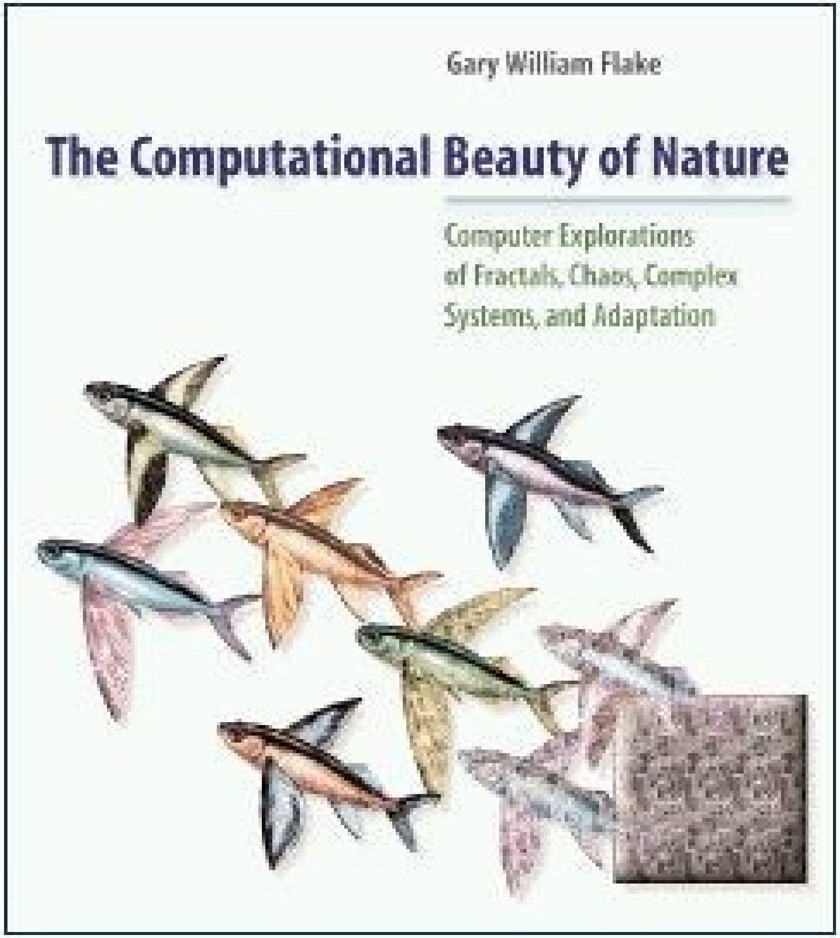
Models of Self-Organization:

Virtual Ants, Loops, Termites, Boids, and Fireflies

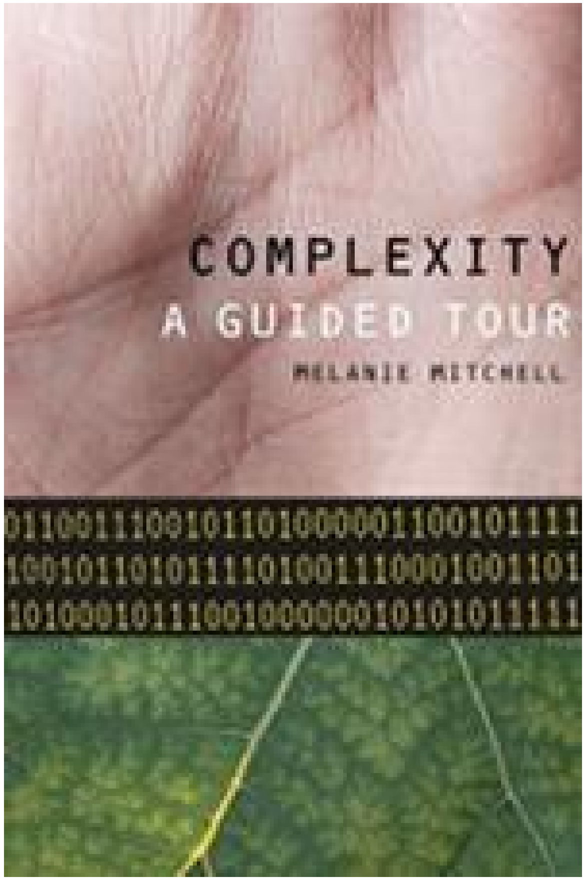
Reading for This Week

- **Chapter 16** of *The Computational Beauty of Nature* (Autonomous Agents and Self-Organization, pp. 261-279)



Reading for Next Week

- **Chapter 13** of *Complexity: A Guided Tour* (pp. 186-208) which discusses the Copycat analogy-making program





