6702 Topics in Computational Sustainability

Introduction

Carla P. Gomes

Cornell University

- Administrative Organization
- 6702 Overview
  - Computational Sustainability
  - 6702 topics
  - Examples of Computational Sustainability Projects @ ICS
  - 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

Instructor: Carla Gomes

Faculty Team: Jon Conrad, Steve Ellner, Carla Gomes, and Mary Lou Zeeman

Teaching Assistants: Bistra Dilkina and Georgios Piliouras

Time: WF 1:25-2:40 pm.

Location: 1150 Snee 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/cs6702/2010sp/

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 on a particular (computational) sustainability topic, a presentation of a research problem in class, or a good annotated bibliography.
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 are meant to identify and discuss one or two *interesting computational research questions* concerning a certain sustainability topic.

The reaction paper should be around 5 pages in length.

The reaction paper is due on March 3rd.

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 17th.

Project presentations will e schedule during the last week 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

Wednesday Feb 3 – Jon Conrad – Intro to Sustainability and Resource Economics

Thursday Feb 4 – Talk : Sustainability Science--- Nature's Role in Sustaining Economic Development, Partha Dasgupta, Thursday, February 4, 4:30-5:30 pm, 233 Plant Science

Our Common Future (Brundtland Report,1987)

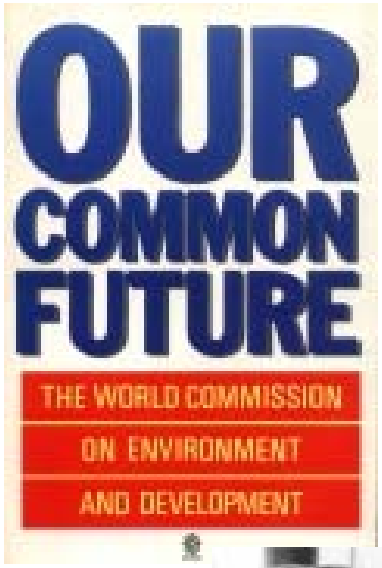
UN World Commission on Environment and Development)

- 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

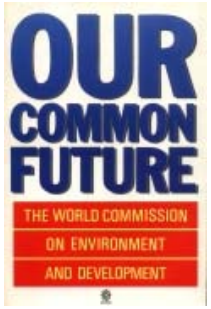
- Great Law of the Iroquois Confederacy: *"In every deliberation, we must consider the impact of our decisions on the next seven generations."*

Nathan Benn/Corbis

Thanks Megan McDonald!

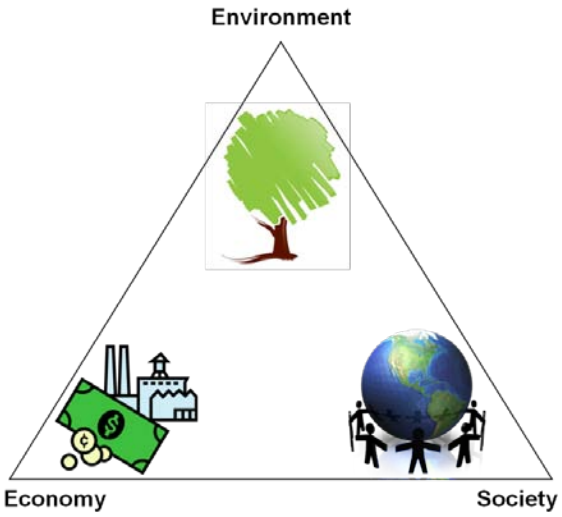
Sustainability is not only about the environment

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.

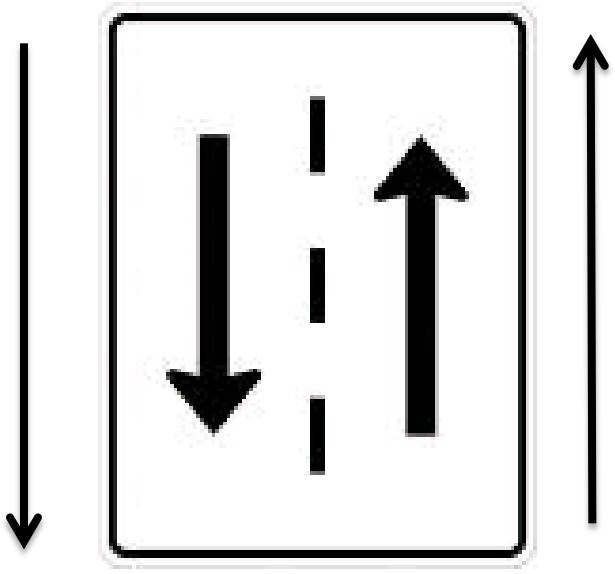
- Such computational problems are unique and present new research challenges, often involving continuous and discrete decisions.

