Transportation: Computing Opportunities & Challenges

Shashi Shekhar

McKnight Distinguished University Professor

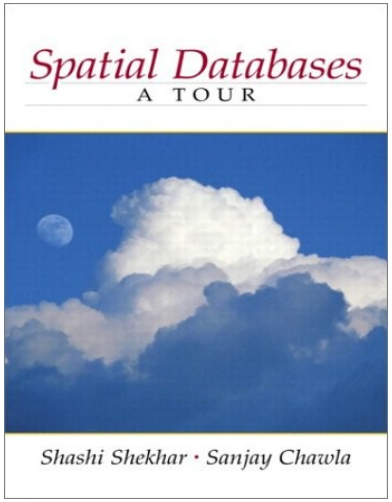
University of Minnesota

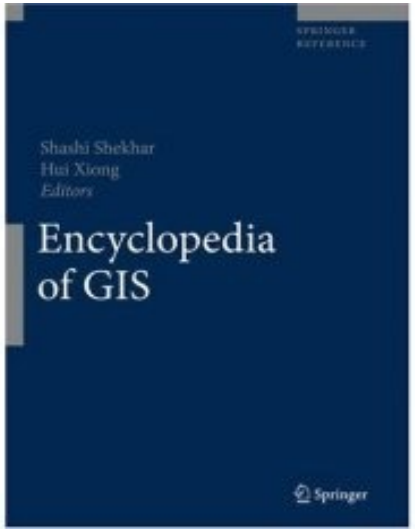
www.cs.umn.edu/~shekhar

USDOE ORNL Workshop on Virtualizing Energy

Fall Creek Falls 2011

September 14rth 16 d, 2011.





Spatial Computing: Where I Come From?

Microsoft Virtual Earth

ESRI ArcGIS

IBM Smarter Planet

Google Earth

acm GIS

SIG SPATIAL

Spatial Statistics

BRIAN D. RIPLEY

WILEY SERIES IN PROBABILITY AND STATISTICS

ORACLE SPATIAL

Spatial Databases
A TOUR

Shashi Shekhar · Sanjay Ch

12th International Symposium on Spatial and Temporal Databases
Minneapolis, MN, USA August 24th – 26th, 2011
The Digital Technology Center at the University of Minnesota

SSTD 2011

GeoInformatica

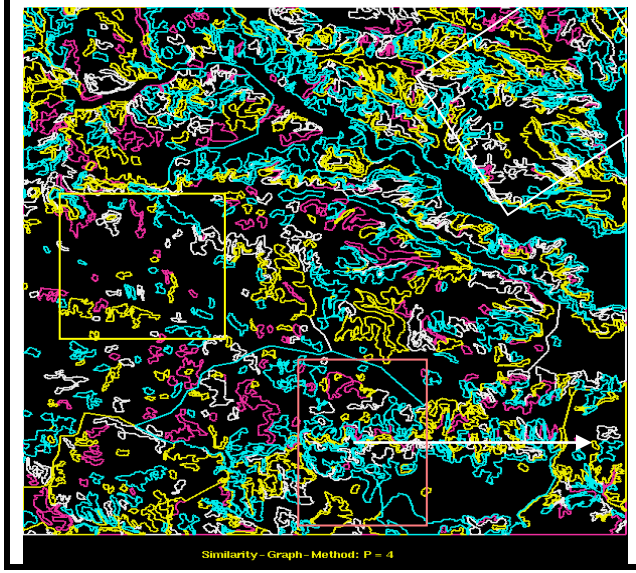
Volume 14, Number 1, January 2010

Springer

GIS
A Computing Perspective
Second Edition

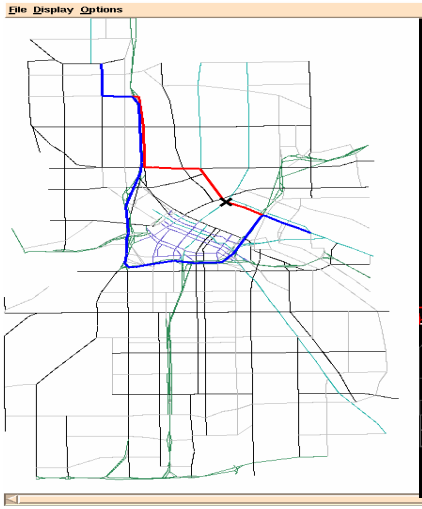
Michael Worboys
Matt Duckham

Spatial Databases: Representative Projects

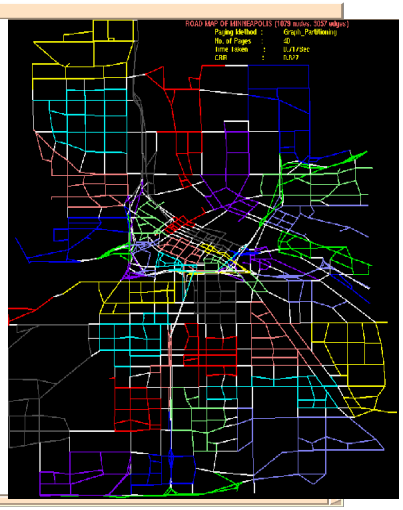


Parallelize Range Queries

Shortest Paths

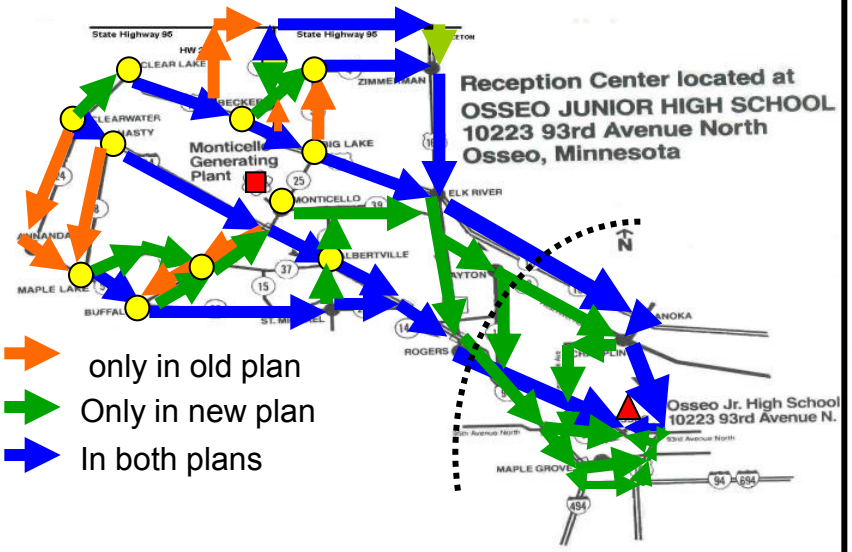


Storing graphs in disk blocks



Evacuation Route Planning

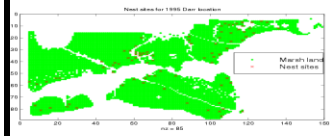
Sustainable Transportation for Disasters