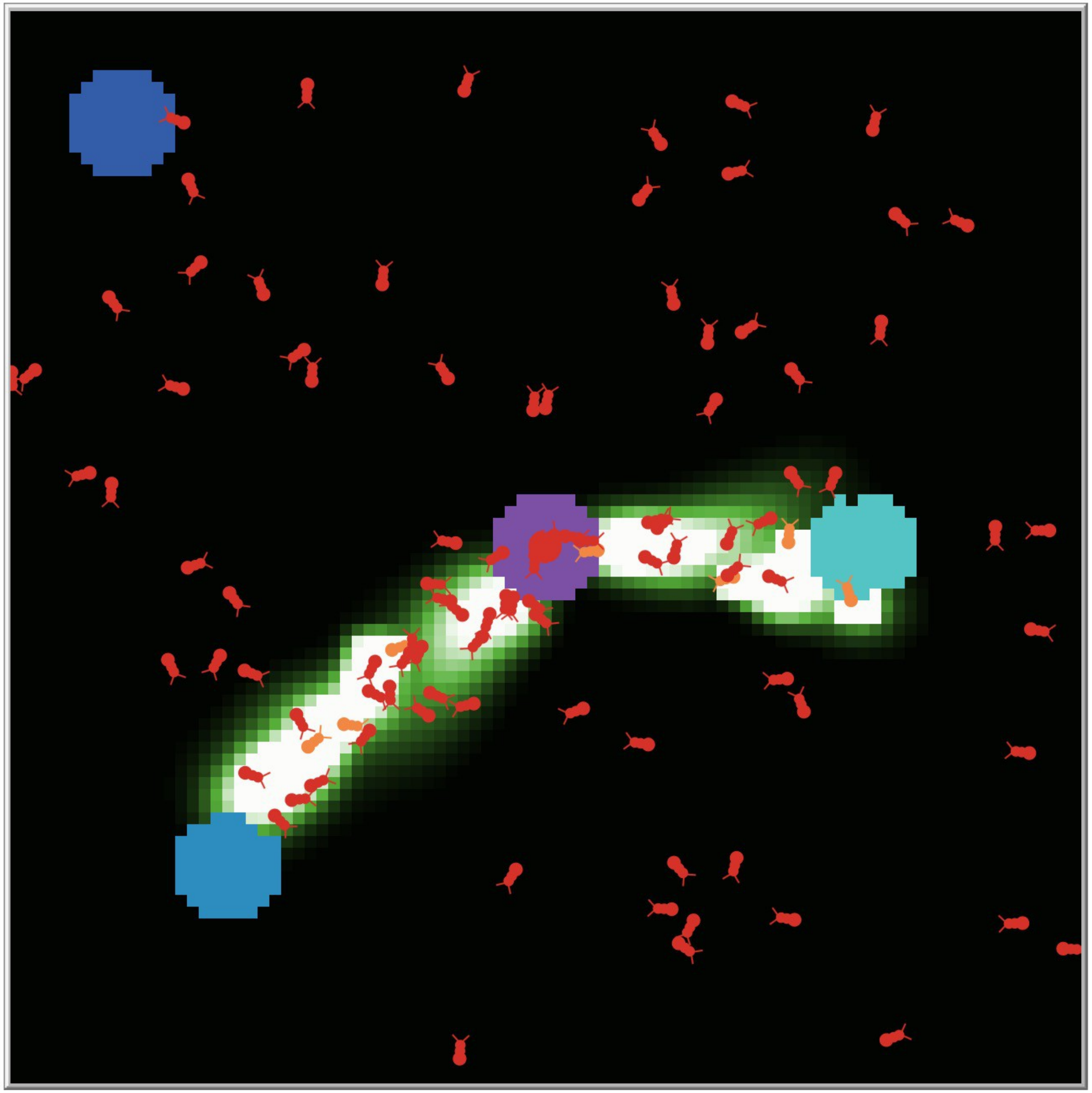


Model of Ant Colony Consuming Food

Rules:

- Each ant moves around randomly in search of food
- When an ant finds a piece of food, it carries the food back to the nest by following the “nest scent” chemical gradient
- An ant with food leaves a pheromone trace behind it as it moves
- When an ant with food reaches the nest, it drops the food and then heads out again in search of more food
- If other ants detect pheromone, they follow the pheromone scent

Model of Ant Colony Consuming Food



Virtual Ants

- Invented by Chris Langton in 1986
- Grid world with circular boundaries
- Grid cells can be either white or black
- On each time step:

1. Ant moves forward into a new cell
2. If cell is **white:** cell turns **black** and ant turns 90 degrees to the **right**

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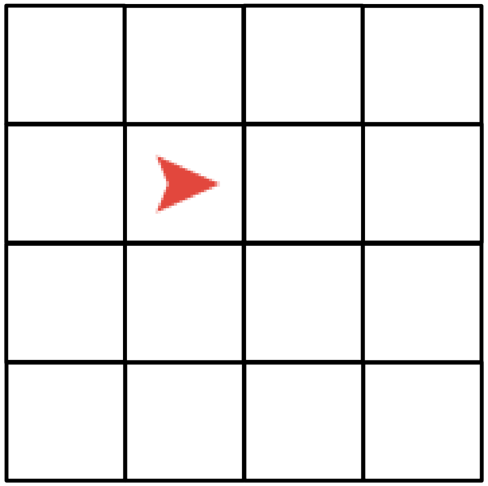

