# Complex Systems 530: Computer Modeling of Complex Systems

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## Lecture 2: Intro to agent-based models
## 1/14/20

# Readings!

- Read
  - “Why Model?”, Epstein 2008
  - Sayama, Chp. 1-2
  - “More is Different,” Anderson 1987
  - Wilensky, Chp. 0-1
- Check-in: Everyone has NetLogo & Python installed?

# How to choose a modeling framework?

- Differential equations, stochastic population-based models, agent-based models, many others!

- Deterministic vs. stochastic?

- Discrete vs. continuous?

- Population-based or individual-based?

- Spatial/non-spatial?

- Different frameworks will have different analytical and computational tractability, interpretability, and assumptions

# How to choose a modeling framework?

- Often can model the same process with many different frameworks (ABMs, ODEs, Markov models, etc.)

- Can also sometimes implement the same or equivalent model in different frameworks

- Discuss for:
  - Infectious disease epidemics
  - Population growth (e.g. birth/death processes)
  - Swarming/flocking (e.g. murmuration, fish schooling)

# How to choose a modeling framework?

- Depends on the problem/question of interest!
- ABMs often particularly advantageous for questions where individual heterogeneity is key (e.g. spatial position of individuals, individuals with varying properties, etc.)
- May also just be more illustrative/clear/interpretable in one framework or another even if equivalent

# How to choose a modeling framework?

- What if the modeling framework you choose affects your results?

- More generally, how to decide how realistic/ simplified to make your model?

- Model comparison & inference robustness assessment—more on this later

Koopman JS. Infection transmission science and models. Japanese journal of infectious diseases. 2005 Dec 1;58(6):S.
Pollock KH. Inference robustness vs. criterion robustness: an example. The American Statistician. 1978 Nov 1;32(4):133-6.

# Top-down vs. bottom-up

- **Top-down**: start with the understanding of the larger system, then break-down or decompose into smaller subsystems

- **Bottom-up**: start with micro-level processes and build up to emergent behaviors at the macro level

# Top-down vs. bottom-up

- Related to Hayek's (1973) consideration of two different Greek conceptions of "order":

- **Taxis**: An arranged, top-down order. A "made" or "designed" order, purposefully built and imposed by a part onto the greater whole.

- **Cosmos**: A grown, bottom-up order. An order that arises spontaneously and unintentionally from the interaction of parts within a whole.

# Top-down vs. bottom-up

- Many models & modeling frameworks can be built/ thought of from either perspective
- Advantages/disadvantages of each?
- What about in the context of complex systems?
- Top-down/bottom-up often conflated with simple models vs. detailed ones, but not quite true

# Agent-based models (ABMs)

# Agent-based models have 3 main components

- **Agents** - independent “agents” move, interact, explore environment, etc.

- **Environment** - agents exist in a non-agent environment (can be static or dynamic)

- **Rules/interactions** - to govern agent behavior, how they interact with the environment, etc.

# Motivating example: video games!





# ABM Advantages

- Can handle situations where population cannot be viewed as aggregates
    - Heterogeneity
- Often a natural description of system - think in terms of individuals & their decisions/actions
    - Builds from micro (individual process) to macro (overall emergent behavior)
- Flexible, can account for more complexity/detail

# ABM Disadvantages

- Often harder to develop, document, and validate
- Fewer analytical tools for understanding dynamics, parameter estimation from data, etc.
- Flexibility towards complexity/complicatedness is both a strength & weakness
    - Can be tempting to make highly complicated & realistic—can make it difficult to know what's going on! Be careful to keep it 'as simple as possible (but not simpler)'

# ABM Dynamics

- Hard to build general mathematical theory of ABM dynamics
- Not always so easy to classify
- Not necessarily equilibrium values to calculate
- Phase plane ideas may not be helpful b/c of spatial aspect, etc.

# ABM Dynamics

- Wide range of possibilities
- Stable constant steady states
- Repeating patterns (oscillation)
- Organized but non-repeating structure/patterns
- Disorder
- All sorts of things!

# We will explore

- Designing, building, and simulating ABMS
- Parameter exploration & sampling - exploring the model behavior
- Interpreting results
- Documenting ABMs!
- Alternative models & inference robustness - how do the inferences/predictions/outcomes/explanatory power of our model change as we add realism?

