Nonlinear Systems: Agent-Based and Computer Intensive Modeling

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Overview of Schedule

- Lectures on Modeling Complex Adaptive Systems. 9-10am MLB #1.
  First week: Rick; next 3 weeks: Scott, Ken.

- Hands-on computer sessions. (Optional)
  Use existing implementations in Swarm:
  - Schelling's Tipping model (segregation)
  - Prisoner's Dilemma models
  - Axelrod's Cultural Diversity model
  - "Sandpile" models of SOC
  In East computer lab, 6:30-8pm.
  – Tomorrow (Tues): Demo some model(s).
  – Wed,Thur: Run models yourself.
    Replicate an experiment (collectively).
  – Next week: (Mon-Tues-Wed(-Thurs?)
    More experiments? Modify a model?

Handouts Today:

- Syllabus (if you don't have it already)
- How to login to CSCS computers
- Overheads from today

Information from you:

- Name
- email (which you are using while at UM)
- Department / Field of Study
- What brings you to CAS class?
- Used linux (unix)?
- Programming skills? Used C language? Used Java?
- Interested in using models we provide?
- Interested in modifying models? (Perhaps working in a small group?)
- Can/plan to attend 6-8:30 pm sessions? (Mon, Tues, Wed, Thur)

Please email **today** to rlriolo@umich.edu

With this info I will make cscs-icpsr02@umich.edu and plan computer exercises for this/next week.

Questions?

Center for the **S**tudy of **C**omplex **S**ystems

- "mission statement"
  Encourage and facilitate education and research in the general area of complex, nonlinear, dynamic and adaptive systems.
- Interdisciplinary center (not a department)
- Associated faculty and students from Biology, Economics, Political Science, Math, Engineering, Computer Science, Anthropology, Physics, Business School, Public Health, Psychology, and more.
- Students can earn a UM Rackham Graduate Certificate in Complex Systems Studies (5 courses – mini-Masters)
- Shared interest in CAS:
  - search for (belief in!) common underlying dynamics and structure across many systems
  - transfer techniques and tools (empirical, analytical, computer modeling)

Nonlinear Systems: Agent-Based and Computer Intensive Models of Complex Adaptive Systems. CAS includes:

- Biological systems (ecologies, brains, cells)
- Economies, markets
- Human organizations (firms)
- Political, cultural systems (cities, states,...)

An Introduction to:

- Cmplx Sys Approach: Bottom-up models
  - Agent-Based computer models
  - Simple math models
- Specific models in various areas (IR, OT, markets,...)
- General concepts from C(A)S studies

Readings:

- Rather a lot (esp. in first week!): read what you can...
- Read ahead a bit: Schellings Segregation model, Axelrod's Cultural Diversity model.

Course will cover key issues / concepts from Complex Systems including:

- Emergence; micro rules to macro patterns
- Distributed systems: no central controllers

- Perpetual novelty; Path dependence
- Dynamics (vs Equilibria)

- Evolution, Learning, Adaptation (Genetic Algorithms)
- Satisficing (vs optimizing)
- Co-adaptation; Niches; Diversity

- Interdependence; Feedback
- Interaction Topology (Networks, Space)

- Self-Organized Criticality (SOC)
- Edge of Chaos; Cellular Automata

Some CAS systems/models:

- Schelling's "tipping" segregation model
- Iterated Prisoner's Dilemma models
- Brian Arthur's El Farol Bar Problem
- Conway's "Game of Life" (Cellular Automata)
- Per Bak's Sandpile model of Self-Organized Criticality (SOC)
- Epstein and Axtell's SugarScape model.
- Axelrod's Cultural Diversity model

Why a Complex Systems Approach?
Focus on aspects that are difficult for other approaches:

CAS Micro-level characteristics

- Medium number of components (agents)
- The agents
  - limited capabilities
  - nonlinear behavior (if/then rules, etc)
  - heterogeneous knowledge, capabilities, relations (who they interact with)
  - heterogeneous (individual) “goals”
  - heterogeneous history, memory
  - adaptive (capabilities, goals, relations)
- Interactions are critical to behavior
- Interactions are (usually) local (spatial and/or spatial topologies)
- Mix of cooperative and competitive interactions.

Macro-level characterisitcs of CAS

- Aggregate features important: GNP, market prices, organizational structure, population size, ...
- Large scale structure/dynamics (patterns) emerge: power laws; cycles, basins of attraction; bifurcation patterns
- Hard/impossible to predict dynamics and structure in detail.
- Path dependent phenomena:
  - sensitivity to initial conditions
  - accumulation of historical accidents
  - multiple "equilibria"
- Nonlinear dynamics common, e.g., tipping phenomena, punctuated equilibrium, etc.
- Perpetual novelty: behavior in "transients" is important, since systems never reach equilibrium!
- New "emergent structures" are important: cells, organisms; tribes, nation states, firms.

How to Model CAS??

Models:

- Description of **part of** the world.
- Capture structure/dynamics **of interest to modeler**.

Key questions:

- What to include?
- What to leave out?

Answering those: **art and craft of modeling**!

KISS (Keep It Simple, Stupid)

- Easier for you to understand
- Easier to analyze, display results
- Easier to describe and explain to others!