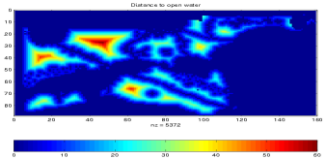
Spatial Data Mining : Representative Projects

Location prediction: nesting sites

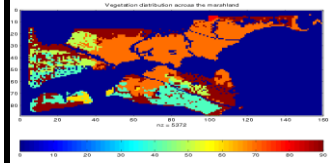
Nest locations



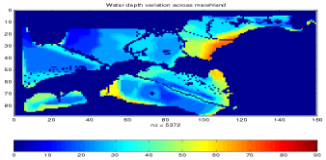
Distance to open water



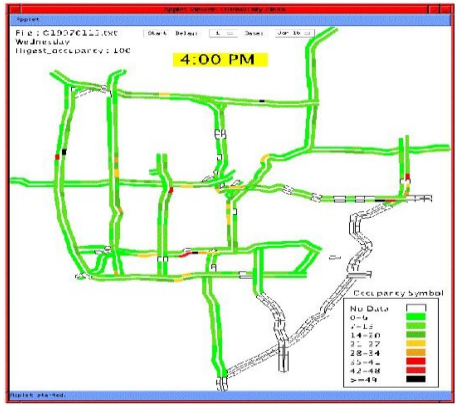
Vegetation durability

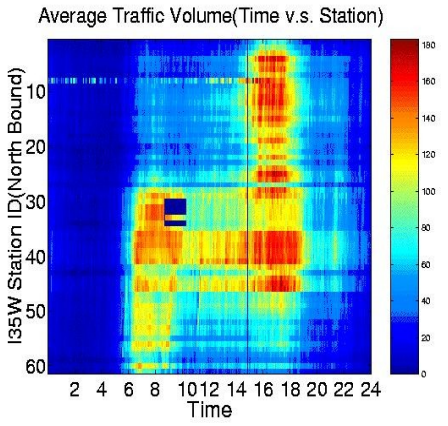


Water depth

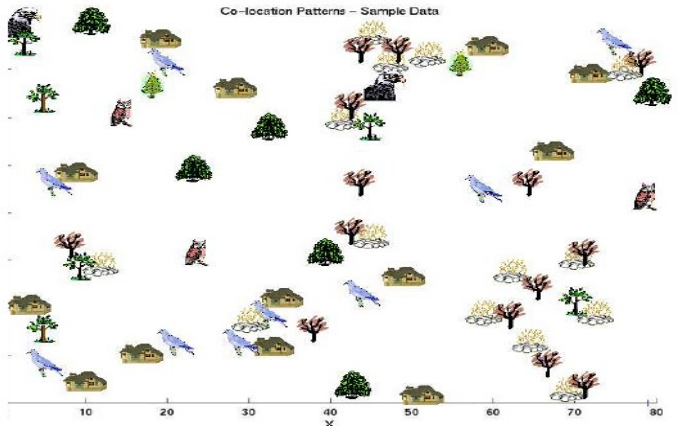


Spatial outliers: sensor (#9) on I-35

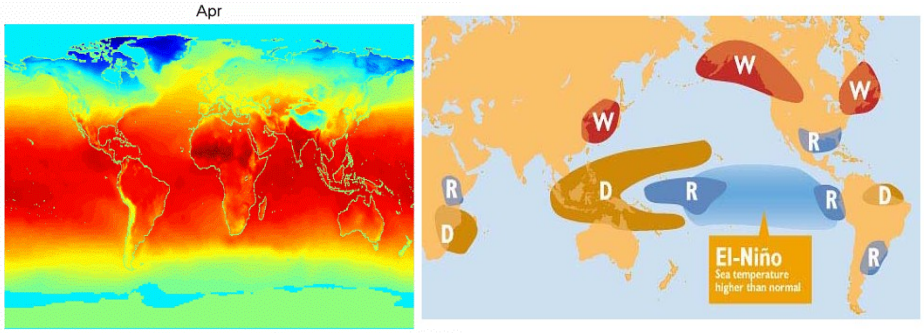




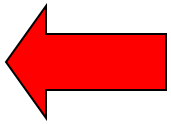
Co-location Patterns



Tele connections



Outline

- My Background: Spatial Computing
- Transportation Science 
- Transportation & Energy Independence
- Eco-Routing
- Summary

Transportation Questions

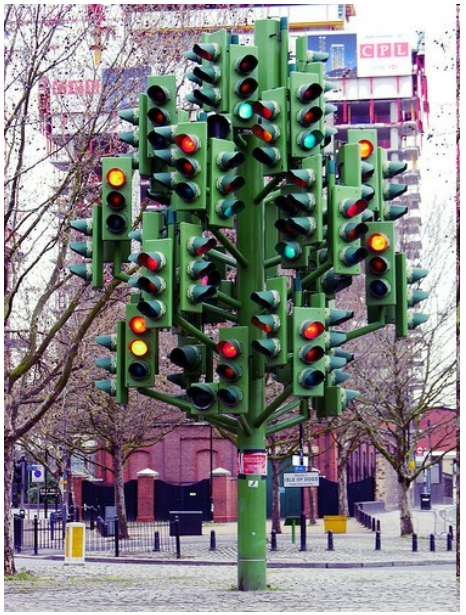
- Traveler, Commuter
  - What will be the travel time on a route?
  - Will I make to destination in time for a meeting?
  - Where are the incident and events?
- Transportation Manager
  - How the freeway system performed yesterday?
  - Which locations are worst performers?
- Traffic Engineering
  - Which loop detection are not working properly?
  - Where are the congestion (in time and space)?
  - How congestion start and spread?
- Planner and Researchers
  - What will be travel demand in future?
  - What will be the effect of hybrid cars?
  - What are future bottlenecks? Where should capacity be added?
- Policy
  - What is an appropriate congestion-pricing function ?
  - Road user charges: How much more should trucks pay relative to cars?

Theories in Transportation Domain

- Physics
  - Traffic: Fluid flow models (e.g. reduce turbulence), control theory
  - How to reduce icing on pavements?
- Chemistry
  - Environmental impact (e.g. salt, incomplete combustion)
- Biology
  - How to reduce crash-injury severity?
  - Effect of age, sleep deprivation, toxins, …
- Psychology
  - Human factors: design of highway signage, vehicle dashboard
  - Activity and agent based models
- Sociology
  - Household decisions, Homophily and social networks
  - Lack of trust => aggressive driving
- Economics, Game Theory
  - Incentive mechanisms
  - Wardrop equilibrium among commuters
    - Ex. All comparable paths have same travel time!

