6702 Topics in Computational Sustainability

Spring 2011

- Administrative Organization

- 6702 Overview

  – Computational Sustainability
  – 6702 topics
  – Examples of Computational Sustainability Projects
  – Schedule

Administrative Organization

Format of 6702

- Focus of 6702 --- new research area of computational sustainability
- Goal – get insights towards the understanding of the boundaries and central methodologies in Computational Sustainability.
- Given the highly multi-disciplinary nature of Computational Sustainability , there will be several guest lecturers representing various disciplines.

Format 6702

→ discussion / seminar course with a project – your participation and involvement is very important!

Administrative Organization

Instructors: Carla Gomes and Bart Selman

Other Faculty and Researchers : Jon Conrad, Theo Damoulas, and other faculty as guest lectures.

Course Assistants: Kiyan Ahmadizadeh, Stefano Ermon, and Ryan Finseth

(Office hours: TBA)

Time: Tuesdays and Thursdays 2:55-4:10 pm.

Location: 315 Upson Hall

Grade options and credits: Letter or S/U; 4 credits

Prerequisites**:** Graduate standing or permission of instructor

Web page: http://www.cs.cornell.edu/Courses/cs6702/2011sp/

Given the multi-disciplinary nature of the material, the course will include several guest lecturers representing various disciplines.

Course Work

The course work consists of three components:

1. Attendance and participation in the talks
2. A reaction paper or talk on a particular (computational) sustainability topic, a presentation of a research problem in class, a good annotated bibliography, or a talk on a topic.
3. A final project, including an initial project proposal.

Grade option: 1, 2, and 3 required.

S/U option: 1 and 2 required.

Students are encouraged to work in interdisciplinary groups.

Reaction Paper

Getting your feet wet!

The reaction papers/talks are meant to identify and discuss one or two *interesting computational research questions* concerning a certain sustainability topic. Often it involves identifying and reviewing a few papers on a certain topic.

The reaction paper should be around 4 pages in length.

The reaction paper is due on February 17.th

Project

The selection of the topic and scope of the final project is mainly up to the student(s).

A short project proposal (2 pages) briefly outlining the project is required.

The project proposal should provide background work and a highlevel plan for the project. (It's okay to leverage from the reaction paper if the project is an extension of the reaction paper. In that case the proposal should outline how to extend the ideas in the reaction paper.)

The project proposal will be due on March 3rd.

Project presentations will be schedule during the last month of classes.

Faculty team and TA's will help with the different phases of the project starting with finding the right topic for you!

6702 Topics in Computational Sustainability
Overview

A few words about Sustainability

Our Common Future (Brundtland Report,1987)

UN World Commission on Environment and Development)

- Raised environmental concerns,
  "there are environmental trends that threaten to radically alter the planet, that threaten the lives of many species upon it including the human species."

- Introduced the notion of sustainability and sustainable development:

  "development that meets the needs of the present without compromising the ability of future generations to meet their needs."

UNITED NATIONS

Gro Brundtland
Norwegian Prime Minister
Chair of WCED

Idea not completely new

- Great Law of the Iroquois Confederacy: *"In every deliberation, we must consider the impact of our decisions on the next seven generations."*

Nathan Benn/Corbis

Thanks Megan McDonald!

Poor Management of our Natural Resources

Pollution





Habitat Loss and Fragmentation



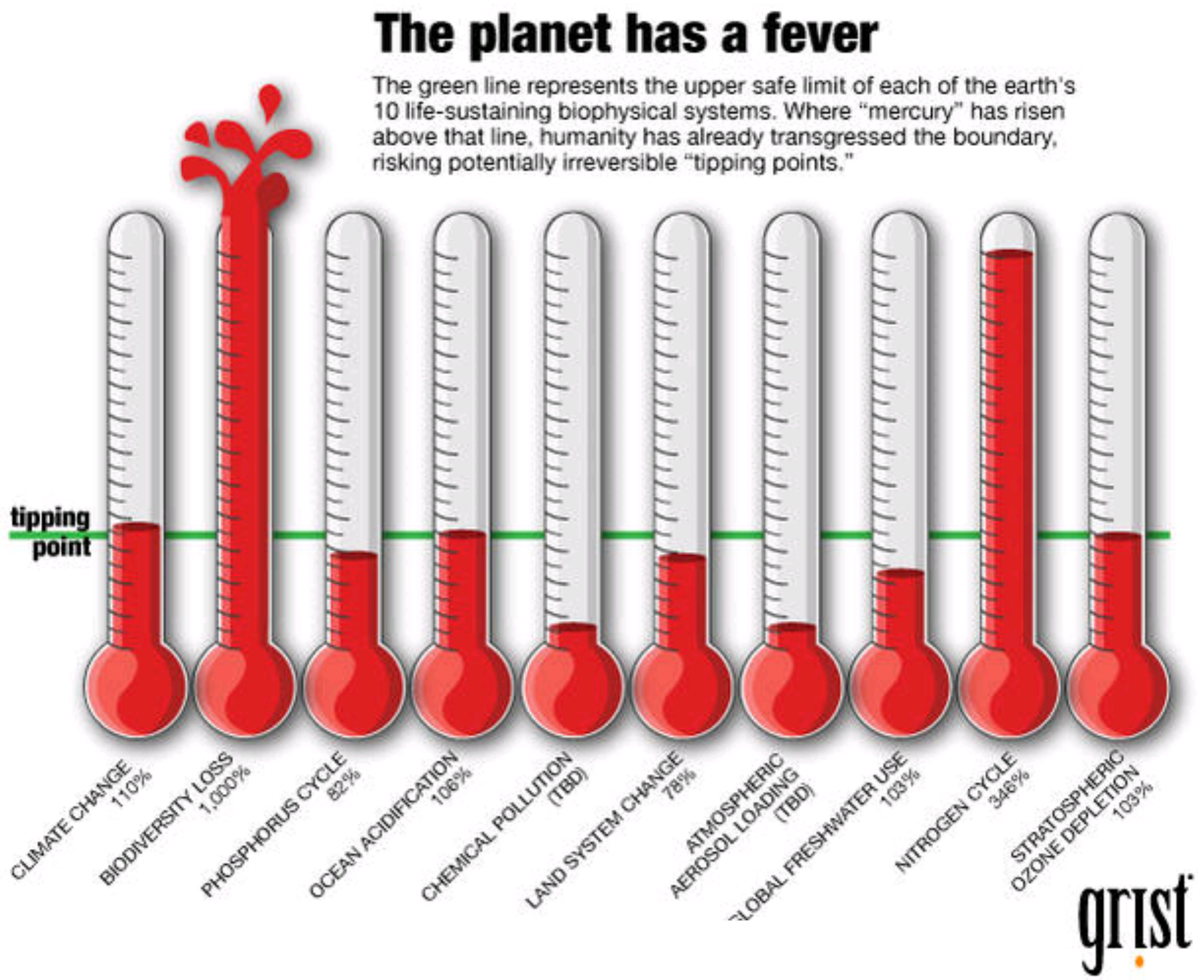


Over-Harvesting






Safe Operating Boundaries: Crucial Biophysical Systems



Source:

