THE UNIVERSITY of NORTH CAROLINA at CHAPEL HILL

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Introduction to system dynamics modeling

Course Website:

http://todd.bendor.org/sd

Syllabus

- Thursday, Nov 8
  - –Morning (10-11:10, 11:20-12:30)
    - What is system dynamics? Why is it useful?
    - Introduction to feedback, feedback loops, and homeostasis
  - –Afternoon (1:30-2:40, 2:50-4)
    - Introduction to stocks and flows
  - –Lab #1 – *learning to model with Vensim*
    - Dynamic equilibrium and system archetypes
    - Introduction to oscillations

Goals for today

- Understand basic system dynamics modeling (SD)
  - Concepts and terminology
  - History
  - Theory (e.g. stocks, flows, feedback, numerical analysis)
  - Software platforms
- Understand the advantages and dis-advantages of SD modeling
- Understand the limitations of SD modeling relative to relative to other modeling techniques (e.g. agent-based modeling)
- Learn some fundamentals of the VENSIM modeling platform
- Learn about the best practices for system dynamics modeling construction

What today is NOT…

- An in-depth SD course
  - See: [WPI System dynamics masters degree]
  - Mastering SD takes a LOT longer than two days
- An in-depth course in Vensim, STELLA, or other modeling platforms
  - See resources on the course website

- All modeling efforts are unique and confront unique challenges.
- Fortunately, most can be overcome with patience, perseverance, and attention to good modeling practices.

Who am I?

- Professor of City and Regional Planning (since 2007! Go Heels!)
- BS in **system dynamics** modeling, focusing on environmental policy
- MS in environmental science, focusing on **system dynamics**
- PhD in Regional Planning, focused on land use modeling using **system dynamics**, cellular automata, and agent-based modeling

- Experience with system dynamics applications, including:
  - auto emissions policies
  - wetland restoration
  - spatial-dynamic modeling
  - invasive species spread
  - infrastructure planning
  - brownfield restoration

- Experience with agent-based modeling of endangered species spread, land use change, and infrastructure planning
  - Just finished a book on agent-based modeling and environmental conflict

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Assumptions I will make

- Computer literacy
- Comfort with **general modeling concepts** and impetus behind using modeling to better understand systems and problems

> [I]t is often more important to clarify the deeper causes behind a given problem and its consequences than to describe the symptoms of the problem and how frequently they occur.
>
> – Bent Flyvbjerg (2006, Pg. 229)

Overview

- What is a model?
- Why model?
- System dynamics modeling
- Components of feedback in systems
- Modeling environmental and urban systems

What is modeling?

- Lots of definitions:
  - “A model is a picture of reality” – *Wittgenstein*
  - A representation or substitute for a real system

  Remember that all models are wrong; the practical question is how wrong do they have to be to not be useful.

  – George Box and Norman Draper (1987, Pg. 74)

- We use them all the time
  - Blueprints, graphs, maps, and wind tunnels are all models
- Rigorous forms
  - Econometric / statistical regression models, mathematical models representations of reality

Why model?

- We already do it
  – Human cognitive processes
  – How do we know that a cow is a cow?
- Informal models – mental “maps”
  – Help us understand and interpret the world around us
- Formalized modeling also helps us to understand the world around us
  – Make our mental models of the world explicit

