Collaborative Mobility: Using Geographic Information Science to Cultivate Cooperative Transportation

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Challenges and opportunities

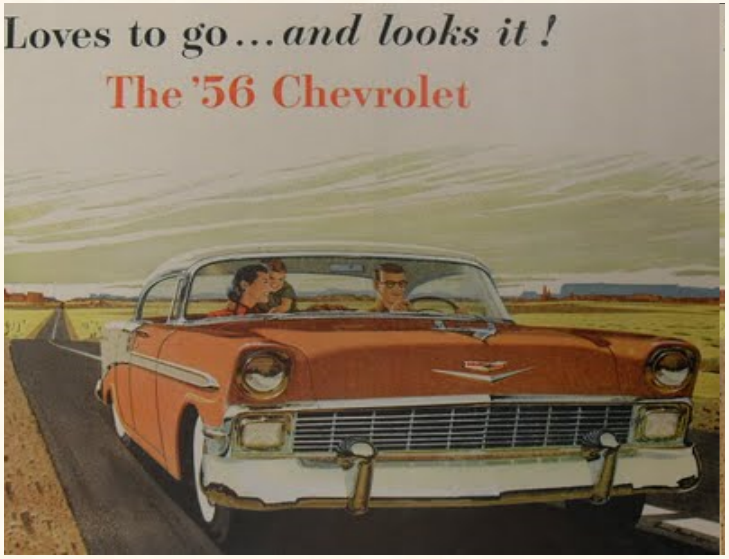
- We live in a time of **unprecedented pressures** on transportation systems

- We also live in a time of **unprecedented opportunities** to:

  - **Understand** transportation systems
  - Cultivate **effective** and **sustainable** transportation outcomes

Transportation challenges

- Transport systems – Good!
  - Mobility
    - We are a highly mobile people!
  - However:
    - Increasing urbanization and motorization
    - Aging infrastructure
    - Flat/declining investment
    - Limits to physical expansion



Transportation challenges

- Transport systems – Bad!
  - Sustainability – transport, cities
  - Public health – air quality, obesity
  - Safety – driving is dangerous!
  - Security – few options creates a brittle system
  - Social equity – extreme commuting, elderly aging-in-place
  - Community – personal contact, social capital

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www.passenlaw.com

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Transportation challenges

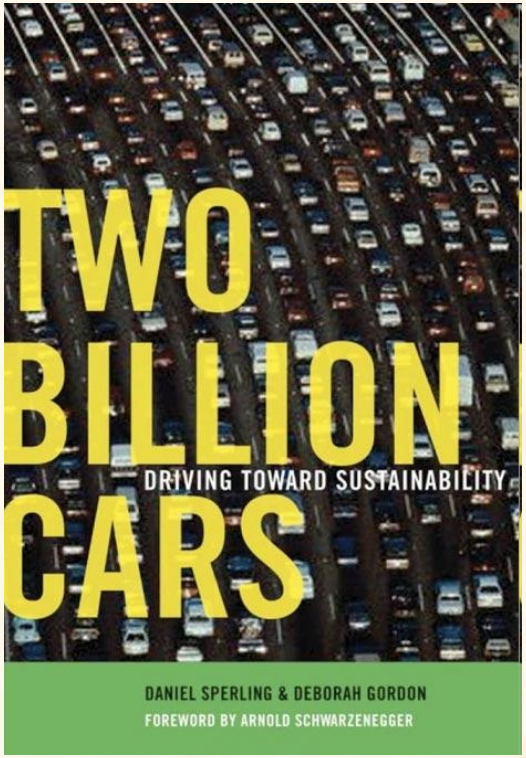
- Collective action failures
  - Game theory
  - Behaviors that are individually rational but collectively irrational
  - Mobility is a great example
    - Individually rational
    - Collective outcomes: congestion, resource depletion, damaged environments, loss of community
    - It gets worse! – Population growth, urbanization in SE Asia, Africa