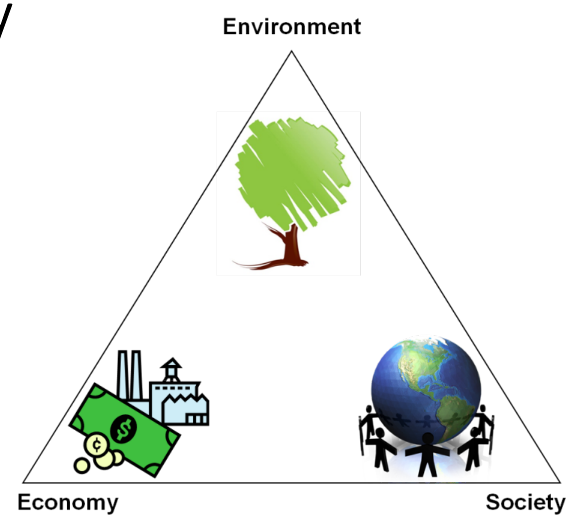
***Planetary Boundaries: A Safe Operating Space for Humanity*, Nature, 2009**

Sustainability is not only about the environment

Our Common Future recognized that environmental, economic and social issues are interlinked.

- → The economy only exists in the context of a society, and both society and economic activity are constrained by the earth's natural systems.

- → A secure future depends upon the health of all 3 systems (environment, society, economy).



Sustainable Development encompasses balancing environmental, economic, and societal needs for sustainable development

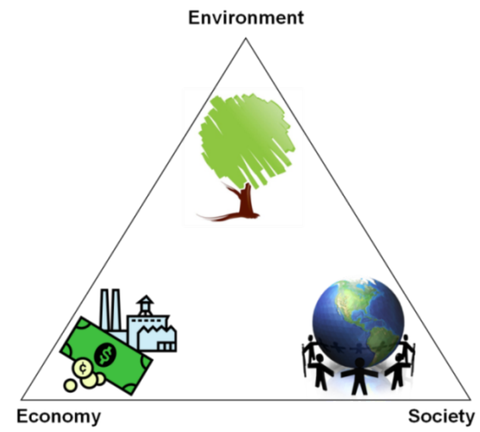
What does it all have to do with computer science?

- Key sustainability issues translate into problems that fall into the realm of computing and information science, even though in general they are not studied by computer scientists.
- Such computational problems are unique and present new research challenges, often involving continuous and discrete decisions.

Computational Sustainability: attempt at a definition

New interdisciplinary field that aims to apply techniques from computer science, and related fields (e.g., information science, operations research, applied mathematics, and statistics) for Sustainable Development.

Sustainable Development encompasses balancing environmental, economic, and societal needs for sustainable development.



Computational Sustainability

Wide interdisciplinary field , encompassing disciplines as diverse as economics, sociology, environmental sciences and engineering , biology, crop and soil science, meteorology and atmospheric science.

Focus:

Develop computational & mathematical models, methods and tools for decision making for a broad range of sustainability related applications:

from decision making and policy analysis concerning the management and allocation of resources

to the design of new sustainable techniques, practices and products.

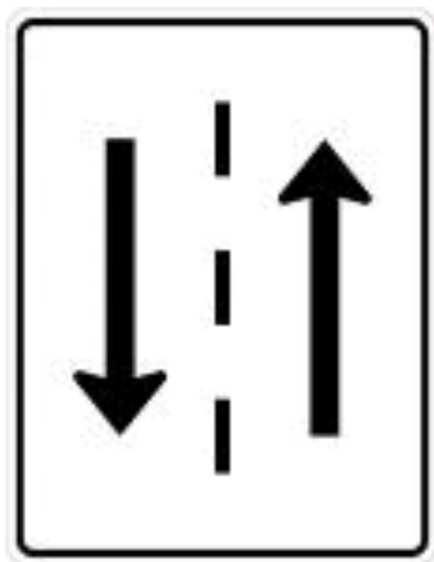
Key challenge: to effectively and efficiently establish interdisciplinary collaborations – the level of interconnectedness of social, economic, and environmental issues makes it really challenging!

Computational Sustainability

Sustainability related fields

New challenging applications

New methodologies
into Computer Science



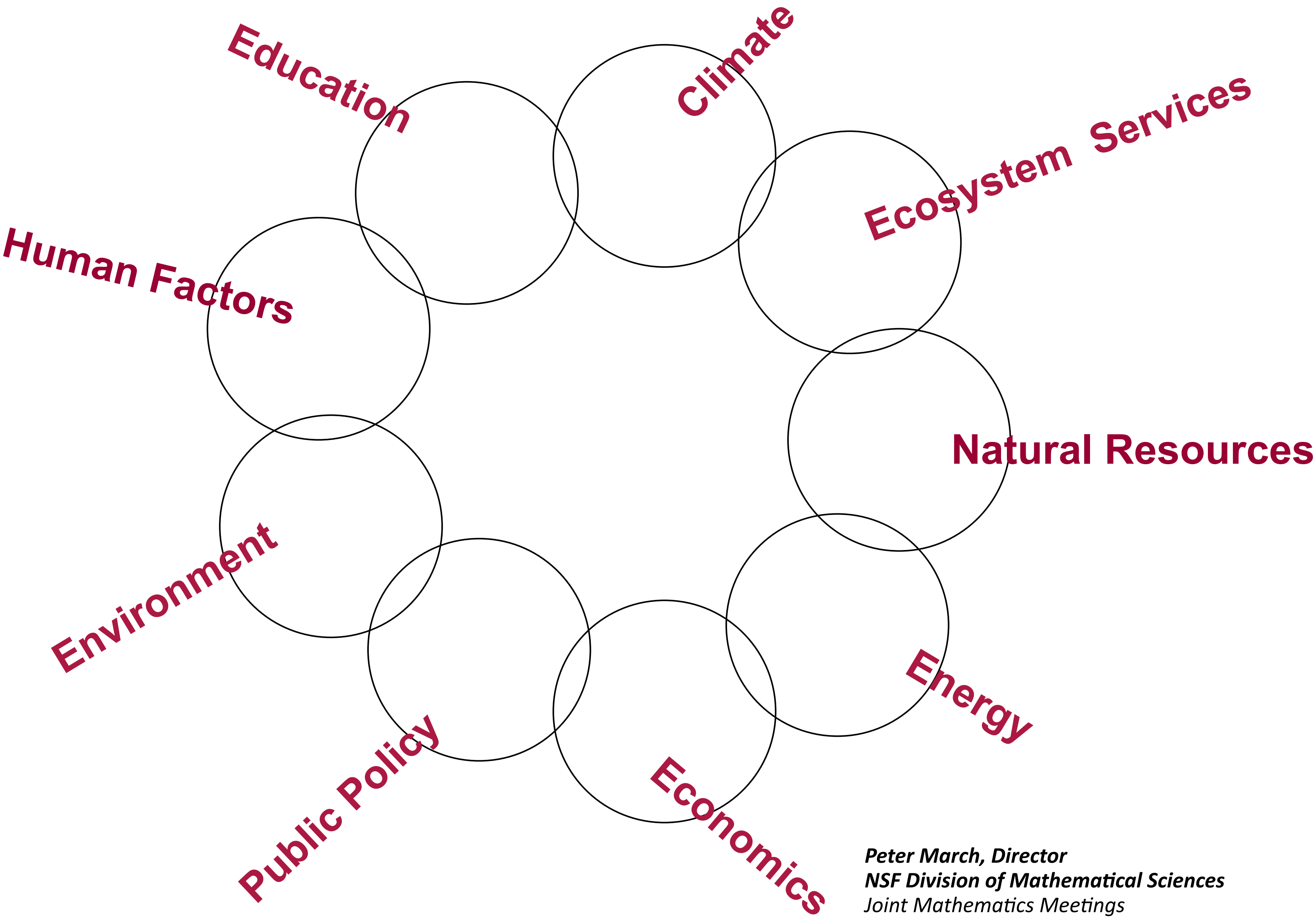
Computational Thinking that will provide new insights into sustainability problems:

Models, algorithms (insights into problem structure), ways of collecting, handling, processing large vols data, smart and friendly interfaces, etc

Computer science and related fields
(Information Science, Operations Research, Applied Mathematics, Engineering, etc)

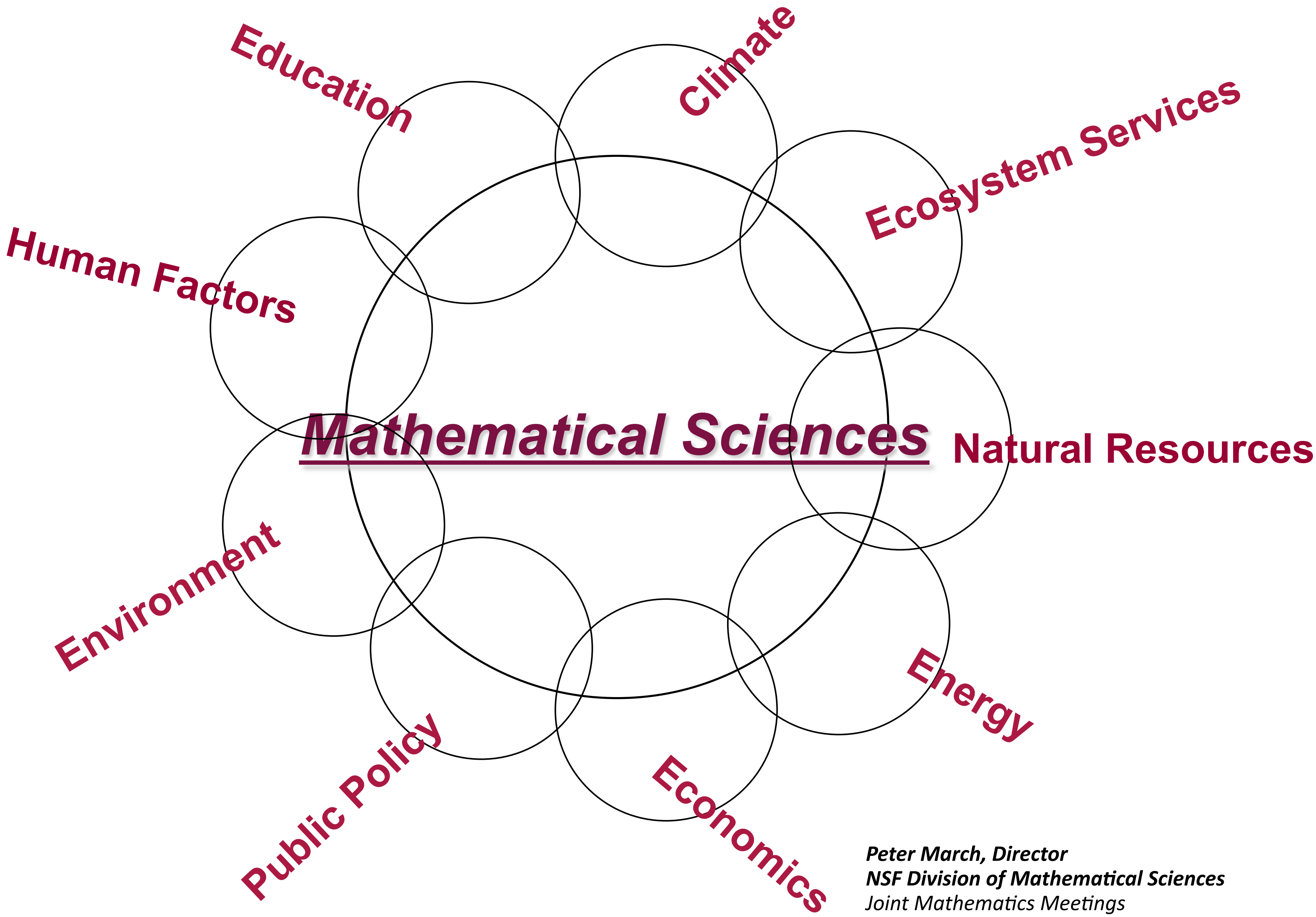
Analogy between Computational Biology and Computational Sustainability

Components of Sustainability



Peter March, Director
NSF Division of Mathematical Sciences
Joint Mathematics Meetings
San Francisco CA - January 15, 2010

