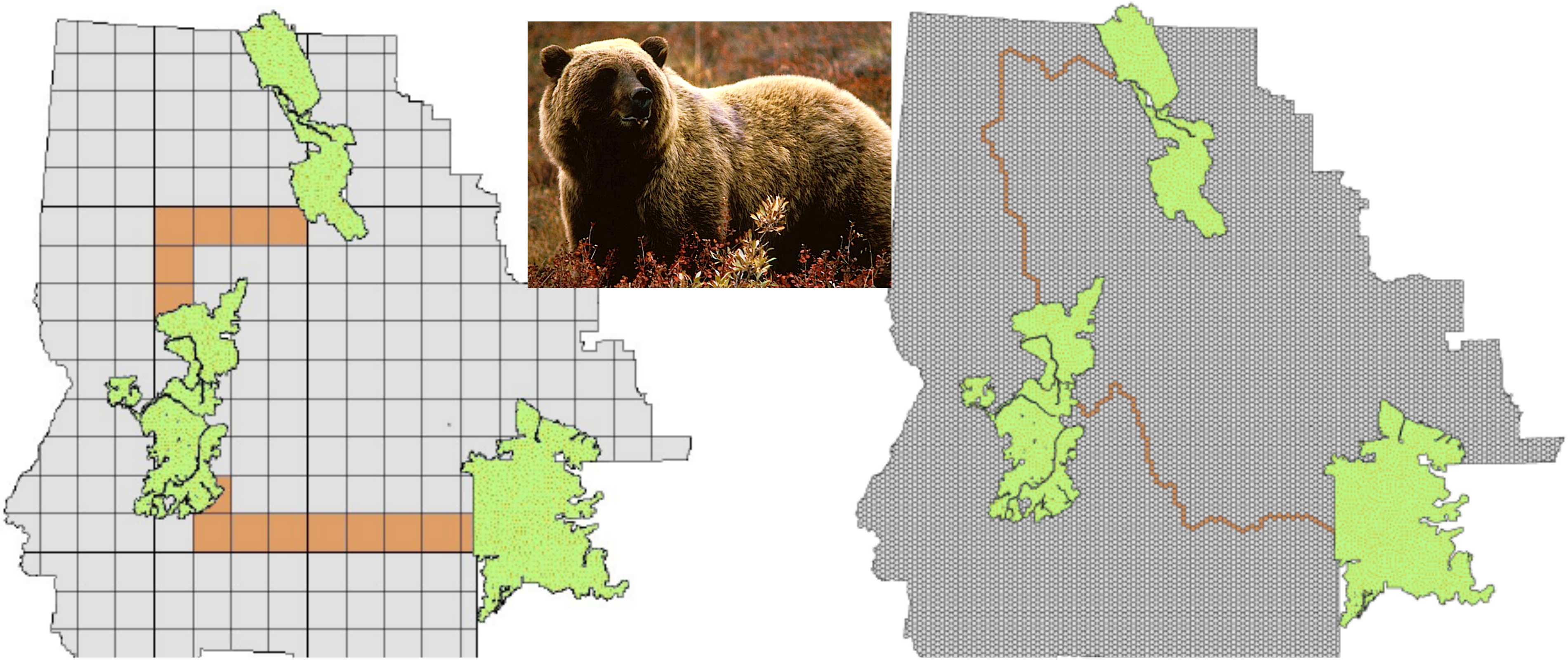
# CS 4959
# Vanderbilt University

# AI and Environmental and Societal Sustainability, and Social Justice

Douglas H. Fisher

# Many problems are a combination of hard and soft constraints (aka optimization under constraints)



**Corridor design:** connect existing habitat reserves (e.g., shown in green); each parcel of land has a ***cost*** (e.g., purchase price) and a ***utility*** (e.g., habitability). ***maximize the total (additive) utility of the corridor (soft constraint, optimization)***, ***without exceeding a fixed (total cost) budget (hard constraint, constraint satisfaction)***

Incorporating Economic and Ecological Information into the Optimal Design of Wildlife Corridors, Conrad, Gomes, van Hoeve, Sabharwal, and Suter. URI: http://hdl.handle.net/1813/17053.

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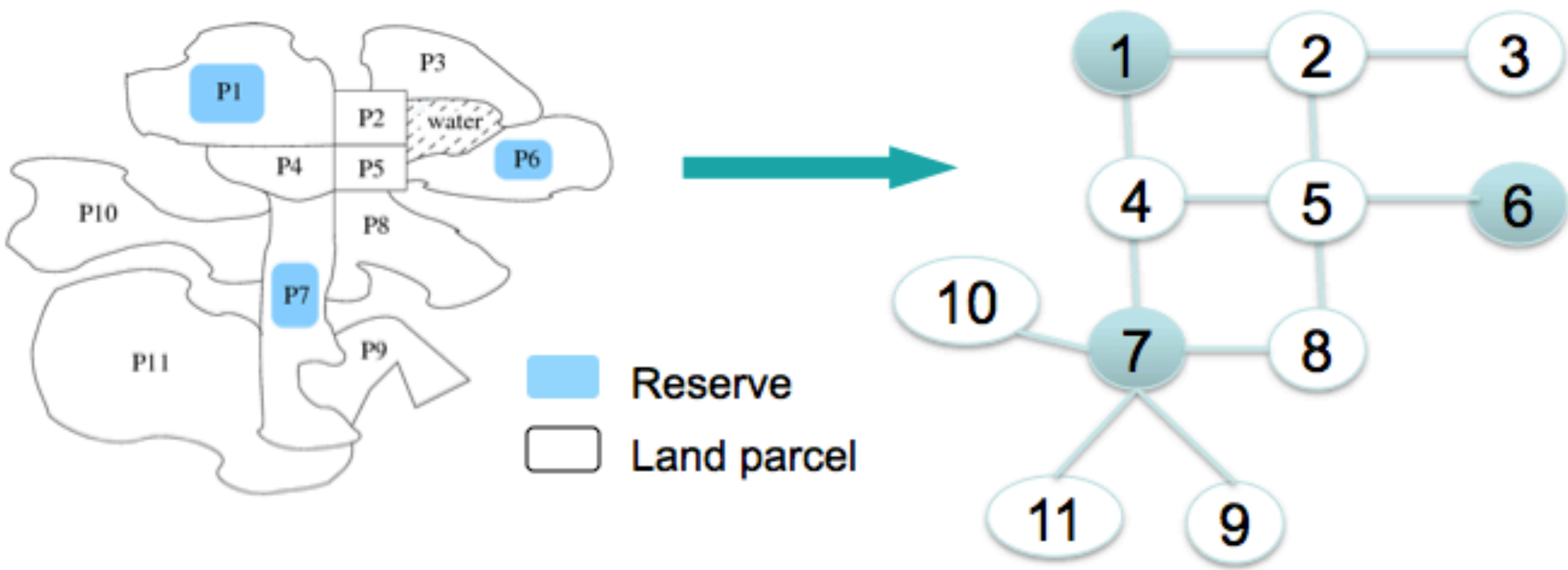
# Modeling Wildlife Corridors as a Network




