Week 2

Agent-Based Modeling as a Method

Review

- What is “modeling and simulation”?
- Course Design
- Objectives
- Readings
- Software
- Assignments

Outline

- Introduction to chaos and complexity
- Why use agent-based models?
  - Advantages
  - Pitfalls
- Brief introduction to NetLogo

I. CHAOS AND COMPLEXITY

“Chaos”

- What do you think of?

Chaos Theory

- Theory of mathematics
- Nonlinear systems
  - Simultaneous equations
- Insight: apparently "random" systems may be deterministic

Nonlinearity

- Linear

$$y = a + bx + e$$

- Nonlinear

$$\frac{dx}{dt} = \sigma(y - x)$$

$$\frac{dy}{dt} = x(\rho - z) - y$$

$$\frac{dz}{dt} = xy - \beta z$$

Problem with nonlinearity

- Cannot break down equations into constituent parts
- “Solutions” hard to come by
  - Depend upon initial conditions
  - Depend upon simultaneous values

Mathematical chaos

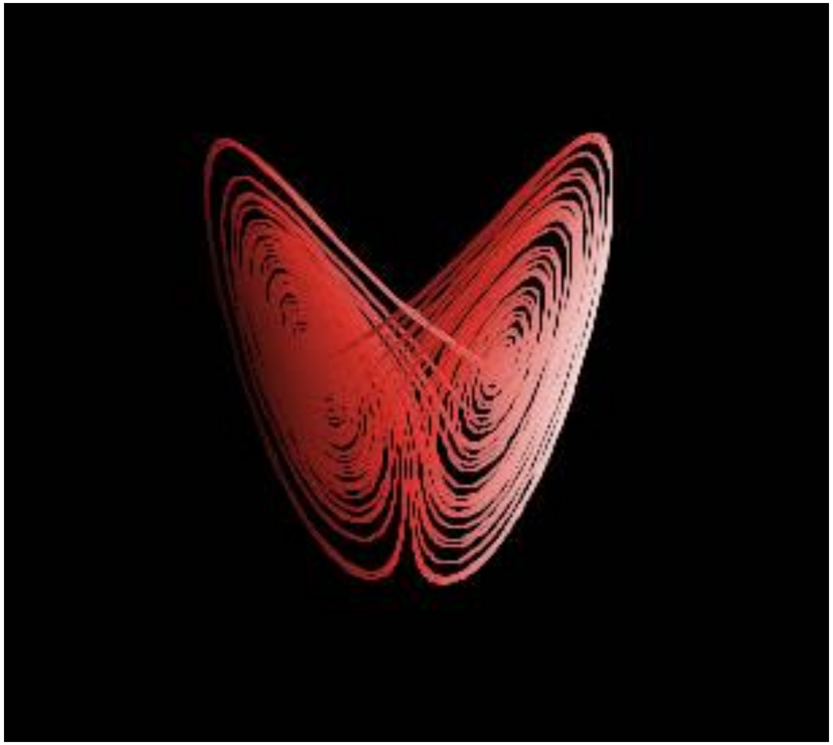
- Deterministic equations
- Erratic behavior *over time*
  - Focus on “dynamics”
- Same system may appear:
  - Stable, predictable
  - Random, changing, unpredictable
  - *Depending upon “initial” conditions*

Why does chaos arise?

- Sensitivity to initial conditions
  - The "Butterfly Effect" (Lorenz)
  - Small initial differences lead to large changes over time
  - Flap of the wings changes the path of a typhoon

Attractors

- Graphical technique to illustrate coherence of chaotic systems
- Types
  - Point
  - Limit cycle
  - Strange



Implications

- Simple systems can produce chaos
  - Saperstein: “the prediction of unpredictability”
  - Rumsfeld:

> “As we know, there are known knowns; there are things we know we know. We also know there are known unknowns; that is to say we know there are some things we do not know. But there are also unknown unknowns—the ones we don’t know we don’t know.”

- Even if chaotic “locally,” there is “global” stability

Implications

- Sensitivity to initial conditions
  - slight differences may lead to vastly different outcomes
- Difference appear random, but aren't
  - Even deterministic systems may appear "noisy" or random
- Hard to study mathematically or statistically
  - Difficult (impossible?) to infer rules or governing laws from chaotic data
  - Old methods focus on stasis, ignore dynamics
  - We require simulation methods

Chaos Theory

- Questions?

Some questions to consider

- Why do riots occur?
- How much vaccination is enough to prevent the spread of the flu?
- Why is there residential segregation in Norfolk?
- How does Google work?
- Why are bell-bottoms and tattoos popular (again)?

Notice . . .

- Each example is:
  - Decentralized, leaderless
  - Massively parallel
  - Interdependent decision-making
  - Spatial
  - “Predictably unpredictable”

“Organization”

- What do we mean?
  - “An organization” (entity)
  - Versus “organization” (state of being)

But physics tell us . . . .