Limitations of Transportation Theories

- Multi-disciplinary questions:
  - Will hybrid cars reduce environmental impact of transportation?
  - Extreme events – evacuation, conventions, …
  - Impact of context – weather, climate, economy, politics, crime, police cars, …
- Mono-disciplinary questions
  - Non-equilibrium phenomena, e.g. location, time and path
  - Critical places & moments: Accident hotspots (hot-moments)? Why?
  - Normality & anomalies: e.g. traffic flow discontinuities – location, cause
  - Regional difference: effectiveness of Ramp meters across places & time-periods

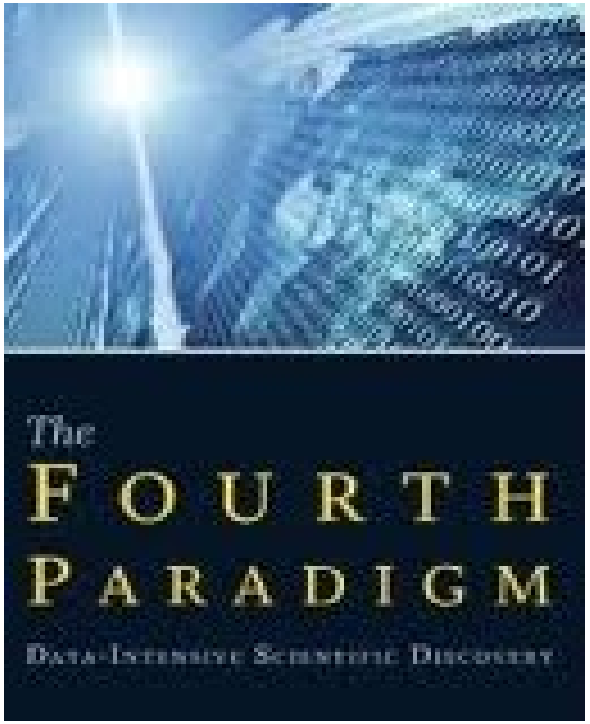


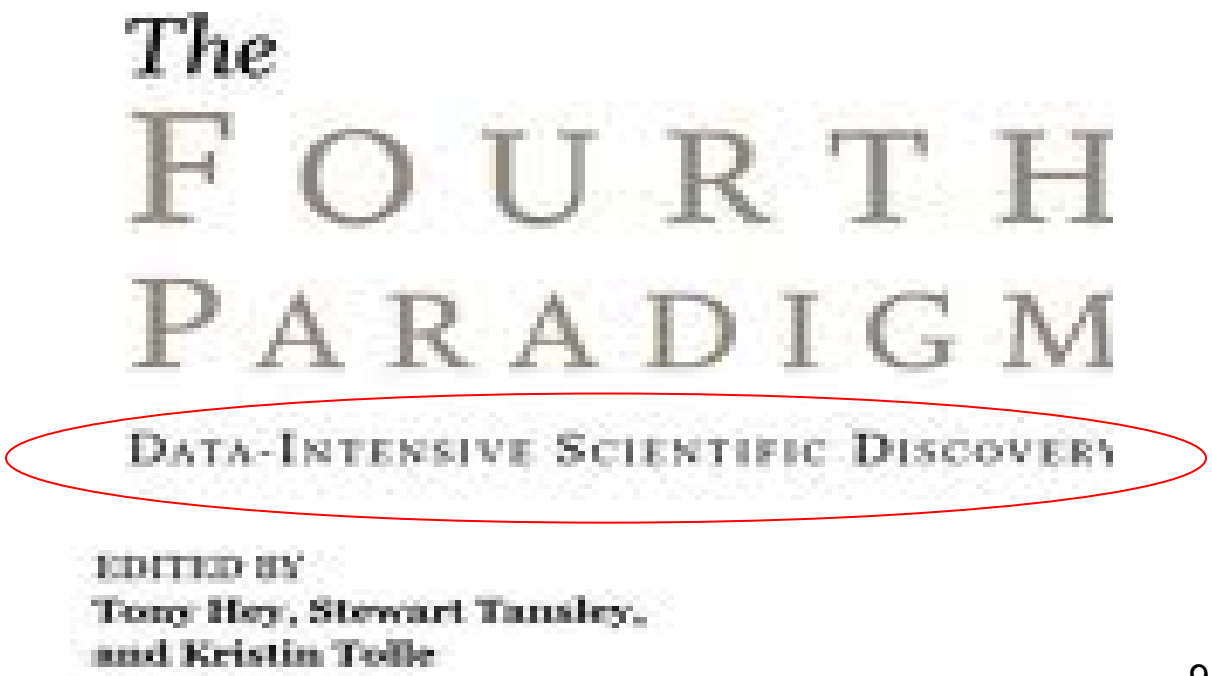
- What are the **options** to complement theory based approaches?

Data-Intensive Scientific Discovery

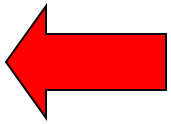
- Classical Approach
  - Travel diaries, NHTS survey (OD matrix), Lab. (mpg rating)
  - Hypothesis driven data collection, Statistical hypothesis testing

- Emerging Data-Intensive Approach
  - Secondary Data: Engine computer, gps, cell-phones, face-book,VGI,
  - Exploratory data analysis for hypothesis generation
  - Ex. Data Mining and Knowledge Discovery





Outline

- My Background: Spatial Computing
- Transportation Science
- Transportation & Energy Independence 
- Eco-Routing
- Summary

Transportation: A Major Energy Consumer

- Energy Consumption
  - 20 to 30% in transportation
  - >= 20,000 TWh
  - Growing car ownership

World energy use per sector[51]				
	2000	2008	2000	2008
	TWh		%*	
Industry	21,733	27,273	26.5%	27.8%
Transport	22,563	26,742	27.5%	27.3%
Residential and service	30,555	35,319	37.3%	36.0%
Non-energy use	7,119	8,688	8.7%	8.9%
Total*	81,970	98,022	100%	100%

Source: IEA 2010, Total is calculated from the given sectors

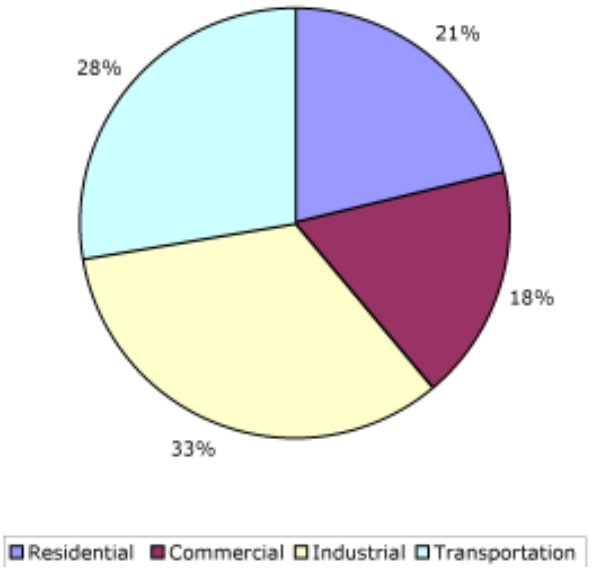
Numbers are the end use of energy

Total world energy supply (2008) 143,851 TWh

Transportation (21% in US)