boxkauto.com

Transportation challenges

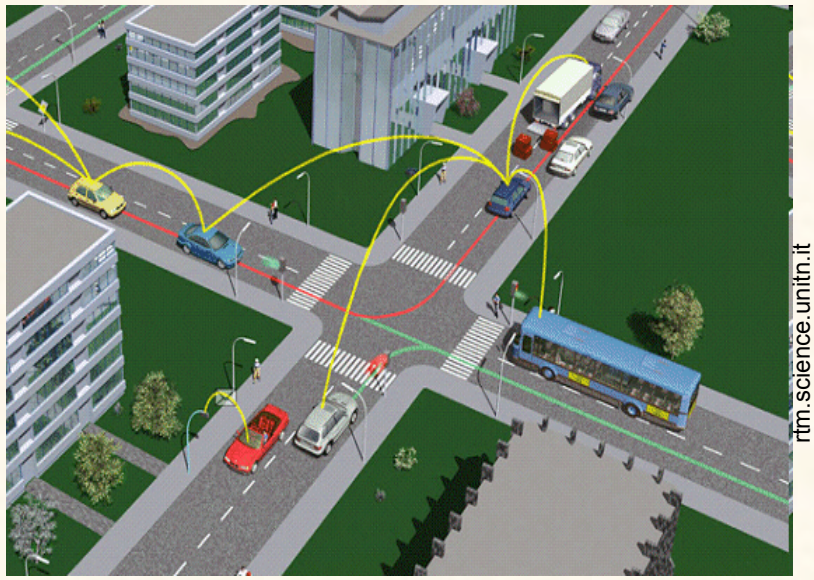
- Transportation monocultures
  - Few mobility options
  - Inflexible - People must adapt to the system
  - Current infrastructure is saturated

- Transportation polyculture
  - Wide spectrum of integrated mobility options
  - Flexible - System adapts to people
  - More efficient and robust



Opportunities

1. Sensed transportation
   - Billions of sensors
     - Vehicles, travelers, and infrastructure
   - Wireless communication
     - Transportation peers, stakeholders and infrastructure
   - Example: Active safety systems
     - USDOT RITA
     - Situation report every 100 Msec
     - Broadcast through Dedicated Short-Range Communications (DSRC)



What should we do with all this information?

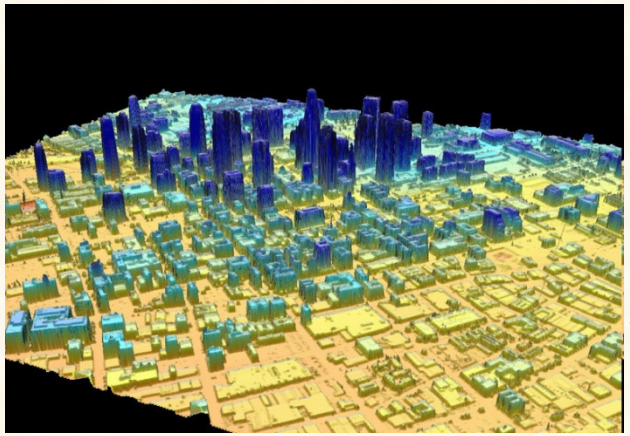
Opportunities

2. GIScience and Technologies

1. **High resolution environmental monitoring** systems such as satellite, airborne remote sensing and geosensor networks

2. **Location-aware technologies** that can report their precise geo-location densely with respect to time

3. **Spatio-temporal** and **moving objects** databases



www.saic.com

LIDAR imagery

lifehacker.com

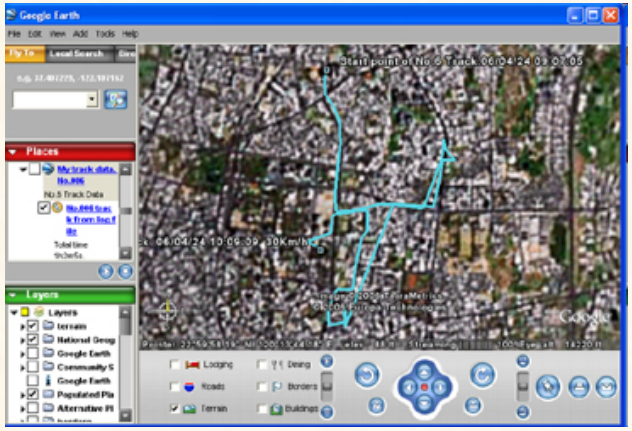
iPhone!

