Unit 6: Cycles
Much of life is cyclical

• Most of our models have gone to equilibrium.

• Much of social life isn’t described by equilibria, but by cycles

  A time of war, a time of peace
  A time to dance, a time to mourn
  A time to cast away stones, a time to gather stones together

• Cycles often require feedback and delay
Ecological Host-Pathogen Model

- A host species can become infected by a lethal pathogen, though contact with infected hosts.
- Only uninfected hosts can reproduce.
Ecological Host-Pathogen Model

Three possible states

- 0: empty
- S: susceptible host
- I: infected host

Transitions

- 0 → S: reproductive rate, $r$
- S → I: transmissibility, $\tau$
- I → 0: virulence, $v$
Empty cells can become susceptible hosts

- Each neighboring $S$ cell has opportunity to reproduce into empty cell with probability $r$.

- Probability of transitioning increases with number of $S$ neighbors. Let $n_s$ be the number of $S$ neighbors. The transition probability for an empty cell is:

$$\Pr(0 \rightarrow S) = 1 - (1 - r)^{n_s}$$
Susceptible hosts can become infected

- Each S cell can become infected by a neighboring I cell with probability \( \tau \).

- Probability of transitioning increases with number of I neighbors. Let \( n_I \) be the number of I neighbors. The transition probability is:

\[
\Pr(S \rightarrow I) = 1 - (1 - \tau)^{n_I}
\]
Infected hosts can become empty cells

- Each $I$ cell can perish with probability $v$ and become empty.
- Probability of transitioning is independent of the neighboring cells:

$$\Pr(I \rightarrow 0) = v$$
Ecological Host-Pathogen Model

Three possible states:
- 0: empty
- S: susceptible host
- I: infected host

Transitions:
- 0 → S: reproductive rate, $r$
- S → I: transmissibility, $\tau$
- I → 0: virulence, $\nu$
spatial host-pathogen model

**CODE:** hostpathogen.nlogo
Summary of results

- The inhibitory/excitatory dynamics and spatial arrangement give rise to oscillations.
- Increased reproductive rate leads to decreased host populations.
- Decreased virulence can lead to increased chance the host population is wiped out.
Historical cycles

• Since agriculture, often talked about as if a story of continued growth

• However, rise and fall of empires appears cyclical
“War made the state and the state made war.” –Charles Tilly

Area controlled by polities in East and Central Asia, 600-1200 CE (from Turchin 2003)
History is complicated
Metaethnic frontier theory

• Groups possess **asabiya** – social solidarity with a sense of shared purpose.

• Regions that share borders with other groups will have increased asabiya.

• High asabiya enhances the ability to wage war on neighboring groups, and assimilate them into an empire. The larger the frontier, the higher the empire’s asabiya.

• As an empire expands,
  ‣ increased access to resources drives further growth.
  ‣ asabiya among those who live far from the frontier will decrease.
  ‣ expanded size decreases ability to wage war along all frontiers.

• If an empire’s asabiya decreases too much, it collapses.
Metaethnic frontier model

• Each cell correspond to a small regional polity, or chiefdom, with an imperial index of 0. Chiefdoms can become absorbed into larger empire.

• Each cell has a level of asabiya, $S$ in $[0, 1]$. If cell is on a boundary with another chiefdom or empire, $S$ grows logistically. Otherwise, $S$ decline exponentially.

• An empire is characterized by its area, $A$, and by the average asabiya of its polities, $\bar{S}$. 
Metaethnic frontier model

• Each time step, each cell considers an attack on its four neighbors if not in the same empire.

• An empire collapses if its average asabiya decreases below a threshold, $\bar{S} < S_{\text{crit}}$

• A successful attack adds the losing cell to the winner's empire. It occurs if the power of the attacking cell is sufficiently greater than the defender.