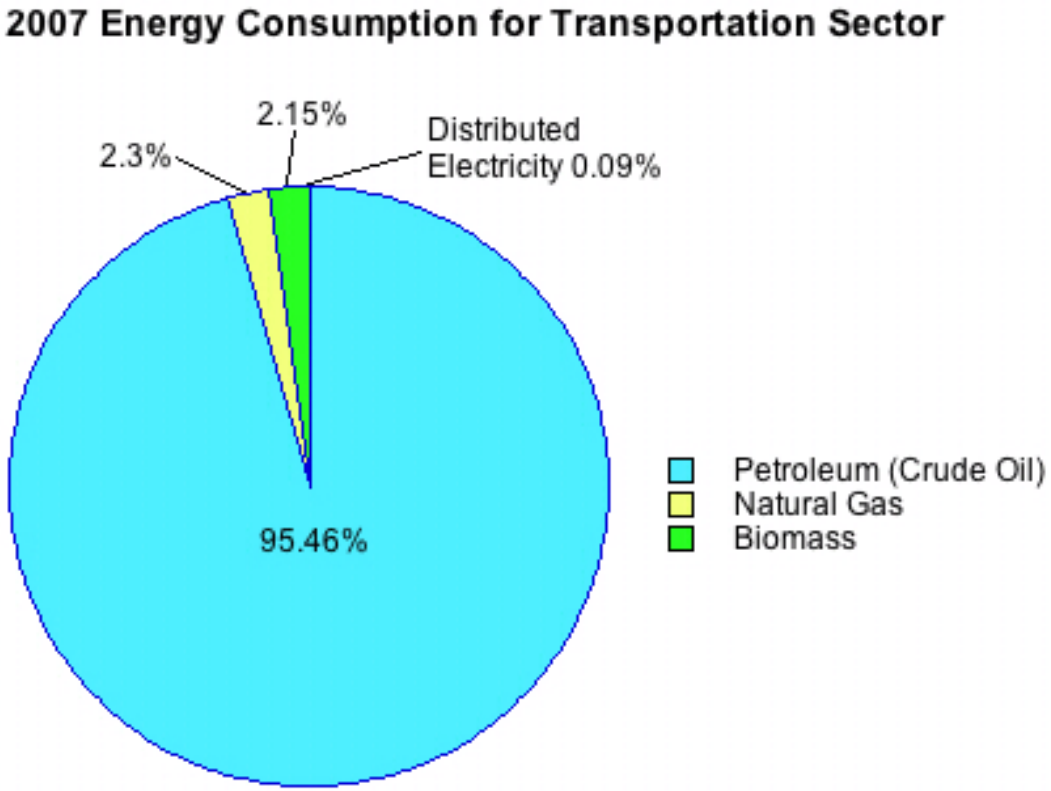
2004 US Primary Energy by Sector

Source: http://www.eia.doe.gov/emeu/aer/consump.html



Transportation Energy Source = Petroleum!

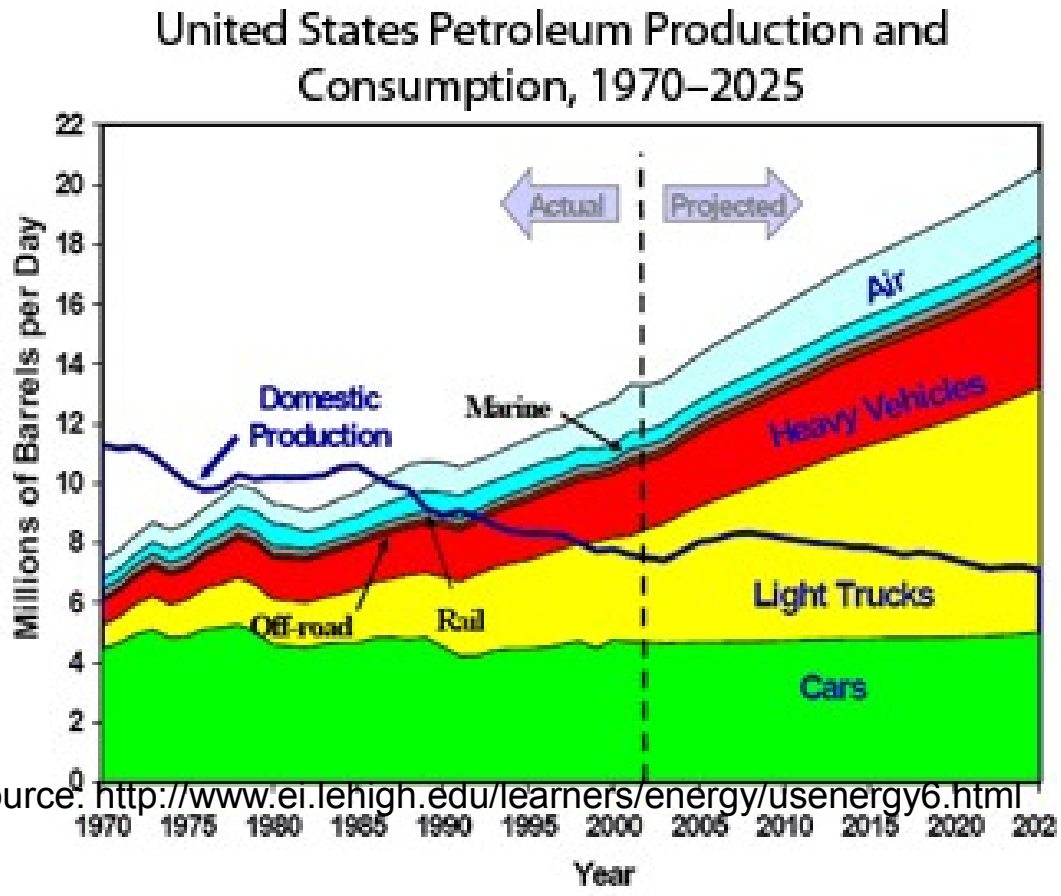
- Transportation energy source
  - Petroleum > 95%
  - consumption > production
    - Large & growing import
    - From volatile regions
- Concerns
  - Economic
  - National Security
- Approaches
  - Long-term: Alternative fuel
  - Short-term: Reduce waste using big-data!



Source: http://www.ei.lehigh.edu/learners/energy/usenergy6.html

Transportation Energy Source = Petroleum!

- Transportation energy source
  - Petroleum > 95%
  - consumption > production
    - Large & growing import
    - From volatile regions
- Concerns
  - Economic
  - National Security
- Approaches
  - Long-term: Alternative fuel
  - Short-term: Reduce waste using big-data!