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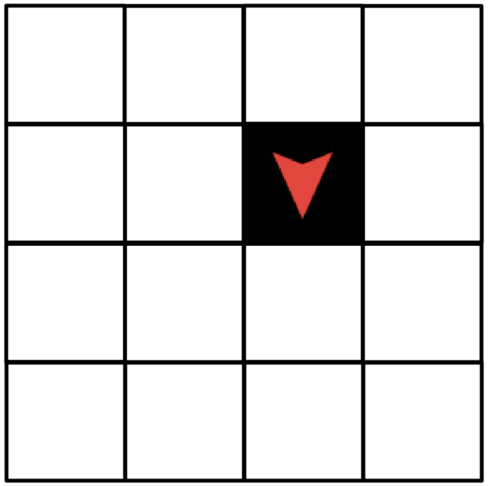

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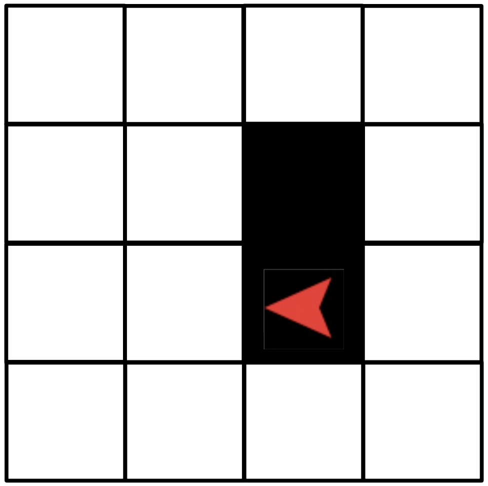

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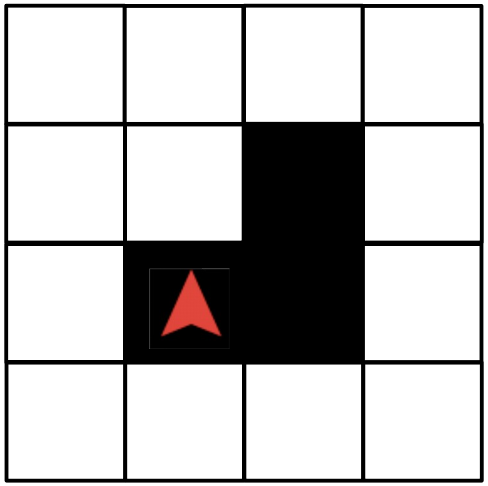

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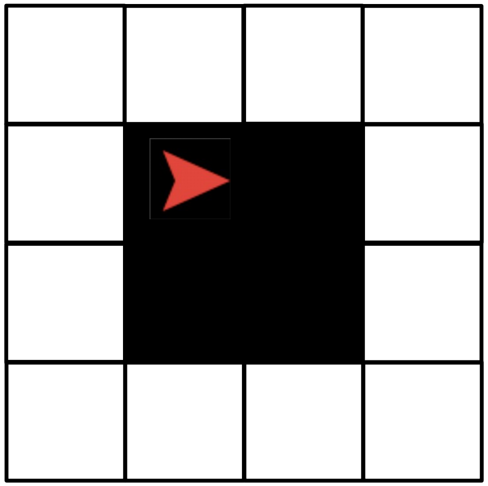

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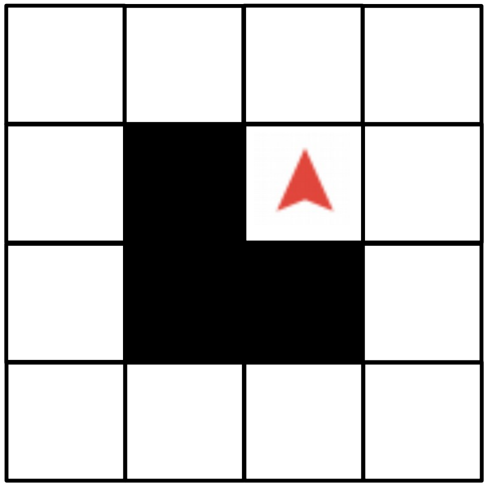

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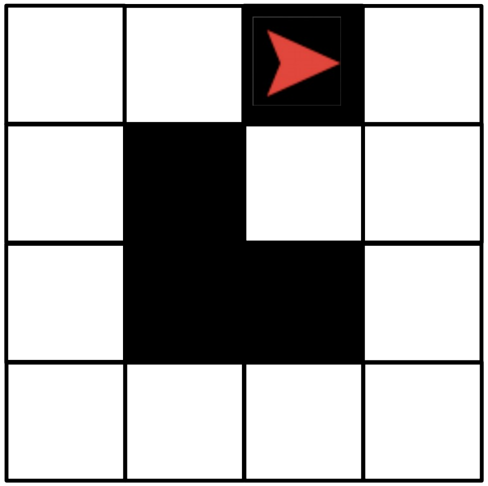

etc...