Computational Sustainability

Sustainability related fields

New challenging applications

New methodologies
into Computer Science



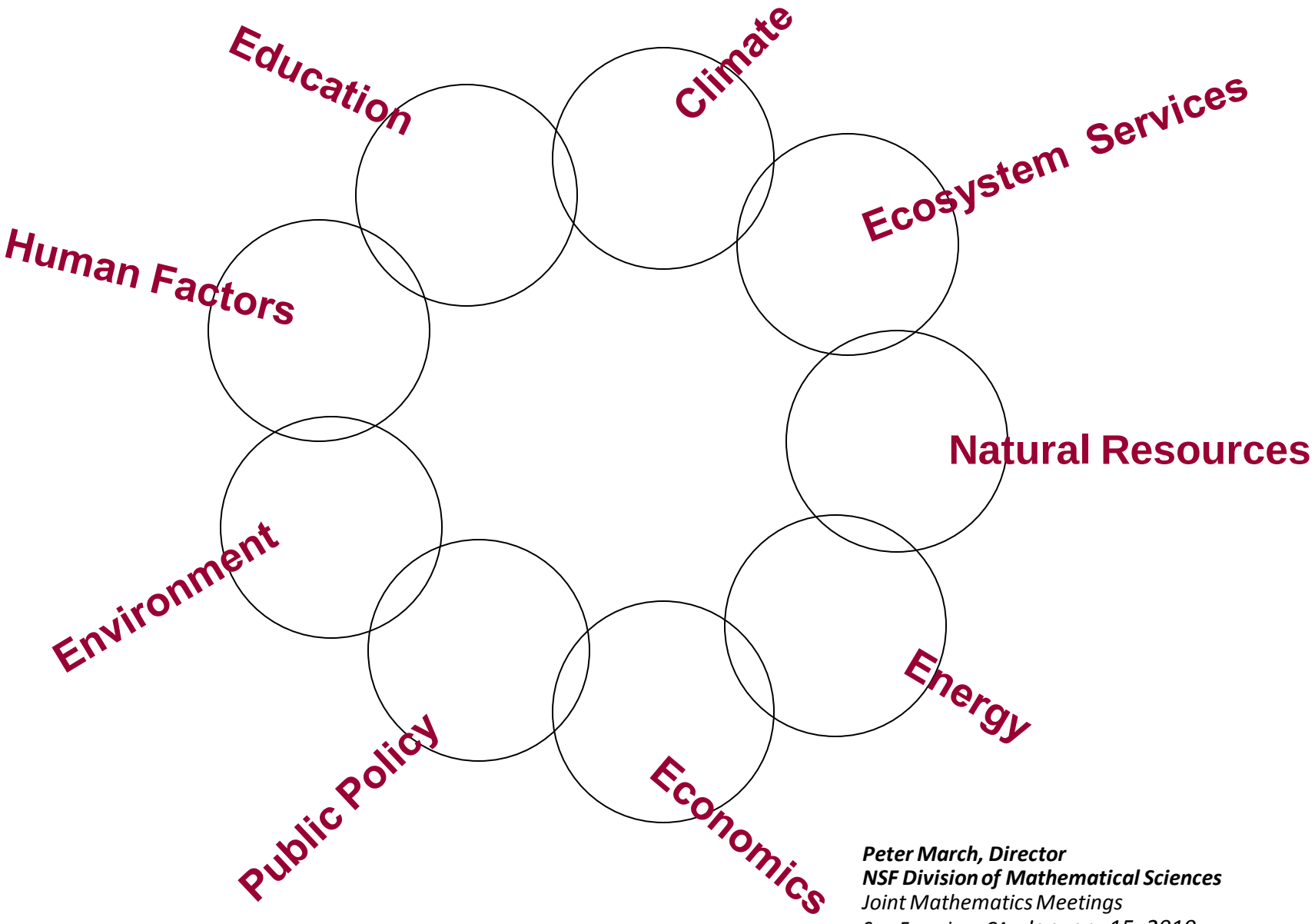
Computational Thinking that will provide new insights into sustainability problems:

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)

