Observations

- Excitable media can support circular and spiral waves
- Spiral formation can be triggered in a variety of ways
- All seem to involve inhomogeneities (broken symmetries):
  - in space
  - in time
  - in activity
- Amplification of random fluctuations
- Circles & spirals are to be expected

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

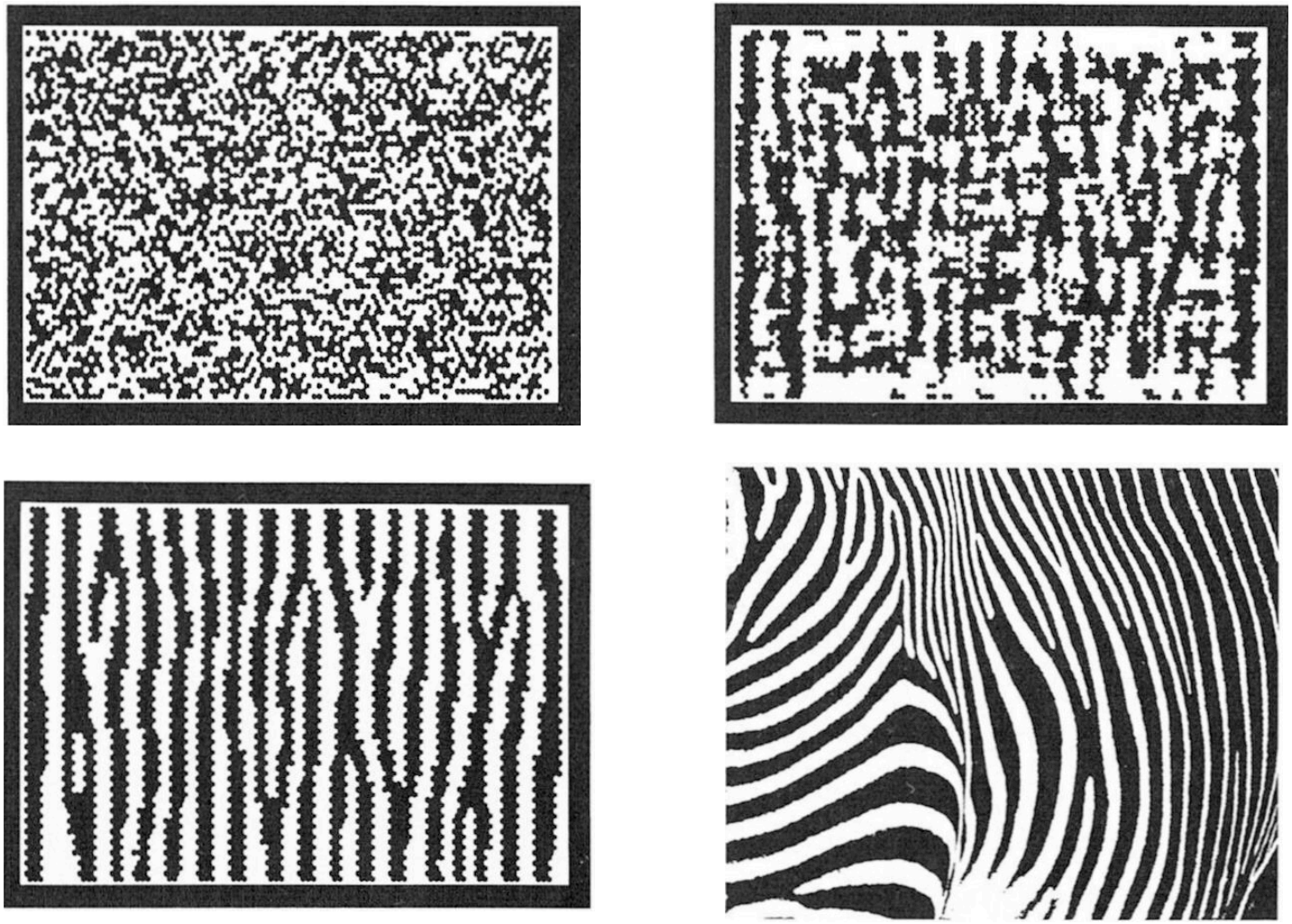
Demonstration of StarLogo Simulation of Streaming