Source: http://www.ei.lehigh.edu/learners/energy/usenergy6.html

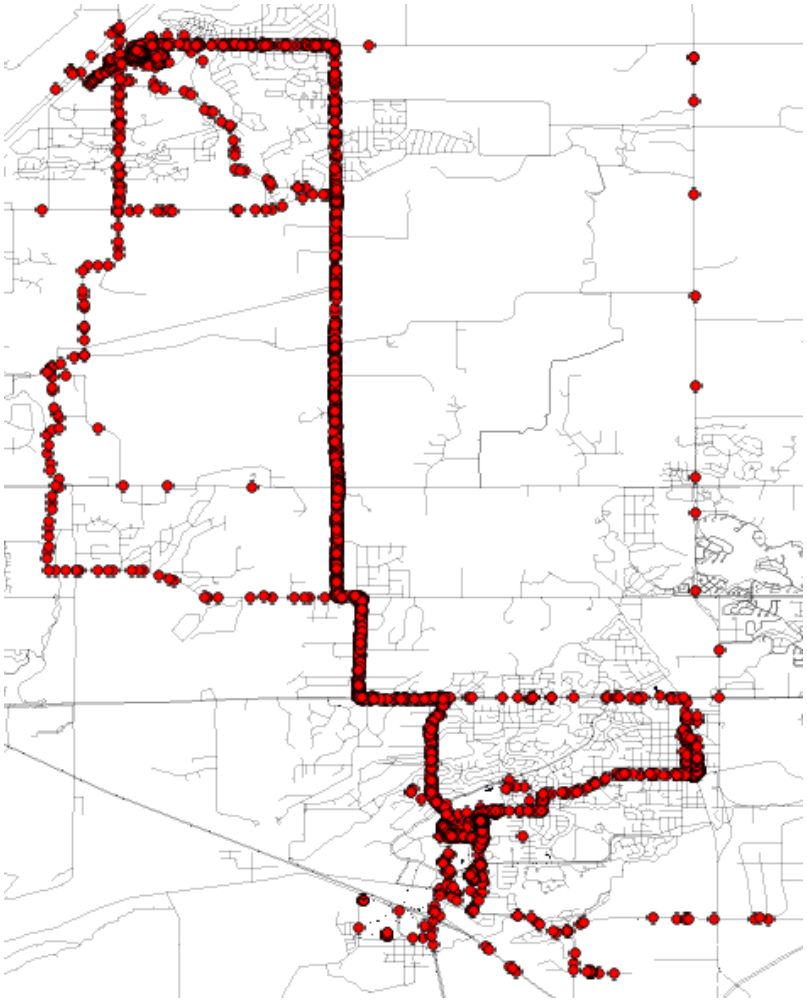
Big Data: Hope to reduce Fuel Waste

- Trajectories
  - GPS, cell-phone,
  - Automatic tolling transponder
  - Automatic Vehicle Location, …
- Other Datasets
  - Loop-detectors: traffic volume, density, occupancy, …
  - Traffic camera - videos
  - Reports on accidents, traffic law violation
  - Travel diaries and surveys
  - Traffic simulator (e.g. DYNASMART) outputs
  - Other sensors: bridge strain, visibility (in fog), ice, …
  - Yellow Pages, street addresses

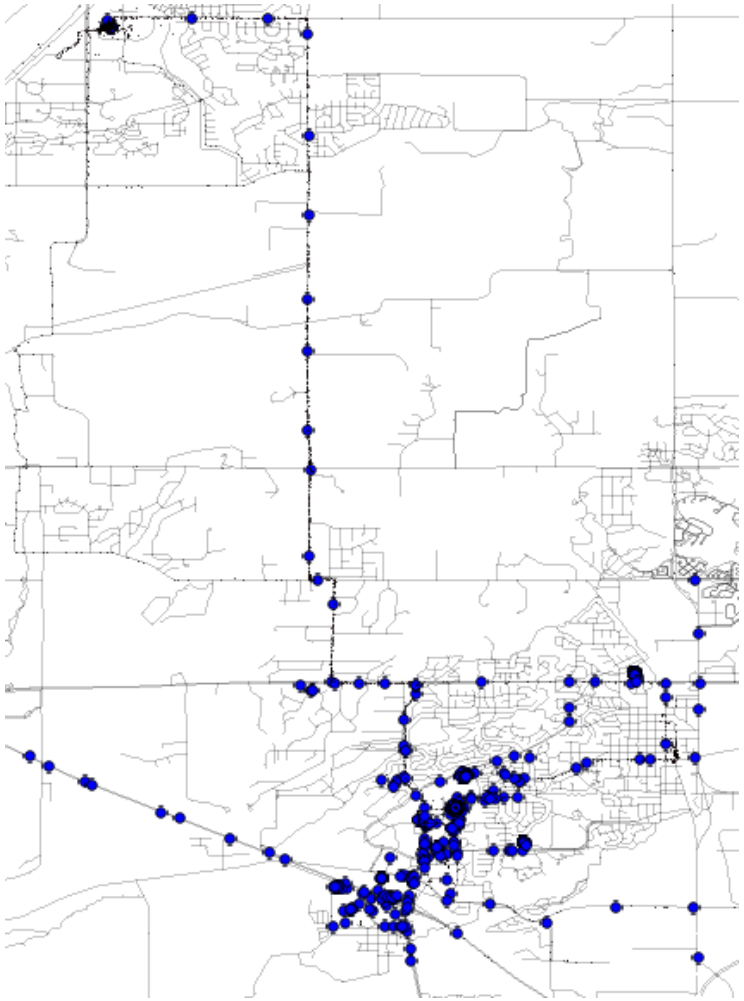
Big Data: Trajectories

Growing popularity of smart-phones and in-vehicle navigation devices
These provide new trajectory datasets, which can help reduce gasoline waste!

Example GPS Track (3 Months, 1 Person)