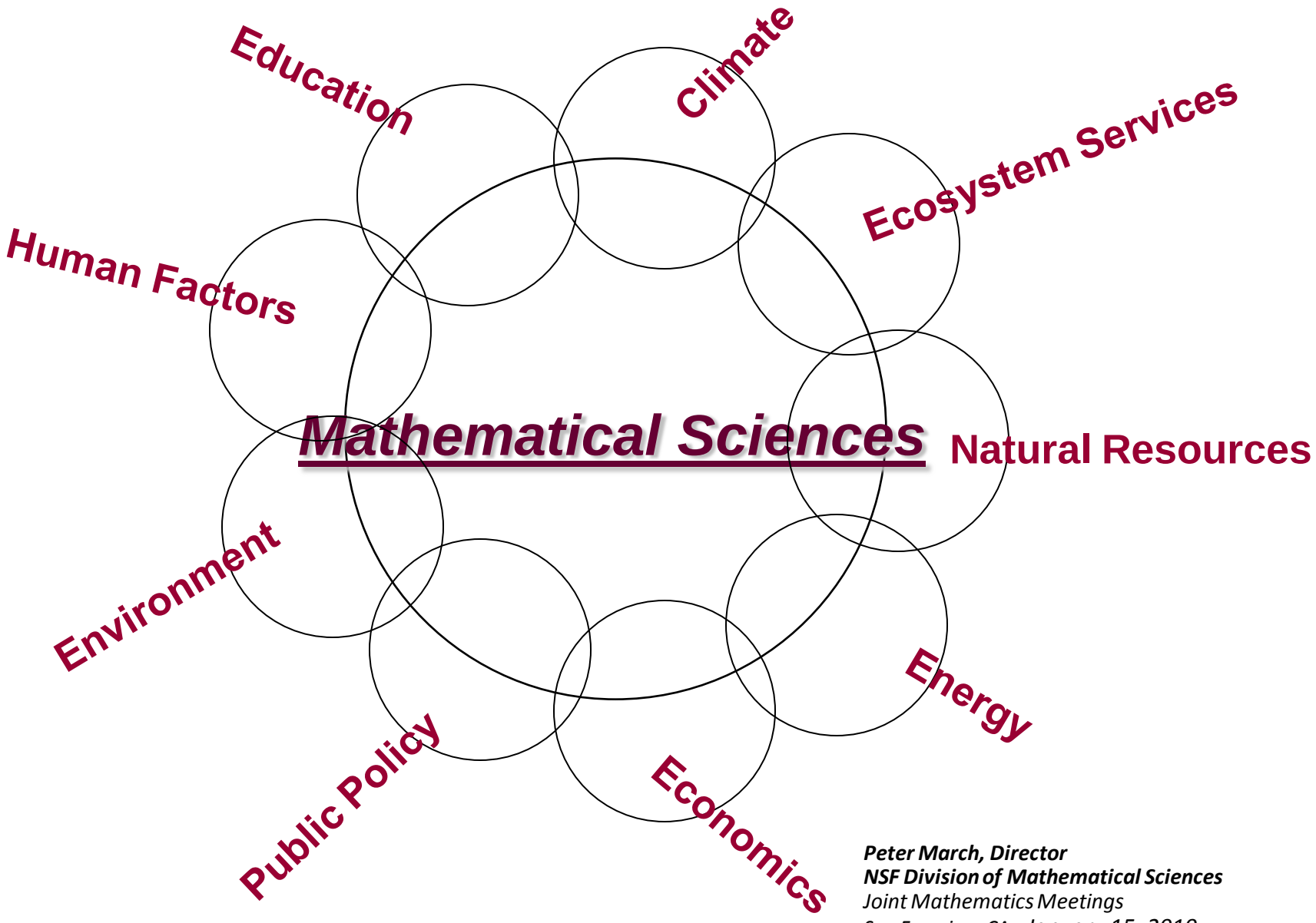
Analogy between Computational Biology and Computational Sustainability

Components of Sustainability



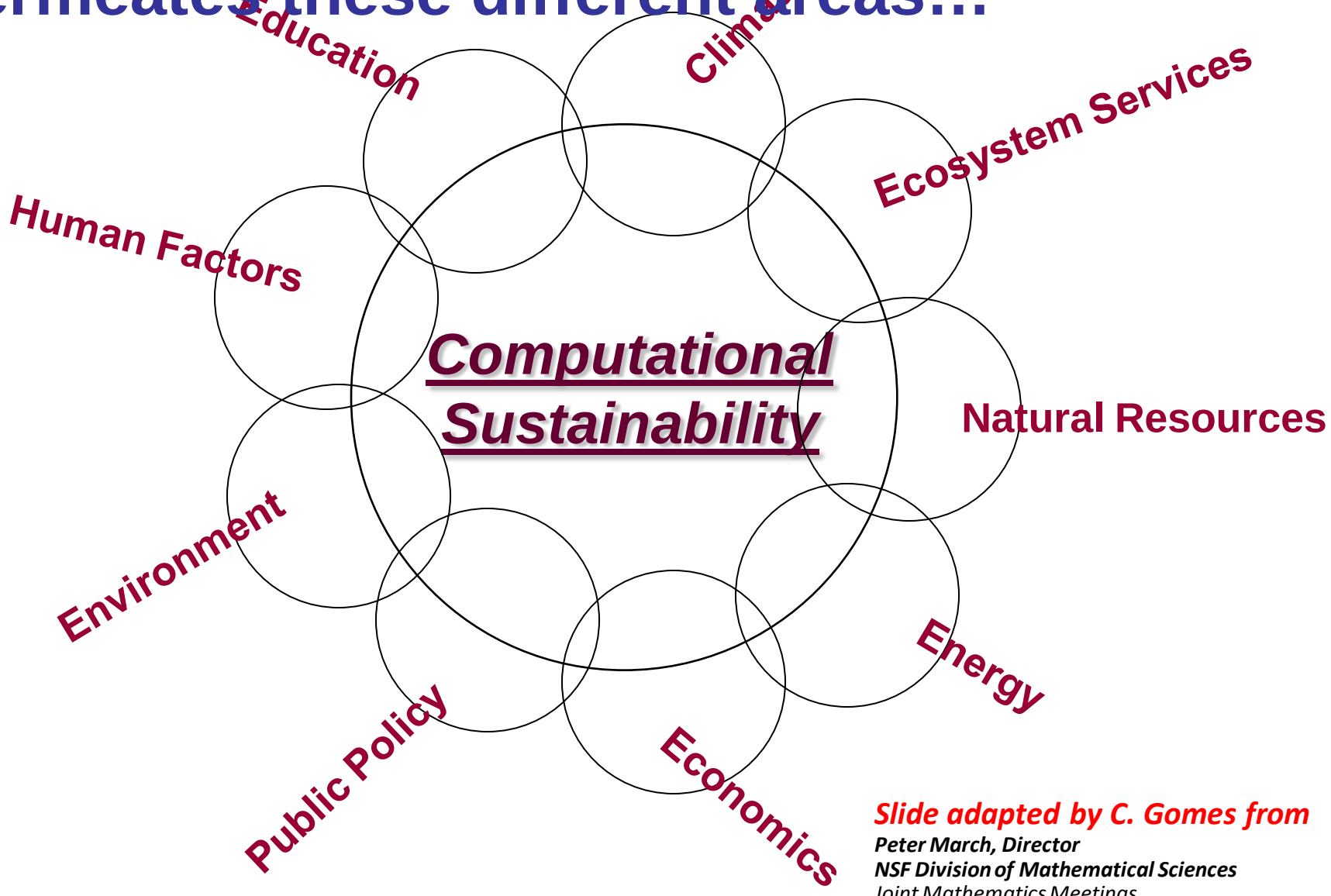
Peter March, Director
NSF Division of Mathematical Sciences
Joint Mathematics Meetings
San Francisco CA - January 15, 2010