Courtesy of Carla Gomes

# The Connection Subgraph Problem (Decision Version)

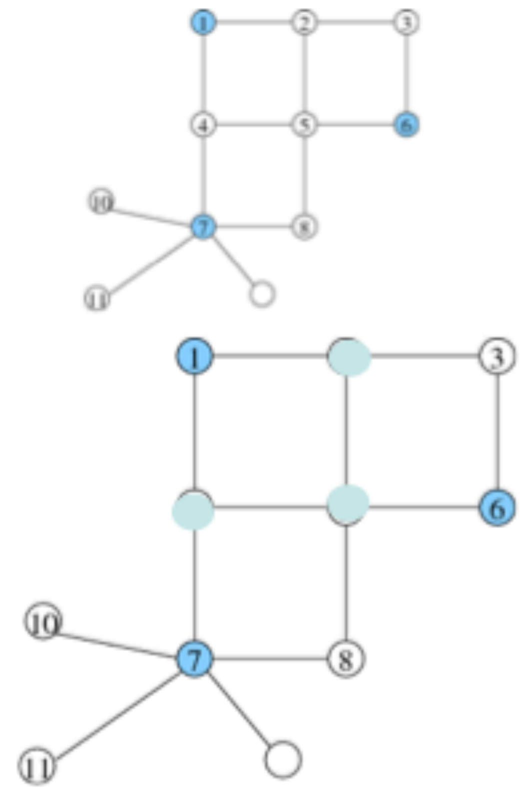
*Input*

- An undirected graph G = (V,E)
- Terminal vertices $T \subseteq V$
- Vertex cost function: c(v)
- Vertex utility function: u(v)
- Cost bound / budget C; desired utility U

*Question*

*Is there a subgraph H of G such that*

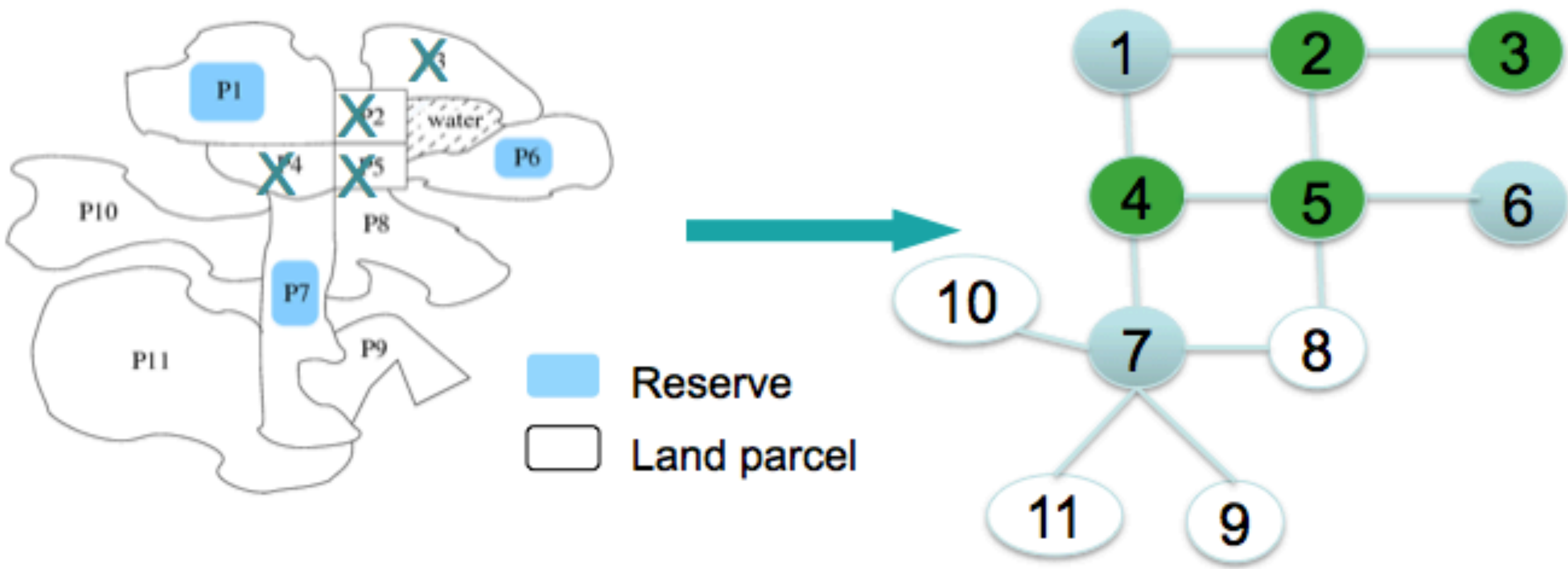
- H is connected and contains T
- $\text{cost}(H) \leq C$; $\text{utility}(H) \geq U$ ?




Courtesy of Carla Gomes

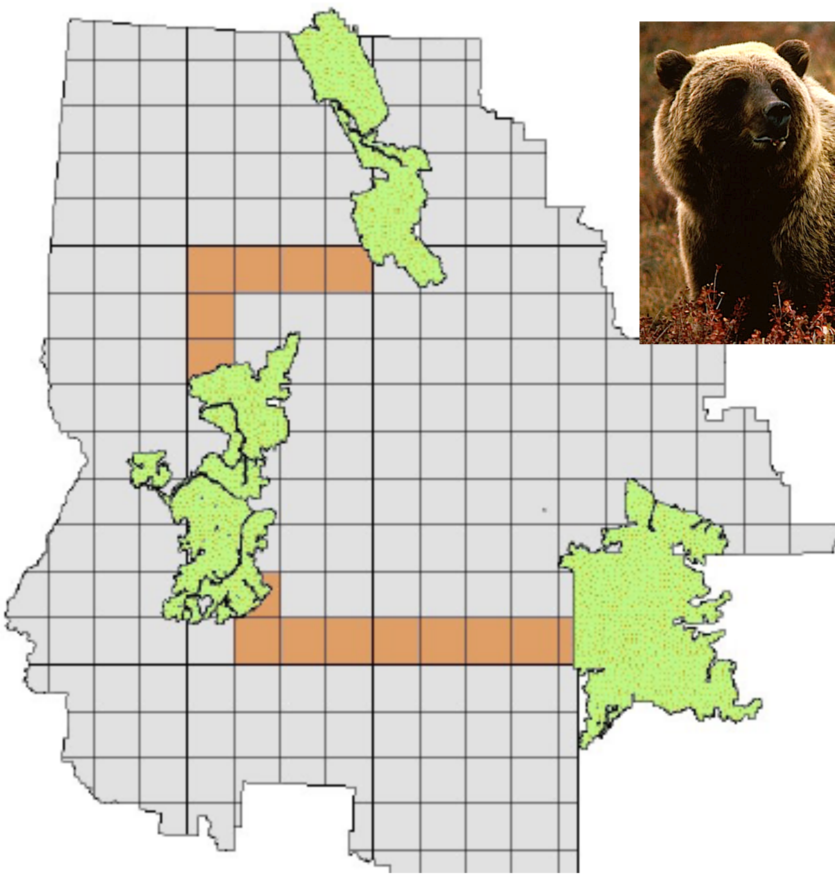
# Modeling Wildlife Corridors as a Network