Mathematics gives Sustainability coherence



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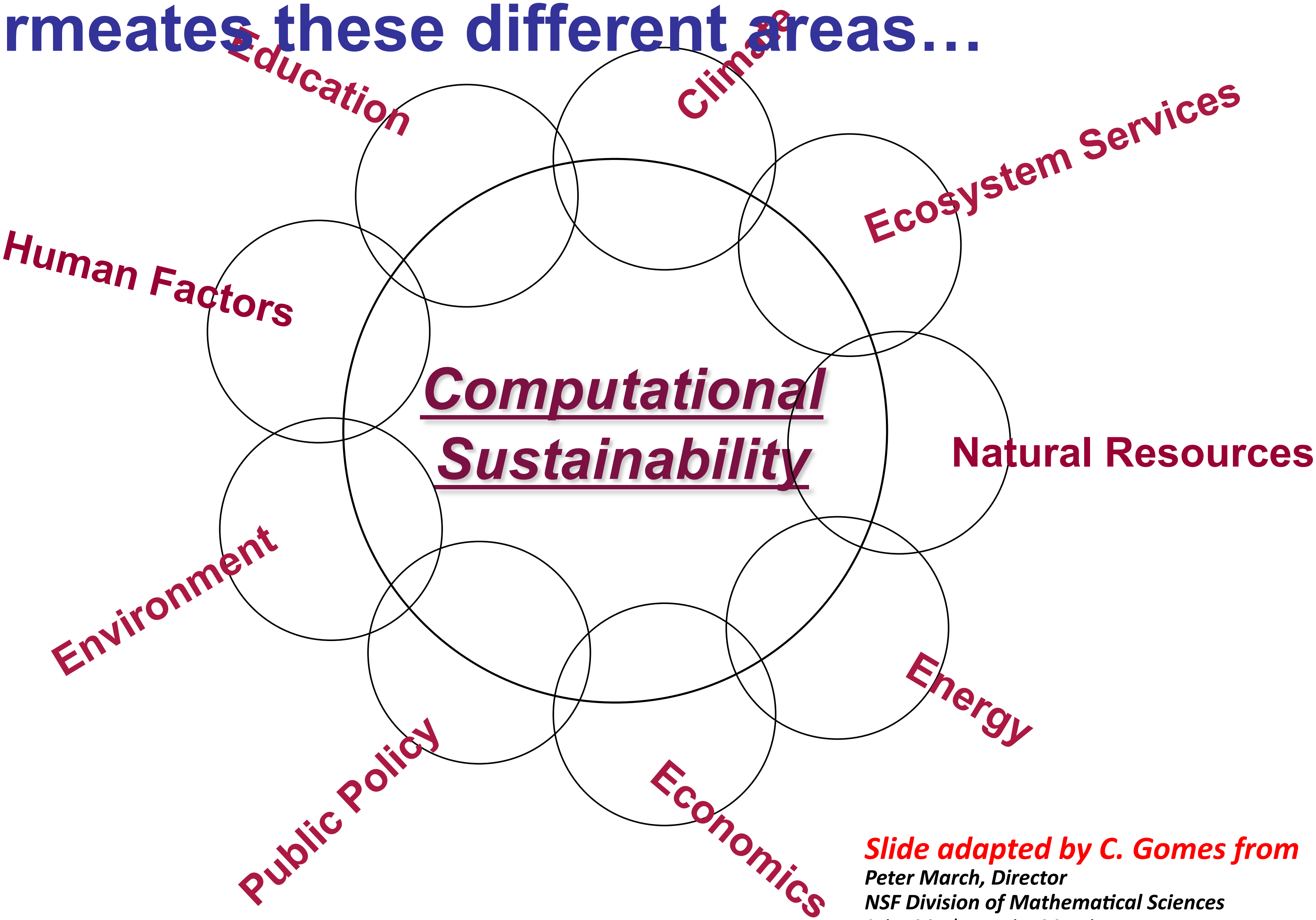
Computational Sustainability permeates these different areas…



Slide adapted by C. Gomes from
Peter March, Director
NSF Division of Mathematical Sciences
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Deep Computational Research Challenges posed by Sustainability

Key sustainability issues concerning the definition of policies for sustainable development translate into large-scale decision/optimization combining a mixture of discrete and continuous effects, in a highly dynamic and uncertain environment

→ different levels of complexity

Study computational problems as natural phenomena

→ **Science of Computation**

Many highly interconnected agent and components;

→ **From Centralized to Distributed Models**

Dynamics (e.g., temporal, spatial, geographic)

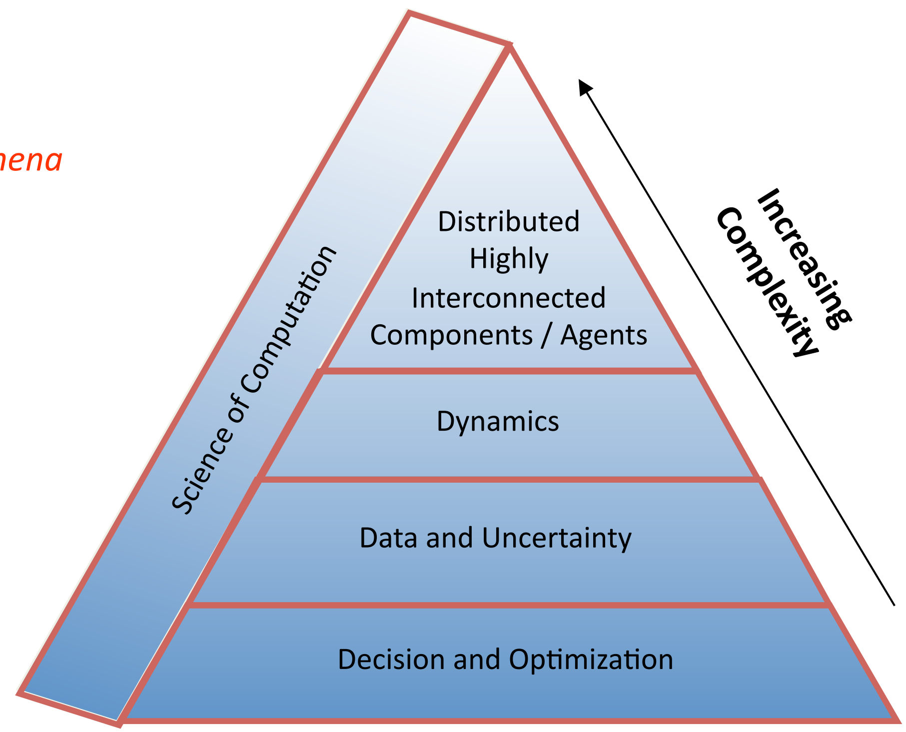
→ **From Statics to Dynamics: Dynamic Models**

Large-scale data and uncertainty

→ **Machine Learning, Statistical Modeling, Stochastic Modeling**

Complex decision models

→ **Constraint Reasoning and Optimization**



Complexity levels in Computational Sustainability Problems

Examples of Computational Sustainability Projects (6702 Spring 2010 and ICS projects)

Conservation and Biodiversity : Wildlife Corridors

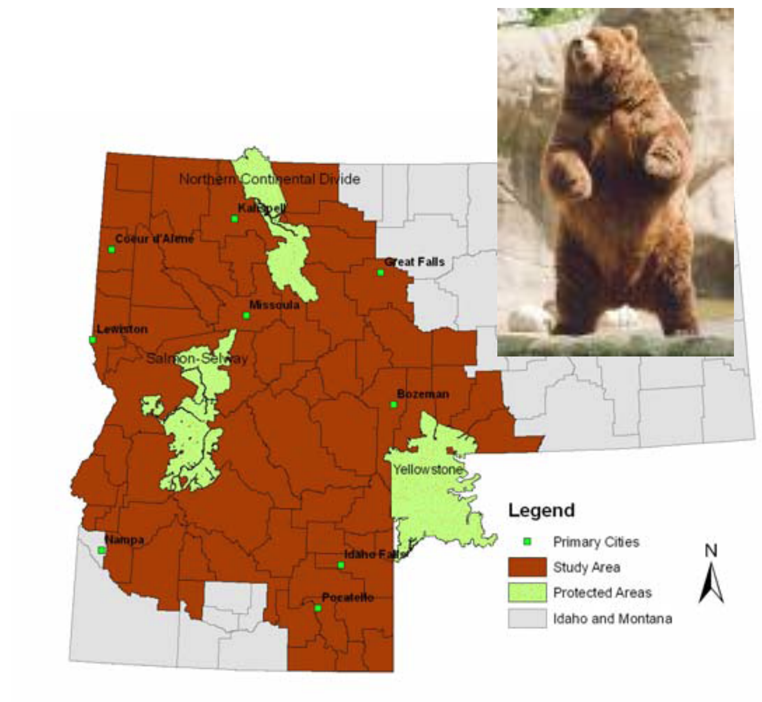
Wildlife Corridors link core biological areas, allowing animal movement between areas.