Mathematics gives Sustainability coherence



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

Computational Sustainability permeates these different areas…



Slide adapted by C. Gomes from

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

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)

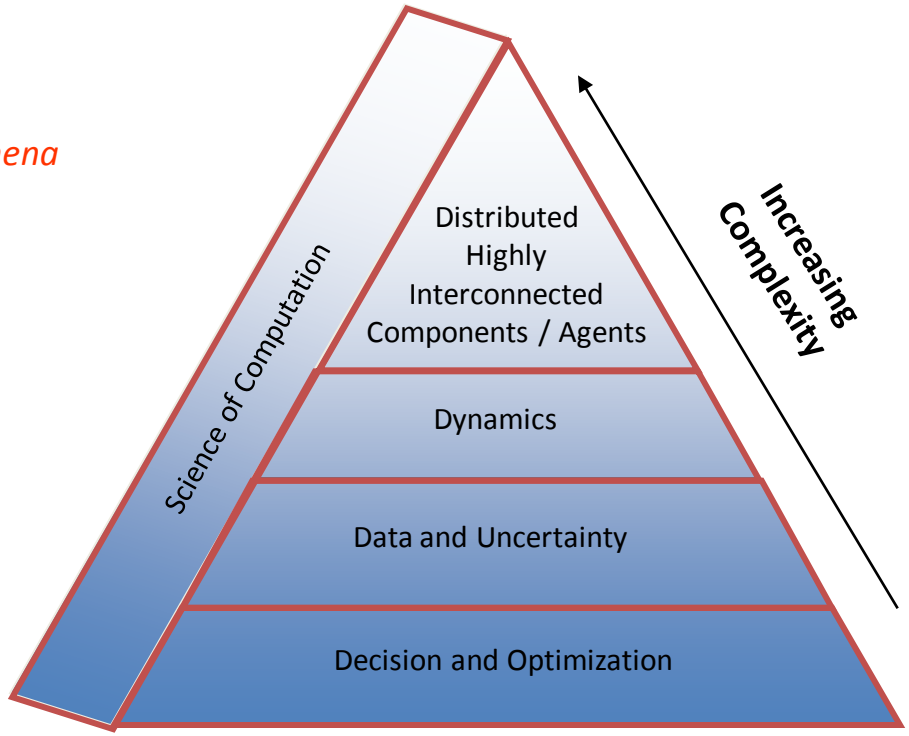
→ **From Statics to Dynamics: Dynamic Models**

Large-scale data and uncertainty

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

Complex decision models

→ **Constraint Reasoning and Optimization**

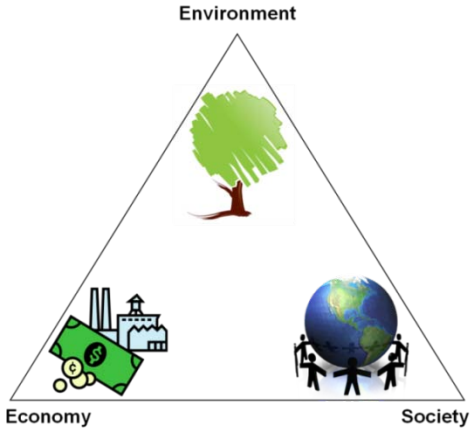


Complexity levels in Computational Sustainability Problems

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!