Time Reversible

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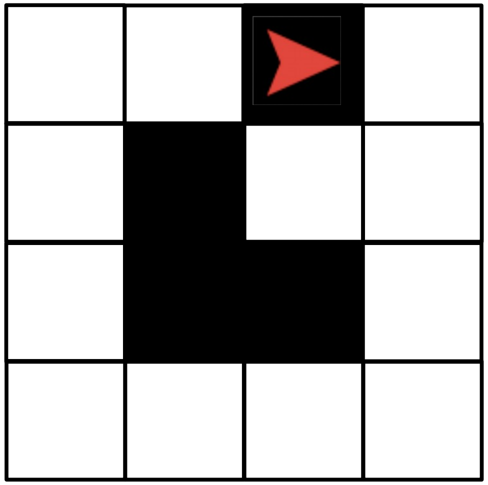
2. Ant moves backwards



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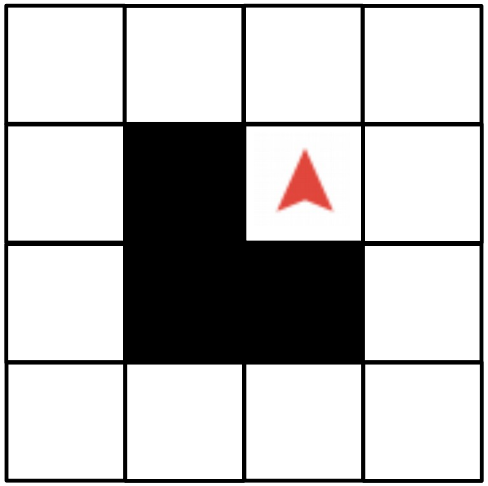

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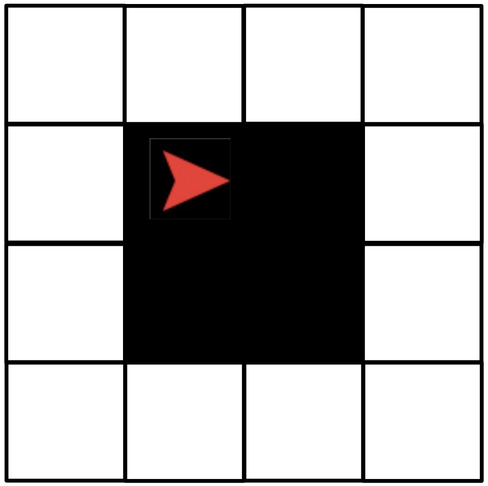

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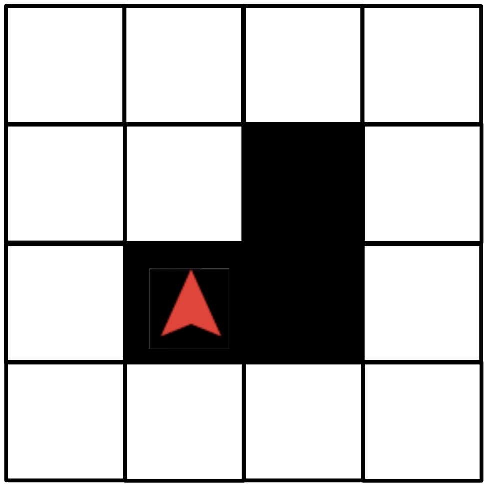

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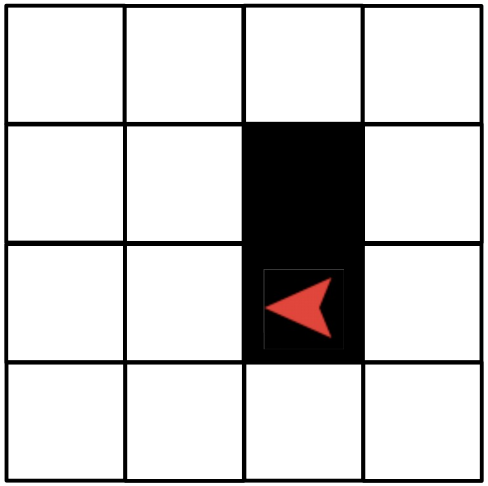

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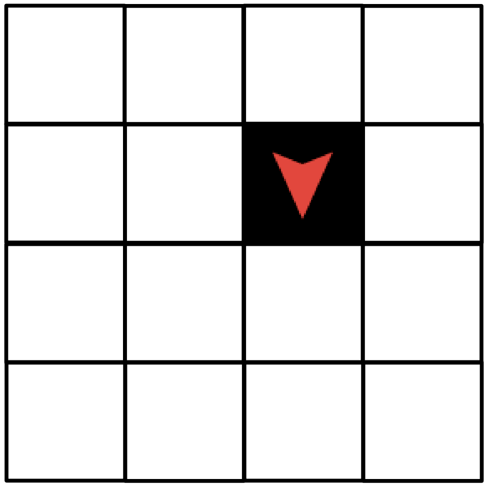

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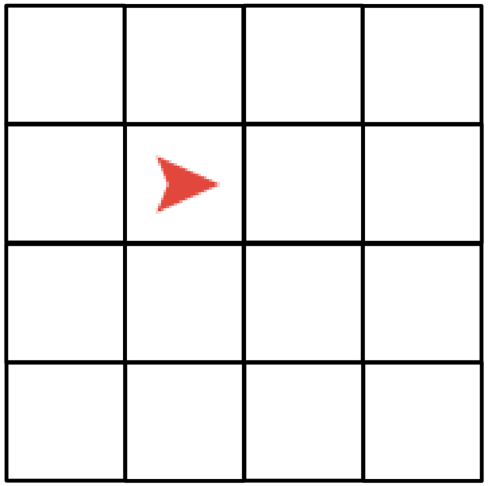