Typically: low budgets to implement corridors.

Example:

Goal: preserve grizzly bear populations in the U.S. Northern Rockies by creating wildlife corridors connecting 3 reserves:

Yellowstone National Park;
Glacier Park and
Salmon-Selway Ecosystem

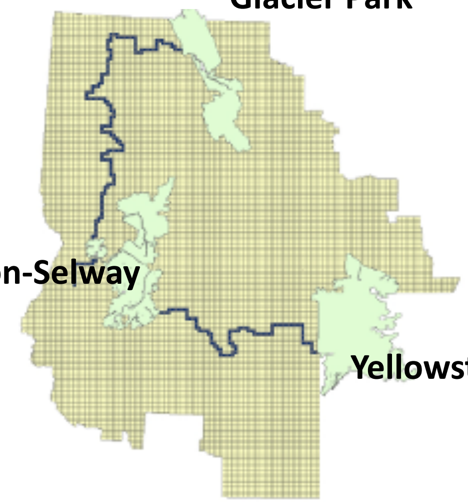


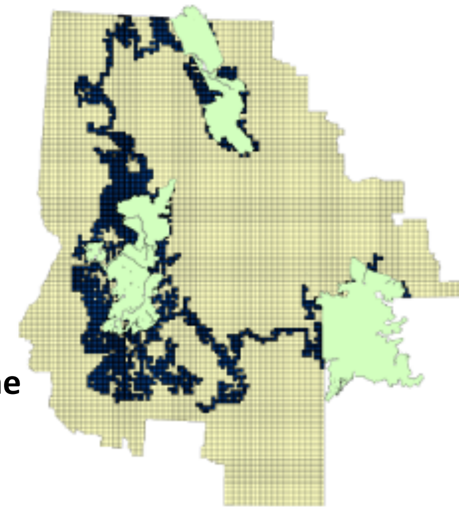
Real world instance:

Corridor for grizzly bears in the Northern Rockies, connecting:

Yellowstone
Salmon-Selway Ecosystem
Glacier Park

(12788 nodes)



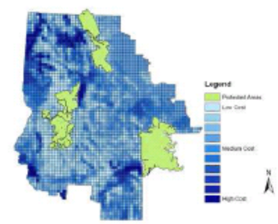


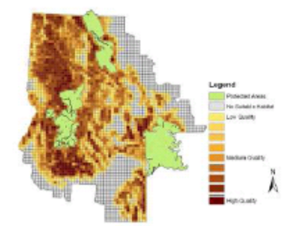
5 km grid (12788 land parcels): minimum cost solution

5 km grid (12788 land parcels): +1% of min. cost

Scaling up Solutions by Exploiting Structure

- Synthetic generator / Typical Case Analysis
- Identification of Tractable Sub-problems
- Exploiting structure via Decomposition
  - Static/Dynamic Pruning
- Streamlining for Optimization
- New Encodings

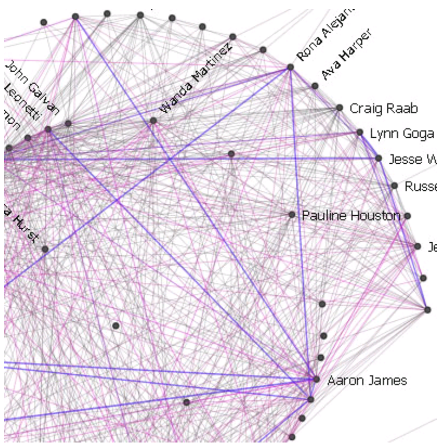




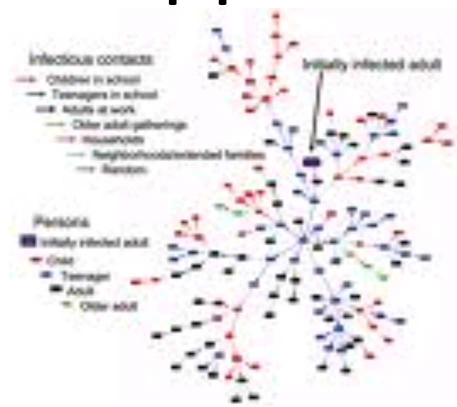
Our approach allows us to handle large problems and reduce corridor cost dramatically (hundreds of millions of dollars) compared to existing approaches while providing guarantees of optimality in terms of utility:

Optimal or within 1% of optimality for interesting budget levels.

Connection Subgraph to study wildlife corridors for grizzly bears: Other applications



Facebook Network



Network of Pandemic Influenza

Robert J. Glass,* Laura M. Glass,† Walter E. Beyeler,* and H. Jason Min* 2006

- What characterizes the connection between two individuals?
  - The shortest path?
  - Size of the connected component?
  - A "good" connected subgraph?
- Which people have unexpected ties to any members of a list of other individuals?

If a person is infected with a disease, who else is likely to be?

[Faloutsos, McCurley, Tompkins '04]

Multiple Species, games and much more

Boynton Middle School Math Day

Wolverines

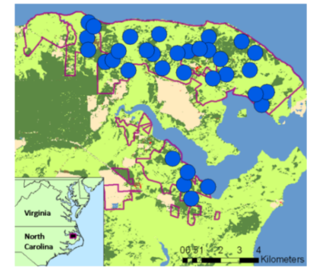
Grizzly Bear

Lynx

Collaborators: Michael K. Schwartz
USDA Forest Service, Rocky Mountain Research Station
Claire Montgomery Oregon State University

Lots of ideas for projects!!!!

- Visualization
- Landscape connectivity
- GIS gadgets
- New problems, models, algorithms → e.g. landscape connectivity
- Games
- etc



Red Cockaded Woodpecker (RCW)

Palmetto Peartree Preserve (3P), The Conservation Fund:

- 10,000 acres of wetland forest in North Carolina
- 32 active RCW territories (as of Sept 2008)

Goal: Increase population level

Management options:

Prioritizing land acquisition adjacent to current RCW popula

Building artificial cavities

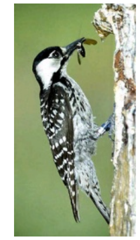
Translocation of birds

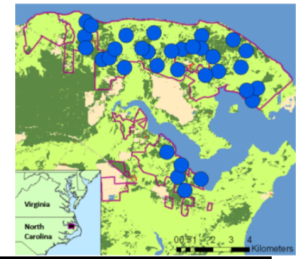
THE CONSERVATION FUND

America's Partner in Conservation

Dilkina, B., Elmachtoub, A., Finseth, R., Sheldon, D., Conrad, J., Gomes, C., Sabharwal, A.,Shmoys, D., Amundsen, O., and Allen, W., 2009

Conservation and Biodiversity: Reserve Design for Bird Conservation





Red Cockaded W.