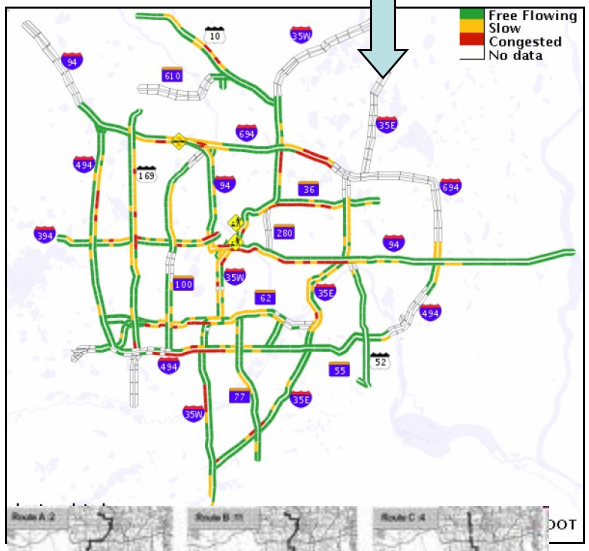


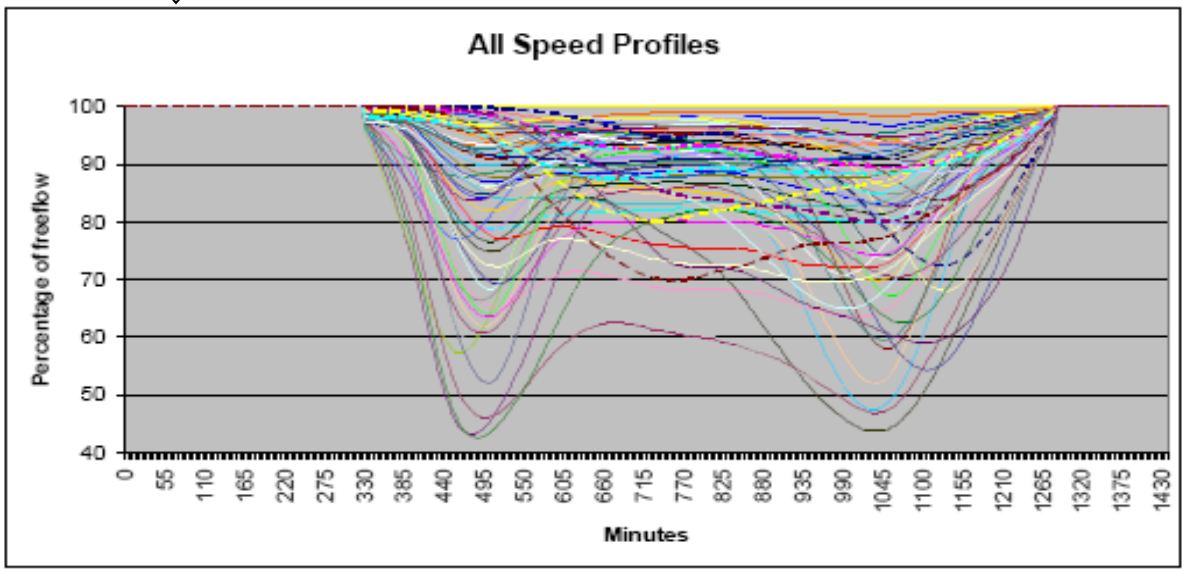
Monday - Friday



Saturday - Sunday

Big Data: Real-time and Historic Travel-time





FT_DailyHistoricData

EID	Freeflow Speed	Weekday Speed	Weekend Speed	Sun	Mon	Tue	Wed	Thu	Fri	Sat
1	.....	.....	.....	.....	.....	.....	.....	.....	.....	
2	.....	.....	.....	.....	.....	.....	.....	.....	.....	
3	.....	.....	.....	.....	.....	.....	.....	.....	.....	
4	.....	.....	.....	.....	.....	.....	.....	.....	.....	
5										S

Historic Daily Speed Profile Table

Speed_0	Speed_1	.....
		.....
		.....

Big Data: Opportunity Size

McKinsey Global Institute

The study estimates that the use of personal location data could save consumers worldwide more than $600 billion annually by 2020. Computers determine users' whereabouts by tracking their mobile devices, like cellphones. The study cites smartphone location services including Foursquare and Loopt, for locating friends, and ones for finding nearby stores and restaurants.

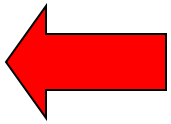
But the biggest single consumer benefit, the study says, is going to come from time and fuel savings from location-based services — tapping into real-time traffic and weather data — that help drivers avoid congestion and suggest alternative routes. The location tracking, McKinsey says, will work either from drivers' mobile phones or GPS systems in cars.

The New York Times

New Ways to Exploit Raw Data May Bring Surge of Innovation, a Study Says

Published: May 13, 2011

Outline

- My Background: Spatial Computing
- Transportation Science
- Transportation & Energy Independence
- Eco-Routing 
- Summary

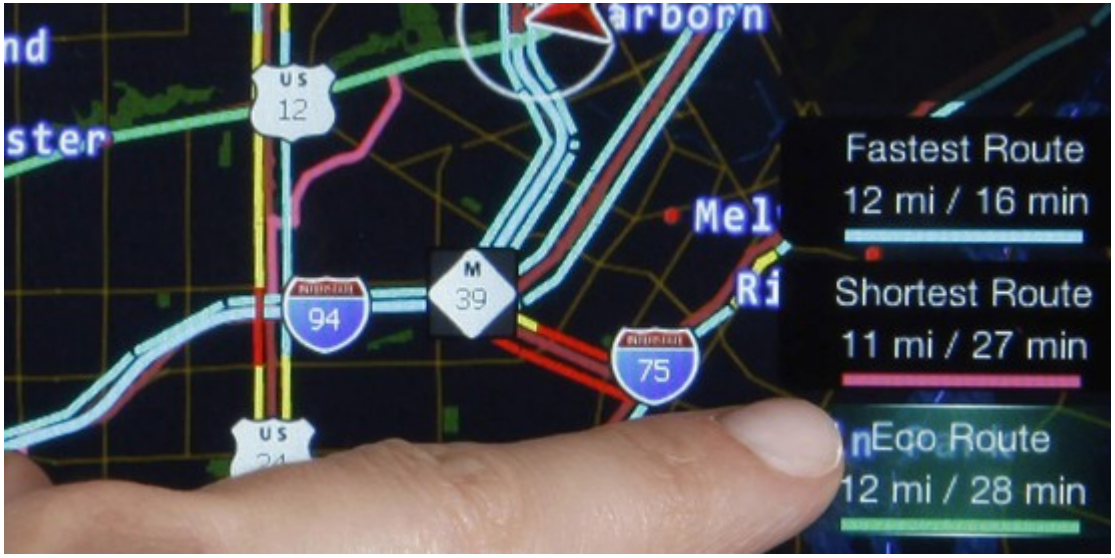
Eco-Routing

The New York Times

U.P.S. Embraces High-Tech Delivery Methods (July 12, 2007)