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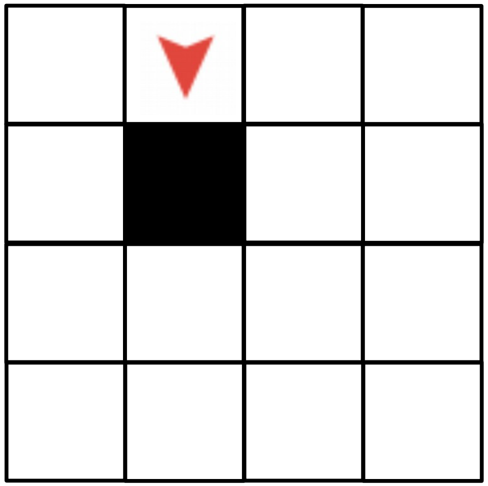
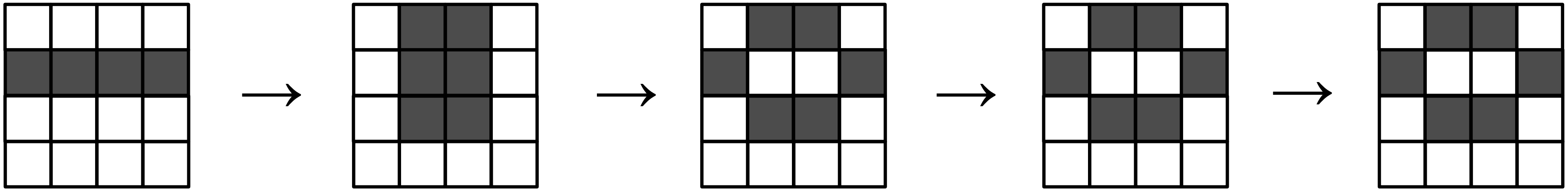


etc...

Time Reversible

- Most CAs are **not** time reversible
- Example: the Game of Life



- For time-reversible CAs, **both the future and the past** are completely determined by the current configuration

Virtual Ants

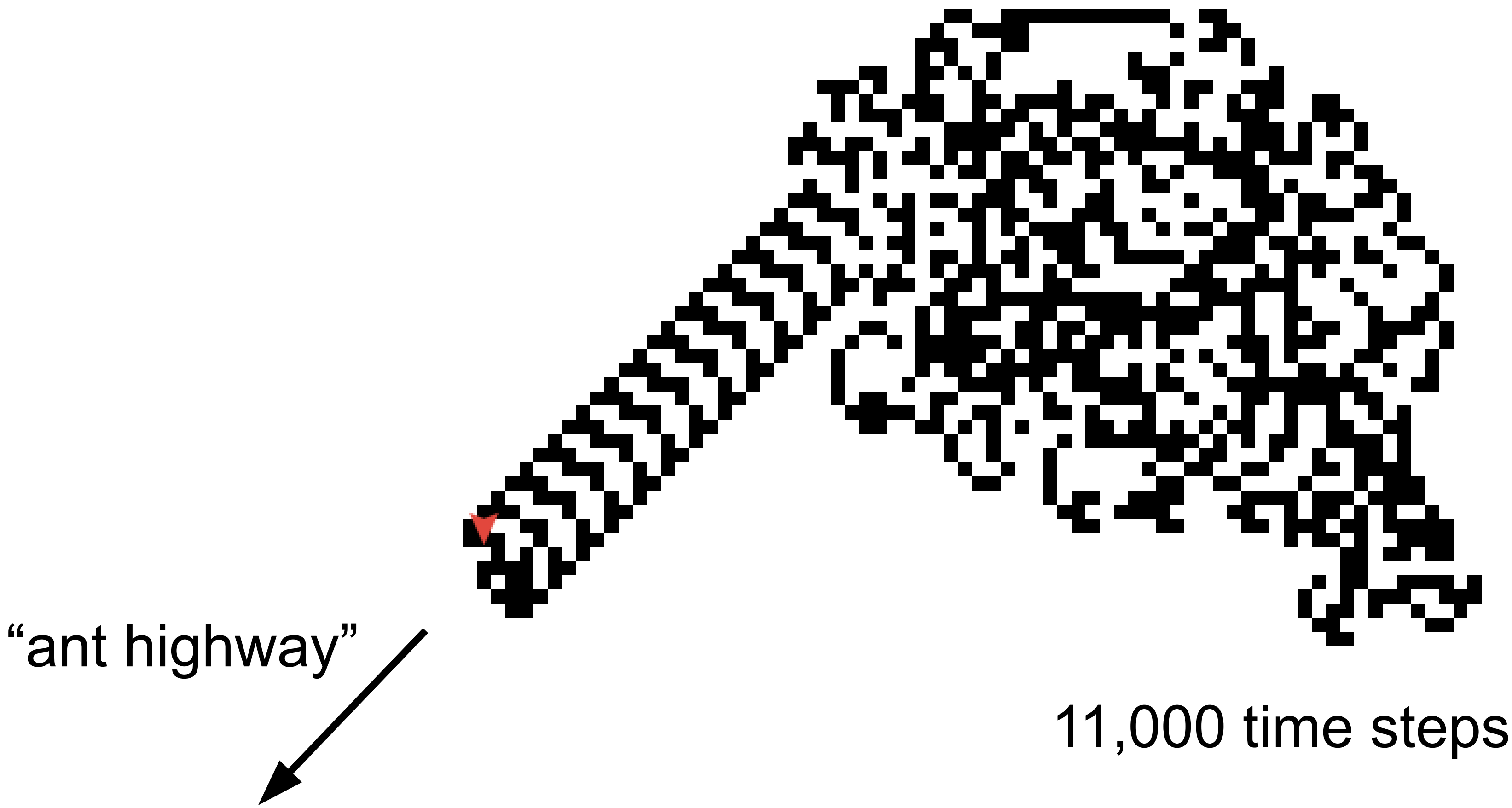
- Long-term behavior of a single virtual ant:

  chaotic ?