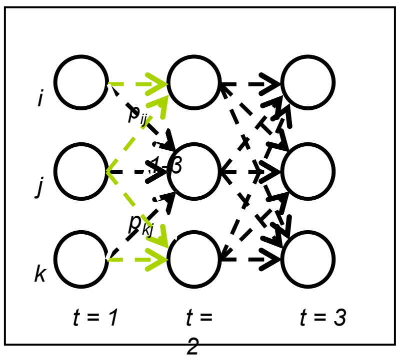
Biological and Ecological Model

Management Decisions:

Land acquisition
Artificial cavities
Translocation of birds

Must explicitly consider interactions between biological/ecological patterns and management decisions

Maximizing the Spread of Cascades



$$\text{maximize } (1/K)\sum_{k=1}^{K}\sum_{i\in\mathcal{R}} x^k(i,T)$$

subject to

$$\sum_{i\in\mathcal{R}}\sum_{t=1}^{T} b(i,t)y(i,t) \le B;$$

$$\sum_{t=1}^{T} y(i,t) \le 1 \quad \forall \text{ territories } i \in \mathcal{R};$$

$$x^k(i,t) \le \sum_{s=1}^{t} y(i,s), \quad \forall \text{ scenarios } k, \text{ territories } i \in \mathcal{R}, \text{ and periods } t;$$

$$x^k(i,1) \le a^k(i,i,1), \quad \forall \text{ scenarios } k, \text{ territories } i \in \mathcal{R};$$

$$x^k(j,t) \le \sum_{i\in\mathcal{R}} a^k(i,j,t)x^k(i,t-1), \quad \forall \text{ scenarios } k, \text{ territories } j \in \mathcal{R}, \text{ and periods } 2\ldots T;$$

$$x^k(i,t) \ge 0, \quad \forall \text{ scenarios } k, \text{ territories } i \in \mathcal{R}, \text{ and periods } t;$$

$$y(i,t) \in \{0,1\}, \quad \forall \text{ territories } i \in \mathcal{R} \text{ and periods } t;$$

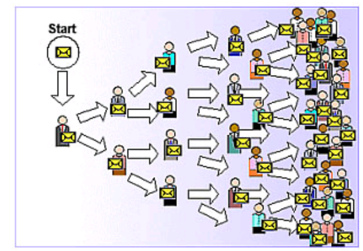
Stochastic diffusion model (movement and survival patterns) in RCW populations

Stochastic optimization model
Decisions: where and when to acquire land parcels
Goal: Maximize expected number of surviving RCW

Computational Challenge: scaling up solutions for considering a large number of years (100+)
→ decomposition methods and exploiting structure

Maximizing (Minimizing) Cascade Spread
Other applications

- A lot of phenomena can be *modeled* as a stochastic diffusion process on a network of nodes
  - Social Networks:
    - Technology adoption/ Viral marketing
    - Rumors / News / Gossip
    - Disease
  - Invasive Species



Viral Marketing

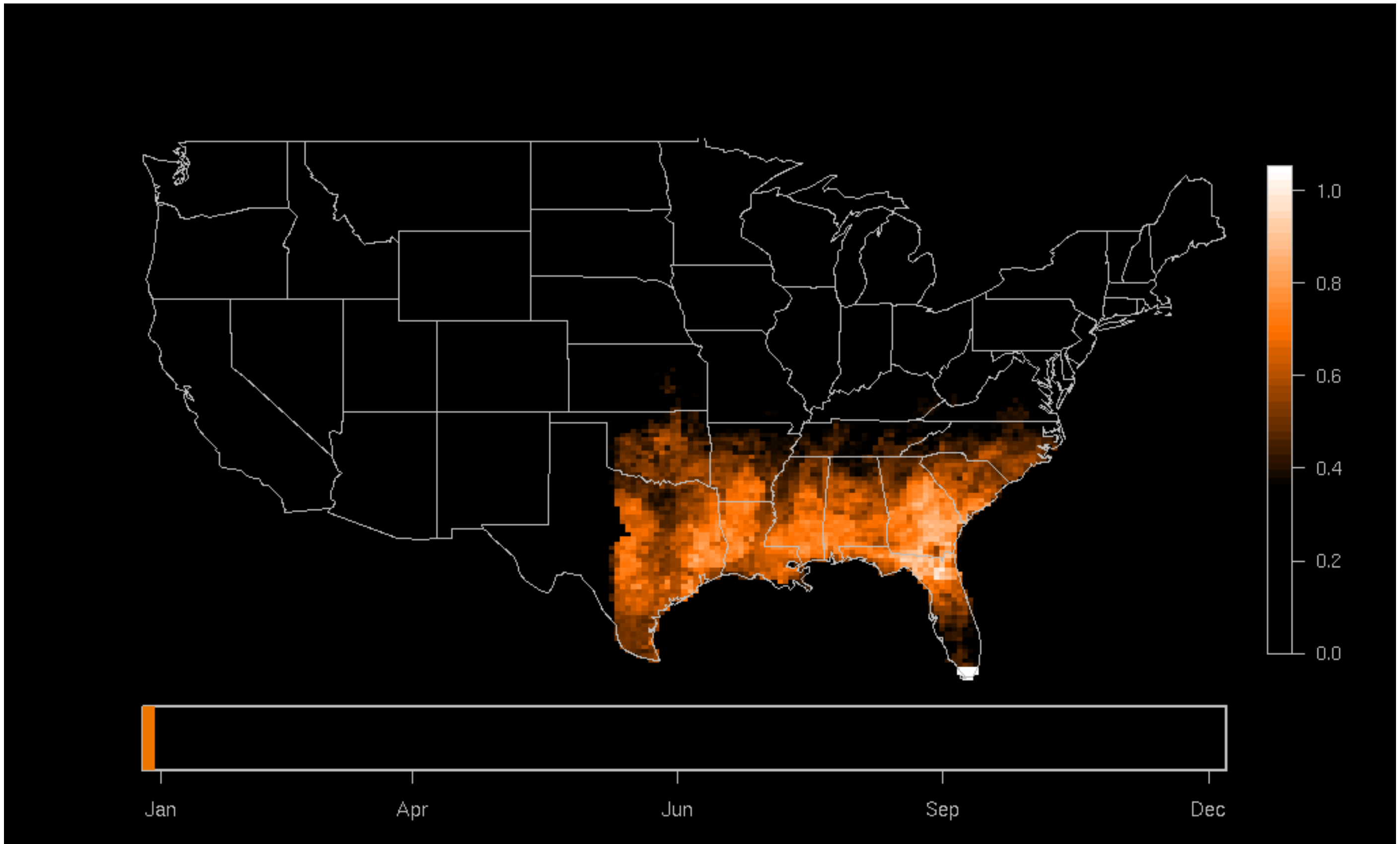
- We often can and want to intervene to influence the expected outcome of the diffusion process - *optimization*

[Domingos and Richardson, KDD 2001]

[Kempe, Kleinberg, and Tardos, KDD 2003]

[Krause and Guestrin 2007]

Conservation and Biodiversity: Predicting Bird Species Occurrence Across Broad Spatial and Temporal Scales



Source: Daniel Fink.