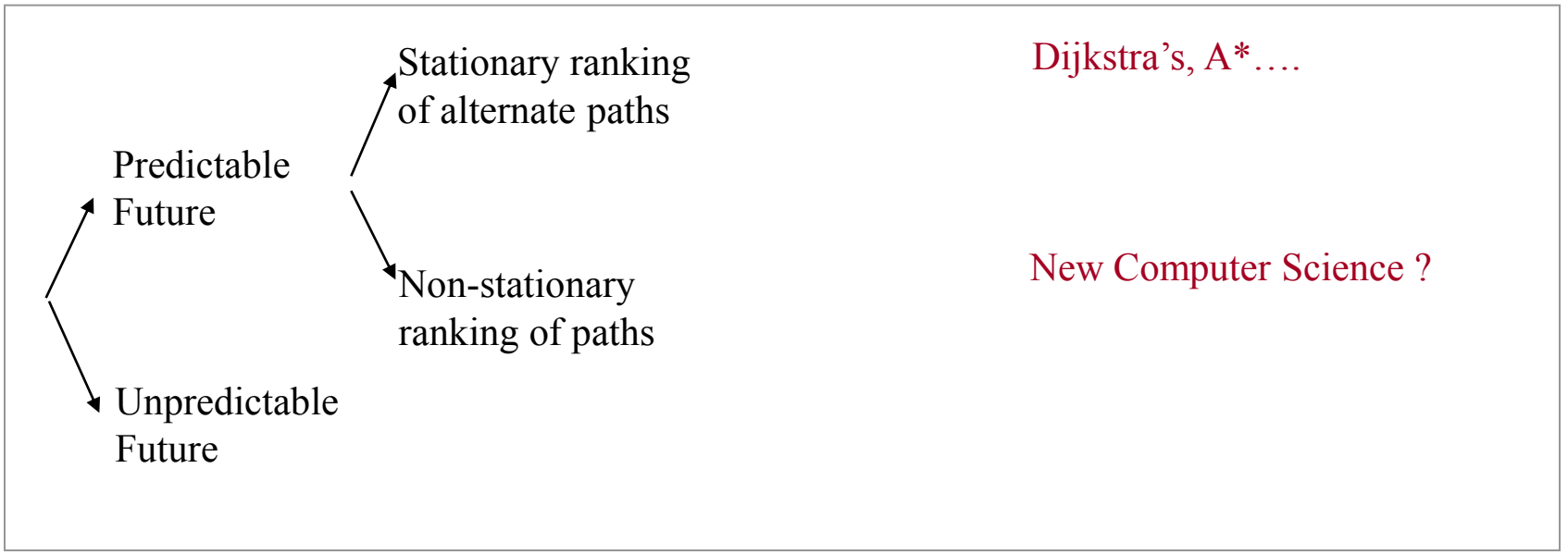
By "The research at U.P.S. is paying off. ……— saving roughly three million gallons of fuel in good part by mapping routes that minimize left turns."

- Minimize fuel consumption and GPG emission
  - rather than proxies, e.g. distance, travel-time
  - avoid congestion, idling at red-lights, turns and elevation changes, etc.



Eco-Routing Questions

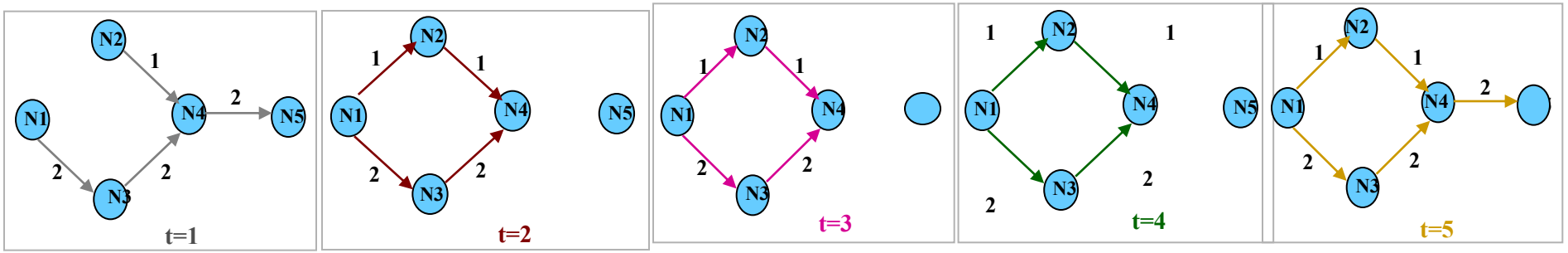
- What are expected fuel saving from use of GPS devices with static roadmaps?
- What is the value-added by historical traffic and congestion information?
- How much additional value is added by real-time traffic information?
- What are the impacts of following on fuel savings and green house emissions?
  - traffic management systems (e.g. traffic light timing policies),
  - vehicles (e.g. weight, engine size, energy-source),
  - driver behavior (e.g. gentle acceleration/braking)
  - environment (e.g. weather)
- What is computational structure of the Eco-Routing problem?



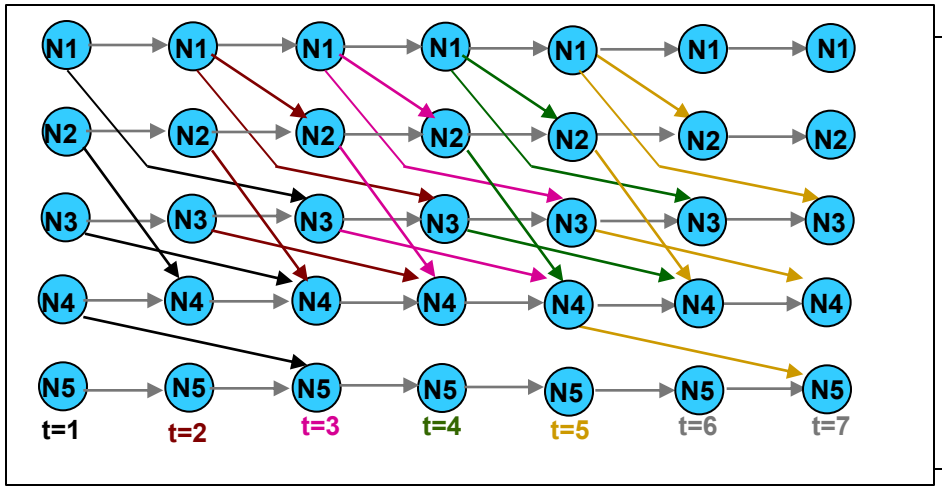
Representations of (Spatio-)temporal Networks

(1) Snapshot Model [Guting 04]

Node: N.. Edge: Travel time →



(2) Time Expanded Graph (TEG) [Ford 65]

