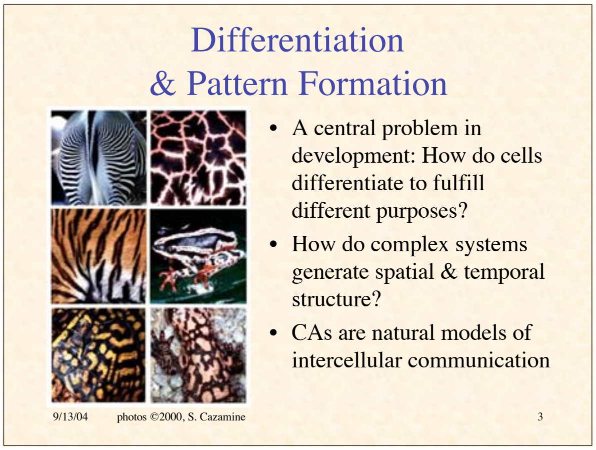
StarLogo Simulation of Streaming Aggregation

1. chemical diffuses
2. **if** cell is refractory (yellow)
3. **then** chemical degrades
4. **else** (it's excitable, colored white)
    1. **if** chemical > movement threshold **then**
        take step up chemical gradient
    2. **else if** chemical > relay threshold **then**
        produce more chemical (red)
        become refractory
    3. **else** wait

Demonstration of StarLogo Simulation of Streaming

Run SlimeStream.slogo



Differentiation & Pattern Formation

- A central problem in development: How do cells differentiate to fulfill different purposes?
- How do complex systems generate spatial & temporal structure?
- CAs are natural models of intercellular communication

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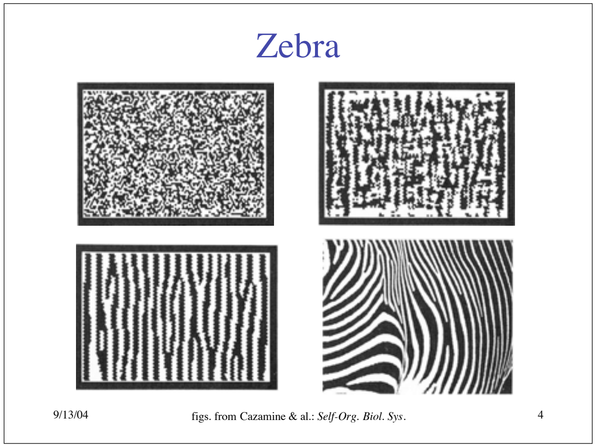
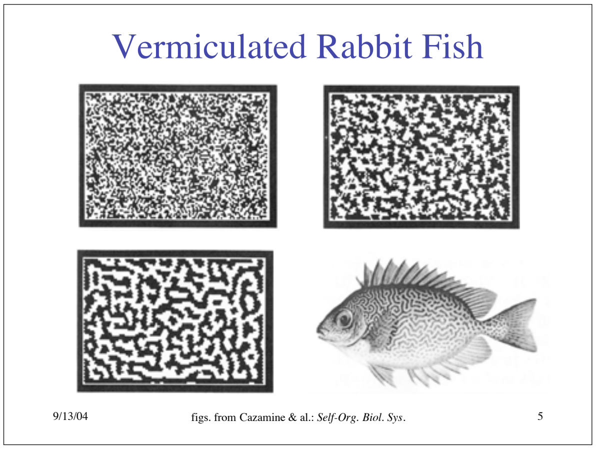