9,000 time steps

Virtual Ants

- Long-term behavior of a single virtual ant:
  periodic! (104-step cycle)

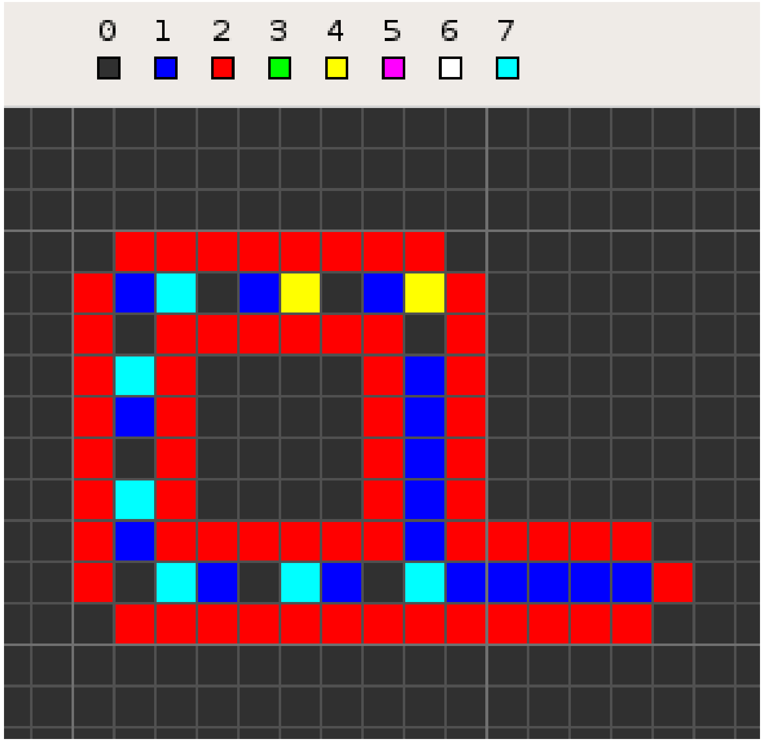


Virtual Ants

- The “highway” trajectory appears to be an **attractor**
- All tested initial configurations eventually converge to it
- **No one knows** if this is true for all configurations
- Cohen-Kung Theorem:
  All virtual ant trajectories are unbounded
- A single virtual ant can simulate a Turing Machine
- Virtual ants are thus capable of **universal computation**

Langton's Loops

- 8-state cellular automaton (states are color-coded)
- Simplification of von Neumann's original 29-state CA
- Capable of **self-replication**
- Not capable of universal computation



Termites

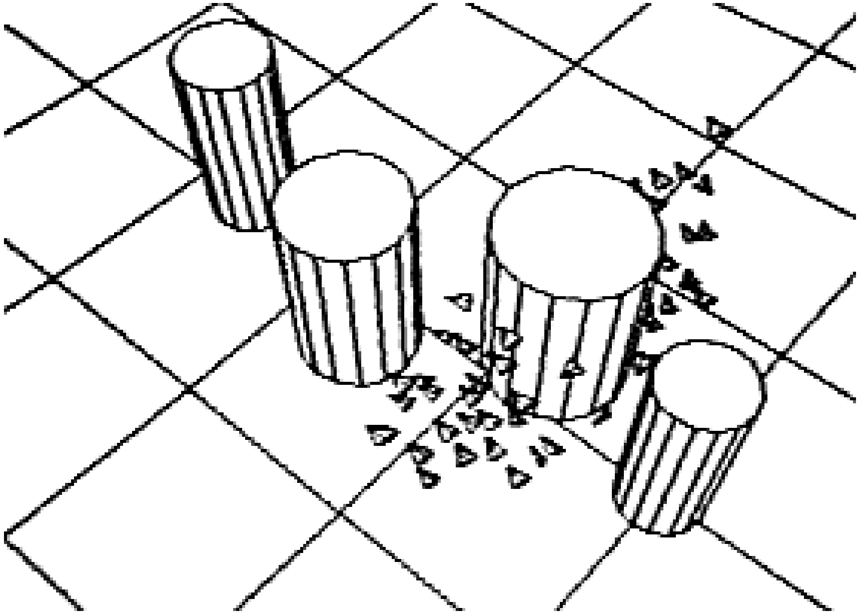
- Studied by Mitchel Resnick at the MIT Media Lab
- Also called **turmites**: ***"Tur***ing machine ter***mites"***
- 2-dimensional Turing Machines
  - Tape is a **2-dimensional infinite grid**
  - Tape head has a **spatial orientation** (N/S/E/W)
- Exactly equivalent in power to ordinary 1-dimensional Turing Machines

