Distributed Learning Dynamics
Convergence in Routing Games.

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Historical perspective on monitoring and routing

Dedicated traffic monitoring infrastructure (since the 1960’):
- Self inductive loops
- Wireless pavement sensors
- FasTrak, EZ-pass transponders
- Cameras
- Radars
- License plate readers

Issues traditional infrastructure
- Installation costs
- Maintenance costs
- Reliability
- Coverage
- Over time: insufficient to meet new mobility demands
Historical perspective on mobile devices

2008 → 2012: web 2.0 on wheels

- iPhone 1 (2008), no GPS
- Android G95 (2009), GPS, as for the subsequent iPhones.
- Massive explosion of GPS enabled smartphones
- Proliferation of GPS collecting apps (Google Maps, INRIX, Waze etc.)

Sensing and communication

- GSM, GPRS, WiFi, bluetooth, infrared, radio,
- GPS, accelerometer, light sensor, camera, microphone
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Source: Asymco.com
Mobile Millennium (2008-2010)

An early instantiation of participatory sensing

- Consortium: NSF, US DOT, Caltrans, Nokia, NAVTEQ, + 10 others
- Late 2008: 5000 downloads of the FIRST Nokia traffic app worldwide
- After a few months: about 60 million data points / day from dozen sources (smartphones, taxis, fleets, etc.)
First historical indirect beneficiary: transportation
Data flow in the Mobile Millennium system

Evaluation Framework (Compare Values, Average Values, Point Distributions)

Data Visualization Framework (Multi color dynamic traffic displays, Graphs, Charts)

Data Warehouse (Reporting, Data Mining, Storage, Non Transactional Processing)

Database (All Transactional Processing)

Process Management (Monitoring, Production execution, Etc)
Example: 0.5% of Mobile Millennium data (one day)
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Implementation at 2% penetration rate

Paradise for data assimilation starts at 2% penetration rate

- However, it is rare to have such penetration uniformly (spatio temporally): thus algorithms need to work on decimated data
Flow reconstruction (inverse modeling)

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Project timeline

- **Initial R&D**: 2008
- **Continued Public-Private R&D on Probe Data Processing**: 2009-2012
- **Industrial Development**: 2008-2012

Key milestones:
- **2008**: Mobile Century
- **2009**: ITS World Congress
- **2010**: Mobile Millennium
- **2011-2012**: Commercialization
- **2012**: Google, Microsoft, telenav, NOKIA, NAVTEQ
Contributions of the Mobile Millennium project

Modeling contributions
- Flow models for integration of Lagrangian data for highways
- Hamilton-Jacobi formulations of flow models for highway systems
- Machine learning models for arterial traffic

Estimation contributions
- Statistical filtering for discretized PDEs (EnKF, PF, etc.)
- Convex optimization approaches to data assimilation (variational formulations, viability formulations)

Experimental contributions
- Building an app and a backend system
- Running experiments at scale
- Integrating private sector feeds and systems with our system

Data quality contributions
- Penetration studies (how much data do we need)
- Producing data for the research community (Mobile Century)
- Procurement
Building a decision support system for road traffic
Illustration (Los Angeles): the I210 corridor

“Classical” control points outlined below

– 20 miles of freeways
– 5 major arterials
– Hundred of traffic lights, meters, changeable message signs
Optimal control problem in freeway operations management
- Minimize arbitrary cost function with boundary control (inflow at on ramps)
Press Releases

Mayor Garcetti Details Agreement with WAZE to Help Reduce Congestion, Increase Safety, and Improve Driving Experience Around L.A.

Posted by Mayor Eric Garcetti on April 21, 2015 • Flag

*App will feature first-ever hit-and-run notifications and AMBER Alerts to aid public safety*

Mayor Garcetti today announced the details of a data-sharing agreement between the City of Los Angeles and Waze, an agreement he previewed in his State of the City Address last week. The Waze app is used by more than 1.3
The “LA problem” (soon in a city near you)

Press Releases

Mayor Garcetti Details Agreement with WAZE to Help Reduce Congestion, Increase Safety, and Improve Driving Experience Around L.A.

Building the city of our dreams starts with you, sign up!

or sign in with Facebook.