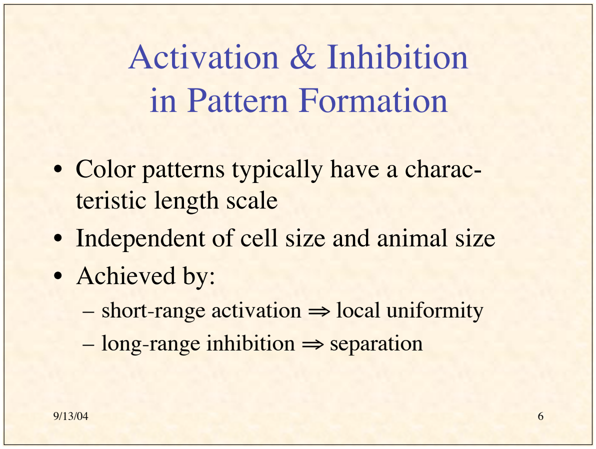
Zebra

figs. from Cazamine & al.: *Self-Org. Biol. Sys.*



Vermiculated Rabbit Fish

9/13/04 figs. from Cazamine & al.: *Self-Org. Biol. Sys*. 5



Activation & Inhibition in Pattern Formation

- Color patterns typically have a characteristic length scale
- Independent of cell size and animal size
- Achieved by:
  - short-range activation ⇒ local uniformity
  - long-range inhibition ⇒ separation

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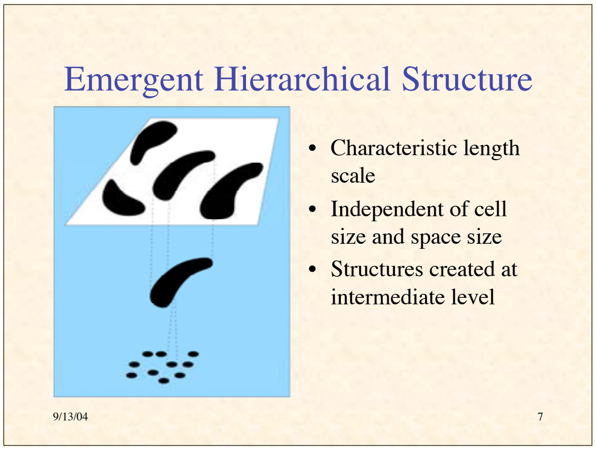

Emergent Hierarchical Structure

- Characteristic length scale
- Independent of cell size and space size
- Structures created at intermediate level

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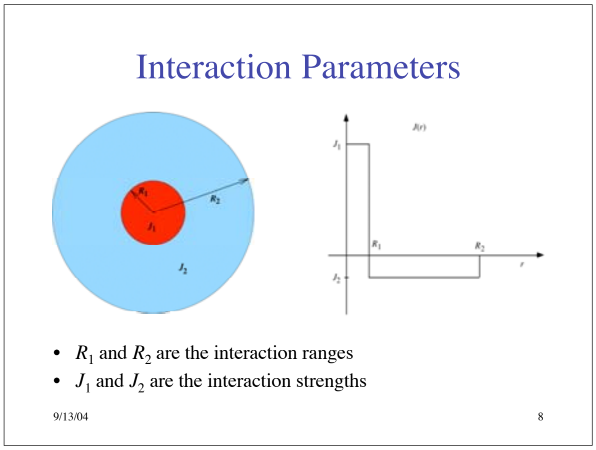

Interaction Parameters

- R_1 and R_2 are the interaction ranges
- J_1 and J_2 are the interaction strengths

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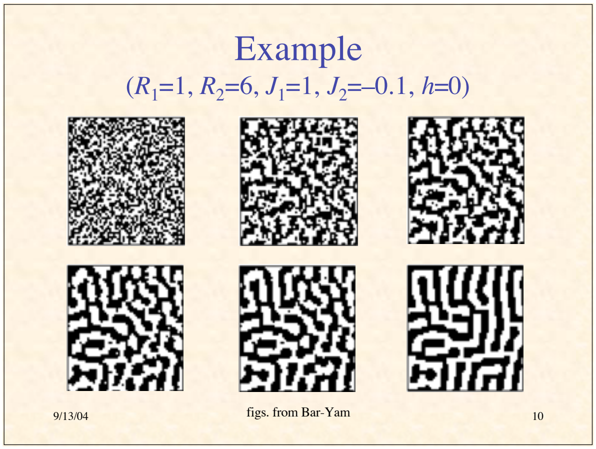
CA Activation/Inhibition Model