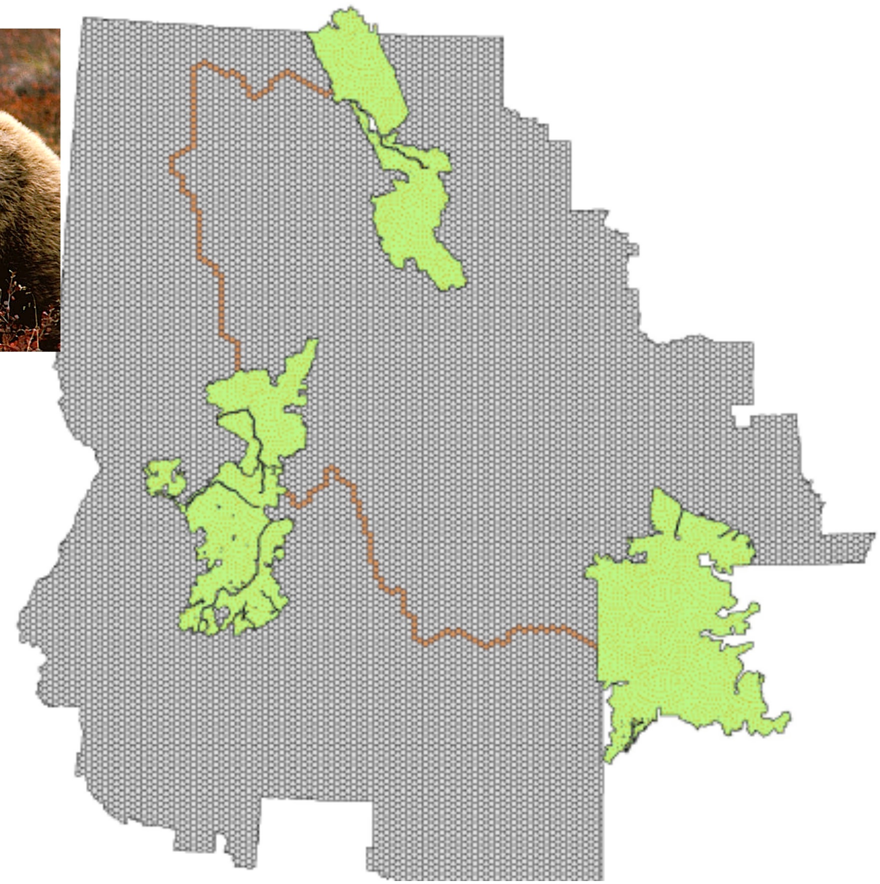
## Corridor connecting the reserves




Courtesy of Carla Gomes

NP Hard in worst case … but structure in habitat problems often facilitates fast, near optimal solutions





For example, a greedy approach that seeks min-cost solution, followed by second phase that adds additional vertices for additional utility (e.g., according to U/C ratio and/or heuristic distance)

When would backtracking occur (i.e., what is a dead end)?

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# Network Models for Wildlife Conservation
## Elaborating one research theme

Motivation: Biodiversity Loss

Mechanism: Wildlife Reserves and Corridors (mitigating land fragmentation)

Constraints: Limited budget, fixed habitability

Computational approaches of optimization and optimization under constraints

- Maximizing utility
- Minimizing Cost
- Maximizing utility without exceeding budget
- Minimizing cost without dropping below threshold utility

Douglas H. Fisher

# Variations: Examples of sustainability driving computing abstractions

Utilities and costs can change (e.g., based on neighboring states)

Available budget unfolds piecemeal over time and under uncertainty

D. Golovin et al., "Dynamic Resource Allocation in Conservation Planning," *Proc. AAAI Conf. Artificial Intelligence*, AAAI, 2011, pp. 1331–1336; www.aaai.org/ocs/index.php/AAAI/AAAI11/paper/view/3617.

Robust Optimization

“Green IT” is not synonymous with Computing and Sustainability
Not even close

# Computing and the Environment

- Gartner Report: ICT responsible for 2% of worldwide $CO_2$ emissions in 2007
- IT’s ecological footprint (energy, e-waste) growing (from laptops to avatars)

**Characterizing ICT’s effects on environment**

2000s

*Direct effects* (“the 2%”) : (changes in) ICT’s direct “ecological footprint”
(e.g., computer power management, manufacture, e-waste)

*Indirect effects* (“the 98%”) : (changes in) other sectors due to ICT
(e.g., smart X, remote conferencing)

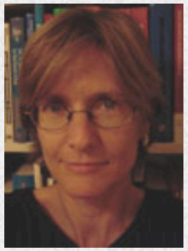
*Systemic effects* : not characterized by point estimates, but temporally
(e.g., ICT in modeling, education and decision making; Data.gov; SciSIP)

*Rebound effects* : ICT’s unintended (typically negative) impact

Ranging from low hanging fruit to deep technical and behavioral research

# A Role for Artificial Intelligence in Sustainable Design

**April 4th, 2011** / in **research horizons**, **workshop reports** / by **Erwin Gianchandani**



*The following is a special contribution to this blog from Doug Fisher (Vanderbilt University) and Mary Lou Maher (University of Maryland, College Park), who recently co-organized the AAAI 2011 Spring Symposium on Artificial Intelligence and Sustainable Design.*

**About 25-30 people attended the first-ever AAAI Spring Symposium on AI and Sustainable Design held on March 21-23, 2011 at Stanford University.** They came from three primary areas:

- *AI and Design*
- *Computational Sustainability*
- *Design for Sustainability*


There was also a virtual participation option, which was made available to co-authors, colleagues, and students of the authors of the papers as a way of broadening participation without requiring additional travel — and as a result 5-10 avatars attended in Second Life. A total of 18 papers were presented over the course of the two-and-a-half days. Participants also engaged in three separate breakout groups to brainstorm forward-thinking research directions at the intersection of AI and sustainable design.

A bit of background: Long-term environmental and societal sustainability requires that artifacts, materials, systems and processes be designed to minimize energy and waste and to maximize reuse and utility; we should hope that the days of designing neat things that are ultimately thrown away are rapidly coming to an end. The 'design for X' paradigm considers downstream objectives, such as reusability, early in the design process. Designers are being challenged to consider factors that had been previously given little attention, like life cycle costs along many dimensions; including energy requirements during manufacture, use and end-of-use phases, and material loss and environmental damage at the end of a product's life. A vision for sustainable design is cradle-to-cradle design (McDonough & Braungart), in which products are designed and built in ways that enable full reuse at low costs (e.g., energy), with nothing thrown out and nothing degraded. Our motivation to organize the workshop stemmed from our presumption that the increased complexity of design necessitated by a desire for very long-term planet sustainability requires application of and advances in artificial intelligence.



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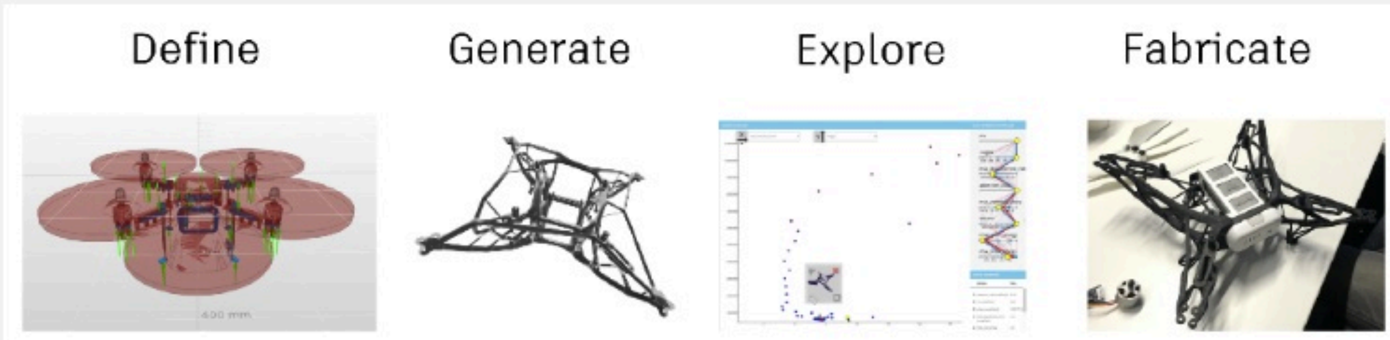
The Bloom Laptop
Designed for Recycling

https://newatlas.com/recyclable-bloom-laptop-concept/16853/

Recent advancements in artificial intelligence and the simulation of complex phenomena have enabled software to play an active, participatory role in the invention of form. Project Dreamcatcher is an experimental design platform with focused research probes into generative design systems.