# Let’s try out an ABM!

- Forest fire model: https://ncase.me/simulating/model/

- What do you notice?

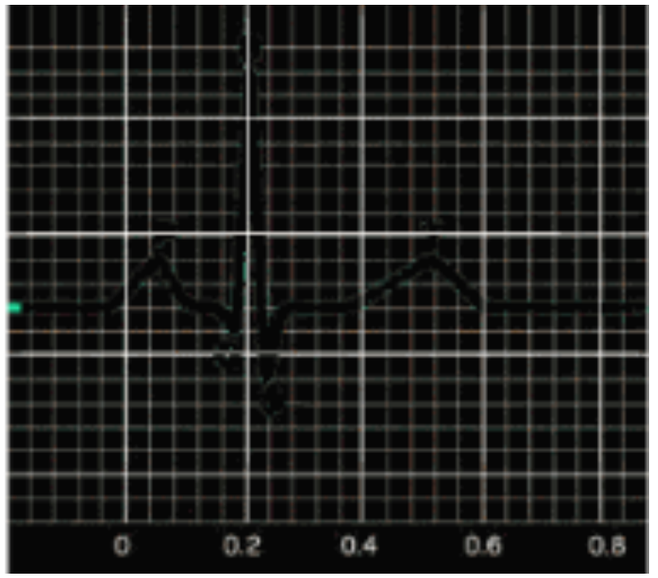
- Any interesting behaviors as you adjust things? You can also add other agent types into the mix!

- What happens if we increase tree growth to 5% and start with all trees?

- Modeling by analogy: what else could this model (or similar) be used for?

# Cardiac dynamics & heart muscle tissue

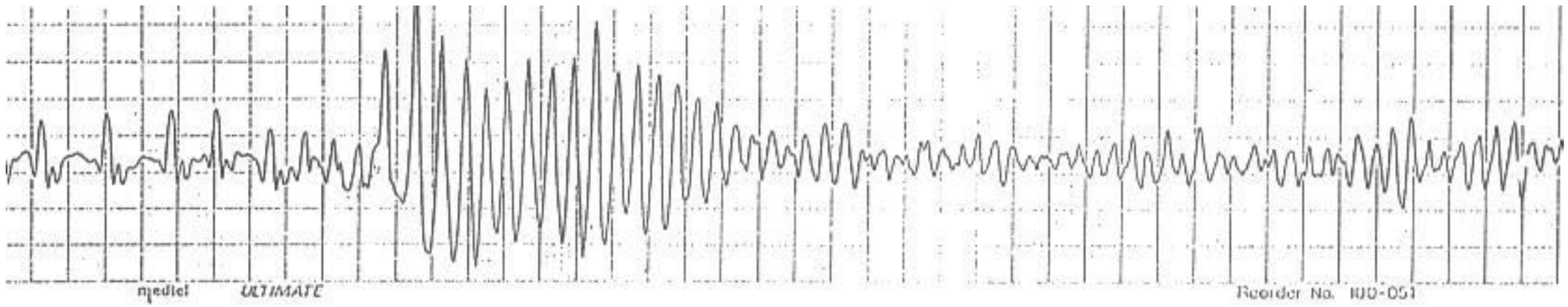
- Normal rhythm: depolarization wave contracts atrium and ventricle in a regular rhythm originating at sinoatrial node & traveling to atrioventricular node




