

Excitable Media

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Examples of Excitable Media

- Slime mold amoebas
- Cardiac tissue (& other muscle tissue)
- Cortical tissue
- Certain chemical systems (e.g., BZ reaction)
- Hodgepodge machine

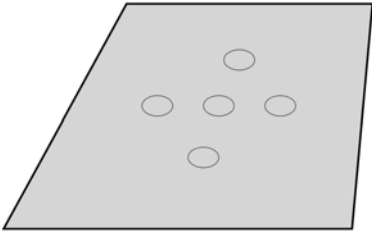
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Characteristics of Excitable Media

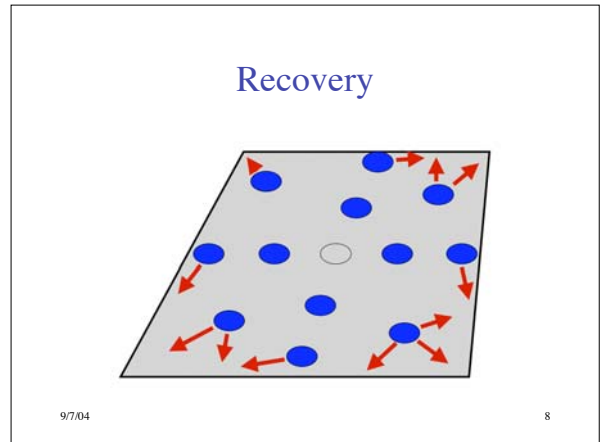
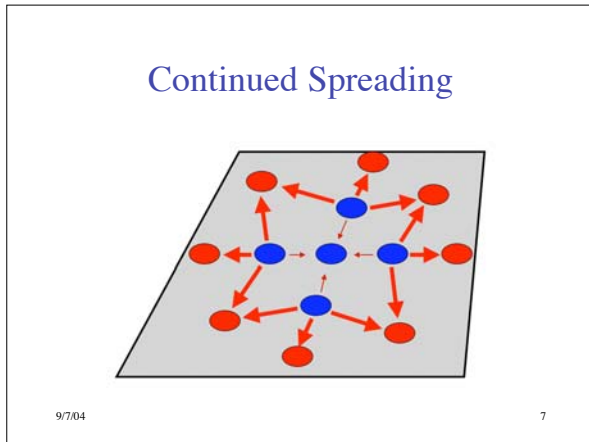
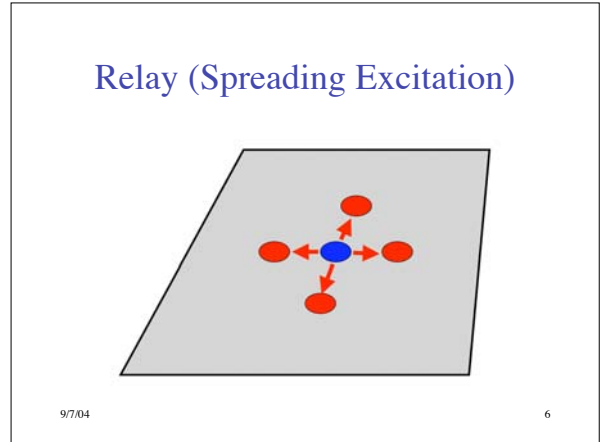
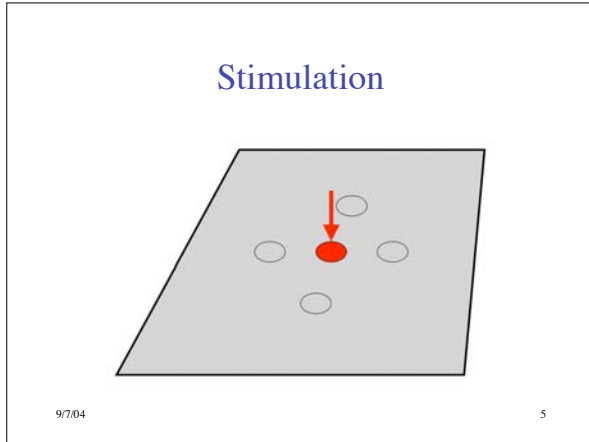
- Local spread of excitation
 - for signal propagation
- Refractory period
 - for unidirectional propagation
- Decay of signal
 - avoid saturation of medium