Opportunities

4. Science and tools for **exploring** and analyzing **massive spatio-temporal data**.

5. Tools for **simulating** transportation, urban and other human systems from the **"bottom-up"**

6. Data standards and infrastructures for **integrating** and **interoperating** data.



Space-time trajectories - real 205.134.232.209

Space-time trajectories - simulated www.anl.gov

Opportunities

3. Social computing

- Weak definition: Using ICTs to facilitate social behavior
- Strong definition: Social information processing - Creation and processing of information through a networked social system

www.perfectcirclepr.co.uk

- Volunteered Geographic Information?
  - "Citizens as sensors"
  - Groups as sensors? – can collaborative groups produce different geo-info than collectives?

Opportunities

- Social computing and cooperation
  (Clay Shirky – Here Comes Everyone)
  - Group formation
    - Many to many communication
  - Group coordination
    - Sharing – Easy: Group is simply an aggregation
    - Cooperation – Harder: Joint synchronization of behaviors
    - Collective action – Hardest: shared creation and responsibility

Cooperative transportation

- What is cooperative transportation?
  - Stakeholders and travelers
    - Share transportation information and resources
    - Cooperate to solve operational problems
    - Use collective action to solve tactical and strategic issues
  - Multiscale decision-making
    - Local/operational: How will we get to work today?
    - Regional/strategic: What do we want our community to look like in 20 years?

www.cityhop.co.nz

Cooperative transportation

- Why cooperative transport? (a partial list)
  - Improve private transportation
    - Wasted capacity
  - Improve public transportation
    - "Last mile, " quasi-public transportation
  - Coordinate multi-modal transportation
    - Currently: loosely-coupled systems
  - Crowdsourcing and self-organization
    - The crowd can be wiser than the few
  - Inclusive planning
    - Engaged citizens = less NIMBYism?
    - Example: Envision Utah (www.envisionutah.org)