http://www.scholarpedia.org/article/Cardiac_arrhythmia

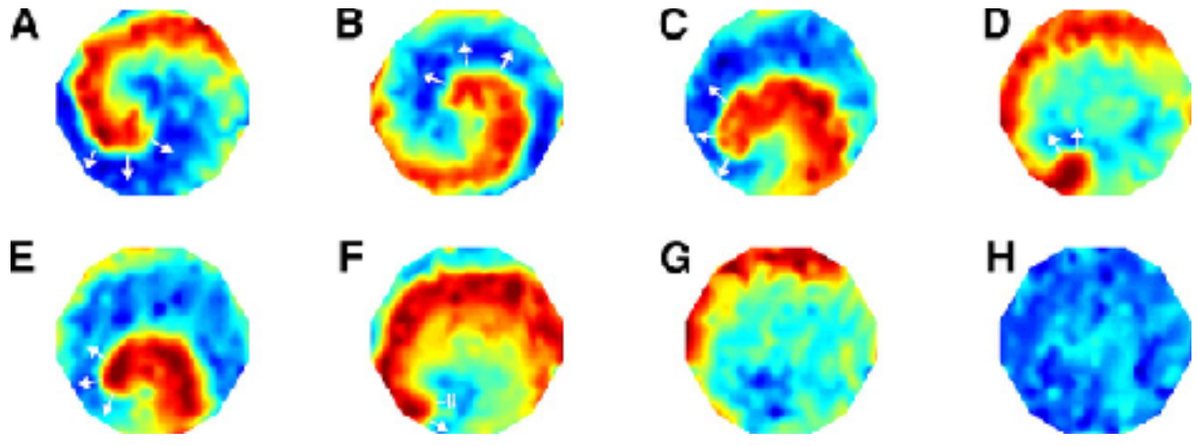
- However, heart can undergo bifurcation to other behaviors—arrhythmias

# Cardiac arrhythmias



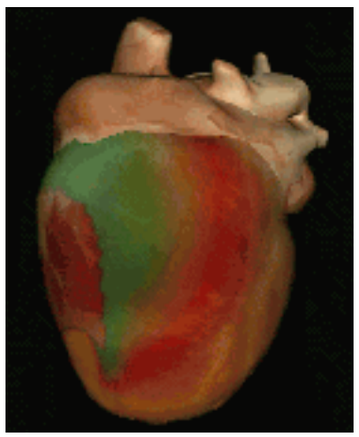

- Tachycardia—>ventricular flutter—>ventricular fibrillation

- These bifurcations can often be understood in terms of spiral waves, period doubling bifurcations, and other spatiotemporal dynamics

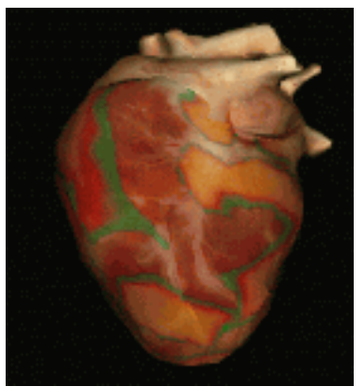



http://ajpheart.physiology.org/content/294/1/H58.figures-only

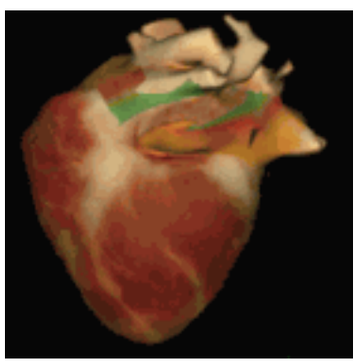
# Spiral/scroll waves in heart arrhythmias



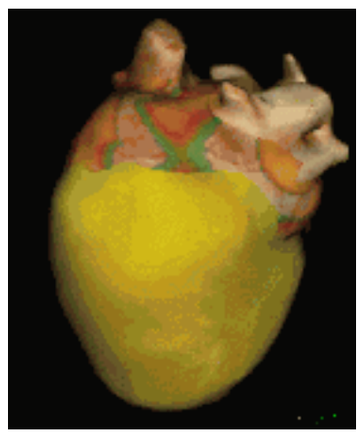
Ventricular tachycardia



Ventricular fibrillation



Atrial flutter



Atrial fibrillation

http://
www.scholarpedia.org/
article/Cardiac_arrhythmia

# Now let’s make one from scratch

- https://ncase.me/sim/?s=blank

- Simple voting model!

- 2 parties/candidates/options - everyone starts with some random initial preference

- They tally the planned votes of their neighbors and if more than half of neighbors are voting the other way, they switch

- What happens?

Wilensky, U. (1998). NetLogo Voting model. http://ccl.northwestern.edu/netlogo/models/Voting. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL.

# Voting model

- Things to try:
  - Award ties differently (e.g. switch if exactly half of neighbors vote the other way)
  - Different initial percentages of each party
- Try with 3 parties
  - What happens? Same patterns?

# More emoji ABMs

- https://ncase.me/sim/

- Explore!