Computer models: great tempation to include too much!

Another key question: What is the purpose of the model?

- Predictive:
  Strongest claims; clear policy implications; most difficult to obtain (CAS–impossible?)
  Note role of abstraction in "predictions:"
  - There will be cycles (vs equil vs chaos)
  - There will be 12-year cycles
  - There will be this particular time series...

- Explanatory:
  Explain observed patterns, but not make detailed predictions. Example: evolutionary models in biology.

- Exploratory:
  Develop intuitions or even theories. Study alternative hypotheses. Determine implictions of assumptions. Examples: Schelling's segregation model; Axelrod's Cultural Diversity model.

Modeling languages

- Text description (informal)

- Mathematical (formal)
  Equations (static, dynamic); logic stmts.
  Precise, robust (over assumptions).
  Must be "simple" to get closed form solutions.
  Numerical methods for analysis/estimation.
  (system dynamics equation-based models).
  Difficulties from:
  - heterogenous, non-continuous space
  - heterogenous agents
  - nonlinear mechanisms (if-then rules)
  - adaptive agents: creating new agents.

- Agent-Based Models (simulations).
  (note I don't call EBM "simulations.")
  Formal; precise. (Text description might not be...)
  "Solve" by running the program!

Agent Based Models / Simulations
Specify simple, locally driven mechanisms and interactions. (Bottom-up approach).

Typically three components:

1. A world
   Some topology with local state/dynamics.
   Ex: 2D array of cells, occupied or not.

2. Agents
   - Sensors (see neighbors and their types)
   - Effectors (move to new cell)
   - Individual state (type, memory, ...)
   - Behavior rules (if ... then ...)
   - Adaptive mechanisms (learn; genetic)

3. Intrumentation for observations
   Not always obvious what to measure, or how to measure it.
   (e.g., what clustering measure? what is a species? what is an new organization?)

EBM: equation based modeling

- Fundemental entities are usually aggregrate variables (GNP, #infected)
- Dynamics: Relate variables by equations (ODE, PDE)
- Top-down, system dynamics approach (macro econ, epidemiology, ...)
- Often based on mean-field assumptions (i.e., ignore or approximate any underlying variance)

ABM: agent (individual) based modeling

- Entities are "agents" each with own state
- Dynamics: behaviors of agents, defining interactions with each other, with objects in the "world," adaptive changes, etc.
- Generally do not include aggregate variables in model dynamics.
- Observe "emergence" of aggregate level dynamics and structure (GNP cycles, trade patterns, nation alliance formation/dissolution).

Why/when use ABM approach:

- Relax constaints and assumptions necessary for equation based approach:
  - Discrete, if-then, nonlinear dynamics.
  - Heterogeneous, adapting agents with complex interaction patterns. Physical vs interaction space distinction.
  - Endogenous, generative adaptive mechanisms.
    The nano-fox problem: Infinite population -> All types always present!
- Validate system at two levels: agent behavior and aggregate observable behavior.

- Conceptual shift:
  - Emphasize dynamics (vs equilibrium)
  - Focus on path dependence, distribution of histories (typical vs. atypical)
  - “Intuitive” representation of (controlable) agents and their behaviors.
  - Generative approach to social science: plausible model if “realistic” agents generate observed phenomena.
  - Construct artificial worlds about which everything is known; experimentation is (relatively) easy. Use to test hypotheses and assumptions, **and to test survey/statistical tools** themselves.

Problems/Cautions with ABM approach

- Verification: is the program debugged.

- Validation (compared to the world):
  - Valid basic mechanisms? May be hard to validate assumptions (e.g., parasitic load, individual search mechanisms, etc.)
  - Valid predictions: what level of abstraction should be predicted?
  - Are results artifacts of some (unknown) implementation details?

- Understanding and describing the models
  - Too many agent types, mechanisms, variables -> unfathomable model.
  - Text description vs model implementation can mislead.
  - Mountains of data: Can be as complex as observations from the world being modeled!

- Computational constraints.
  How to avoid biases introduced by small populations (drift), short run length (missed events), limited number of replications (misleading sample of histories) or limited sample of parameter space (special cases).

- Not as “general” as equations.
  - No analytic solutions
  - Results may be tied to specific details and conditions.

Readings for today:

- Page: Complexity topics, from A to Z!
- Casti: Would Be Worlds; modeling, types of models, uses of models. (Afterwords bookshop on Main Street–$5!)
- Rauch: Seeing Around Corners.
- Bonabeau: Agent-based modeling: Methods and techniques for modeling human systems.
- Bankes: Exploratory vs. consolidative models. Pitfalls of trying to make quantitative, predictive models of very complex systems.
- Parunak etal: ABM vs EBMs, for modeling supply chain dynamics.

Course web page:

www.pscs.umich.edu/~rlr/icpsr

Contains:

- syllabus
- online copies of some of the lecture notes
- online copies of handouts
- pointers to lab related pages

Also a "Swiki": a set of pages which you can edit/add to via any web browsers.

- General announcements (changes in schedule, ...)
- Lab related info
- Discussion pages!
  Please feel free to start discussions here.

See the Help pages (icon on page) to learn about editing and using the Swiki. The login and password are:

We've not tried this before...so please feel free to experiment!