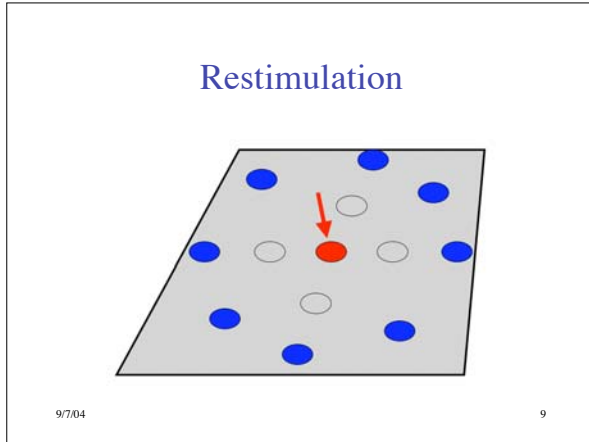
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Behavior of Excitable Media



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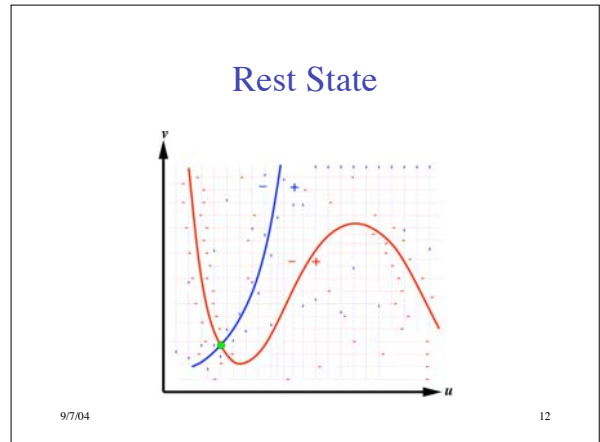
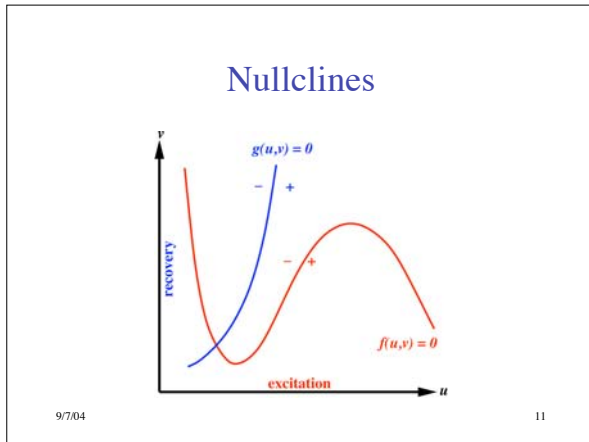
Typical Equations for Excitable Medium (ignoring diffusion)