Eastern Phoebe
Migration

CORNELL LAB of ORNITHOLOGY

Information Sciences

Seasonal patterns of relative abundance for Eastern Phoebe, using eBird traveling counts less than 5 miles long (2004 – 2007) and considering local habitat characteristics controlling for variation in detection rates. The data are fit with **bagged decision tree models.** To account for habitat selectivity, remotely sensed habitat information compiled at a 15 x 15 km scale is included in the analysis. Variation in detection rates is modeled as a function of both effort spent watching birds and the length of the traveling count, Variation in availability for detection is modeled as a function of the observation time of day and date.

Daniel Fink,Wesley Hochachka, Art Munson, Mirek Riedewald, Ben Shaby, Giles Hooker, and Steve Kelling, 2009.

Wind Energy and Bird Conservation

Existing and proposed wind farms in US and MX (2008)

- 26,000+ turbines, 1.5% of potential

“Build-out” to reach potential would require >1.7 million turbines

- Areas with most favorable winds are also often associated with migratory pathways

Need *research* for establishing guidelines for locating wind farms

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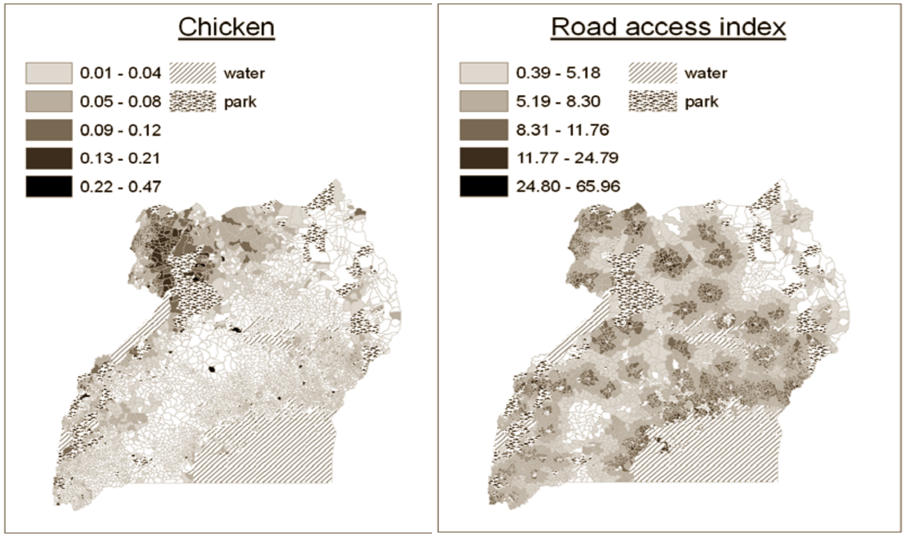
Andrew Farnsworth and Ken Rosenberg 2009

Poverty Alleviation and Climate Change

- Poverty interventions need to be targeted to specific areas
- Asset-based investments have spatially-varying marginal returns

- Where and Which assets to invest in to have best poverty impact?

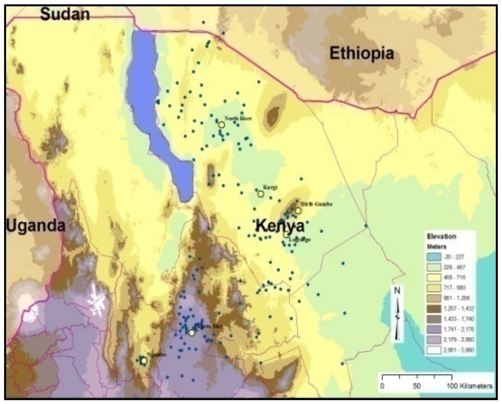


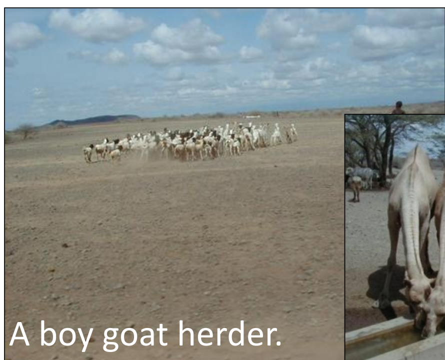
A map of estimated average marginal returns to given asset that are significantly greater than zero.

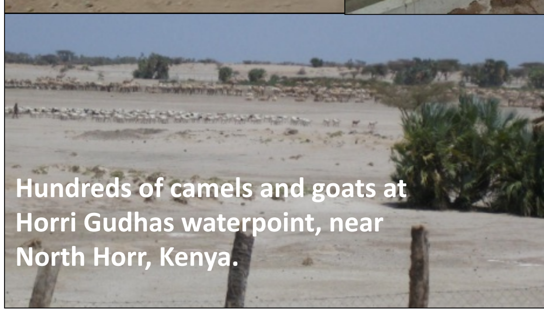
[C. Lang, C. Barrett and F. Naschold. Targeting maps: An asset-based approach to geographic targeting.]

Lots of ideas for projects!!!!

Natural Resource Management: Pastoral Systems in Africa




A boy goat herder.


Hundreds of camels and goats at Horri Gudhas waterpoint, near North Horr, Kenya.

Pastoralists in East Africa maintain herds of animals such as cattle, camels, sheep, and goats.

Due to the high variability in rainfall they migrate looking for water and forage resources, traveling sometimes as far as 500 km.

Goal: Understand (and predict) migratory patterns (and the decision models) of pastoralists to help devise policy interventions to improve the well being of these populations

Russell Toth, Christopher B. Barrett

Yunsong Guo and Carla Gomes and The Damoulas

Natural Resource Management:
Policies for harvesting renewable resources

Talks: Jon Conrad
Mary Lou Zeeman

Economy

Y_t

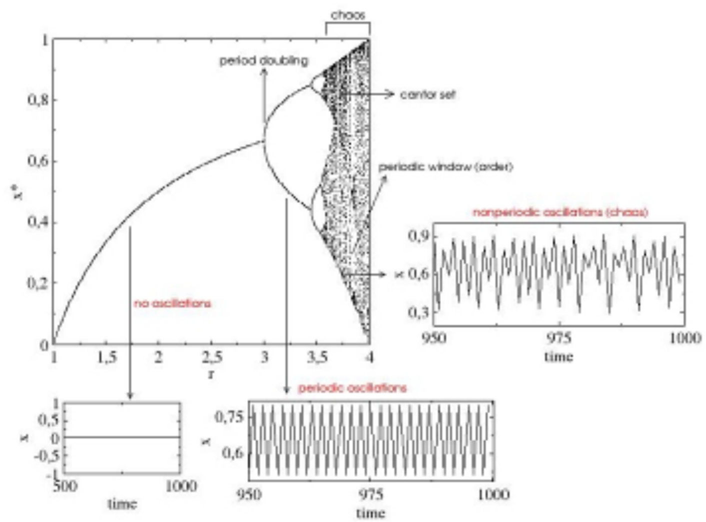
Harvest of a Renewable Resource: Tuna

$$X_{t+1} - X_t = F(X_t) - Y_t$$

X_t = the fish stock (tuna)
Y_t = the rate of harvest
$F(X_t)$ = the net growth function

Non-linear dynamics

Example of a Biological Growth Function F(x):
Logistic map: $x_{t+1} = r\, x_t (1 - x_t)$, r is the growth rate



Increasing Complexity: more complex models and multiple species interactions

Empirical results Pacific Halibut in Alaska) suggest that periodic harvesting policies outperform standard constant escapement policies:

Under which conditions does it happen?