6702 Topics

Seminar /Project Topics

Computational topics:

- constraint satisfaction and optimization problems,
- probabilistic reasoning and inference,
- machine learning methods,
- game theory,
- agent-based models,
- social networks and HCI and
- dynamical models.

Seminar /Project Topics

Natural Resource Protection

- Reserve design, site selection, and fish barrier removal (constraint satisfaction & optimization)
- Ecosystems (Sensor Networks)
- Ecosystems (machine learning and large scale climate modeling)
- Ocean Ecosystem Services
- Ecosystems (pedagogical model)

Economics and Human Behavior

- Human –environmental systems Well-Being and Poverty
- Over-Population
- Infectious Diseases
- Ecosystem Services (Incentives)
- Social Networks, HCI

Energy Resources

- Smart Grid and Electric Cars
- Wind
- Biofuels
- Material Discovery

Human-Built Systems and Land Use

- Agriculture
- Sustainable Cities
- Energy efficiency - Sustainable Management of Data Centers
- Life cycle analysis

Guest Speakers

Non-Cornell Guest Speakers (confirmed)

- Ole Amundsen (The Conservation Fund)
- Andreas Krause (Computer Science, Caltech)
- Steve Phillips (Computer Science, ATT Labs)
- Warren Powell (Operations Research, Princeton)
- Brian Williams (Computer Science, MIT)

Cornell Guest Speakers (confirmed)

- Antonio Bento, Jon Conrad, Tim Mount (Applied Economics)
- Daniel Fink, Steve Kelling, Ken Rosenberg (Lab of Ornithology)
- Yrjo Grohn (Population Medicine and Diagnostic Sciences)
- Laurie Drinkwater (Horticulture)
- Robert Howarth (Ecologicy and Environment Biology)
- Natalie Mahowald (Earth & Atmospheric Sciences)
- Bob Thomas and Max Zhang (Engineering)

Examples of Computational Sustainability Projects @ ICS

Conservation and Biodiversity : Wildlife Corridors

Friday Jan 29

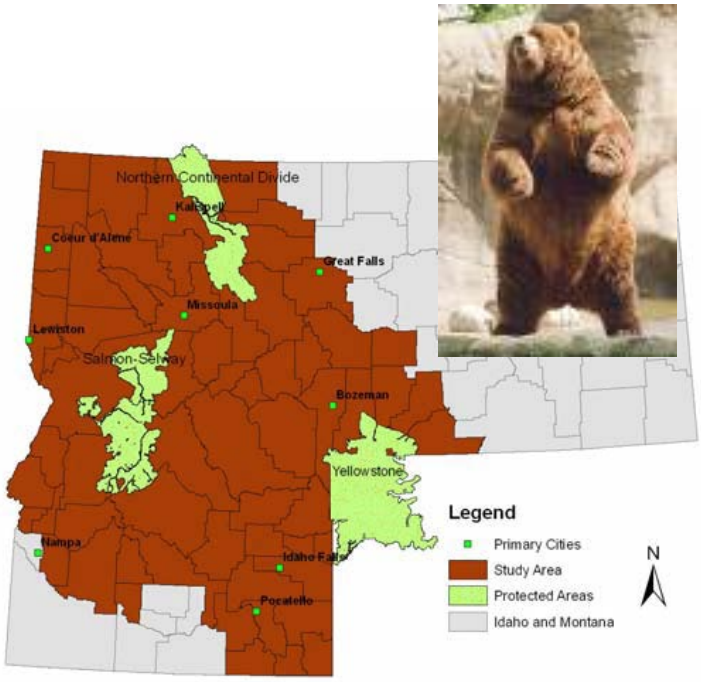
Wildlife Corridors link core biological areas, allowing animal movement between areas.

Typically: low budgets to implement corridors.

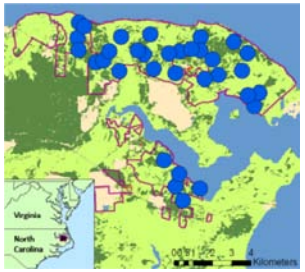
Example:

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



Talks Feb 10; Feb 17



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 populations

Building artificial cavities

Translocation of birds

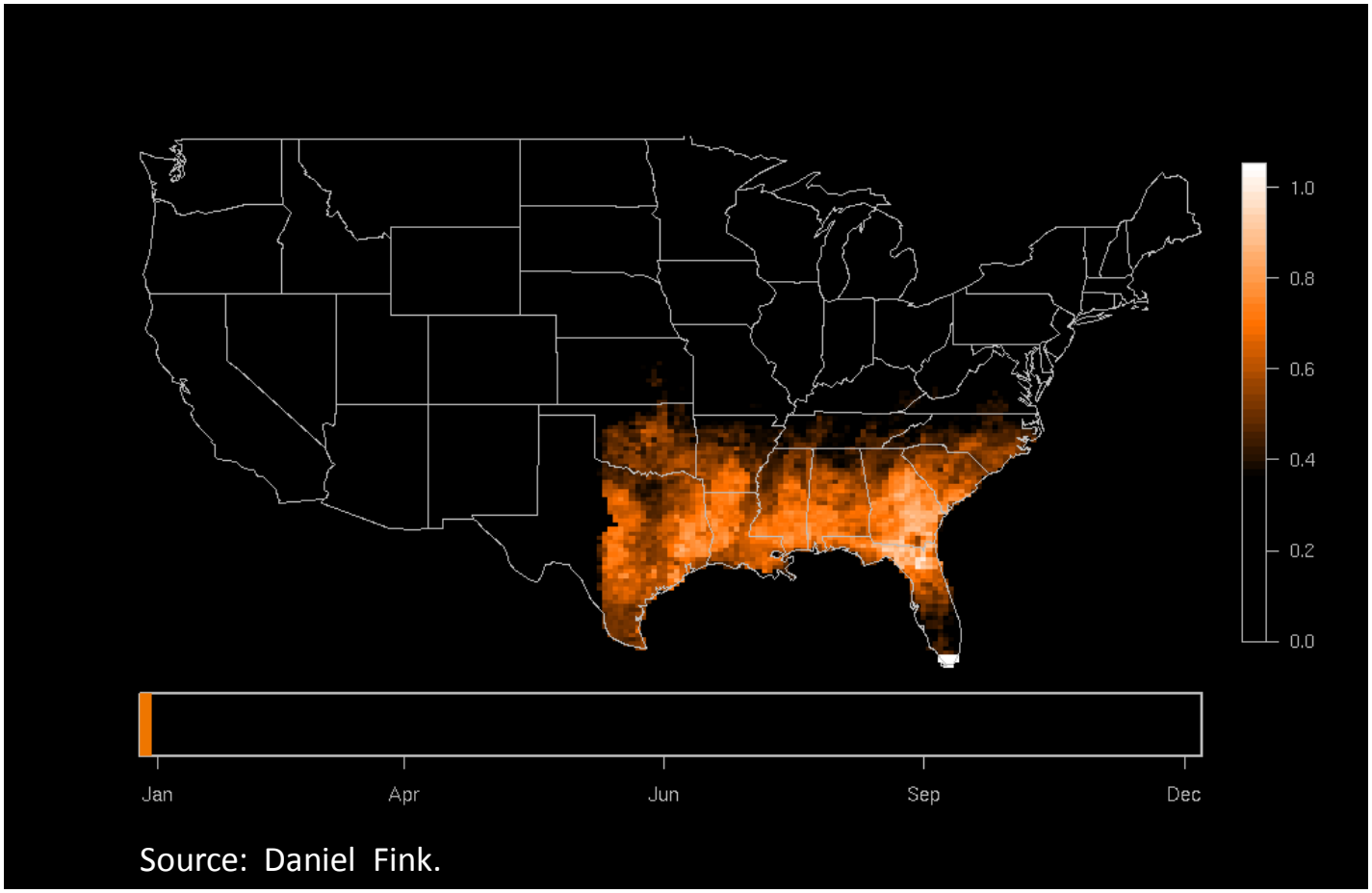
THE CONSERVATION FUND

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

Talk Feb 12

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



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.

Talk Feb 19

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

CORNELL LAB of ORNITHOLOGY

Andrew Farnsworth and Ken Rosenberg 2009

Conservation and Biodiversity: Other related projects

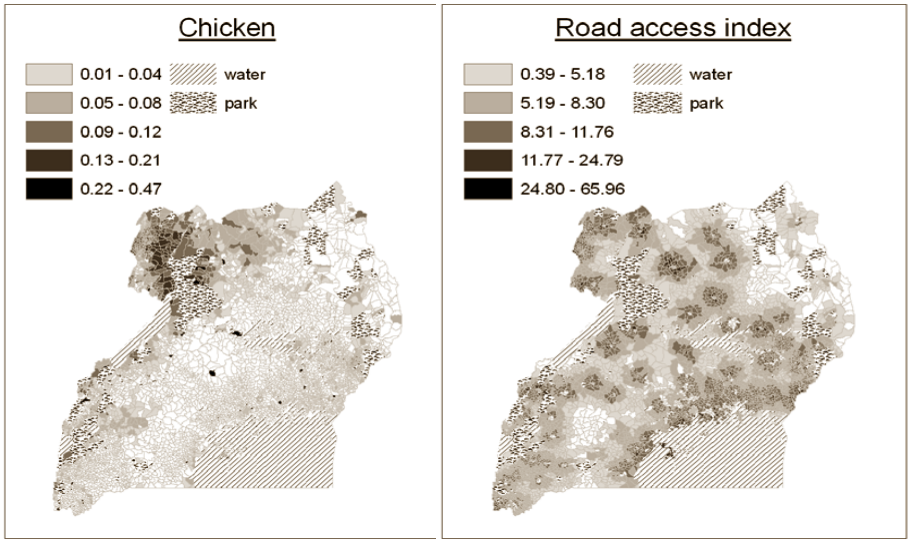
- Optimal Protection of Wintering and Breeding Sites

- Fish Passage Barrier Removal for Migratory Fish (Talk: Feb 24)

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?