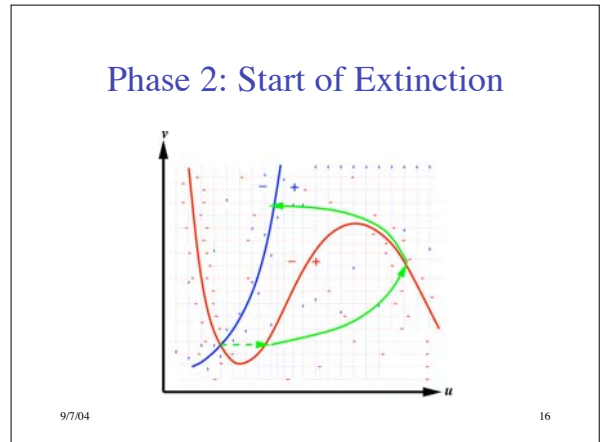
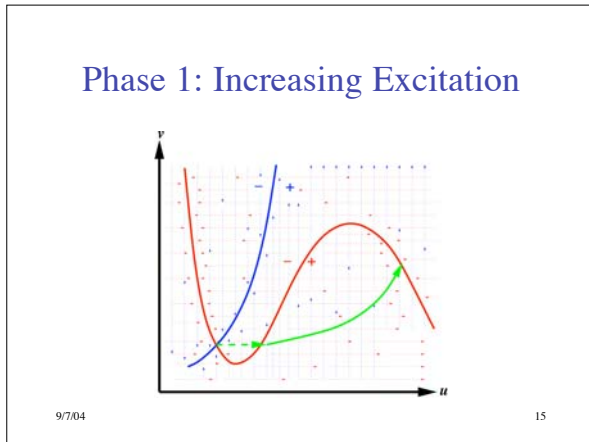
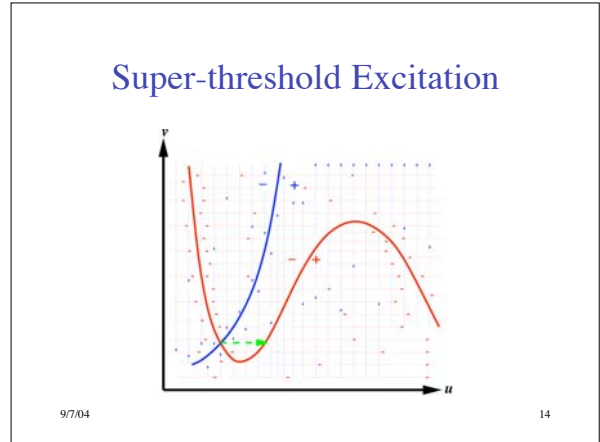
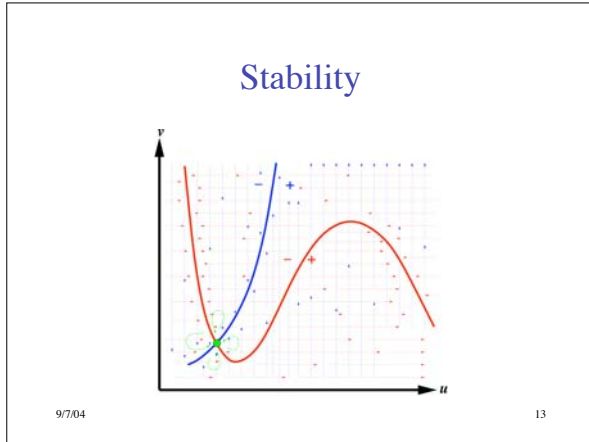
- Excitation variable:

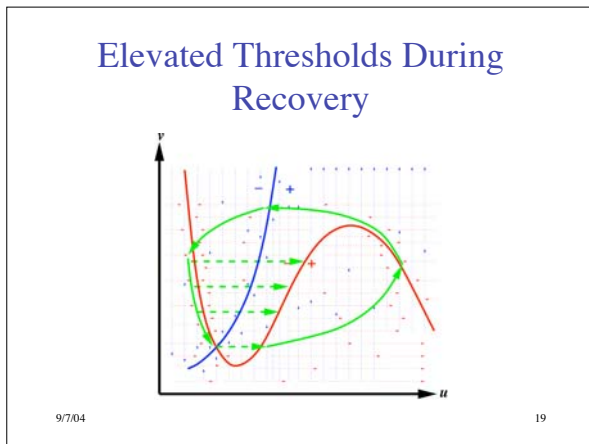
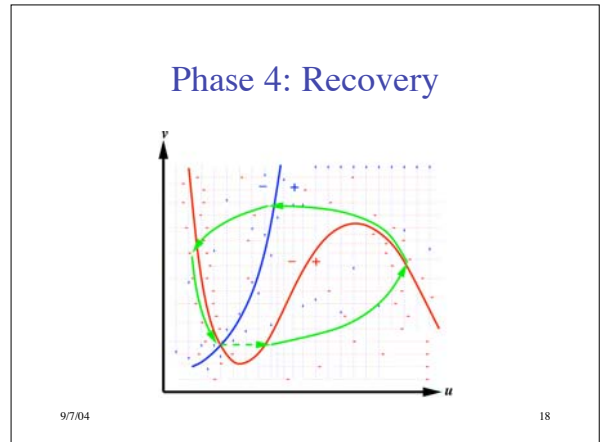
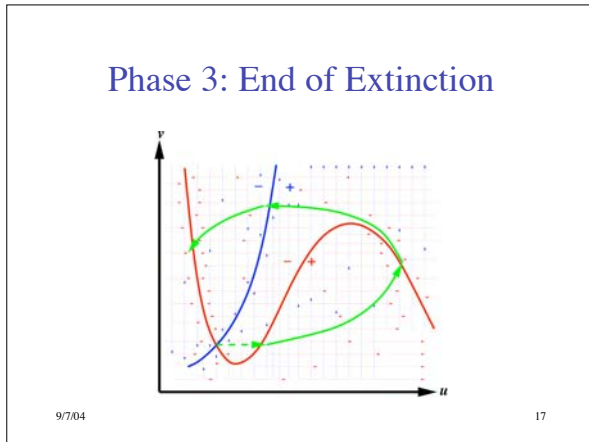
$$\dot{u} = f(u, v)$$
- Recovery variable:

$$\dot{v} = g(u, v)$$

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Modified Martiel & Goldbeter Model for Dicty Signalling