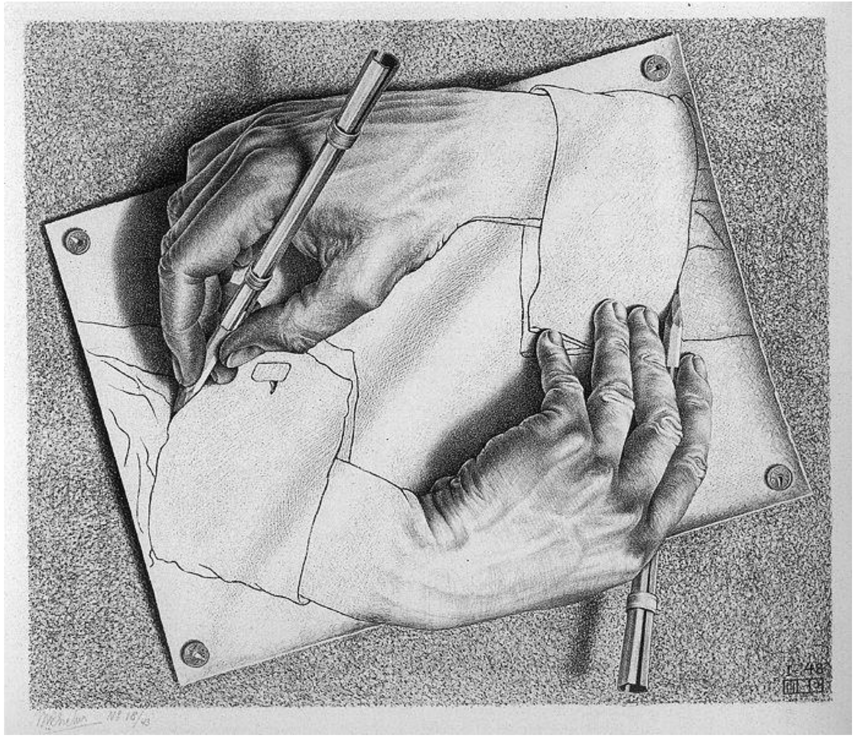
- "Entropy"
- Second Law of Thermodynamics

Self Organization

- Waldrop 1992: “matter’s incessant attempts to organize itself into ever more complex structures, even in the face of the incessant forces of dissolution” p. 102
  - “Autopoiesis”

Self Organization

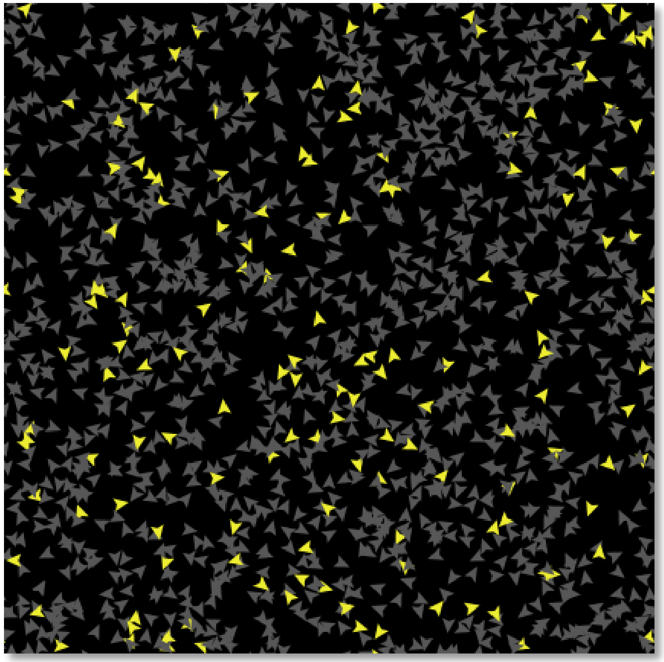
- Organization "for free"
  - No external guidance
  - No leadership
  - Contra Second Law

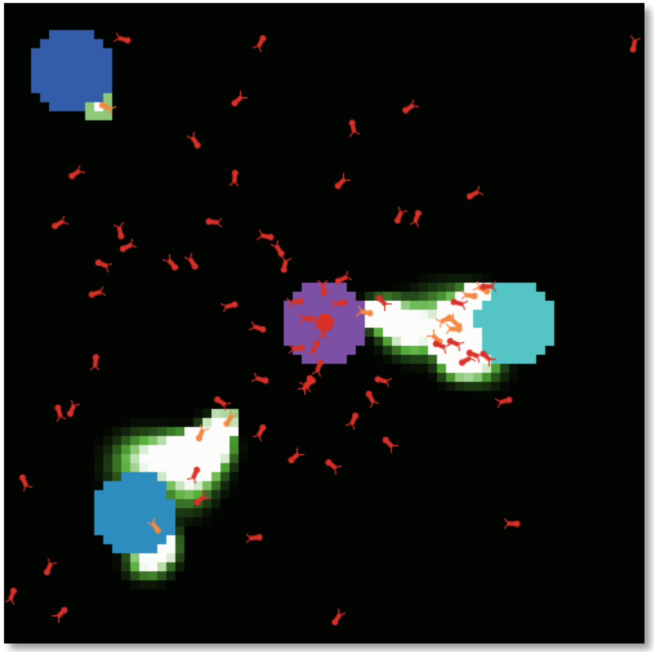


M.C. Escher, *Drawing Hands* (1948)