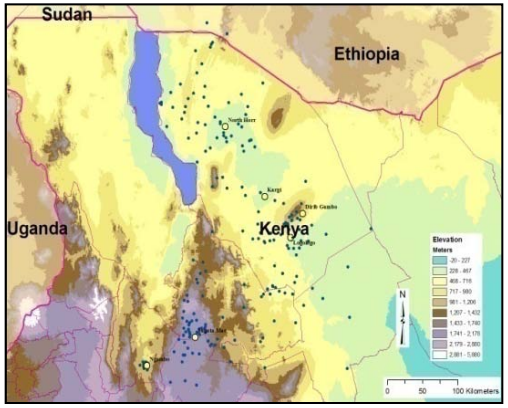


A map of estimated average marginal returns to given asset that are significantly greater than zero.

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

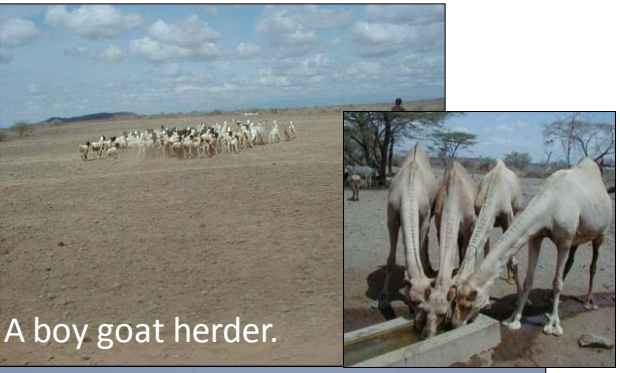
Bistra Dilkina – interested in the computational aspects of this projectl!

Natural Resource Management: Pastoral Systems in Africa



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.


A boy goat herder.


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

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

Natural Resource Management: Policies for harvesting renewable resources

Talks: Jon Conrad
Mary Lou Zeeman

Economy

Y_t

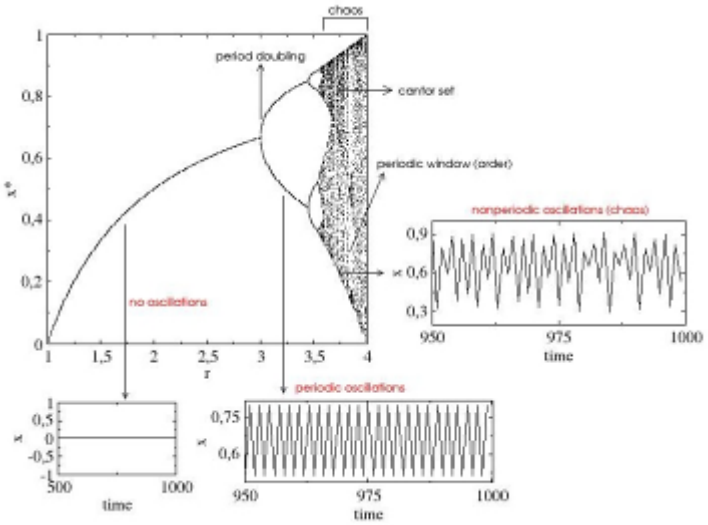
Harvest of a Renewable Resource: Tuna

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

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

Natural Resource Management: Other related projects

- The Impact of Periodic and Constant Harvesting Policies on 'TAC'-Regulated Fisheries Systems
- The Effect of Reduced Ship Strike on the North Atlantic Right Whale
- Bioeconomics Meets Biocomplexity: Controlling the Gypsy Moth Population