# The Dreamcatcher Workflow.




“What if a CAD system could generate thousands of design options that all meet your specified goals? It’s no longer what if: it’s Project Dreamcatcher, the next generation of CAD. Dreamcatcher is a generative design system that enables designers to craft a definition of their design problem through goals and constraints. This information is used to synthesize alternative design solutions that meet the objectives. Designers are able to explore trade-offs between many alternative approaches and select design solutions for manufacture.”

https://autodeskresearch.com/projects/dreamcatcher

# Computational Sustainability

Gomes (2009) articulated research activity at the nexus of computing and sustainability, labeling it *computational sustainability*, with goals "*to develop new computational models, methods, and tools to help balance environmental, economic, and societal needs for a sustainable future.*"

Gomes, C. (2009). "Computational Sustainability: Computational Methods for a Sustainable Environment, Economy, and Society" *The Bridge, Frontiers of Engineering Vol 39* No. 4 Winter National Academy of Engineering.

# AI for Computational Sustainability

**AI as a partner in human decision making**, with AI tools and agents designed to meet people where people are, "fit" to human limitations, but not confined by these limitations -- indeed, AI designed so that the hybrid human/AI decision maker goes well beyond the capabilities of the human alone or the AI alone. A paradigm of AI as "*cognitive prosthesis*" (Ford, Glymour, & Hayes, 1997)

A second paradigm, also consistent with better, hybrid (collective) decision making, is **AI agents serving as positive role models** and collaborators in otherwise human collectives (Maher & Fisher, 2012)

Ford, K., Glymour, C., & Hayes, P. (1997). "Cognitive Prostheses", *AI Magazine*, V. 18, N. 3, p. 104.

Maher, M. L., & Fisher, D. H. 2012. "The Role of AI in Wisdom of the Crowds for the Social Construction of Knowledge on Sustainability." AAAI Spring Symposium

# Exemplar Projects in Computational Sustainability

Descriptions taken from http://www.compsust.net

### Materials Discovery

**What**: Rapid characterization of crystal structures from high-throughput X-ray diffraction experiments.
**Why**: Identify new materials for fuel cells, energy storage, and solar fuel generation.
**How**: Pattern decomposition, constraint and probabilistic reasoning, crowdsourcing.

### Big Data for Africa

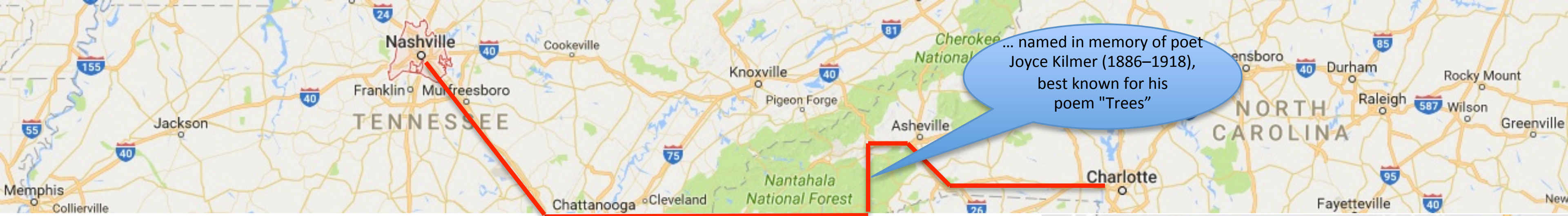
**What**: Deploy 20,000 low-cost weather stations across Africa.
**Why**: Improve weather predictions, which is directly related food security.
**How**: Optimal placement, bayesian networks, multi-scale probabilistic modeling.

### Green Security Games

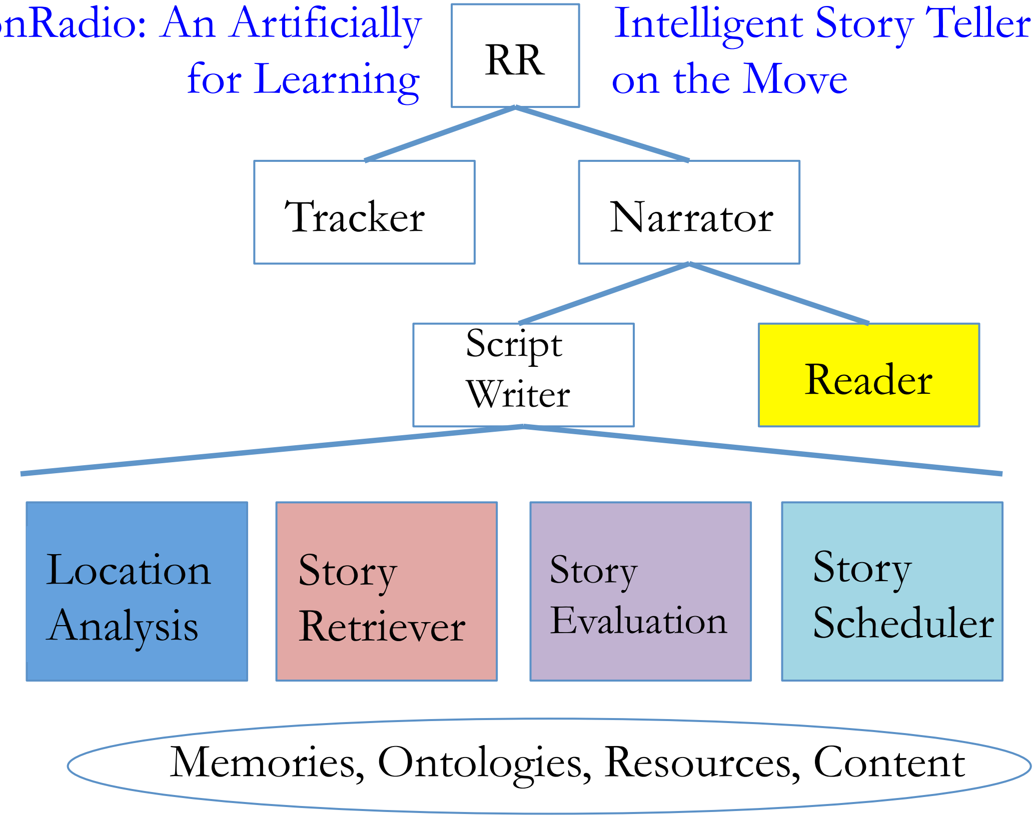
**What**: Protection Assistant for Wildlife Security (PAWS).
**Why**: Provide randomized patrol routes to combat poaching activity and protect wildlife.
**How**: Game theory-based analysis, spatio-temporal analysis, human behavior modeling, optimization.