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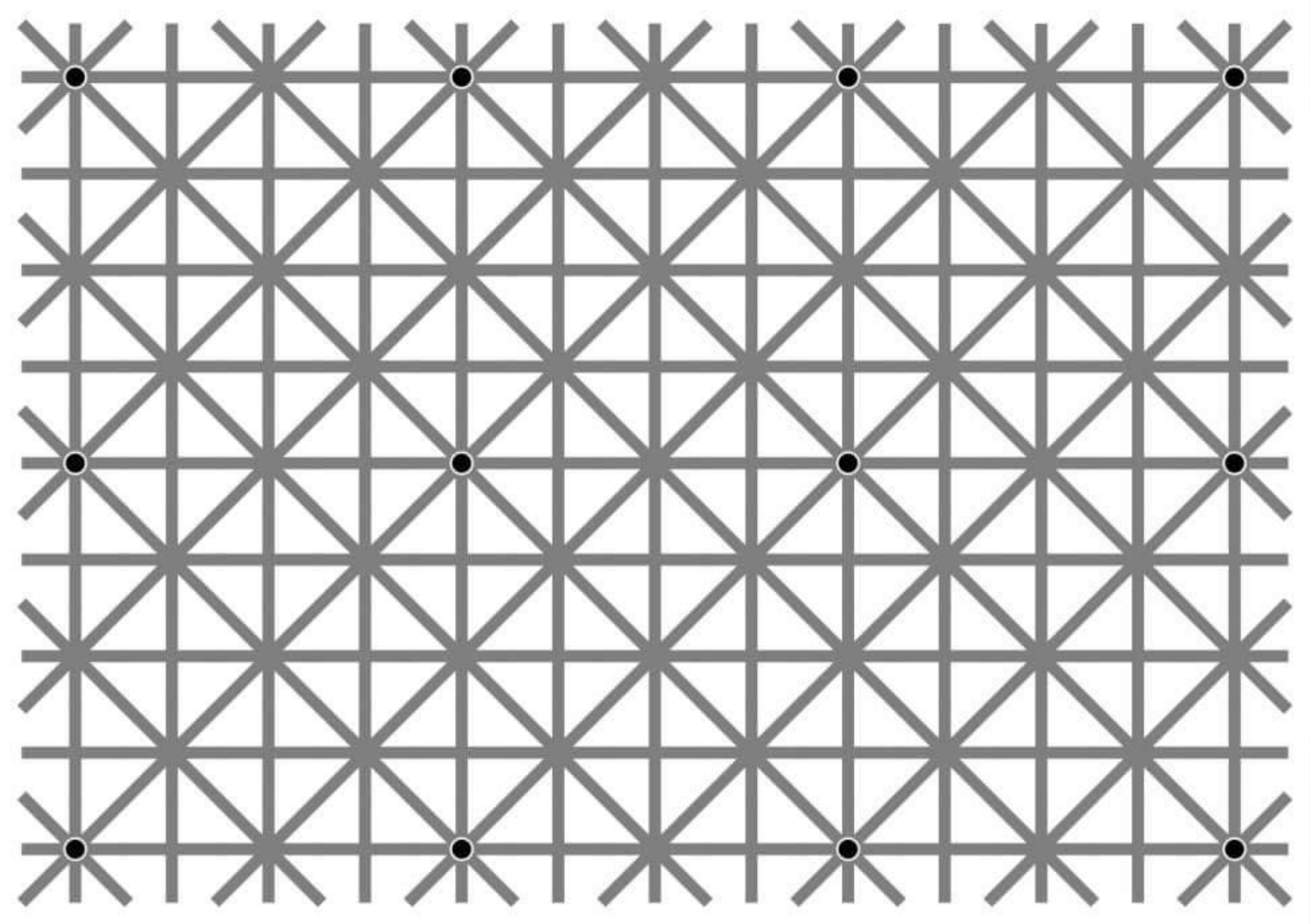
How many black dots do you see?



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Premise of system dynamics

- We may be clever when thinking about optical illusions, are baffled when approaching dynamic problems

- Models give us a chance to experiment, practice, and learn
- Models give others a chance to build from our work

Modeling for Learning

- Learn from comparing simulations
- Irreversibility of real-world actions
  - Value of digital laboratory
- Forecasting models are often simpler than "learning" models
- We will reach for understanding and for good management heuristics (i.e., "rules of thumb")