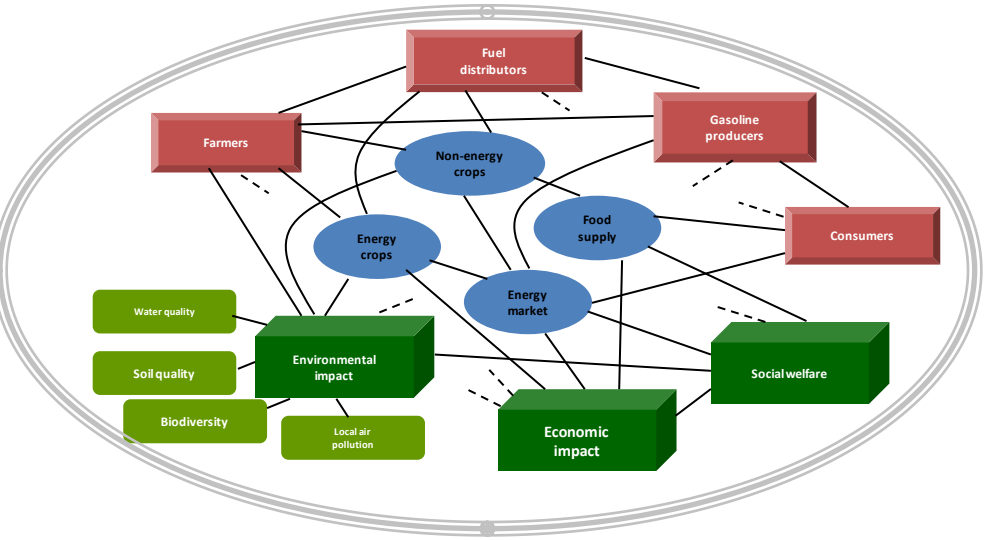
Talk: Antonio Bento

Renewable Energy: Biofuels

Energy Independence and Security Act

(Signed into law in Dec. 2007)

Ambitious mandatory goal of
36 billion gallons of renewable fuels by 2022
(five-fold increase from 2007 level)



First generation Biofuels

Advanced Biofuels (“*Cleaner*”)
(non food crops and biomass)




Switchgrass **Wood Waste** **Animal Waste** **Municipal Waste**

Renewable Energy: Biofuels

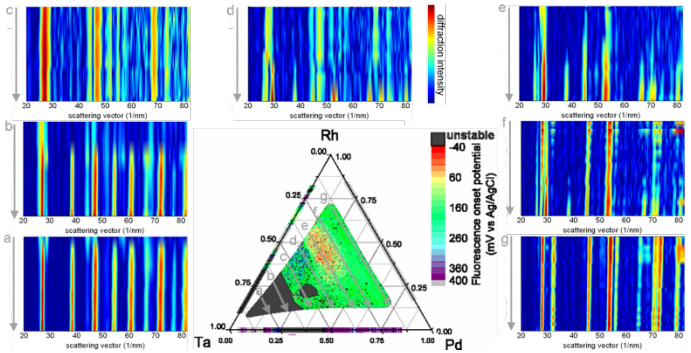
1) Equilibrium Models for Biofuels Policies – Antonio Bento and students Joel Landry, Richard Klotz, Kevin Roth, Nirav Patel, Alex Latzka, Simon Taranta, Max Weiz, and George Kang

2) Distributional and Efficiency Impacts of Increased U.S. Gasoline Taxes – Antonio Bento, Lawrence H. Goulder, Mark R. Jacobsen, and Roger H. von Haefen

3) Multi-scale Models for Process Configuration for Biofuel Production – Larry Walker, Lindsay Anderson, and students Anne-Laure Cuvilliez, Walter Bergstrom, and Travis Stanislaus

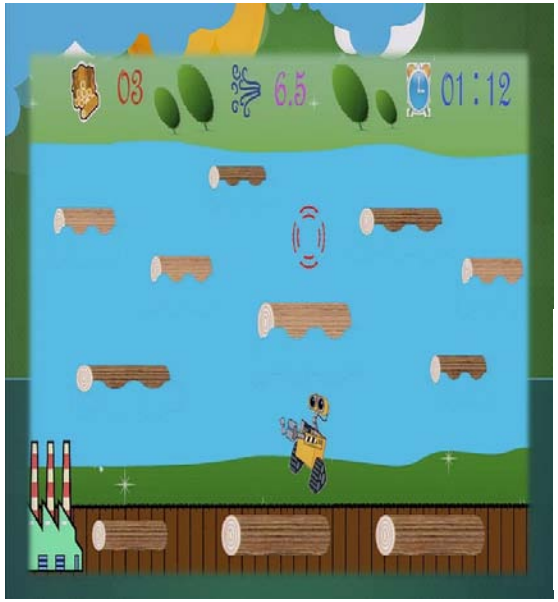
Material Discovery

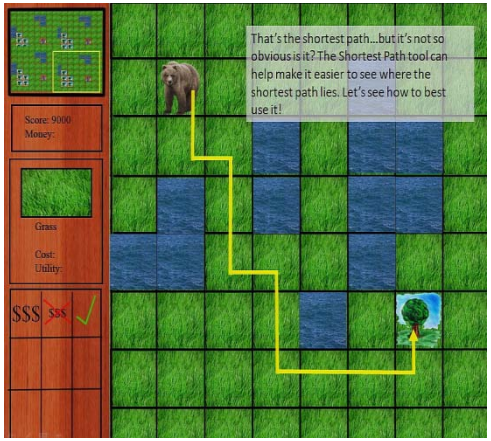
- New computational ways of analyzing x-ray diffraction patterns of compositions of elements in order to help identify new materials with important properties (e.g., design of new fuel cell technology).
- Using combinatorial methods in materials research has proven to be a powerful approach to the optimization 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

- Schedule

  See 6702 Web page:
  http://www.cs.cornell.edu/Courses/cs6702/2010sp/

- Climate Workshop

  http://www.image.ucar.edu/Workshops/TOY2010/focus03/