Self Organization

- Examples





“Emergence”

- Definitions
  - Gilbert and Troitzsch
  - Pepinsky, pp. 373-4: “those phenomena that appear at an aggregate level, based not on specific micro-level interactions of agents but rather on the complex and often unpredicted effects of many such interactions”
- Irreducible phenomena of systems that paradoxically arise from micro-level interactions
- **GOAL OF ABM: simulate emergence from “the bottom up” (micro-level interactions)**

Second-Order Emergence

- Probably unique to social systems
- Agents recognize emergent structures
- Emergence thus affects agent behavior
  - “Double hermeneutic” (Giddens)

Implications

- The phenomenon of emergence requires us to model interactions across levels of analysis
  - Agents and structures
- Mathematics is no help

Chaos and Complexity

- Questions?

II. WHY USE ABM?

Uses of ABM

- Gilbert & Troitzsch's seven uses
  - Gain a better understanding
  - Prediction
  - Substitute for human expertise
  - Training
  - Entertainment
  - **Discovery**
  - **Formalization**

Why use ABM? (1)

- Theory: fidelity to actual system
  - Nonlinearity
    - Cannot be understood analytically
    - Unpredictable
  - Space
    - Physical (GIS)
    - Network
  - (Bounded?) rationality of actors (Simon)
  - Dynamics rather than equilibria

Why use ABM? (2)

- Methodology
  - Formalization: expose hidden assumptions
    - Pepinsky, p. 374: “Simulation forces the researcher to examine deeply the assumptions that she makes about the environment, the agents, the rules and parameters.”
  - Relationships between levels of analysis
    - Emergence
    - The agent-structure debate (Wendt)
  - Quasi-experimentation
  - Counter factuals (Fearon)
  - “micro foundations”

Why use ABM? (3)

- Agent learning
  - Inverts rational choice assumption
  - Change through learning
  - Appeal of ABM to constructivists
    - Hoffmann
    - Lustick

	Rational Choice	**ABM**
Assumptions	Interests	Behavior
Inferences	Behavior	Interests

ABM for IS

- Core concerns of IR
  - Change through actor learning
    - Gilpin (1981): “interaction,” “systemic” and “system” change
  - Reciprocal influence of agents and structures
    - Wendt (1987)
  - Counterfactual reasoning
    - Fearon (1991)

IS examples

- Pepinsky, p. 371
  - Political behavior
  - Arms races
  - Trade and economics
  - Ethnic conflict
  - Escalation
  - War and conquest
- Lots of others we'll read this semester

Why use ABM?

- Questions?

Logic of Simulation

- Combination of induction and deduction
  - *Deduction*: formal specification of
    - Actors
    - Variables
    - Rules of behavior
  - *Induction:* analyze inductively
    - Data generated by model
    - Alternative "histories" of the modeled system
- Computational social science
  - "Third way" (Axelrod 1997)
  - "From the bottom up" (Epstein and Axtell 1996)

Epistemology

- “Underspecified and incomplete”
- Two issues
  - Explanation vs. Prediction
  - Point vs. Trend Prediction

Explanation vs. Prediction

- Gilbert and Troitzsch
  - ABM best for “discovery” and explanation
  - Not good for prediction
- *Prediction* is not the only epistemological criterion
  - Scientific realism vs. positivism
  - Theories that predict well but are based on the wrong explanation are problematic

Point vs. Trend Prediction

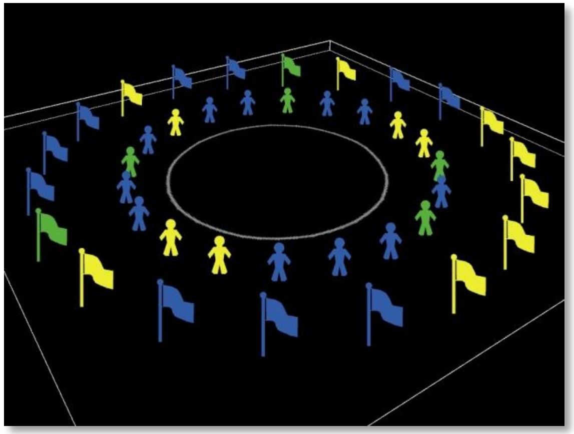
- Types of prediction
  - ABM good for “trend” prediction
    - Explore the statistical distribution of outcomes in the model
    - Provide a good sense of probabilities of events
  - ABM not good for “point” prediction
    - Due to sensitivity of macro parameters to micro values