Run SlimeStream.slogo

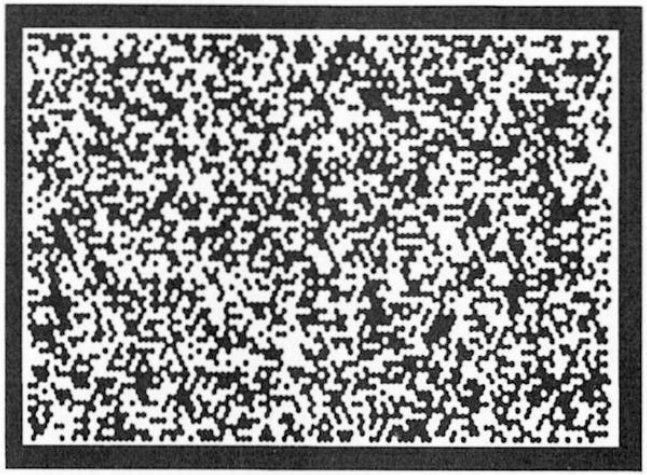
Differentiation & Pattern Formation

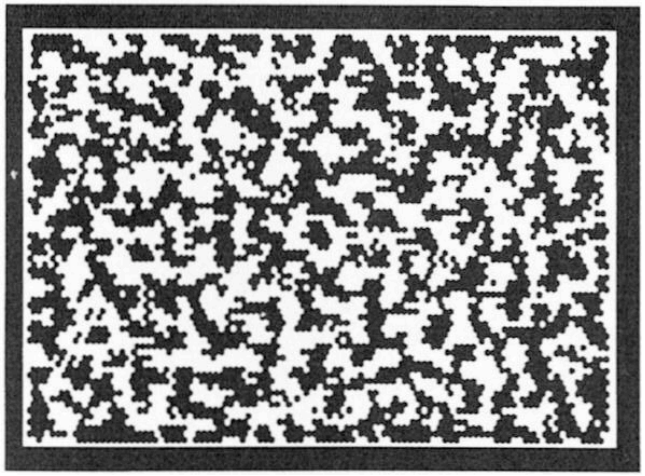
- A central problem in development: How do cells differentiate to fulfill different purposes?
- How do complex systems generate spatial & temporal structure?
- CAs are natural models of intercellular communication