- Let states $s_i \in \{-1, +1\}$
- and h be a bias parameter
- and r_{ij} be the distance between cells i and j
- Then the state update rule is:

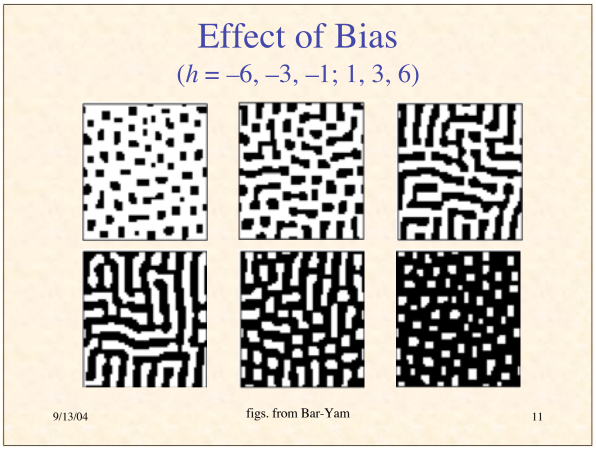
$$s_i(t+1) = \text{sign}\left[h + J_1 \sum_{r_{ij}<R_1} s_j(t) + J_2 \sum_{R_1<r_{ij}<R_2} s_j(t)\right]$$



Example

(R_1=1, R_2=6, J_1=1, J_2=–0.1, h=0)

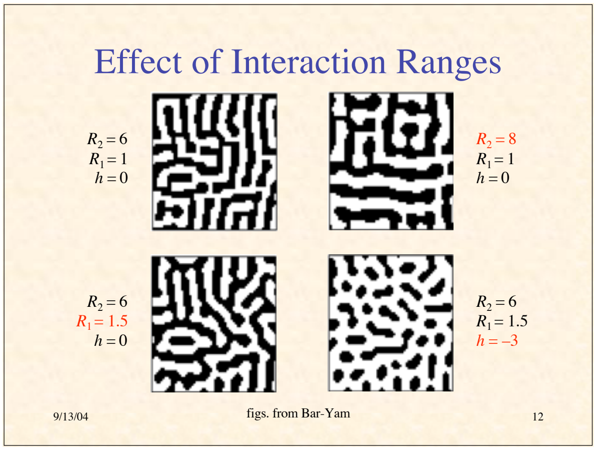
figs. from Bar-Yam



Effect of Bias

(h = –6, –3, –1; 1, 3, 6)

figs. from Bar-Yam



Effect of Interaction Ranges

$R_2 = 6$
$R_1 = 1$
$h = 0$

$R_2 = 8$
$R_1 = 1$
$h = 0$

$R_2 = 6$
$R_1 = 1.5$
$h = 0$

$R_2 = 6$
$R_1 = 1.5$
$h = -3$

figs. from Bar-Yam

Differential Interaction Ranges

- How can a system using strictly local interactions discriminate between states at long and short range?
- E.g. cells in developing organism
- Can use two different *morphogens* diffusing at two different rates
  - activator diffuses slowly (short range)
  - inhibitor diffuses rapidly (long range)

Digression on Diffusion

- Simple 2-D diffusion equation:

$$\dot{A}(x,y) = c\nabla^2 A(x,y)$$

- Recall the 2-D Laplacian:

$$\nabla^2 A(x,y) = \frac{\partial^2 A(x,y)}{\partial x^2} + \frac{\partial^2 A(x,y)}{\partial y^2}$$

- The Laplacian (like 2nd derivative) is:
  - positive in a local minimum
  - negative in a local maximum