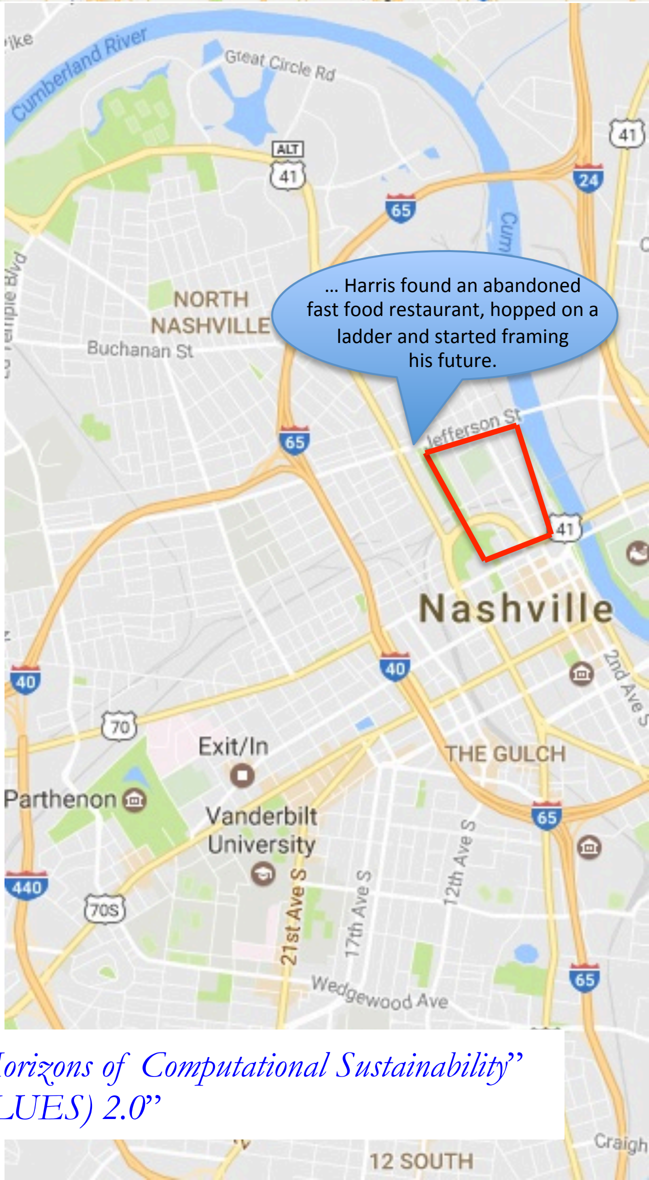
### Landscape-Scale Conservation

**What**: Socio-ecological corridor in the Ecuadorian Andes.
**Why**: Protect endangered Andean bear and other species in a significant biodiversity hotspot, while improving livelihoods of local communities.
**How**: Spatial capture-recapture, stochastic optimization, spatio-temporal modeling.



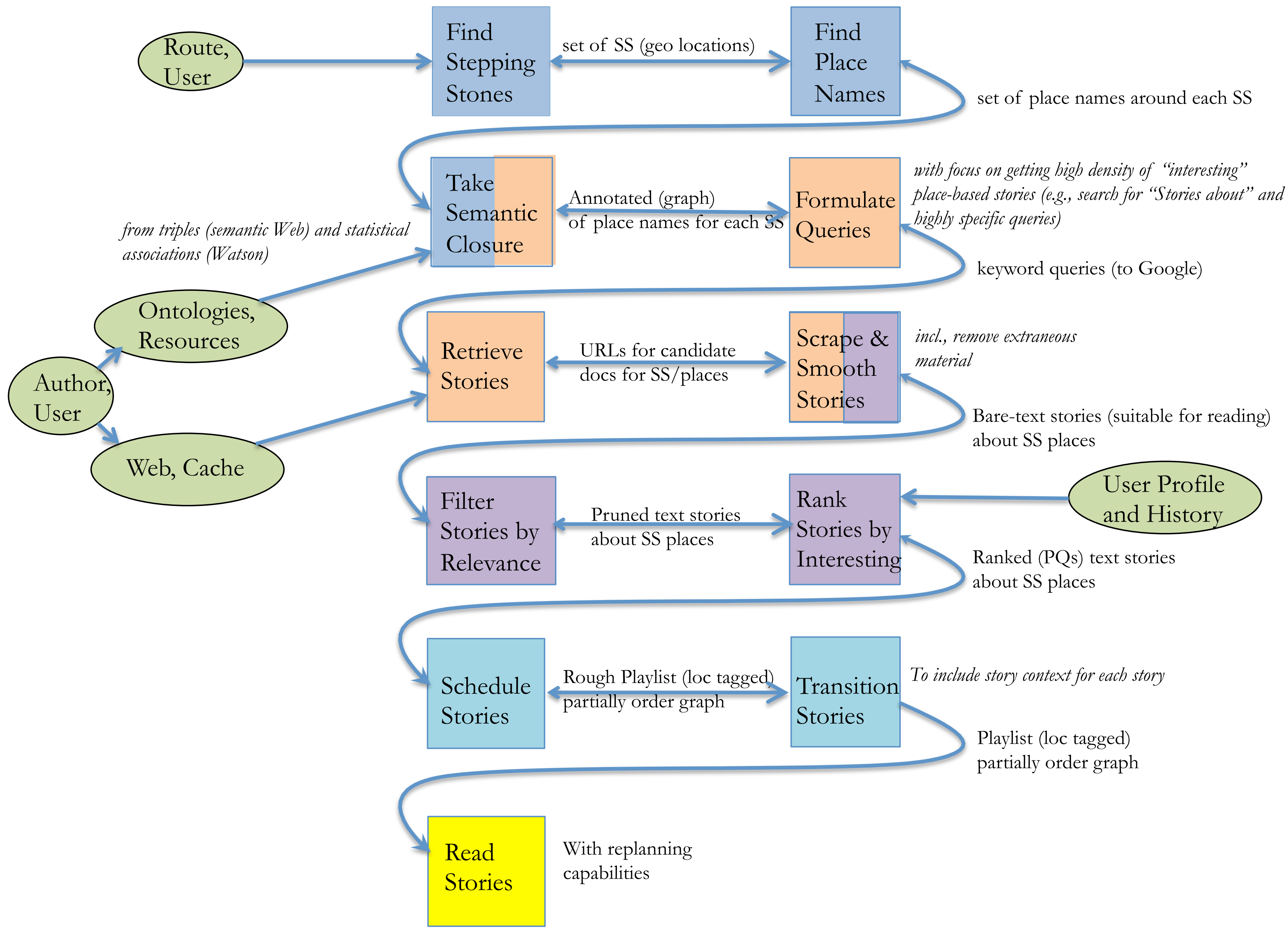

# RegionRadio: An Artificially Intelligent Story Teller for Learning on the Move




*Doug Fisher, Emily Markert, Abigail Roberts, Kamala Varma,*
*Hannah Braun, John Kim, Mateus Winkelmann*
*Chris Acker*

NSF Award #1521672 "*Collaborative Research: CompSustNet: Expanding the Horizons of Computational Sustainability*"
NSF Award #1623690 "*EXP: Bridging Learning in Urban Extended Spaces (BLUES) 2.0*"

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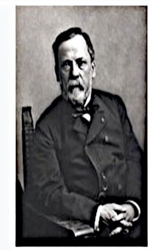
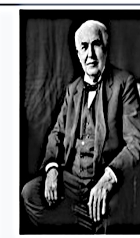
# Computational Sustainability as Use-Inspired Basic Research


Stokes, D. E. (1997). *Pasteur's Quadrant: Basic Science and Technological Innovation*. Washington, DC: Brookings Institution

Fisher, D. (2012b) "Sustainability" in *Leadership in Science and Technology: A Reference Handbook*, W. S. Bainbridge, Ed: SAGE Publications, pp. 201-209.

Bryant, R. et al., (2011). *Science, Engineering, and Education of Sustainability: The Role of Information Sciences and Engineering*, Computing Community Consortium of the Computing Research Association.


**Applied and Basic research**

| | | Considerations of use? | |
|---|---|---|---|
| | | **No** | **Yes** |
| **Quest for fundamental understanding?** | **Yes** |  Pure basic research |  Use-inspired basic research |
| | **No** | – |  Pure applied research |

https://en.wikipedia.org/wiki/Pasteur's_quadrant

Can we track reuse and repurposing of computational sustainability research results

# History of Computing and Sustainability

https://en.wikibooks.org/wiki/Artificial_Intelligence_for_Computational_Sustainability:_A_Lab_Companion/Introduction

**climate modeling** (from 1950s forward) illustrates this long pairing nicely: "To be sure, the computer at Phillips's disposal was as primitive as the dishpan (its RAM held all of five kilobytes of memory and its magnetic drum storage unit held ten). So his model had to be extremely simple." (Weart, ongoing)

Weart, Spencer, The Discovery of Global Warming, American Institute of Physics

**Transporation Modeling, Simulation, and Planning**

**Wildlife and Conservation Planning**

In the area **of social modeling**, it is not a stretch to consider computational simulations on the evolution of *cooperation* to have direct sustainability implications (Axelrod, 1984)[8]; in fact, Axelrod's supposition that for cooperation to arise, the future must cast a sufficient "shadow" on the present is an insight that can be realized through mathematics and computation (e.g., policy learning, virtual worlds, visualization) to mitigate the myopia and egocentrism of decision making.