• Power depends on 3 factors:
  ‣ Power increases with average asabiya
  ‣ Power increases with total size
  ‣ Power decreases with the region's distance from imperial center

• Power of cell $i$ in empire $j$ is:

$$P_i = A_i \bar{S}_i \exp \left[ -\frac{d_{ij}}{h} \right]$$
metaethnic frontier model

**CODE:** metaethnic.nlogo
Is the theory right?

“If you didn’t grow it, you didn’t explain it.”
–Epstein (1999)

The inverse is not necessarily true.

If you did grow it, you have not necessarily explained it, only failed to reject a possible explanation.

“If you did grow it, you have not necessarily explained it, only failed to reject a possible explanation.

“The qualitative similarity between historical polity trajectories and the simulated ones does not, of course, constitute any ‘proof’ that the theoretical and empirical dynamics are driven by the same mechanisms… Nevertheless, the observation that several features of the model’s output match the observed dynamics is, at the very least, an encouragement to further theory developing and testing.” –Turchin (2003, p 71)
Further directions

The evolution of contagion

Evolution in Spatial Predator–Prey Models and the “Prudent Predator”: The Inadequacy of Steady-State Organism Fitness and the Concept of Individual and Group Selection

C. Goodnight, E. Rauch, H. Sayama, M. A. M. de Aguiar, M. Baranger, and Y. Bar-Yam

1New England Complex Systems Institute, Massachusetts 02138; 2University of Vermont, Burlington, Vermont 05401; 3Massachusetts Institute of Technology, Cambridge, Massachusetts 02139;

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We review recent research which reveals: (1) how spatially distributed populations avoid overexploiting resources due to the local extinction of over-exploitative variants, and (2) how the conventional understanding of evolutionary processes is violated by spatial populations so that basic concepts, including fitness assignment to individual organisms, are not applicable, and even kin and group selection are unable to describe the mechanisms by which exploitative behavior is bounded. To understand these evolutionary processes, a broader view is needed of the properties of multiscale spatiotemporal patterns in organism–environment interactions. We discuss measures that quantify the effects of these interactions on the evolution of a population, including multigenerational fitness and the heritability of the environment. © 2008 Wiley Periodicals, Inc. Complexity 13: 23–44, 2008
Further directions
More on historical cycles
Further directions
Growing artificial societies

Growing Artificial Societies
Social Science from the Bottom Up
Joshua M. Epstein
Robert Axtell

Generative Social Science
Studies in Agent-Based Computational Modeling
Joshua M. Epstein

How to Make a Polity (in the Central Mesa Verde Region)
Stefani A. Crabtree, R. Kyle Bocinsky, Paul L. Hooper, Susan C. Ryan, and Timothy A. Kohler

The degree to which prehispanic societies in the northern upland Southwest were hierarchical or egalitarian is still debated and seems likely to have changed through time. This paper examines the potentiality of village-spanning polities in the northern Southwest by simulating the coevolution of hierarchy and warfare using extensions to the Village Ecodynamics Project’s agent-based model. We additionally compile empirical data on the population size distribution of habitations and ritual spaces (kivas) and the social groups that used them in three large regions of the Pueblo Southwest and analyze these through time. All lines of evidence refute an “autonomous village” model during the Pueblo II period (A.D. 800–1145); rather, they support the existence of village-spanning polities during the Pueblo II and probably into the Pueblo III period (A.D. 1145–1285) in some areas. One or more polities connecting the northern Southwest, with tribute flowing to an apex in Chaco Canyon, appears plausible during Pueblo II for the areas we examine. During Pueblo III, more local organizations likely held sway until depopulation in the late thirteenth century.
Further directions

Autocatalysis

Reaction-Diffusion Model as a Framework for Understanding Biological Pattern Formation

Shigeru Kondo¹* and Takashi Miura²

The Turing, or reaction-diffusion, hypothesis has been used to explain self-regulated spatial patterns, and mathematical models have been developed, each, giving this model the potential for experimental biologists to study a wide variety of morphological patterns in which the RD model is effective.

Characteristics of Pattern Formation and Evolution in Approximations of Physarum Transport Networks

Jeff Jones*
University of the West of England

Keywords
Pattern formation, transport networks, Physarum polycephalum, reaction-diffusion, emergent behavior
Next up: Coda