Reaction-Diffusion System

diffusion

$$\frac{\partial A}{\partial t} = \boxed{d_\mathrm{A}\nabla^2 A} + \boxed{f_\mathrm{A}(A,I)}$$

$$\frac{\partial I}{\partial t} = \boxed{d_\mathrm{I}\nabla^2 I} + \boxed{f_\mathrm{I}(A,I)}$$

reaction

$$\frac{\partial}{\partial t}\begin{pmatrix} A \\ I \end{pmatrix} = \begin{pmatrix} d_\mathrm{A} & 0 \\ 0 & d_\mathrm{I} \end{pmatrix}\begin{pmatrix} \nabla^2 A \\ \nabla^2 I \end{pmatrix} + \begin{pmatrix} f_\mathrm{A}(A,I) \\ f_\mathrm{I}(A,I) \end{pmatrix}$$

$$\dot{\mathbf{c}} = \mathbf{D}\nabla^2\mathbf{c} + \mathbf{f}(\mathbf{c}), \quad \text{where } \mathbf{c} = \begin{pmatrix} A \\ I \end{pmatrix}$$

Example: Activation-Inhibition System

- Let σ be the logistic sigmoid function
- Activator *A* and inhibitor *I* may diffuse at different rates in *x* and *y* directions
- Cell is “on” if activator + bias exceeds inhibitor

$$\frac{\partial A}{\partial t} = d_\mathrm{Ax}\frac{\partial^2 A}{\partial x^2} + d_\mathrm{Ay}\frac{\partial^2 A}{\partial y^2} + k_\mathrm{A}\sigma\left[m_\mathrm{A}(A + B - I)\right]$$

$$\frac{\partial I}{\partial t} = d_\mathrm{Ix}\frac{\partial^2 I}{\partial x^2} + d_\mathrm{Iy}\frac{\partial^2 I}{\partial y^2} + k_\mathrm{I}\sigma\left[m_\mathrm{I}(A + B - I)\right]$$

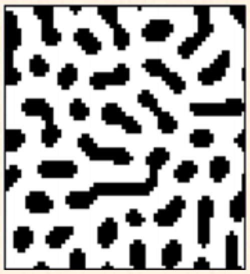
Demonstration of StarLogo Program for Activation/Inhibition Pattern Formation

Run Pattern.slogo

Abstract Activation/Inhibition Spaces

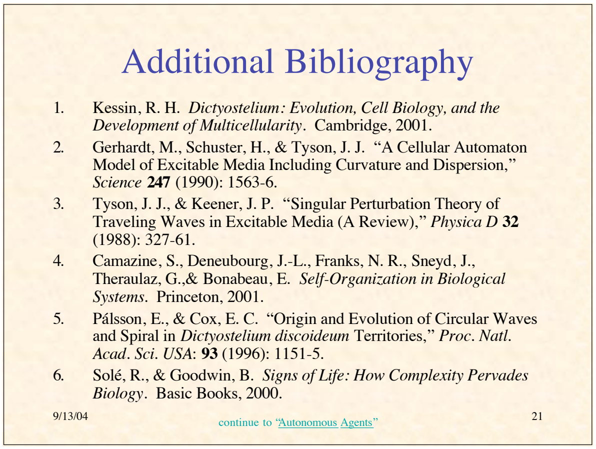
- Consider two axes of cultural preference
  - E.g. hair length & interpersonal distance
  - Fictitious example!
- Suppose there are no objective reasons for preferences
- Suppose people approve/encourage those with similar preferences
- Suppose people disapprove/discourage those with different preferences
- What is the result?

Emergent Regions of Acceptable Variation



A Key Element of Self-Organization

- Activation vs. Inhibition
- Cooperation vs. Competition
- Amplification vs. Stabilization
- Growth vs. Limit
- Positive Feedback vs. Negative Feedback
  - Positive feedback creates
  - Negative feedback shapes



Additional Bibliography

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continue to "Autonomous Agents"