Traffic cam image from Salt Lake City

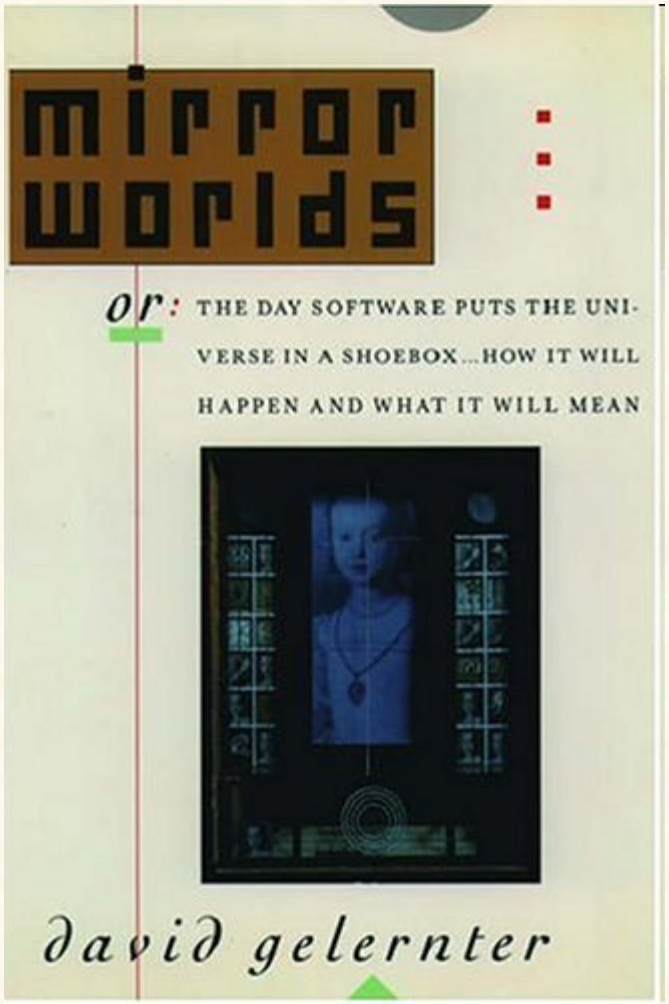
Cooperative transportation

- Transport 2.0
  1. Seamless, multimodal system
     - Web of integrated transport services
     - More providers and stakeholders
     - Multifaceted public sector
  2. **Cooperative decision environment**
     - Navigate, solve problems, explore, engage
     - Group-forming and group-organizing tools

Illustration by Fred Estrada, ESRI

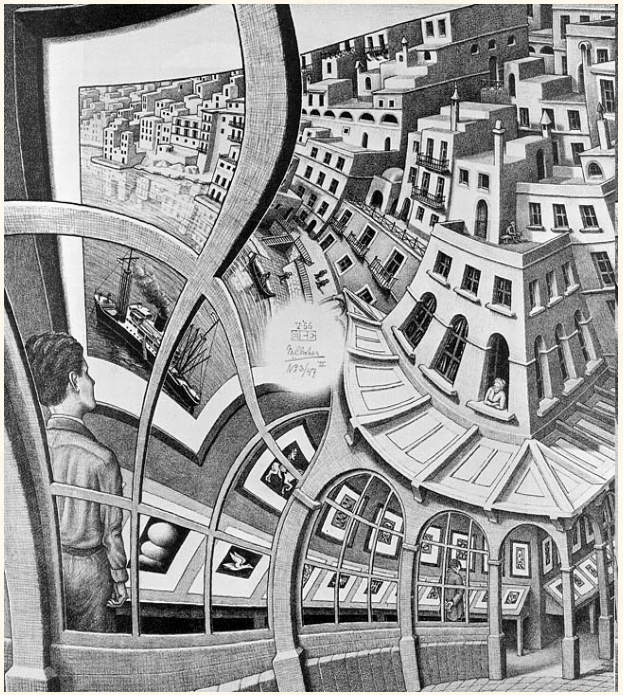
Mirror worlds

- A **real-time, comprehensive, detailed, interactive** and **discoverable portrayal** of a complex **real-world system.**
- Not an alternative reality but a **reflection of reality** that is **tightly coupled to the real-world.**
- A tool for investigating and managing reality
  - Help managers, citizens, users understand and manage real world systems



Mirror worlds

- What is a mirror world?
  - **A live picture**
    - A **comprehensive** depiction of the state of a complex system in **real time**
  - A deep picture
    - An **integrated** representation with **varying levels of detail**
  - Agents
    - **Extract, process and report** information
    - Make **simple decisions**
  - A sense of experience
    - Search and retrieve **information**
    - **Previous** and **analogous states**



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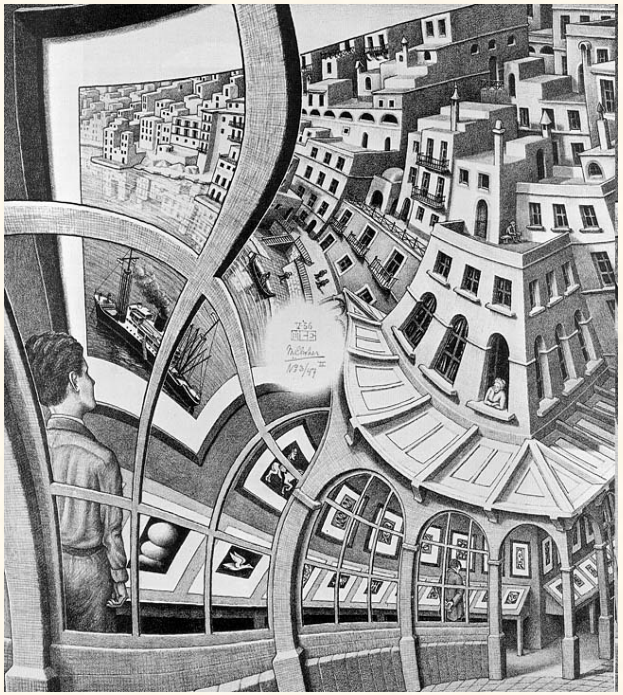