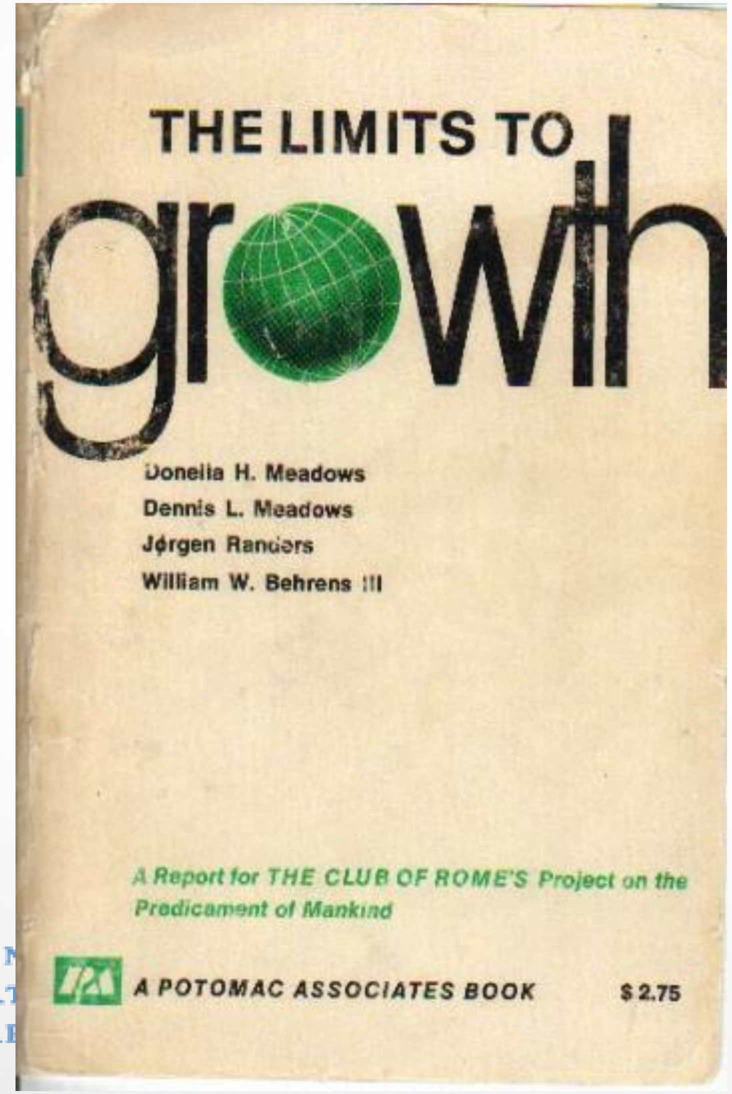
Definition of system dynamics

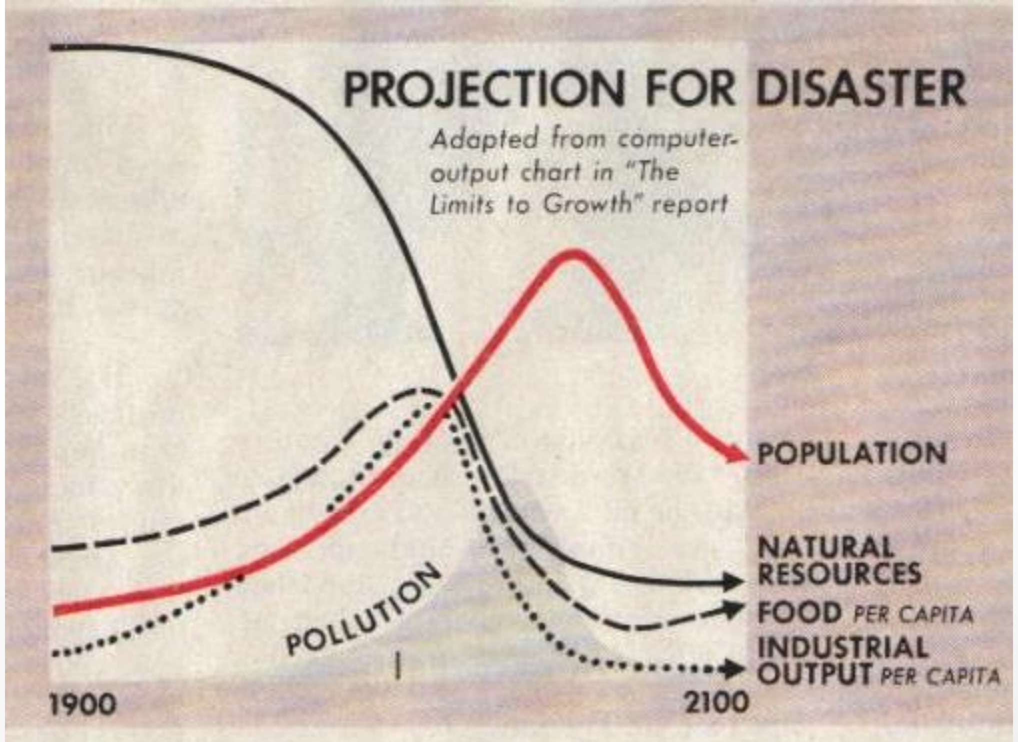
"An approach to understanding the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system. What makes system dynamics different from other approaches to studying complex systems is the use of **<u>feedback loops</u>** and **<u>stocks and flows</u>**."