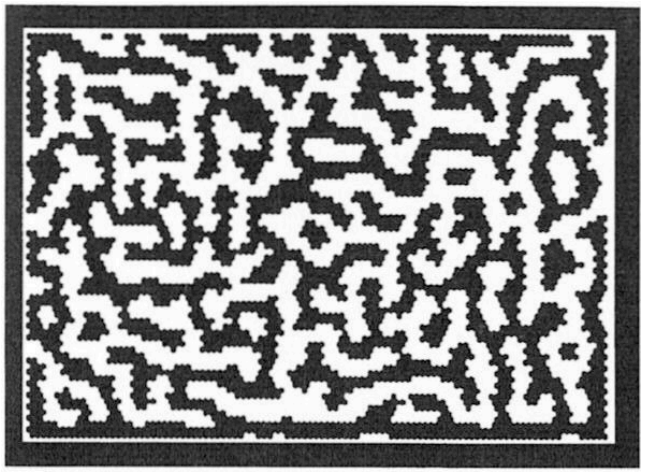
Zebra

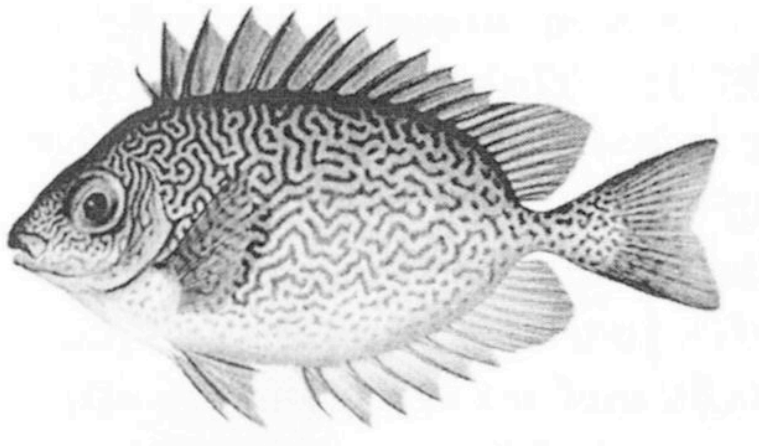


Vermiculated Rabbit Fish





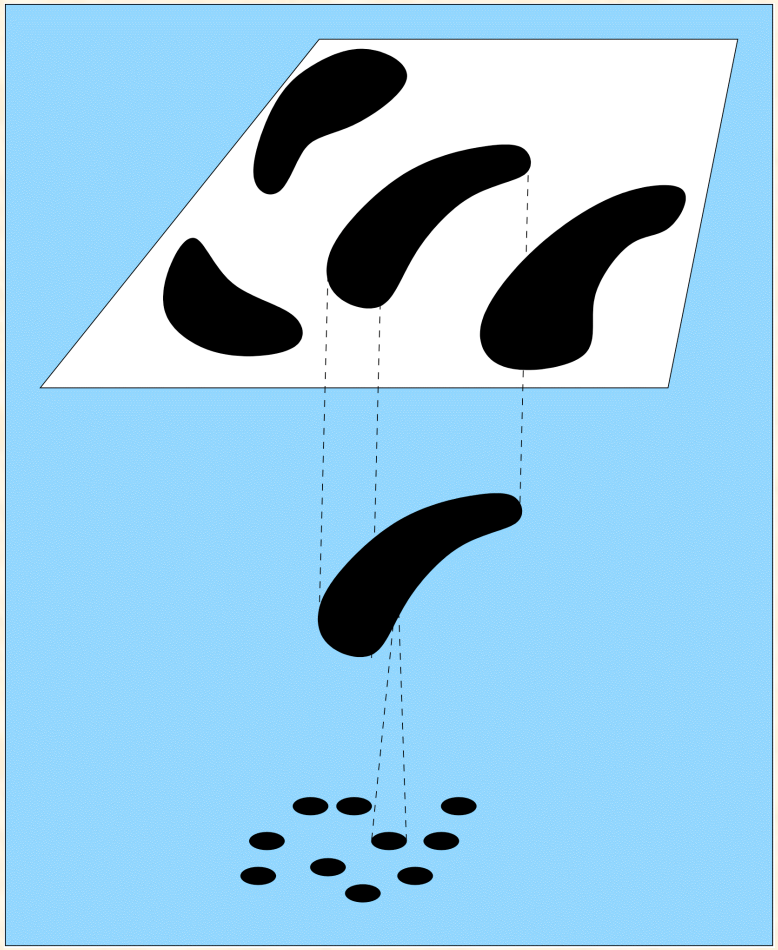




Activation & Inhibition in Pattern Formation

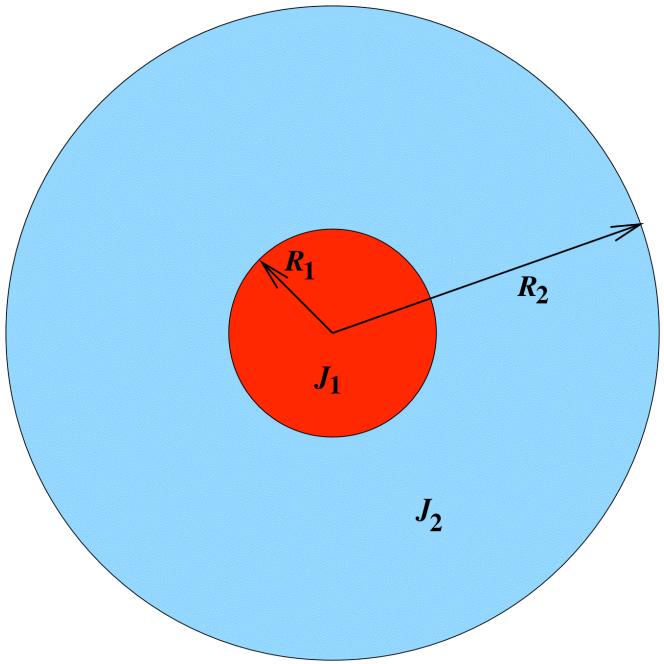
- Color patterns typically have a characteristic length scale
- Independent of cell size and animal size
- Achieved by:
  - short-range activation local uniformity
  - long-range inhibition separation