How to characterize and compute optimal periodic policies?

We are interested in identifying policy decisions
(e.g. when to open/close a fishery ground over time).

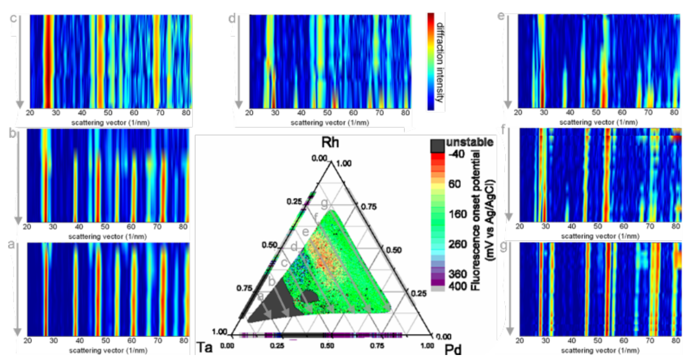
Uncharted territory: Combinatorial optimization problems with an underlying dynamical model.

Class of Computationally Hard Hybrid Dynamic Optimization Models

Conrad , Ermano, Li , Gomes, Yakubu, Zeeman 2009

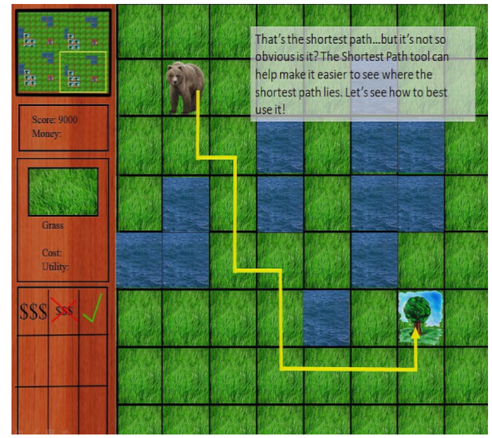
Material Discovery

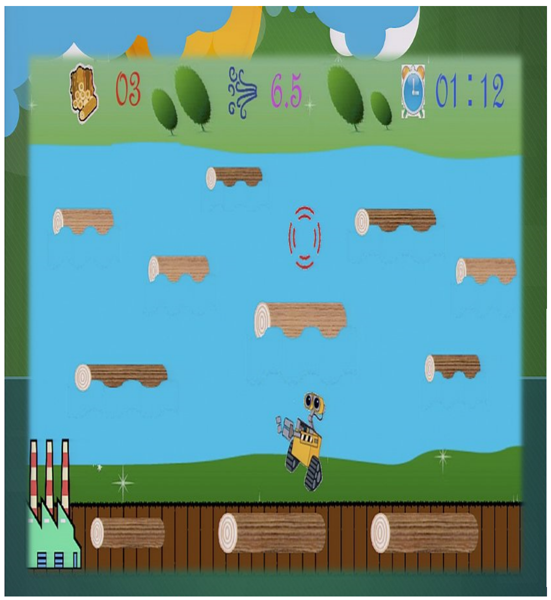
- New computational ways of analyzing x-ray diffraction patterns of compositions of elements in order to help identify new materials with important properties (e.g., design of new fuel cell technology).
- Using combinatorial methods in materials research has proven to be a powerful approach to the optimization and discovery of inorganic materials.
- Typically, a library of samples containing a broad range of compositions is evaluated and characterized.



R. LeBras, Gomes, Gregoire, Sabharwal, Van Dover

Educational Videos and Game Development





David Schneider & students

Project Ideas

- *Description of a computational sustainability research problem*

- *Novel Models:*
  Biodiversity conservation - study some aspect of biodiversity conservation planning by creating an optimization model/technique with exper
  Socioeconomic aspects of sustainability - How can economic incentives and sustainability coexist? How do we address realistic concerns (e.g. discounting of future costs, tragedy of the commons). Mechanism design for conservation or carbon emission credits

  Data Modeling, simulation, and Analysis:
  Statistical/machine learning approaches for time-series spatially explicit data of land cover (for conservation or climate change prediction)
  Species Distribution Modeling - Machine learning techniques to obtain more accurate species distribution models from uncertain and missing data (Lab of Ornithology)
  Ecosystem Modeling - Population Dynamics in Networks (Co-evolution of Population, Networks)
  Modeling of Disease Outbreaks - (Overlay with Google maps, Identify hotspots)

  Analysis of Bibliographic Network:
  Social Network Analysis of the Computational Sustainability community - use research paper citations to identify the key papers/people in computational sustainability
  Social Network Analysis of the Computational Sustainability research topic - use research paper citations to to track the time series development of the research topic

- *Computer Games/Applications:*
  Design a computer game that introduces some computational sustainability concept to kids
  Design an iPhone application addressed towards adults but with sustainability overtones (e.g. eco-SimCity)
  Design a Facebook game or application that allows individuals to receive social recognition by publicizing their eco-friendliness.
  Design a prediction market application for sustainability questions (i.e. predict the highest temperature for the next August)
  Design an artificial market for carbon emission credit
- Extension of UrbanSim to incorporate a different computational model

Project Ideas

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Project Ideas

Survey paper:

Critical survey of methodologies to evaluate impacts of biofuels.

Critical survey on approaches to *quantifying* biodiversity.

Critical survey of incentives for CO2 offsetting addressing in particular computational issues.

Critical survey of agent-based models for a particular topic – limitations and oppprtunities

Critical survey of GIS systems for certain kinds of problems – limitations and opportunities

Critical survey of UrbanSim

SYSTEMS ENGINEERING SEMINAR SERIES
CORNELL UNIVERSITY

Date : Friday, February 4, 2011

Time : 12:00 p.m. - Lunch Buffet - 258 Rhodes Hall
12:15 p.m. - Presentation - 253 Rhodes Hall

Speaker : Mark Z. Jacobson
Department of Civil and Environmental Engineering
Stanford University

Title : Powering the World with Wind, Water, and Sun

See 6702 Web page:
http://www.cs.cornell.edu/Courses/cs6702/2011sp/