Termites

- 2-D grid world with randomly scattered “wood chips”
- Termites’ “goal”:
  - Arrange wood chips into neat piles
- Termites’ rules:
  - Wander around at random until you bump into a wood chip
  - If you are not carrying a wood chip, pick up the chip you bumped into
  - If you are already carrying a wood chip, drop it

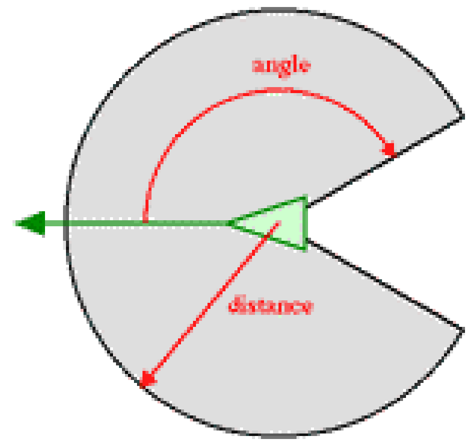
Boids

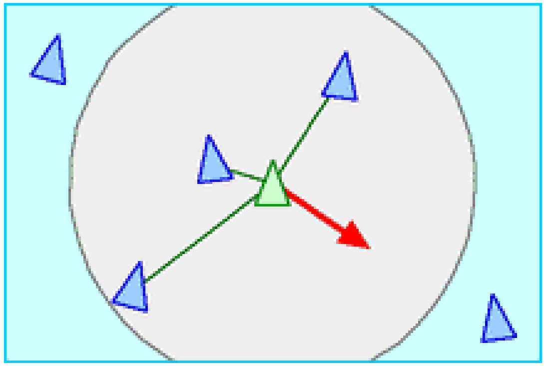
- Model of bird flocking (or fish schooling) behavior
- Developed by Craig Reynolds in 1987
- Used to create swarms of bats and herds of penguins in the movie *Batman Returns*
- Boid rules are very simple:
  - Separation
  - Alignment
  - Cohesion

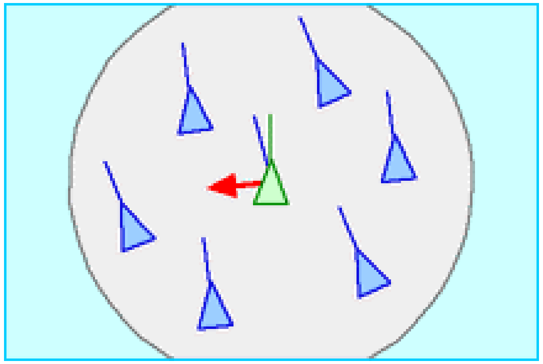


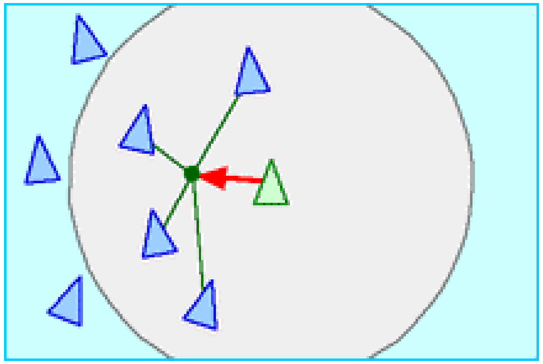
Boids: Rules

A boid's neighborhood:









Separation

avoid crowding
and collisions

Alignment

match heading
of other boids

Cohesion

move toward
center of neighbors

Boids: Rules

$\mathbf{V}_{\mathbf{old}}$	the previous direction of movement
$\mathbf{V}_{\mathbf{sep}}$	the **direction** specified by the Separation rule
$\mathbf{V}_{\mathbf{align}}$	the **direction** specified by the Alignment rule
$\mathbf{V}_{\mathbf{cohere}}$	the **direction** specified by the Cohesion rule
w_{sep}	the **weight** of the Separation rule
w_{align}	the **weight** of the Alignment rule
w_{cohere}	the **weight** of the Cohesion rule
m	a **momentum** parameter between 0 and 1

Boids: Rules

Direction of current "forces":

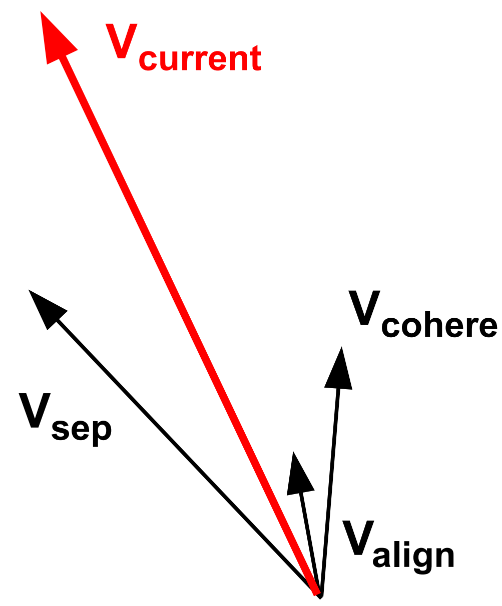
$$\mathbf{V}_{\mathbf{current}} = w_{sep}\,\mathbf{V}_{\mathbf{sep}} + w_{align}\,\mathbf{V}_{\mathbf{align}} + w_{cohere}\,\mathbf{V}_{\mathbf{cohere}}$$