Variables (functions of x, y, t):

- β = intracellular concentration of cAMP
- γ = extracellular concentration of cAMP
- ρ = fraction of receptors in active state

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Equations

$$\frac{d\beta(x,y,t)}{dt} = s\Phi(\rho, \gamma) - \beta k_i - \beta k_t \quad [1]$$

Rate of change in intracellular [cAMP] = Production of cAMP - Intracellular hydrolysis - Secretion of cAMP

$$\frac{d\gamma(x,y,t)}{dt} = \frac{k_r}{h}\beta - k_c\gamma + D\nabla^2\gamma \quad [2]$$

Rate of change in extracellular [cAMP] = Secretion of cAMP - Extracellular hydrolysis + Diffusion of cAMP

$$\frac{d\rho(x,y,t)}{dt} = f_2(\gamma)(1 - \rho) - f_1(\gamma)\rho \quad [3]$$

Rate of change in fraction of active receptor = Dephosphorylation of receptor - Phosphorylation of receptor

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Positive Feedback Loop

- Extracellular cAMP increases (γ increases)
- \Rightarrow Rate of synthesis of intracellular cAMP increases (Φ increases)
- \Rightarrow Intracellular cAMP increases (β increases)
- \Rightarrow Rate of secretion of cAMP increases
- (\Rightarrow Extracellular cAMP increases)

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Negative Feedback Loop

- Extracellular cAMP increases (γ increases)
- \Rightarrow cAMP receptors desensitize (f_1 increases, f_2 decreases, ρ decreases)
- \Rightarrow Rate of synthesis of intracellular cAMP decreases (Φ decreases)
- \Rightarrow Intracellular cAMP decreases (β decreases)
- \Rightarrow Rate of secretion of cAMP decreases
- \Rightarrow Extracellular cAMP decreases (γ decreases)

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Dynamics of Model

- Unperturbed \Rightarrow cAMP concentration reaches steady state
- Small perturbation in extracellular cAMP \Rightarrow returns to steady state
- Perturbation > threshold \Rightarrow large transient in cAMP, then return to steady state
- Or oscillation (depending on model parameters)

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Circular & Spiral Waves Observed in:

- Slime mold aggregation
- Chemical systems (e.g., BZ reaction)
- Neural tissue
- Retina of the eye
- Heart muscle
- Intracellular calcium flows
- Mitochondrial activity in oocytes

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Cause of Concentric Circular Waves

- Excitability is not enough
- But at certain developmental stages, cells can operate as pacemakers
- When stimulated by cAMP, they begin emitting regular pulses of cAMP

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Spiral Waves

- Persistence & propagation of spiral waves explained analytically (Tyson & Murray, 1989)
- Rotate around a small core of non-excitable cells
- Propagate at higher frequency than circular
- Therefore they dominate circular in collisions
- But how do the spirals form initially?