"Model"

- All agent-based models:
  - Represent the environment of the system
  - Stipulate relevant actors
  - Specify rules (algorithms) and parameters
  - Explore behavior over (simulated) time
- NOTE: does not require assumption of linearity
  - Or indeed of any functional form
  - Contra regression analysis
- Clausewitz: "The map is not the territory"

Notes about vocabulary

- "Target" vs. "Model"
- Simulation
  - "creating an artificial representation [model] of a real world system [target] in order to manipulate and explore the properties of that system." Pepinsky, p. 369



Notes about vocabulary

- “Inputs”
  - Similar to “independent” variables”
- “Outputs”
  - Similar to “dependent” variables
- “Parameters”
  - Not “variables” because we are not sampling
- Time vs. simulated time
  - Time in the model may or may not correspond to actual time
- Data
  - “Empirical”: from the target
  - “Meta”: from the model

Epistemology

- Questions?

Steps of Research

1. Puzzle
2. Definition of target
3. Observations of target
4. Assumptions and design the model
   a. "Environment"
   b. "Agents"
   c. Parameters and rules
   d. Time
5. Simulate
6. Record data
7. *Verification*
8. *Validation*
9. *Sensitivity analysis*

Pitfalls (1)

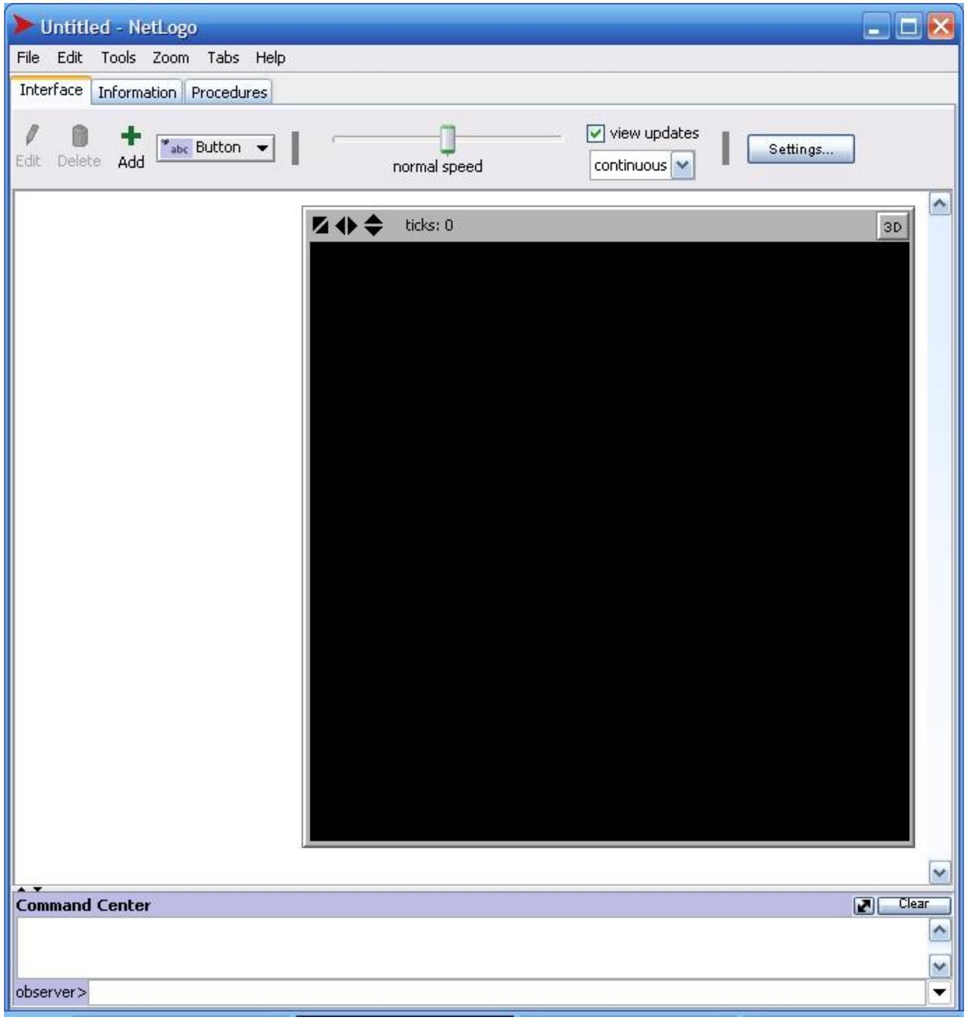
- Incorrect model specification
  - Agents: "thick ontological presuppositions" (Pepinsky)
  - "In that there is little consensus about the nature of the international system, simulation may not be an acceptable research tool for this enterprise." p. 379
  - Importance of **validation**
- Reliance on strong assumptions
  - Space: "strict locality of interactions"
  - Relevant agents