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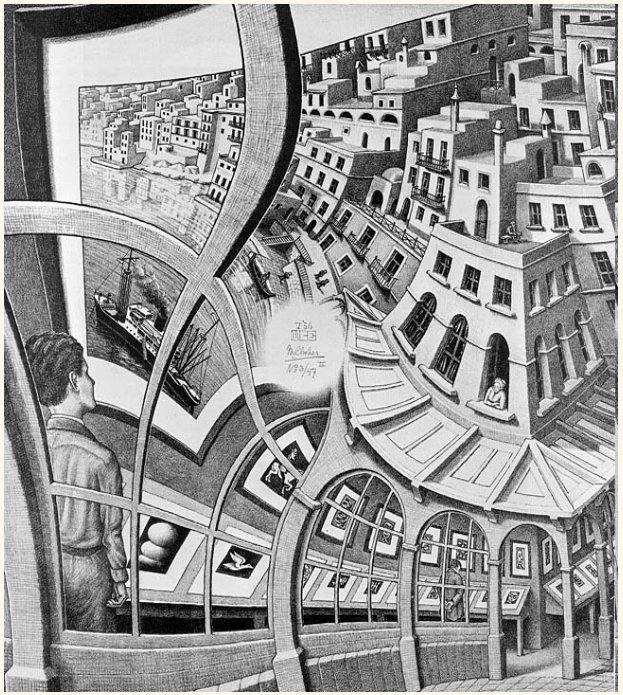

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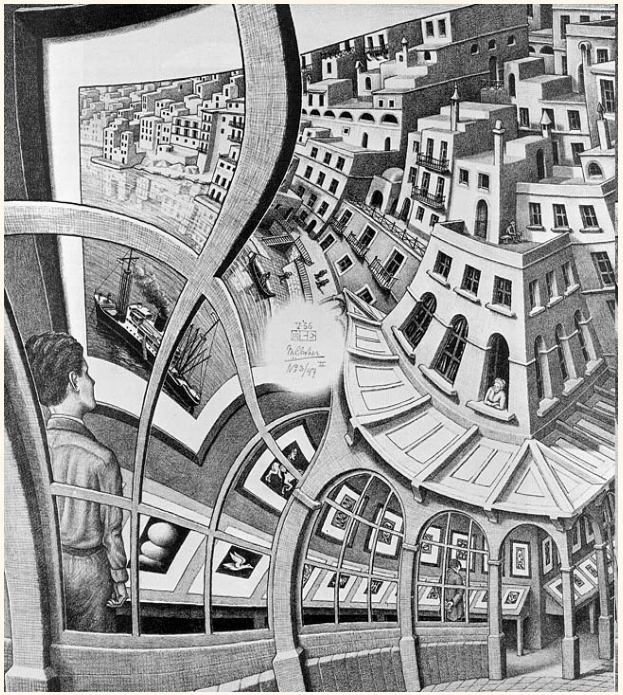

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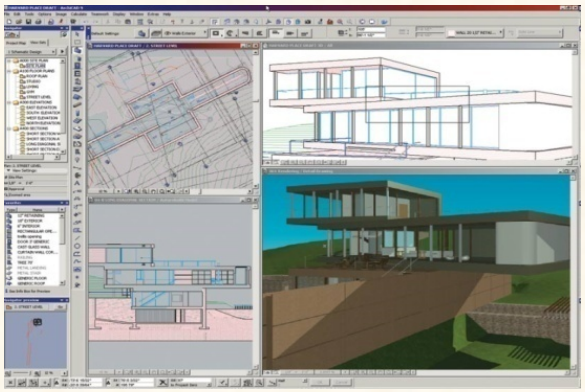
Mirror worlds