Axelrod, Robert. 1984. The Evolution of Cooperation. New York: Basic Books
(a fun podcast: http://www.radiolab.org/story/104010-one-good-deed-deserves-another/ )

# History of Computing and Sustainability

https://en.wikibooks.org/wiki/Artificial_Intelligence_for_Computational_Sustainability:_A_Lab_Companion/Introduction

**Decision-Support Systems**

Serra, P., Sanchez-Marre, M., Lafuente, J., Cortes, U., Poch, M. (1994). Depur: a knowledge based tool for **wasterwater treatment** plants. Engineering applications of artificial intelligence

Cortes, U., Anchez-Marre, M. S., Ceccaroni, L. (2000). Artificial Intelligence and Environmental Decision Support Systems, Applied Intelligence

**Optimization**

Williams, J. C., ReVellea, C. S., Levin, S. A. 2005. Spatial attributes and **reserve design models:** A review, Environmental Modeling and Assessment 10: 163–181, Springer 2005

**Machine Learning**

Dzeroski, S., Todorovski, L., Bratko, I., Kompare, B., Krizman, V. 1999. "**Equation Discovery** with Ecological Applications,"

Todorovski, L., Džeroski, S., Langley, P., Potter, C. (2003). "Using equation discovery to revise an Earth ecosystem model of the carbon net production" Ecological Modelling, 170, pp. 141--154.

Phillips, S.J., Dudık, M., Schapire, R.E., 2004. A **maximum entropy approach to species distribution** modeling. In: Proceedings of the 21st International Conference on Machine Learning

**Machine Learning for the Environment** working group (2006), National Center for Ecological Analysis and Synthesis http://www.nceas.ucsb.edu/projects/1092

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# History of Computing and Sustainability

https://en.wikibooks.org/wiki/Artificial_Intelligence_for_Computational_Sustainability:_A_Lab_Companion/Introduction

**Recognizing 1st and higher order effects of computing (including unintended)**

A. Kohler and L. Erdmann, (2004) "Expected Environmental Impacts of Pervasive Computing," Human and Ecological Risk Assessment

OECD Workshops on ICTs and Environmental Challenges (2008) and on ICT and CC (2009)

Bryant, Fisher, Gianchandani, Gomes, Rouse (2011) Science, Engineering, and Education of Sustainability: The Role of Information Sciences and Engineering, version 18, Computing Community Consortium

NSF Science, Engineering, and Education for Sustainability (SEES) initiative (2010 at about 10% of budget)

**Recent AI for Computational Sustainability**

NSF Expeditions of Computing award on Computational Sustainability (2008), Gomes (PI)

NSF Expeditions of Computing award on Data Mining and earth Dynamics (2010), Kumar (PI)

**International Conferences on Computational Sustainability** (2008, 2009, 2012, 2016)

**Special Computational Sustainability tracks (starting 2011) at AAAI and IJCAI** (following two strategies for infusion) 14 CompSust papers at AAAI-17 and innumerable others in **affiliated workshops**, including W1: AI and OR for Social Good; W2: AI, Ethics and Society; W3: AI for Connected and Automated Vehicles; W5: AI for Smart Grids and Buildings

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# Computing Centric Categorization of Computational Sustainabilty

Eaton, Gomes, and Williams (2014)

- Active Information Gathering
- Sequential Decision Making
- Stochastic Optimization
- Uncertainty
- Probabilistic Graphical Models
- Ensemble Methods
- Citizen Science
- Spatiotemporal Modeling
- Remote Sensing
- Information Retrieval
- Vision + Learning (add Listening to this --DF)
- Crowdsourced Data
- Agent-Based Modeling
- Constraint-based Reasoning
- Game Theory and Mechanism Design

- add robotics to this --DF

**These categories are descriptive of current reality, not prescriptive of what is possible**

Eaton, E., Gomes, C., & Williams, B. (2014). Editorial Introduction to the Summer and Fall Issues on Computational Sustainability, *AI Magazine*, V. 35, No. 3. Association for the Advancement of Artificial Intelligence.

# Sustainability Centric Categorization of Computational Sustainabilty

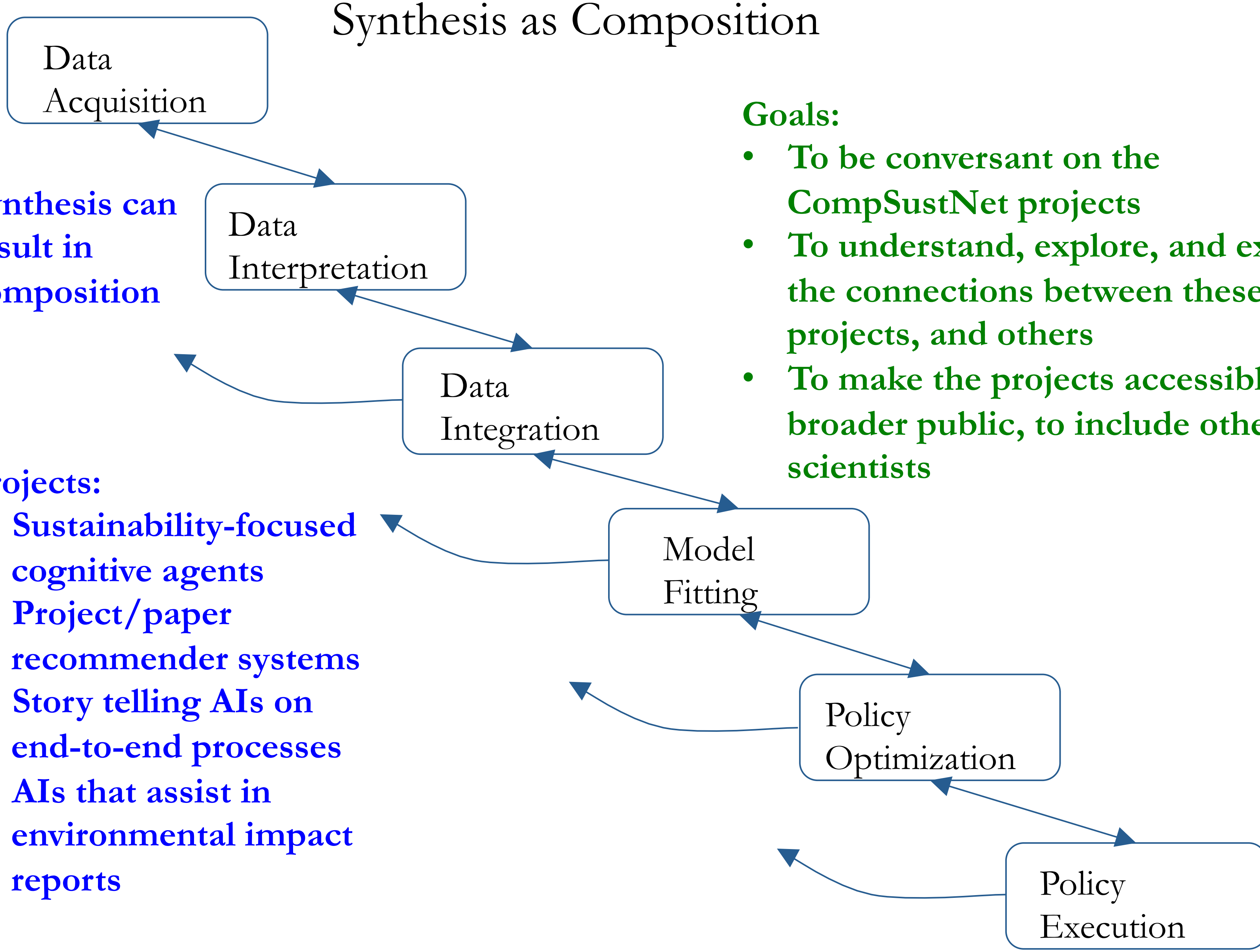
Eaton, Gomes, and Williams (2014)

- Conservation & Urban Planning
- Species Distribution Modeling
- Environmental Monitoring and Assessment
- Policy Planning
- Health
- Agriculture
- Transportation
- Energy and The Smart Grid

**These categories are descriptive of current reality, not prescriptive of what is possible**

Eaton, E., Gomes, C., & Williams, B. (2014). Editorial Introduction to the Summer and Fall Issues on Computational Sustainability, *AI Magazine*, V. 35, No. 3. Association for the Advancement of Artificial Intelligence.