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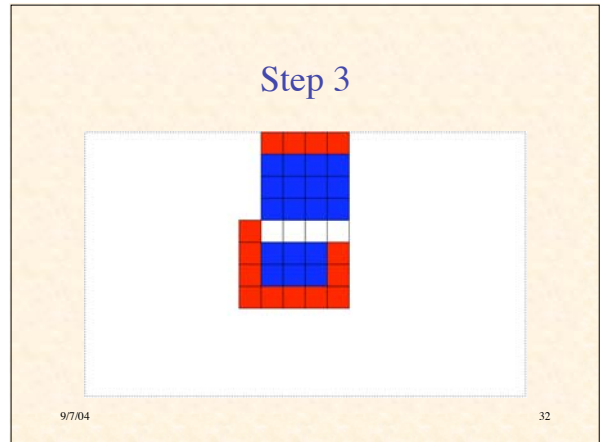
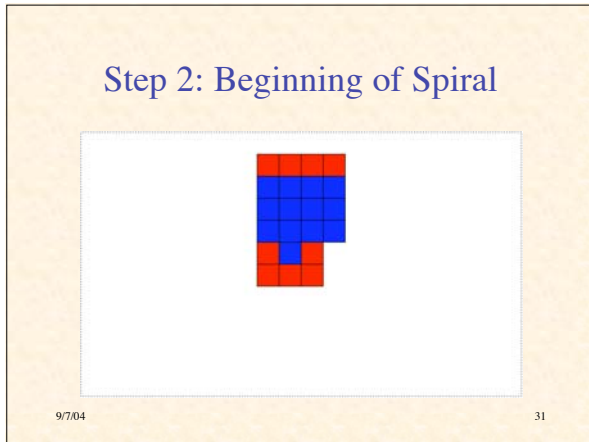
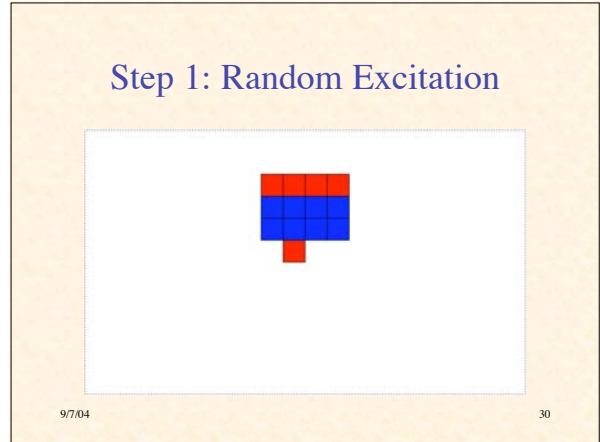
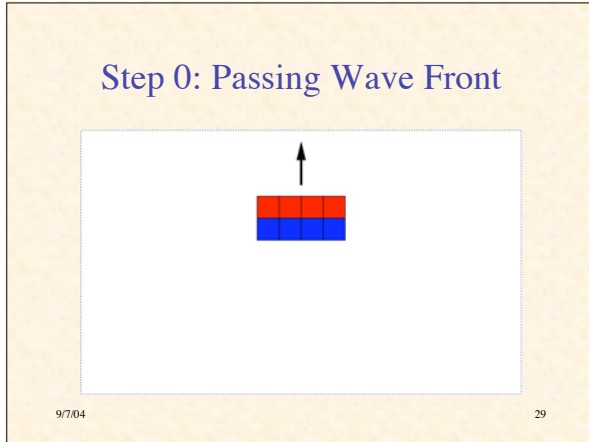
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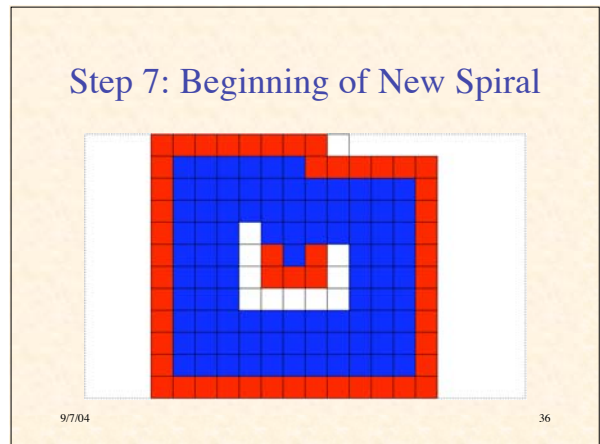
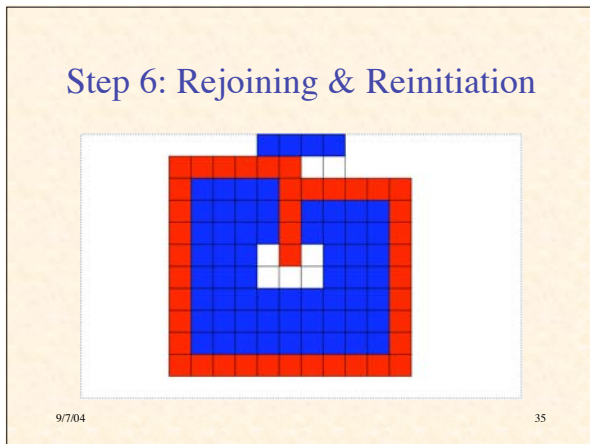
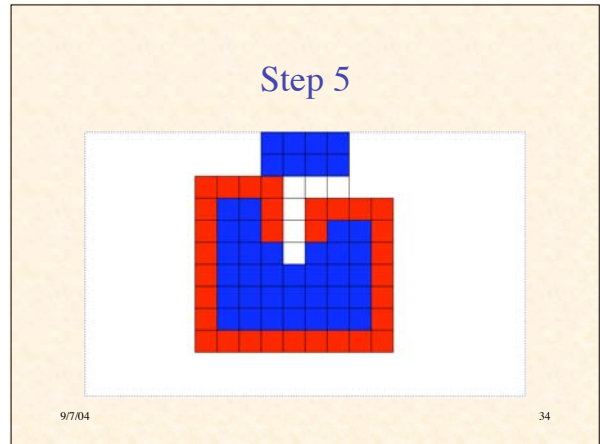
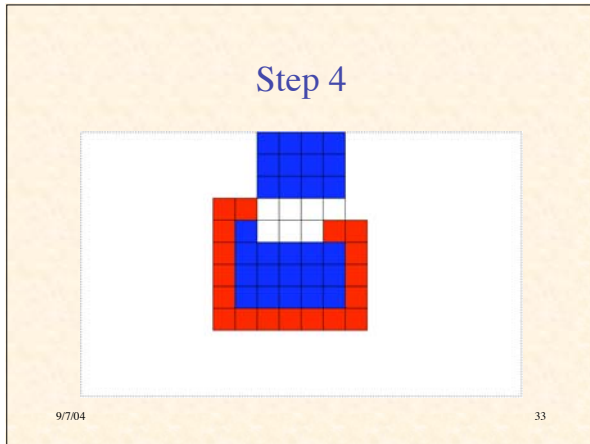
Some Explanations of Spiral Formation