- Why *Mirror Worlds*?
  - Managing complex systems
    - Shared problem-solving and self-organization
  - The new public square
    - E-government
  - The new conference room
    - Building Information Models
  - The new laboratory
    - Role playing experiments

blog.seattlepi.com



www.cadalyst.com

www.futuretimeline.net

Mirror worlds

- Mirror Worlds: Not just another…
  - Spatial decision support system
    - Exploratory questions
    - Ongoing engagement -> Greater insight
    - Shared awareness (Clay Shirky)
      - Awareness plus awareness of awareness
  - Grand simulation environment
    - Predict the present (Hal Varian; Duncan Watts)
      - Why plan based on predictions of complex systems?
      - Understand the present; plan to maximize good options

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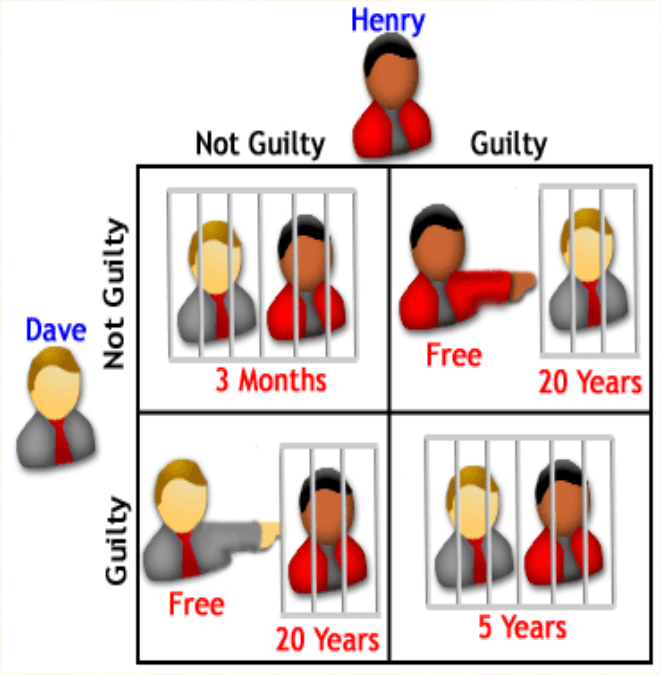
www.edc.ncl.ac.uk

Thinking spatially about cooperation

- Why GIScience and cooperative transportation?
  - Trivially – transportation is geographic
    - But geospatial infrastructure issues are not!
  - Mirror Worlds are very geographic
    - Geo-sensors + Digital Earth + LBS + SDSS + GKD + social computing
  - Is cooperation spatial (and temporal)?
    - Are there fundamental GIScience issues in facilitating cooperative behavior?

Thinking spatially about cooperation

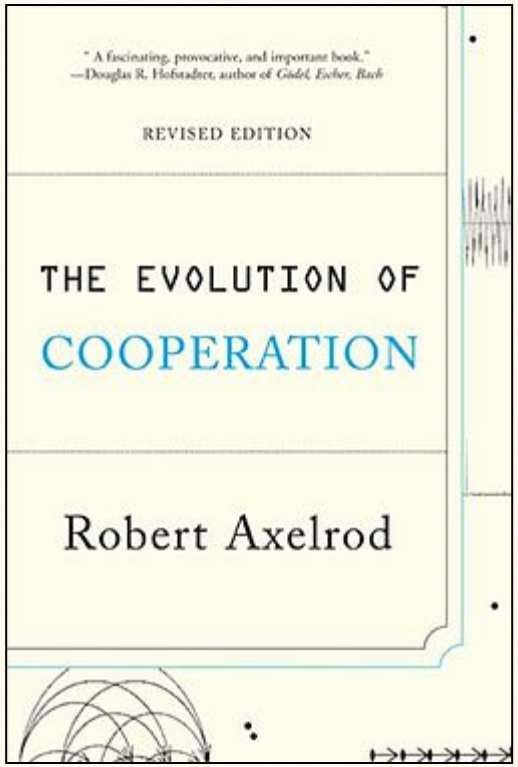
- Competition and cooperation
  - Prisoner's Dilemma
    - Game theory
    - Fundamental model of competition versus cooperation
  - Optimal strategy: both defect
    - Nash equilibrium
    - No cooperation, even though it would be better for both!