Early days of system dynamics

- Developed in 1950's by Jay Forrester and colleagues at MIT
  - Based on electrical engineering control theory
    - Electrical circuits exhibit great examples of feedback
- Scientific process for understanding and modeling "**systems**" as they change over time ("**dynamically**")
- *Urban Dynamics*
- *Industrial Dynamics*

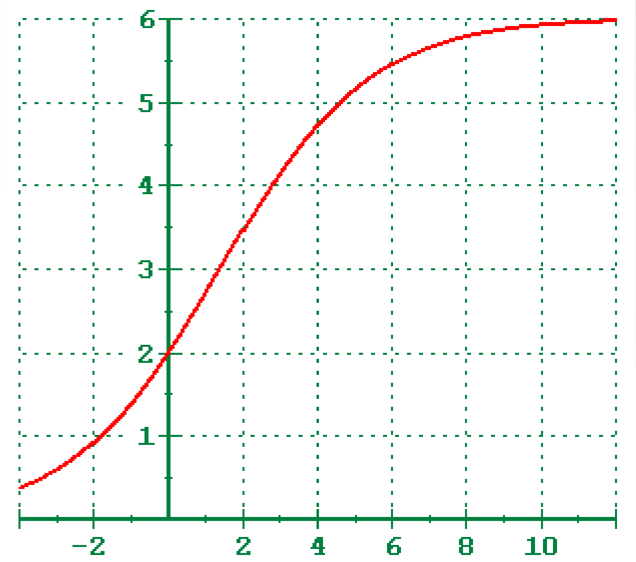
The most widely read book using system dynamics?

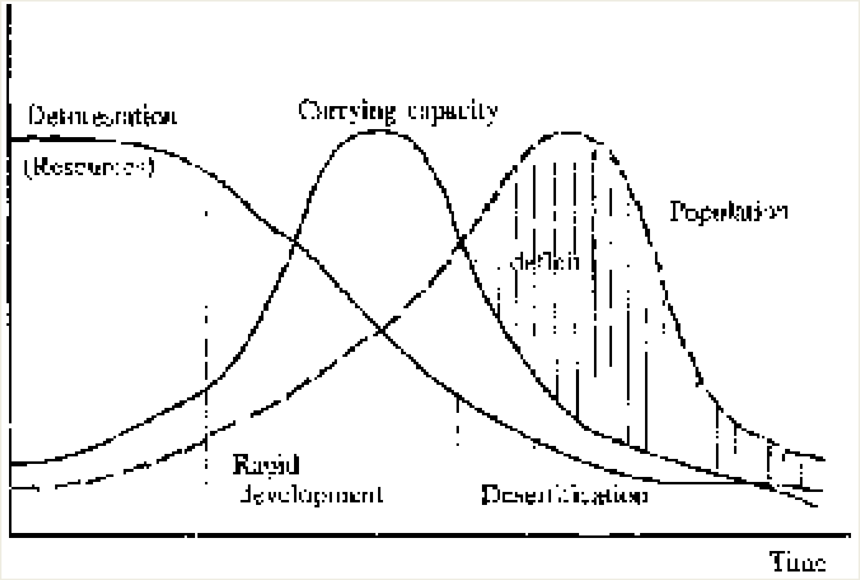




Environmental and urban dynamics

- Environmental and urban systems often combine feedbacks
  - Growth and limitation
- Urban Dynamics (1969)
  - Overshoot and collapse of cities
- Populations
  - Overshoot and collapse
  - Oscillation