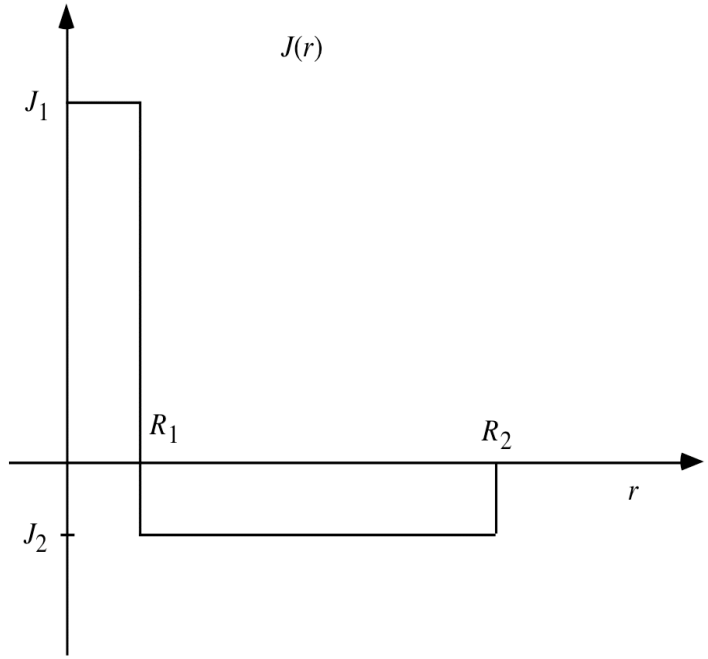
Emergent Hierarchical Structure



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

Interaction Parameters





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

