1	20	0.1	2	-0.1	100	900
min state	1	20	0	100	-50	100	400

Other Examples

- http://demonstrations.wolfram.com/ACellularAutomatonBasedHeatEquation/
- http://demonstrations.wolfram.com/GarbageCollectionByAnts/
- http://demonstrations.wolfram.com/FoodSearchingModelForAnts/
- http://demonstrations.wolfram.com/3DBoidModel/
- http://demonstrations.wolfram.com/ParticleSystemFountain/
- http://demonstrations.wolfram.com/topic.html?topic=Cellular+Automata&sortmethod=recent

In Conclusion...

Thank You!

Any Questions?