Pitfalls (2)

- Sensitivity of parameter specification: Chaos
  - Importance of **verification** and **sensitivity analysis**
- Quasi-experimentation: testing the *model*, not the *target* itself
- Epistemological and ontological claims tend to be obscured by the methodology
- Lack of consensus on epistemology of simulation

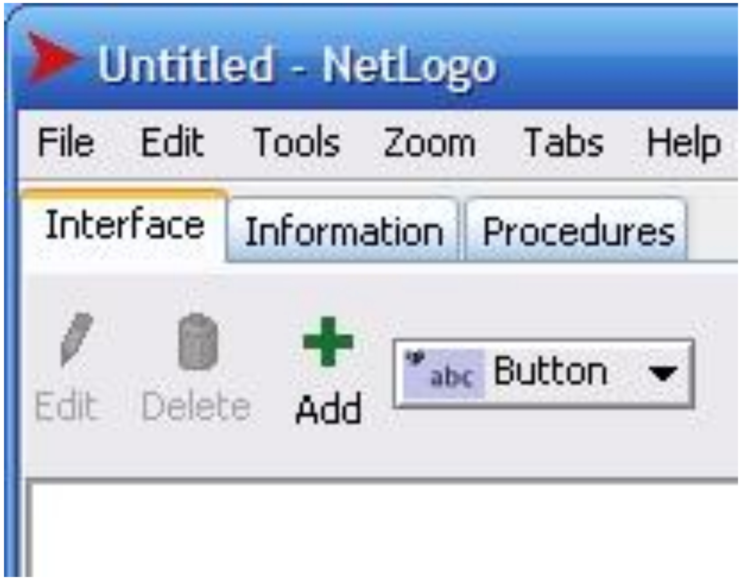
III. INTRODUCTION TO NETLOGO

Interface Elements

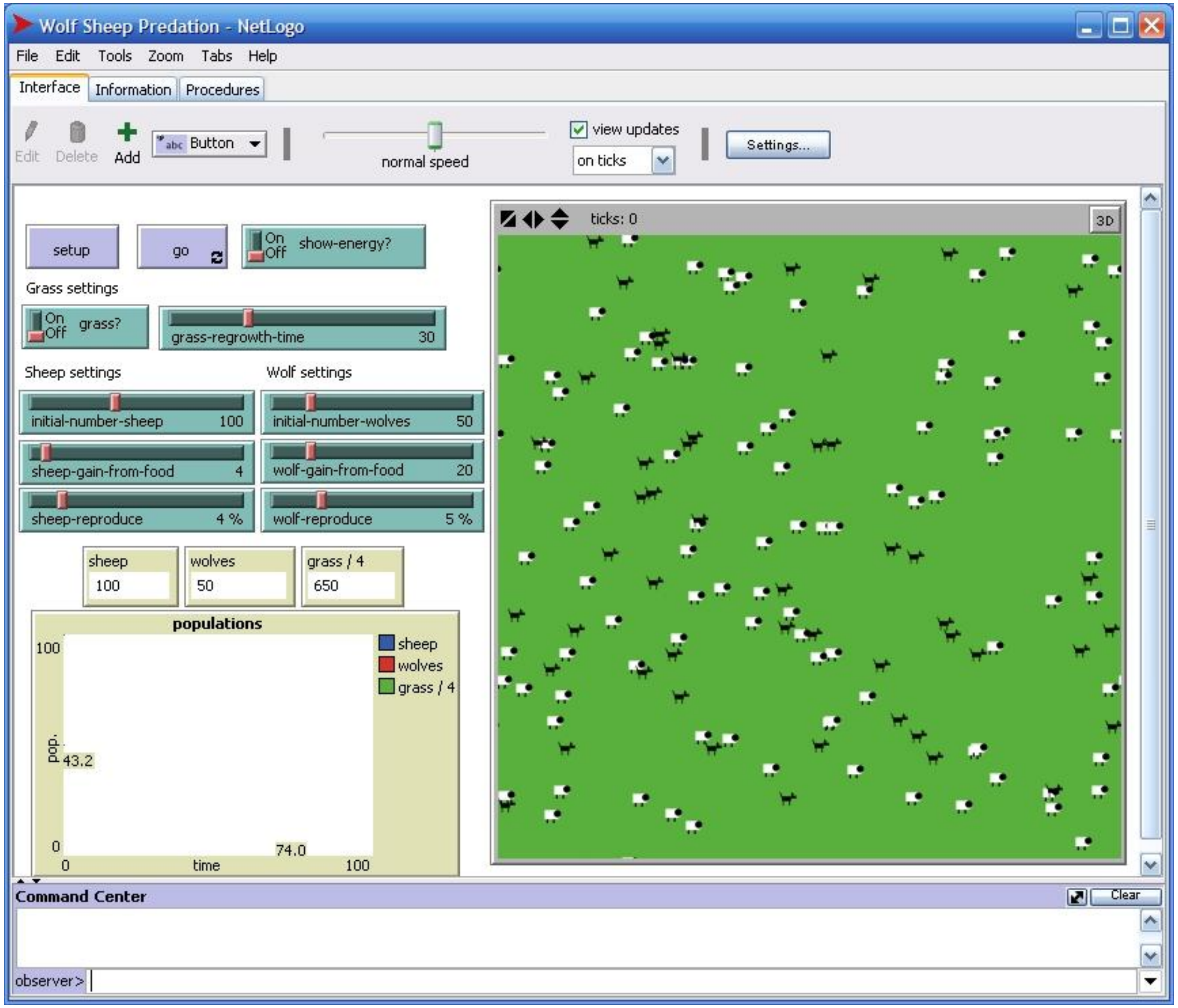


Elements of NetLogo

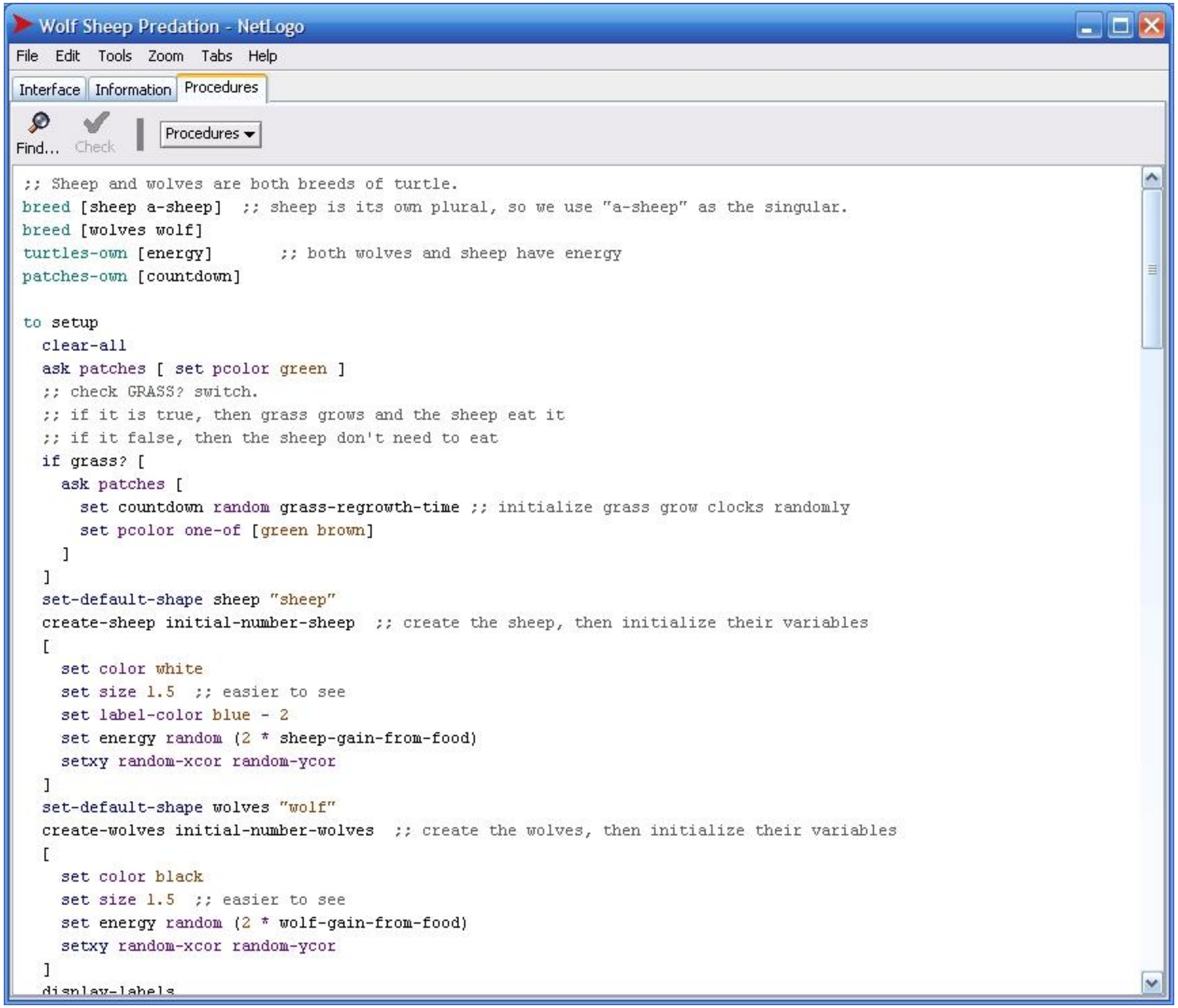
- Interface tab
- Procedures tab
- Information tab