# Synthesis as Composition




**Synthesis can result in composition**

**Projects:**

- **Sustainability-focused cognitive agents**
- **Project/paper recommender systems**
- **Story telling AIs on end-to-end processes**
- **AIs that assist in environmental impact reports**

**Goals:**

- **To be conversant on the CompSustNet projects**
- **To understand, explore, and expand the connections between these projects, and others**
- **To make the projects accessible to a broader public, to include other scientists**

**Adapted from Tom Dieterich presentation at** *AI for Social Good*
http://cra.org/ccc/artificial-intelligence-social-good-speakers/

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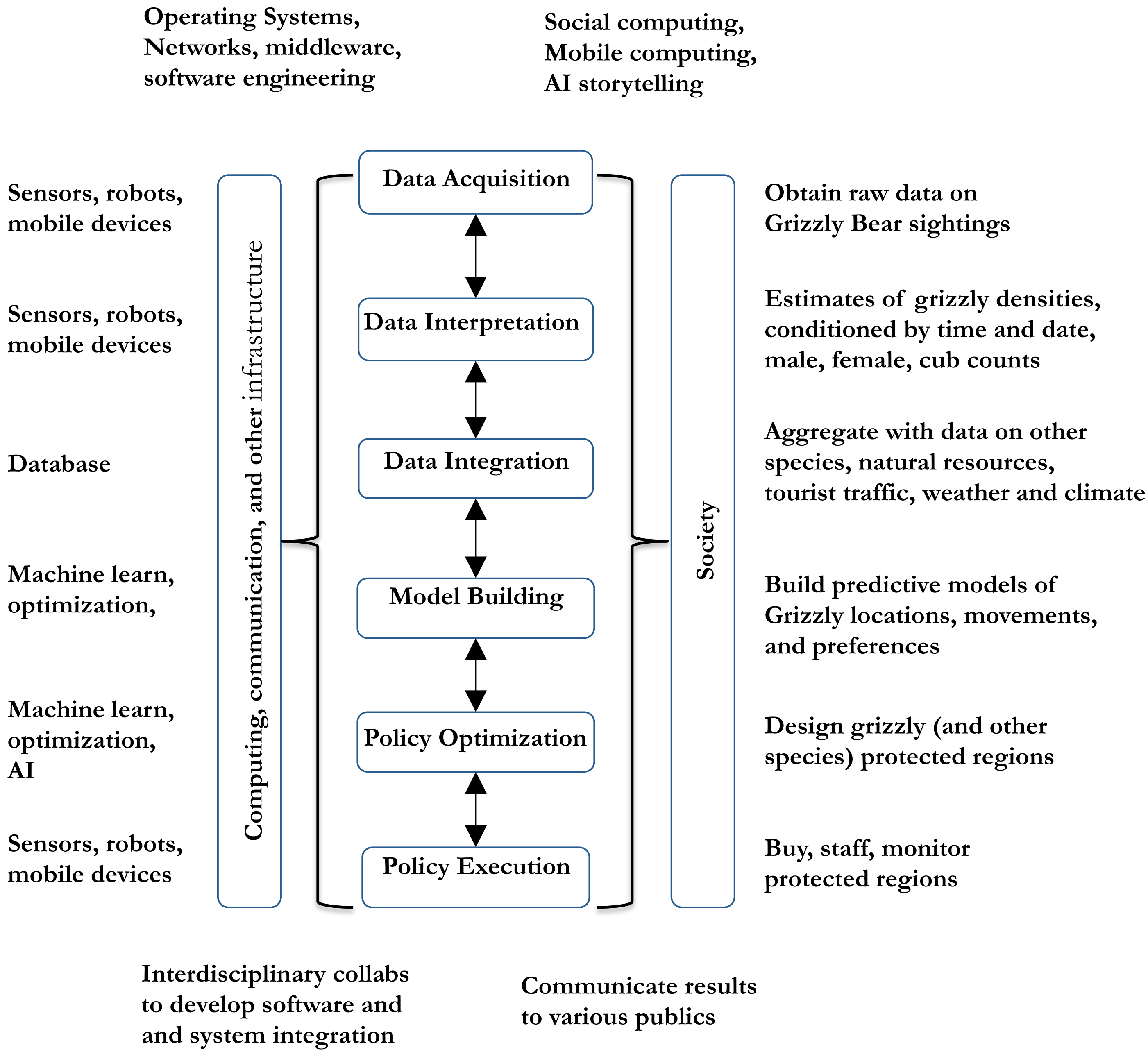


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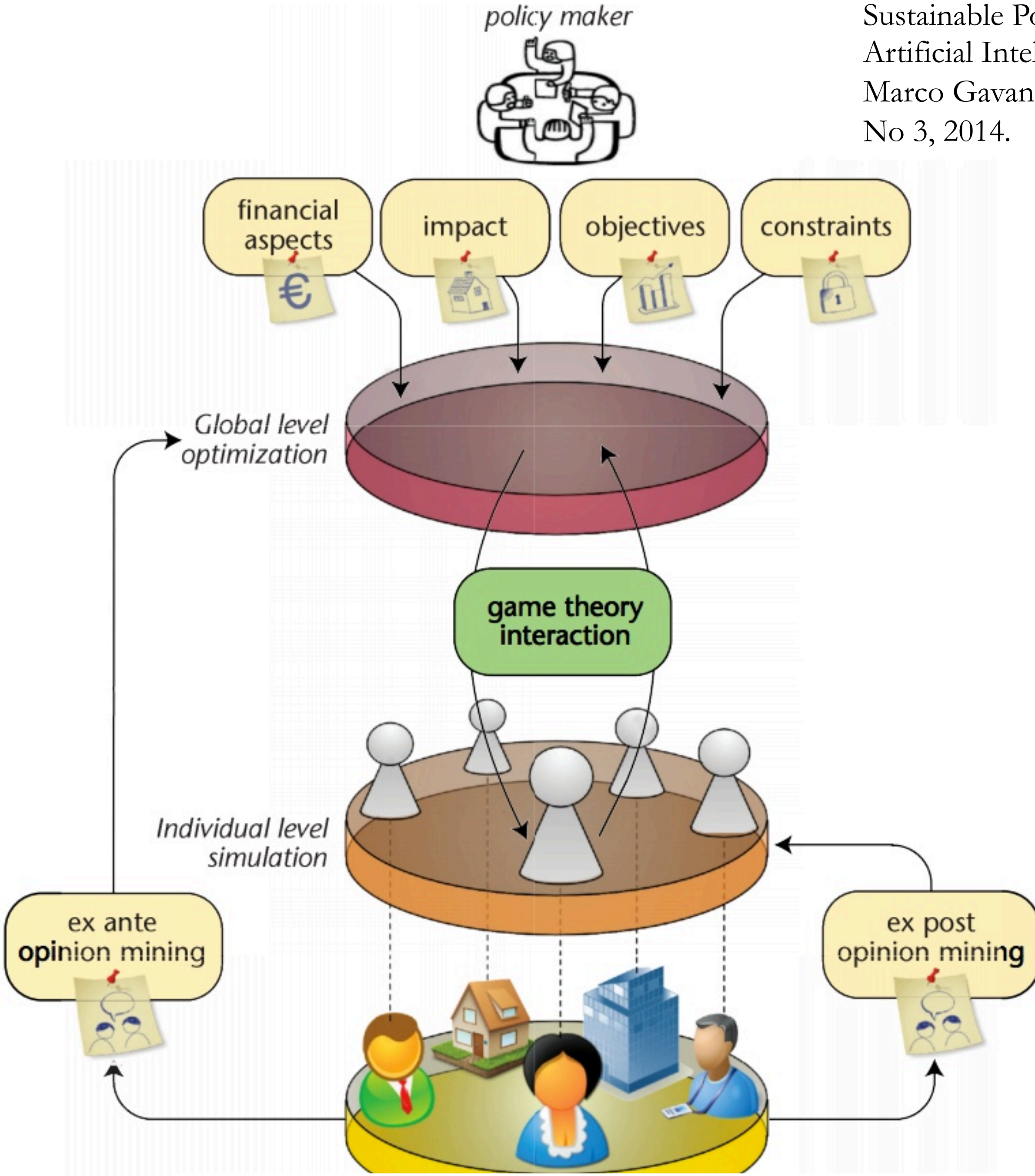
Sustainable Policy Making: A Strategic Challenge for Artificial Intelligence by Michela Milano, Barry O'Sullivan, Marco Gavanelli in AI Magazine, Vol 35, No 3, 2014.