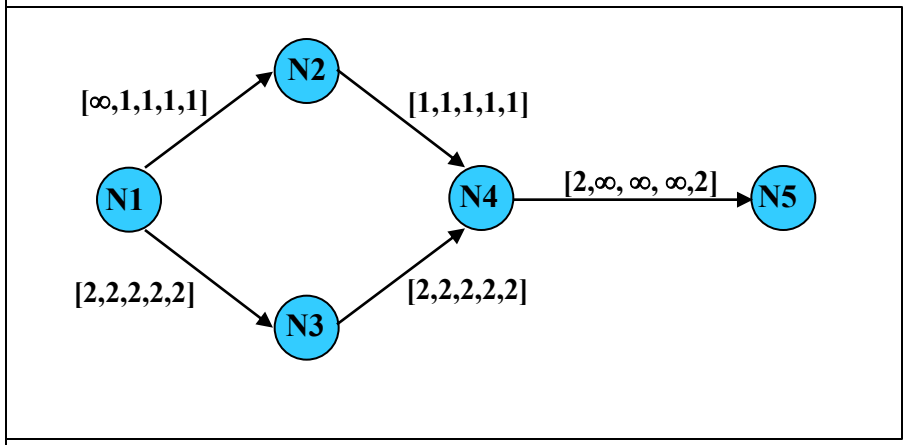


Holdover Edge

Transfer Edges

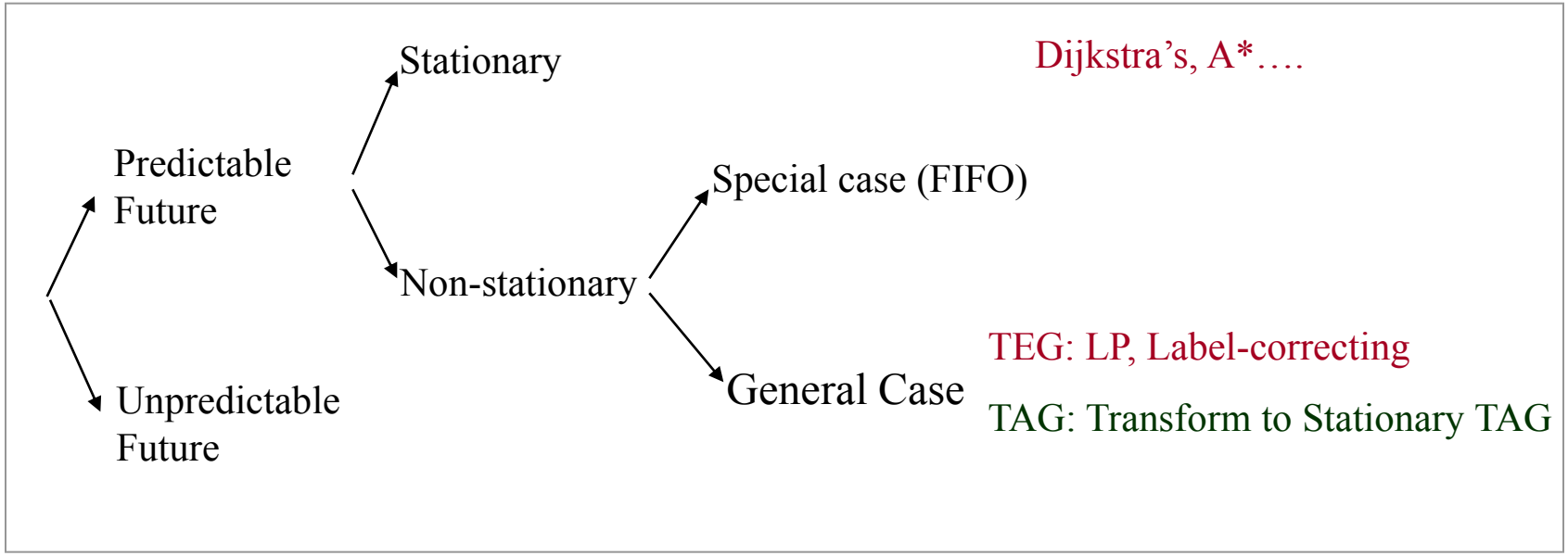
(3) Time Aggregated Graph (TAG) [Our Approach]

- Attributes aggregated over edges and nodes.

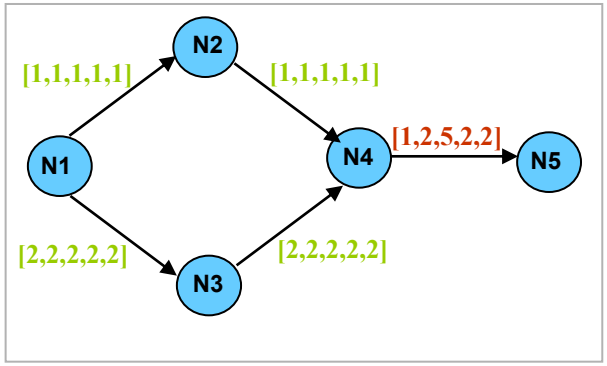


Edge $\xrightarrow{[m_1,\ldots..,(m_T]}$ m_i- travel time at t=i

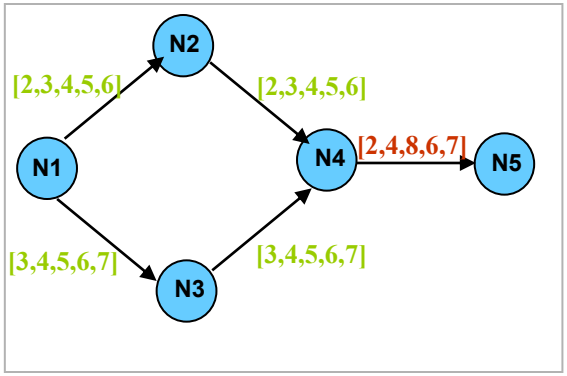
Routing in ST Networks: Scalable Methods



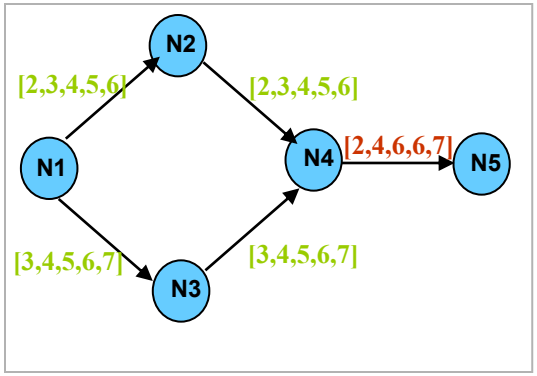
travel times → arrival times at end node → Min. arrival time series



Non-stationary TAG



→



Stationary TAG

Revisit Shortest Path Problem

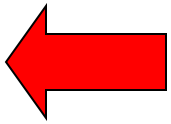
- New Routing Questions
  - Best start time to minimize time spend on network
  - Account for delays at signals, rush hour, etc.

- Time-Variant Flow Network Questions

Static	Time-Variant
Which is the shortest travel time path from downtown Minneapolis to airport?	Which is the shortest travel time path from downtown Minneapolis to airport at different times of a work day?
What is the capacity of Twin-Cities freeway network to evacuate downtown Minneapolis ?	What is the capacity of Twin-Cities freeway network to evacuate downtown Minneapolis at different times in a work day?

Outline

- My Background: Spatial Computing
- Transportation Science
- Transportation & Energy Independence
- Eco-Routing
- Summary



Summary

- New challenges for Transportation
  - Classical approaches are limited
    - Multi-disciplinary problems, e.g., energy independence
  - Computational Simulation & Data-Intensive Scientific Discovery
    - Complements classical approaches: Hypothesis generation

- Transportation is critical for Energy Independence
  - It accounts for 20% to 30% of energy consumption
  - It's energy source is largely Petroleum
  - Eco-routing may save billions of gallons of fuel each year

- Time to give serious consideration to computational methods!

McKinsey Global Institute

Big data: The next frontier for innovation, competition, and productivity