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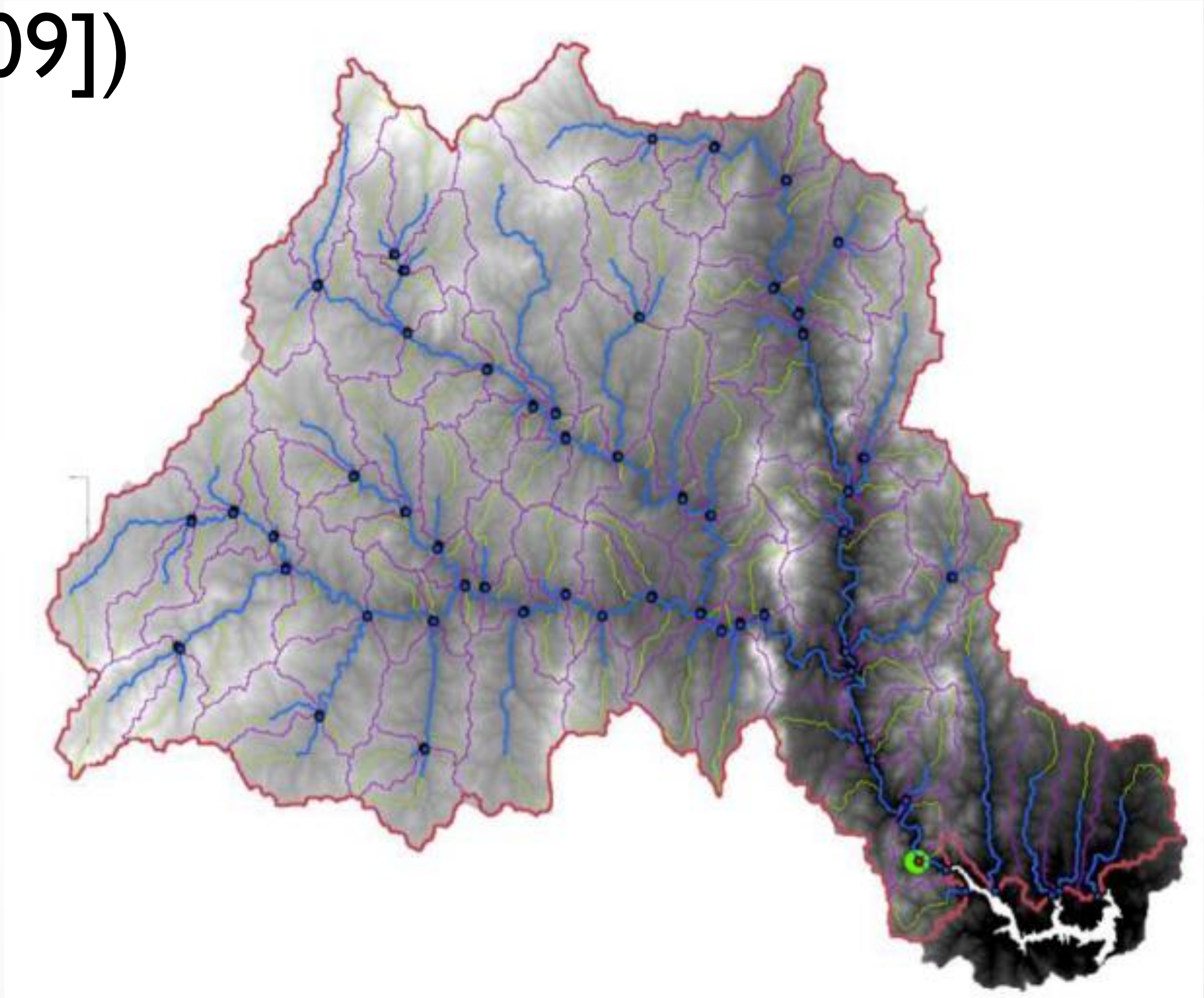
SD Applications (https://www.systemdynamics.org/cases)

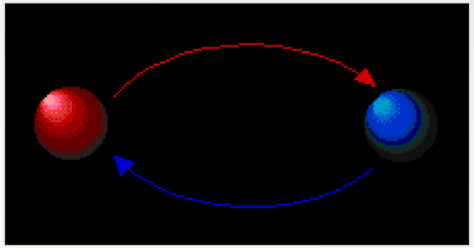
- Health care (e.g., diabetes and obesity pop. dynamics, HIV spread)
- Social work (e.g., "swamping" half way houses)
- Diffusion of innovation (e.g., electric car diffusion)
- Climate adaptation (e.g., political power and coastal hardening)
- International development interventions (e.g., Sahel)
- Backlash against fuel economy (e.g., Gas tax vs. CAFE standards)
- Climate policy (e.g., C-ROADS)
- Project management (e.g., Big Dig)