aaroneo.com

Thinking spatially about cooperation

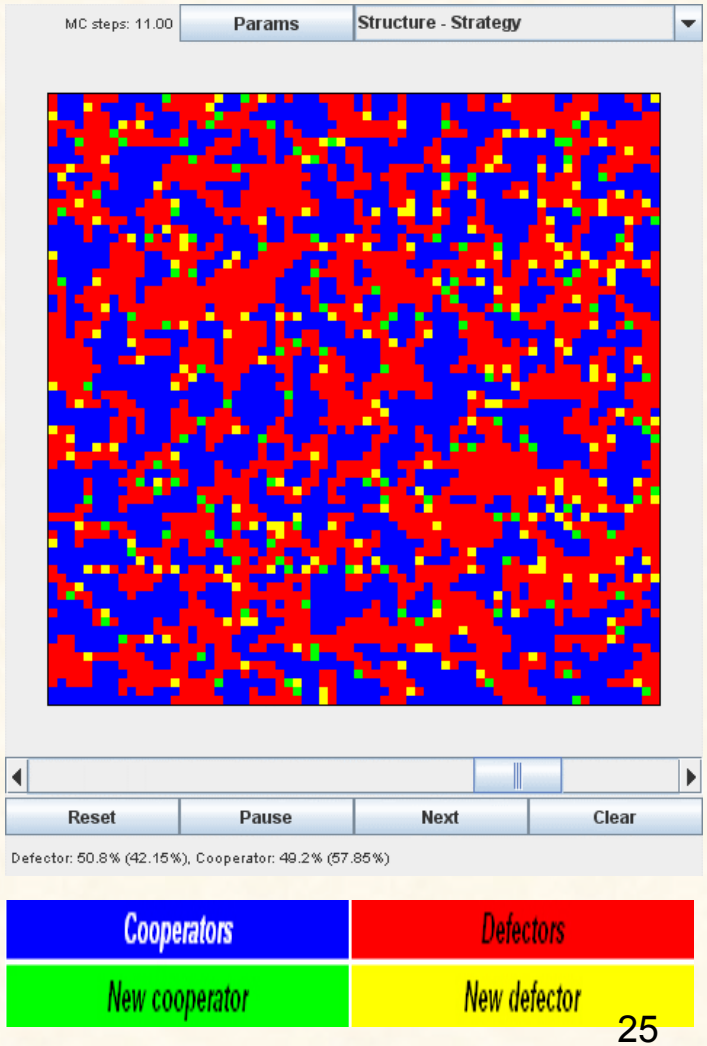
- Cooperation across time
  - Iterated Prisoner's Dilemma (IPD)
    - Repeated play over time
    - Knowledge of past plays – reputation
  - Robert Axelrod's tournament
    - Altruistic strategies perform better than greedy strategies
      - Tit-for-Tat, Pavlov
    - Be nice, but not too nice, forgiving and transparent



Thinking spatially about cooperation

- Cooperation across space
  - Spatial Prisoner's Dilemma
    - Evolutionary game - inheritance
    - Lattice structure
    - Defectors win in a "well-mixed" population
    - Space facilitates cooperation
      - Limits interactions to neighborhoods
      - Allows clusters of mutual cooperation

www.univie.ac.at/virtuallabs



Thinking spatially about cooperation

- Cooperation across space
  - Beyond lattices
    - Cooperation depends on spatial structure relative to benefit/cost ratio
  - Why?
    - Kin selection: Interactions of "related" individuals
  - Other comments
    - Parameter space for cooperation can be small
    - Complex dynamics are typical

$$\frac{\text{benefit}}{\text{cost}} > \#\text{neighbors} \rightarrow \text{cooperation}$$