New boid direction (no momentum):

$$\mathbf{V}_{\mathbf{new}} = \mathbf{V}_{\mathbf{current}}$$

New boid direction (with momentum):

$$\mathbf{V}_{\mathbf{new}} = m\,\mathbf{V}_{\mathbf{old}} + (1 - m)\,\mathbf{V}_{\mathbf{current}}$$



Fireflies

- Some species of fireflies (especially in southeast Asia) exhibit remarkable flash synchronization

- Each firefly has an internal “clock”
- Flash occurs at beginning of clock cycle
- All fireflies begin at a random point in their clock cycle
- Enough flashes in the vicinity of a firefly resets its clock
- Eventually they all begin flashing in unison

Fireflies

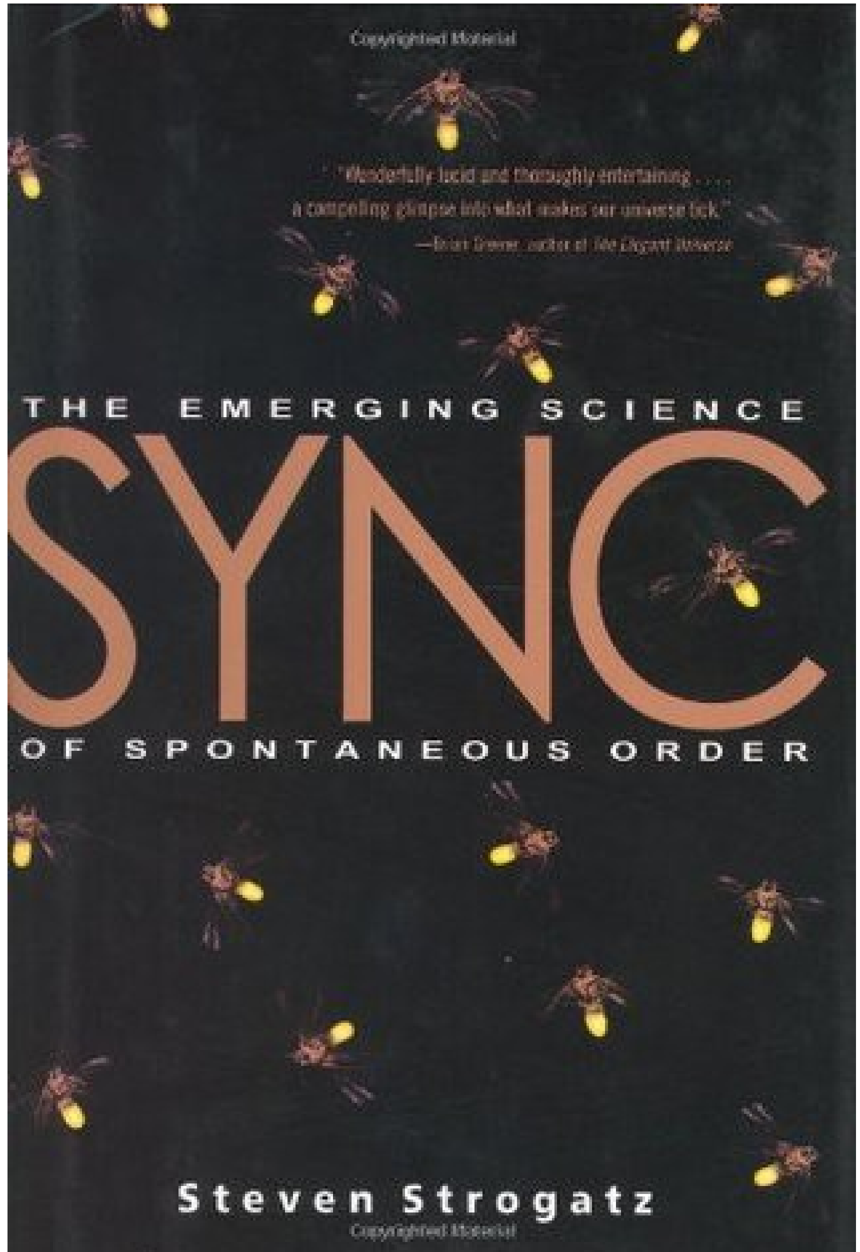
“ … a great belt of light, some ten feet wide, formed by thousands upon thousands of fireflies whose green phosphorescence bridges the shoulder-high grass …

The fluorescent band composed of these tiny organisms lights up and goes out with a precision that is perfectly synchronized, and one is left wondering what means of communication they possess which enables them to coordinate their shining as though controlled by a mechanical device.”

—Joy Adamson, 1961

author of *Born Free*

Highly Recommended Reading



Demos of Self-Organization

- Ant Colony Foraging for Food
- Langton's Virtual Ants and Loops
- Termites Gathering Wood Chips
- Boids Flocking Behavior
- Firefly Synchronization