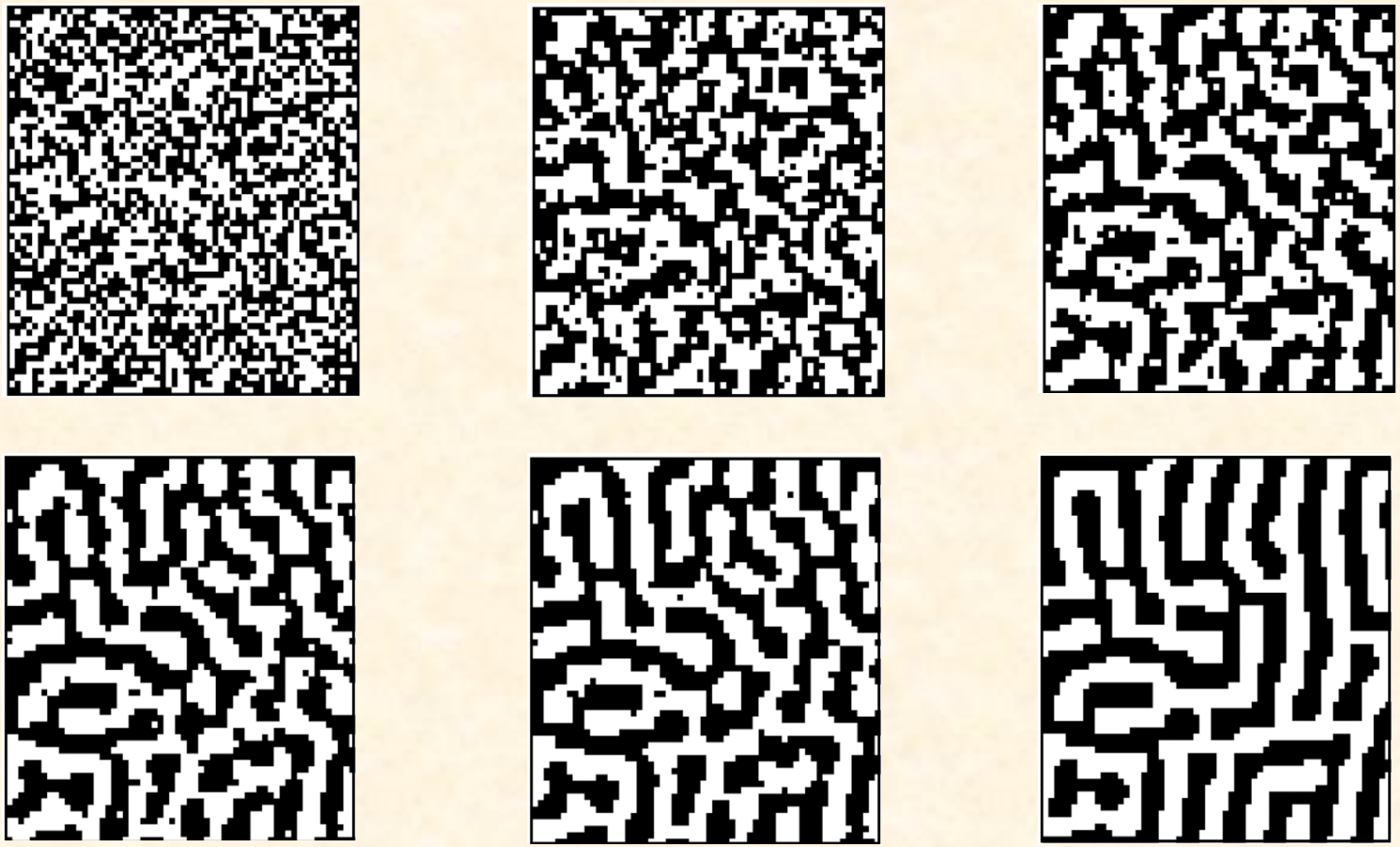
CA Activation/Inhibition Model

- 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

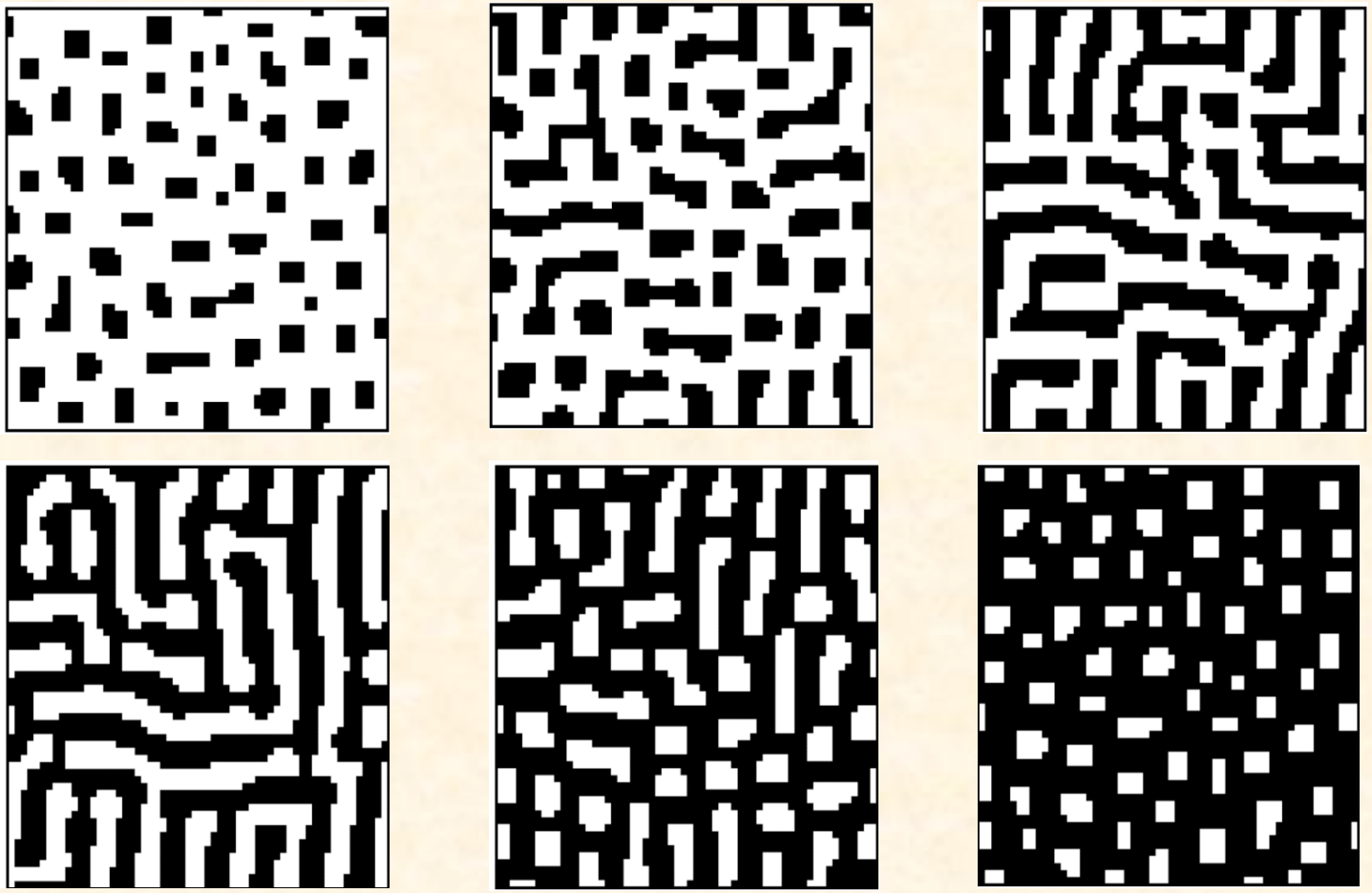
(R_1=1, R_2=6, J_1=1, J_2=–0.1, h=0)