Amazingly simple rule due to biologist Martin Nowak

Thinking spatially about cooperation

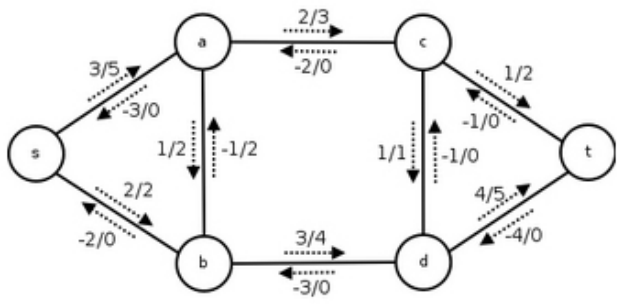
- Other spatial Prisoners' Dilemmas
  - Social/dynamic networks (Fehl et al 2011 *Ecology Letters*)
    - Players can break links after bad interactions
    - Co-evolution of behaviors and social networks
  - Continuous PDs (Ifti et al. 2004 *J Theoretical Biology*)
    - Players have degrees of cooperation
    - Neighborhood size, topology are critical
    - Cooperation robust, to a limit
- Neighborhoods: Fundamental units of cooperation
  - Space, time and networks

Thinking spatially about cooperation

- Neighborhoods in cooperative transportation
  - Are there natural units of cooperation?
    - Home, work? The routes between?
    - The highway I am currently traveling?
    - People with similar patterns?
    - Cities, regions?
  - What type of neighborhoods do we need?
    - Operational, tactical, strategic decisions
  - How do we facilitate neighborhoods using geographic information?
    - Group forming and coordination
    - Shared awareness

Thinking spatially about cooperation

- Cooperation in transportation science
  - User optimal (UO) flow
    - Travelers minimize average cost
    - Everyone travels on minimum cost route
  - System optimal (SO) flow
    - Travelers minimize marginal cost
    - Not everyone travels on minimum cost route
    - Coercion or cooperation



  - Only a small number of travelers need to be "pro-social" (Avineri 2009)

Conclusion

- Humanity is facing dire collective failures in the 21st century
  - Mobility is a prime example, but not the only one
- Some failures can be resolved through cooperative behavior
  - Better collective outcomes, but requires compromise
- Locational information/services and social media have potential for facilitating collaborative systems
  - LBS: Shapes interactions across time, space and network
  - Social media: Group forming, coordination and shared awareness

Research challenges

- Cooperation science
  - Under what conditions will people cooperate?
  - What are the limits of cooperation?
    - How many need to cooperate?
  - What else can we discover about the geography of cooperation?
    - Spatial and temporal expressions
      - What are the natural units of cooperation in different contexts?
    - The role of geographic information and knowledge
      - Can spatio-temporal thinking facilitate cooperation over space and time?

Research challenges

- Pervasive geographic information
  - How do we deploy and support location aware technologies and services?
  - Is there a business model for collaboration?
    - Or is it a public good?
  - How do we deal with varying data quality?
    - Including volunteered geographic information
  - How do we protect locational privacy?
  - How will people react to unprecedented access to geographic information?

4. Conclusion: Research challenges

- Spatio-temporal knowledge delivery
  - Three facets of Big Data
    - Volume, scope and **speed**
  - How do we act quickly enough?
    - Before the data are stale
  - Technical and conceptual dimensions
    - Technical: Detecting patterns quickly
    - Conceptual: Making appropriate decisions quickly
      - Measure and nudge (instead of predict and constrain)
        - Predict the present (Hal Varian, Duncan Watts)
        - Choice architectures (Thaler and Sunstein)

4. Conclusion: Research challenges

- Educating the scientist and practitioner
  - New science, technologies and data will place unprecedented demands on education
  - What is the appropriate mix of transportation science, computer science and GIScience?
  - Both foundational and continuing education
    - Everyone – academic and practitioner – will need to continually re-educate throughout their careers

Thank you! harvey.miller@geog.utah.edu

- Some readings
  - De Waal, F. (2010) The Age of Empathy: Nature's Lessons for a Kinder Society
  - Miller, H. J. (2008) "Transport 2.0: Meeting Grand Challenges with GIScience," ArcNews, Winter 2008/2009.
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