*Policy making is an extremely complex process occurring in changing environments and affecting the three pillars of sustainable development: society, economy and the environment. Each political decision in fact implies some form of social reactions, it affects economic and financial aspects and has substantial environmental impacts. Improving decision making in this context could have a huge beneficial impact on all these aspects. There are a number of Artificial Intelligence techniques that could play an important role in improving the policy-making process such as decision support and optimization techniques, game theory, data and opinion mining and agent-based simulation. We outline here some potential use of AI technology as it emerged by the European Union (EU) EU FP7 project ePolicy: Engineering the Policy Making Life Cycle, and we identify some potential research challenges.*

https://www.aaai.org/ojs/index.php/aimagazine/article/view/2534

# Under-Represented Areas of AI in Computational Sustainability

All areas are underpresented relative to potential in computational sustainability, but these seem particularly missing

- Natural Language Processing
- Argumentation (e.g., Bench-Capon & Dunne, 2007)
- Story Telling and Narrative (interactive entertainment, but there are serious games)
- Cognitive architectures and integrative intelligence (e.g., Langley, Laird, & Rogers, 2008)
- An HCI strategy for computational sustainability tools (e.g., designing for and evaluating uptake)

Bench-Capon, T. J. M., Dunne, P. E. (2007). Argumentation in artificial intelligence, Artificial Intelligence Vol 171, Issue 10, July 2007, Pages 619–641

Langley, P., Laird, J., and Rogers, S. (2008). "Cognitive architectures: Research issues and challenges", *Cognitive Systems Research*, Vol 10, No. 2, pp. 141-160

# Aspirations and Challenges: Holistic, Integrated, Social Intelligence

- Environmental and societal sustainability are ideal domains for grounding general AIs
- AI cognitive architectures are platforms for synthesizing across currently disparate computational sustainability projects, using strategies of abstraction and composition
- Challenges (akin to Wagstaff (2012) ML impact challenges) that would require integrative intelligence and communication
    - An AI-composed environmental impact report (which anticipated negative medium-to-long term higher order consequences)

Wagstaff, K. (2012). "Machine Learning that Matters" Appearing in *Proceedings of the 29th International Conference on Machine Learning,* Edinburgh, Scotland, UK.

# Aspirations and Challenges: Education

**Goals: to infuse computational sustainability into the fabric of higher education, and K-12**

- **As with research, a course on computational sustainability can provide a holistic treatment of computing**

- **Campus Courses on computational sustainability (see Wikibook addendum and** Fisher, Bian, & Chen, 2016)

- **AI for Computational Sustainability Wikibook and Wikipedia entry**

Fisher, D., Bian, Z., and Chen, S. (2016) "Incorporating Sustainability into Computing Education" In *IEEE Intelligent Systems column on AI and Sustainability*, V. 31, N. 5.

# Virtual Seminar Open to World

## Computational Sustainability Virtual Seminar Series

The Computational Sustainability Virtual Seminar Series will present talks by researchers and educators in Computational Sustainability, and is being sponsored by CompSustNet, with support from the National Science Foundation's Expeditions in Computing program.

To sign up for seminar announcements, send an email to compsustnet_seminar-l-request@cornell.edu with the word **join** as the subject (leave the message body empty).

### Seminar Schedule

| Date/Time | Speaker | Title |
|---|---|---|
| Tue Sep 27, 2016, 4-5pm EDT (UTC-4) | Stefano Ermon, Stanford University | Measuring progress towards sustainable development goals with machine learning |
| Tue Oct 11, 2016, 4-5pm EDT (UTC-4) | Thomas Dietterich, Oregon State University | Solving MDPs for Ecosystem Management: Lessons Learned |
| Tue Oct 25, 2016, 4-5pm EDT (UTC-4) | Milind Tambe and Eric Rice, University of Southern California | How Can AI be Used for Social Good? Key Techniques, Applications, and Results |
| Tue Nov 8, 2016, 4-5pm EST (UTC-5) | Bistra Dilkina, Georgia Institute of Technology | Network Design Approaches to Multi-species Biodiversity Conservation |
| Tue Nov 29, 2016, 4-5pm EST (UTC-5) | Warren B. Powell, Princeton University | A Unified Framework for Handling Decisions and Uncertainty In Energy and Sustainability |
| Thu Dec 15, 2016, 4-5pm EST (UTC-5) | Daniel Sheldon, University of Massachusetts Amherst and Mount Holyoke College | Advances in Probabilistic Inference and Machine Learning for Ecosystem Monitoring |

**http://www.compsust.net/seminar.php**

# Want to add to the history? Perhaps Grads and Undergrads?

https://en.wikipedia.org/wiki/Computational_sustainability

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## Computational sustainability

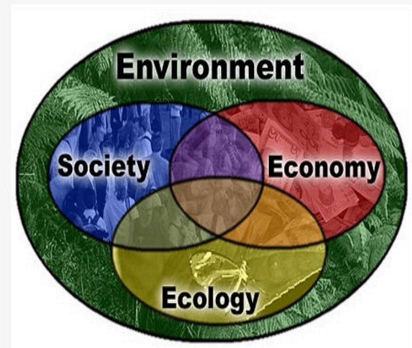
From Wikipedia, the free encyclopedia

**Computational sustainability** is a broad field that attempts to optimize societal, economic, and environmental resources using methods from mathematics and computer science fields.[1] Sustainability in this context is the ability to produce enough energy for the world to support its biological systems. Using the power of computers to process large quantities of information, decision making algorithms allocate resources based on real-time information.[2]

Applications are widespread. Smart grids implement renewable resources and storage capabilities to control the production and expenditure of energy.[3] Intelligent transportation system analyze road conditions and relay information to drivers so they can make smarter decisions based on real time traffic information.[4]

A subtopic of sustainability

**Computational Sustainability**




**Also relevant to:**

Global Warming Renewable Energy Sustainable Development

**Aspects of Computational Sustainability:**

Smart Grid Sustainable Agriculture Intelligent Transportation Systems Sustainability

V • T • E

**Contents** [hide]



← **Limited**

# Artificial Intelligence for Computational Sustainability: A Lab Companion

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https://en.wikibooks.org/wiki/Artificial_Intelligence_for_Computational_Sustainability:_A_Lab_Companion

## Preamble

[edit]

This laboratory companion is designed to introduce students of artificial intelligence (AI) to problems of environmental and societal sustainability, together with projects and problem sets at the intersection of AI and sustainability. The lab text can accompany any primary AI

Search this book

Douglas H. Fisher