figs. from Bar-Yam

Effect of Bias

($h = -6, -3, -1; 1, 3, 6$)



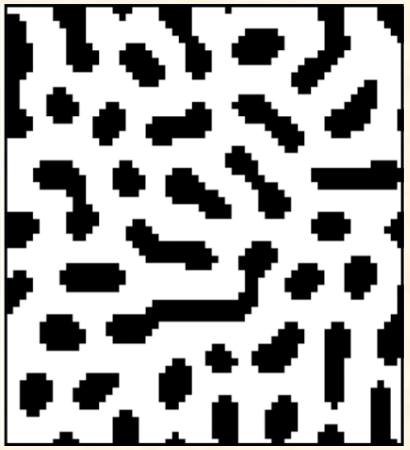
figs. from Bar-Yam

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

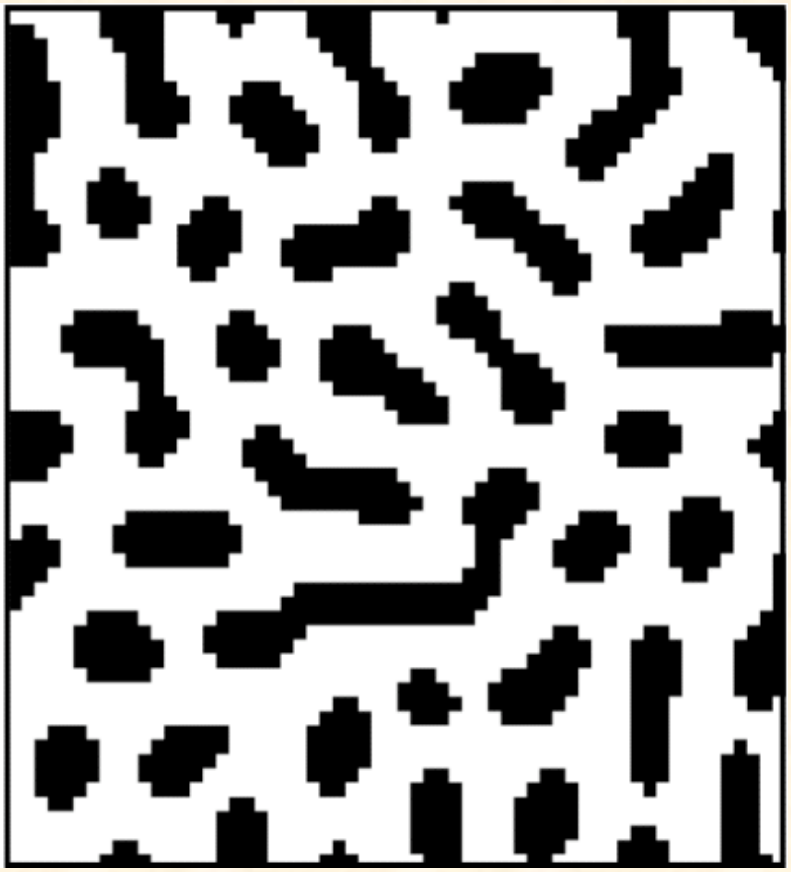
Demonstration of StarLogo Program for Activation/Inhibition Pattern Formation

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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