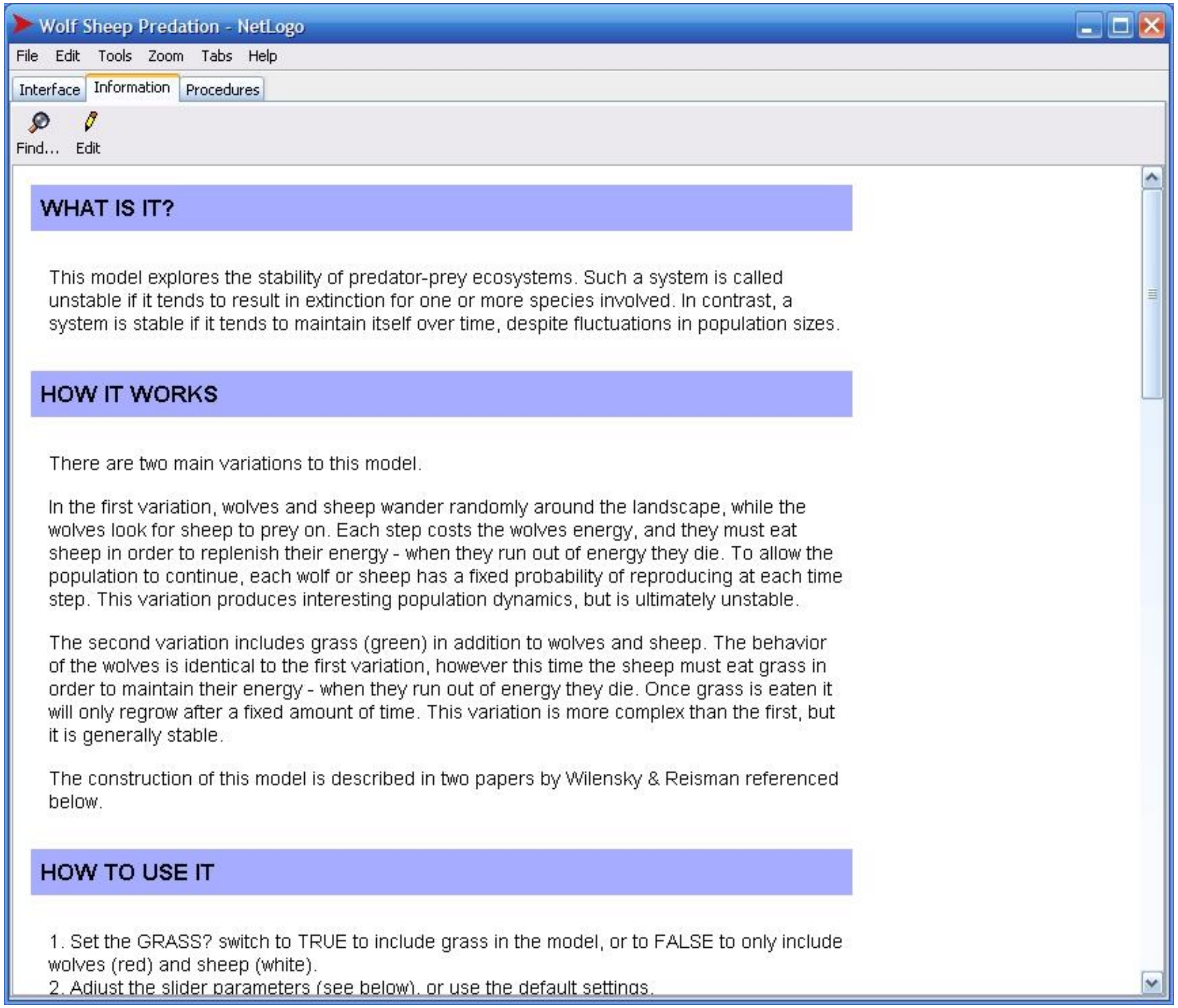
Interface Tab



Procedures Tab

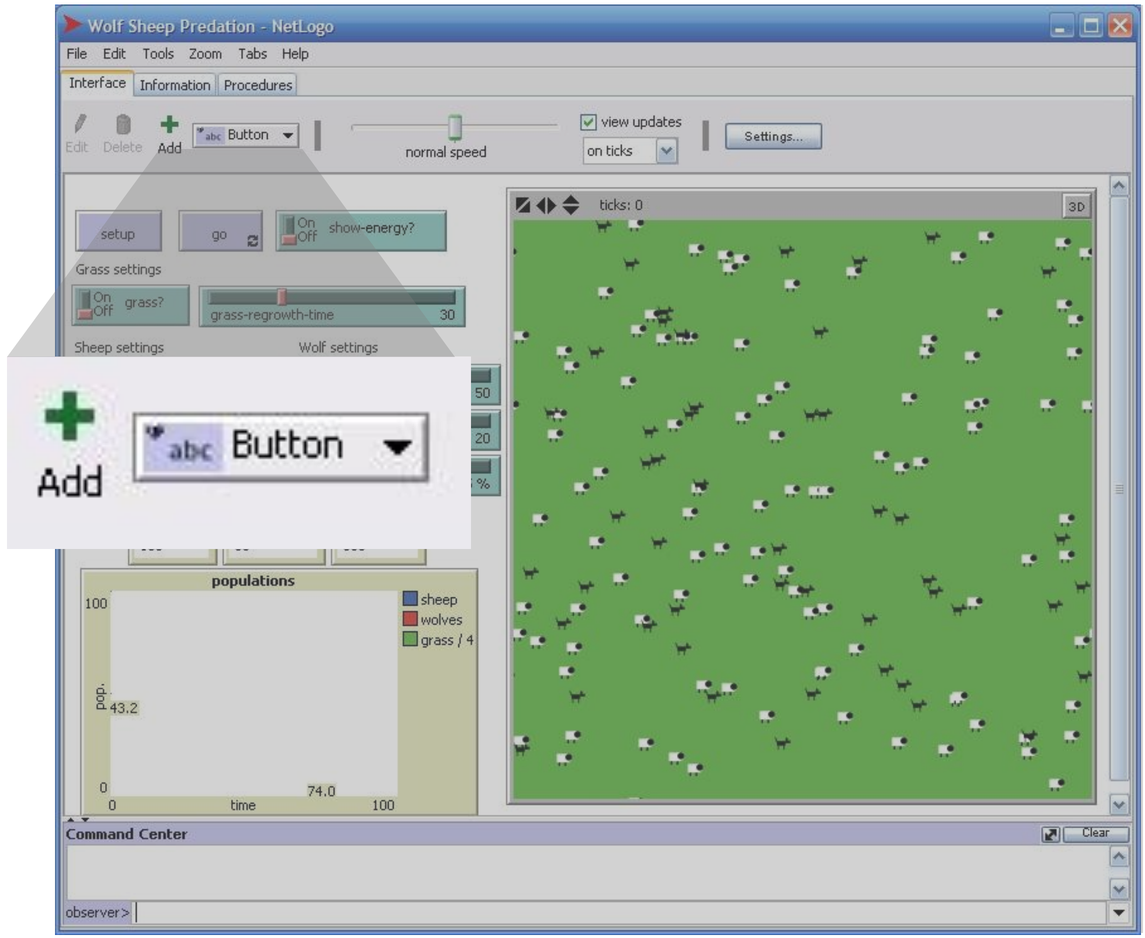


Information Tab



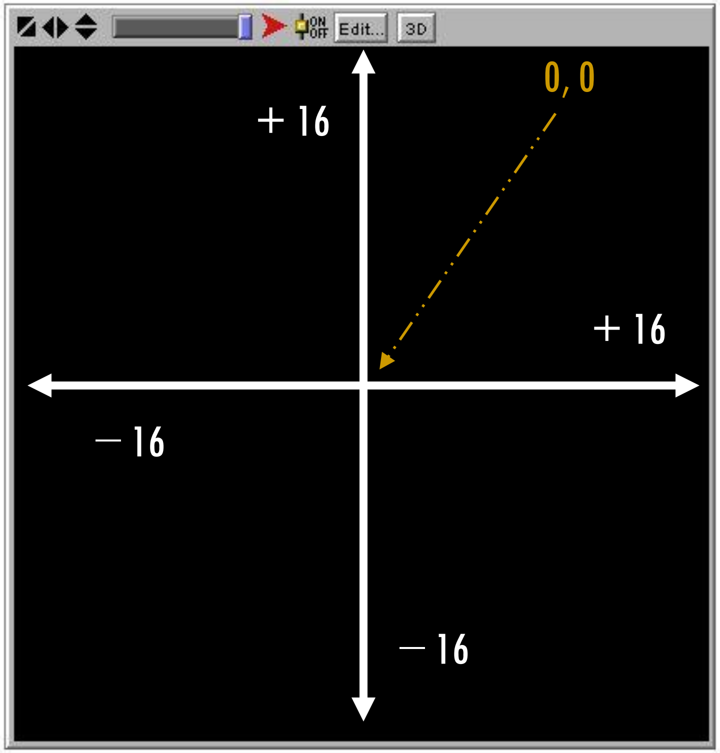
Graphical User Interface Elements

- Buttons
- Sliders
- Switches
- Choosers
- Monitors and plots



The NetLogo "World"

- A matrix
  - 33 x 33 square patches
  - **Cartesian coordinates**
- World is customizable
  - Size, Scale
  - Shape of patch (square versus hexagon)
  - Wrapping (none, top-bottom, left-right, all)
  - Origin



Introduction

- Questions?