An aside: modeling across time and spatial scales (examples from Ford [2009])

seconds	water flow through two bottles (ch 6)
	Joe fills the gas tank (ch 3)
minutes	hikers head up the hill (BWeb)
	water temperature control (BWeb)
hours	body temperature control (BWeb)
	spread of an epidemic (ch 8)
days	temperature control on daisyworld (ch 11)
	salmon smolts migration to ocean (ch 15)
	salmon population life cycle (ch 15)
	The Idagon river simulator (BWeb)
months	genetics and industrial melanism (BWeb)
	Mono Lake brine shrimp population (ch 5)
	Mono Lake water balance (ch 5)
	DDT accumulates in the ocean (ch 22)
	CO2 accumulates in the atmosphere (ch 23)
years	cleaner cars and feebates (ch 16)
	cycles in real-estate construction (ch 19)
	cyles in predator-prey populations (ch 20)
	overshoot of the Kaibab deer population (ch 21)
hmyrs	rock cycle (ch 6), in hundreds of millions of yrs



System



- System – A set of interacting components that influence or affect each other
  - Classic problem posed by statistical inference
- Environmental system
  - Ecosystems = interacting biotic and abiotic components
- Urban system
  - Interacting social systems (social networks, communities, cultures, economies) and physical systems (air, land, water, environment, transport)
- Health system
  - Interacting individuals, policies, institutions, diseases, and treatments

Dynamics

- Change over time
- Bathtub – Faucet and drain
  - Accumulation of water
- Bank account – receipts and expenditures
  - Accumulation of money in account

System dynamics modeling

- Tools for representing changing interactions of system components
- Based on four fundamental concepts
  - Flows – change or movement of information or material
  - Stocks – accumulations of information of materials (system states)
  - Feedback – representation of relationships between components
  - Delays – feedbacks and changes take time

Core system dynamics concepts

- Simple processes can generate complicated behavior
- System dynamics provides unified approach for understanding problems
- Assists with your own mental models by making dynamic problems explicit
  - Accumulations (stocks), Change (flows), Feedback (interactions between the two), delays
- Urban/public health/policy problems involve **LOTS** of feedback
  - Complicated by lots of interacting factors!

Scientific process of system dynamics

1. “Reference mode” - understanding past behavior
   - Graphical
     - Population dynamics over time
     - Employment over time
     - Automobile Adoption
     - Wildlife population
       - Bee die-off
       - Kaibab Plateau deer
   - Use to understand system ***<u>structure</u>***
     - Structure vs. behavior

2. The dynamic hypothesis

- Use reference mode to understand causal linkages
- Based on systemic archetypes
  - Basic:
    - Linear growth, decline
    - Exponential growth, decline
    - Oscillation
  - Combinations
    - Logistic growth
    - Growth with limit cycle (oscillation)
    - Overshoot and collapse

3. Create quantitative, dynamic simulation model

- Stocks, flows, feedback, and delays
- Test model
  - Parameterizing a model – "calibration"
  - Replication of past data – "validation"
  - Finding policy 'levers'
    - How does policy affect a system?
    - Projections based on a series of scenarios
      - Forecast = most likely scenario
- Problems? - Iterative process!!
  - Go back to reference mode

Worried about the math?

- You do not need to have studied calculus to understand systems, change, or system dynamics.
  - The SD method (and texts we use) assumes you have learned introductory algebra and that you know how to read and interpret graphs
- System Dynamics is premised on representing interactions between system elements in simple mathematical terms
  - E.g. If I give you distance and speed: What is time traveled?
- We build SD models in a visual manner
  - Tedious job of numerical simulation left to the software

Your job is to concentrate on the structure of the model

- Calculus experience?
  - The software is integrating the effect of flows over time.
- Have you taken differential equations?
  - Models are equivalent to a set of coupled, first-order differential equations
- The great leveler for varied math experience:
  - The equations are almost always highly nonlinear, so there is little hope of finding an analytical solution
  - The software will find a numerical solution

Model structure allows modeling by analogy

Arizona wildlife management and World Bank intervention in Sahel Desert

- Kaibab Plateau in Arizona
  - 1920s pressure from ranchers
    - Government-led control of coyotes, "wildcats," and mountain lions
  - Deer population skyrockets…and collapses
- System structure
  - Destroyed forage
  - No new forage
- Analogous to Sahel desert example (the "Logic of Failure" by Dörner, 1996)
  - Better water supply → more cattle → less water supply → desperate cattle → destroyed forage → collapse