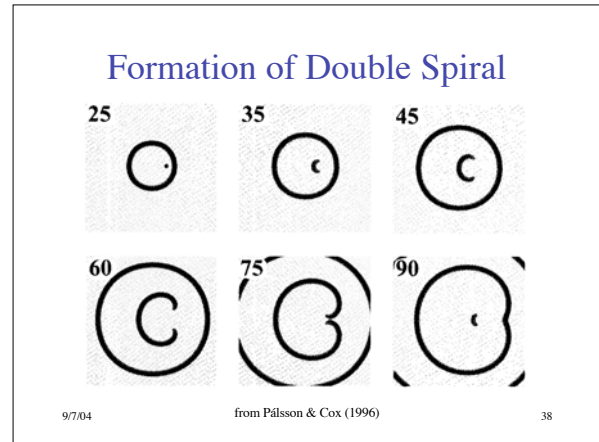
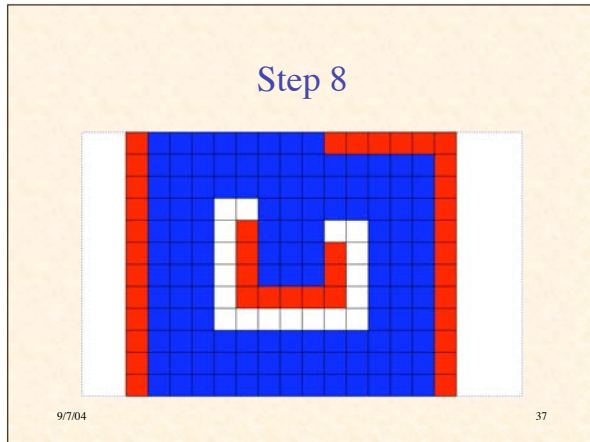
- “the origin of spiral waves remains obscure” (1997)
- Traveling wave meets obstacle and is broken
- Desynchronization of cells in their developmental path
- Random pulse behind advancing wave front

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StarLogo Simulation Of Spiral Formation

- Amoebas are immobile at timescale of wave movement
- A fraction of patches are inert (grey)
- A fraction of patches has initial concentration of cAMP
- At each time step:
 - chemical diffuses
 - each patch responds to local concentration

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Response of Patch

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if patch is not refractory (brown) then
  if local chemical > threshold then
    set refractory period
    produce pulse of chemical (red)
  else
    decrement refractory period
    degrade chemical in local area
    
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Demonstration of StarLogo Simulation of Spiral Formation

[Run SlimeSpiral.slogo](#)

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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

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