Los Angeles and Waze Team Up to Combat Traffic Congestion

When Americans think of traffic they think of Los Angeles, even if they’ve never visited. So it makes sense that the LA mayor’s office has announced that the city is partnering with traffic app Waze to help combat the congestion. The deal allows data to be shared between the two parties—the city will alert Waze about hazards, construction and crashes while the app will give the city a wealth of data to analyze how traffic moves. Ideally this will allow for changes that will improve commutes.
The “LA problem” (soon in a city near you)

Locals upset at Google's Waze for sending traffic to their streets

LA residents complain that Waze creates congestion on roads once only known to those who live there.

by Donna Tam / @DonnaTam / December 14, 2014 11:25 AM PST
The “LA problem” (soon in a city near you)

Locals upset at Google’s Waze for sending traffic to their streets

LA residents complain that Waze creates congestion on roads once only known to those who live there.

Waze Has No Concept Of The Hell That Is LA Traffic

Waze markets itself as a hip, modern, community-based app that helps urban drivers save time and stay safe on the road, but Waze is the very same company that is repeatedly fucking over Angelenos during rush hour traffic.

Waze consistently recommends something people are referring to on Reddit as the “suicide left,” which entails turning from a small side street onto a busy, multi-lane road during peak traffic hours without a stoplight. Other users also complain that the app will suggest clearing the entire road straight across. Not only do these options waste time as drivers either wait for a chance to cross or turn, but these suggestions are also dangerous.
The “LA problem” (soon in a city near you)

Angry LA residents are trying to sabotage Waze data to stop side-street congestion

BY MICHAEL CARNEY
ON NOVEMBER 17, 2014
‘Cut-through’ traffic caused by Waze app must stop, L.A. councilman says

A Los Angeles city deal with traffic app Waze may be great, but some local communities are being inundated with “cut-through” traffic that must stop, a Los Angeles City Councilman said Tuesday.

Paul Krekorian introduced a motion to help local neighborhoods, saying Waze should send drivers away from residential streets and onto major roadways as part of the company’s data-sharing agreement with the city.

Mayor Eric Garcetti announced last week that the city is sharing road closure data with Waze to improve its service, and in return the city is getting live updates about traffic patterns.
Is steering mobility towards Nash eq. good?

- System now could potentially be doing worse than Nash.
- Nash is obviously not as good as system optimum (hence price of anarchy, value of altruism etc.)
- How bad / good is displacing current equilibrium towards Nash, which is what apps are doing?
But the broader mobility also includes

**Mobility solutions not yet fully connected with public infrastructure**

- Mobility apps (Google, Waze etc.)
- Mobility as a service companies
Problem formulation

**Distributed learning dynamics in routing games**

- Each player routes population $k$ according to distribution (corresponding to one OD pair)

- At each iteration, the population $k$ discovers their outcome $\ell_k^{(t)}$
Problem formulation

Distributed learning dynamics in routing games

- Each player routes population $k$ according to distribution $p \sim x_k^{(t)}$ (corresponding to one OD pair)

- At each iteration, the population $k$ discovers their outcome $\ell_k^{(t)}$

- The routing of population $k$ at the next step is subsequently updated according to the following law

$$x_k^{(t+1)} = u_k \left( x_k^{(t)}, \ell_k^{(t)} \right)$$

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Online Learning Model

1: for $t \in \mathbb{N}$ do
2: Play $p \sim x_k^{(t)}$
3: Discover $\ell_k^{(t)}$
4: Update $x_k^{(t+1)} = u_k \left( x_k^{(t)}, \ell_k^{(t)} \right)$
5: end for
Distributed learning dynamics in routing games

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Coupled sequential decision problem

This also represents the process of apps (companies) routing users
  - Each gives shortest path (given previous information)
  - Previous information is mostly statistical (experience from previous day and some statistical forecast)

All paths proposed are nearly equal:
  - Shortest path (55mins)
  - Third shortest path (58 mins)
  - Second shortest path (56 mins)

Routing does in general not depend on
  - Forecast of the network loading using demand data (incomplete today)
  - Forecast of the network using potential impact of routing (i.e. routed users) on the network
  - Knowledge of what competitors of the app are doing (in the present case, Apple, INRIX, 511, etc.)
Coupled sequential decision problem

Waze
Google
Apple
INRIX
Bing (Microsoft)

$p_{\text{Waze}} \sim x^{(t)}_{\text{Waze}}$
$p_{\text{Google}} \sim x^{(t)}_{\text{Google}}$
$p_{\text{Apple}} \sim x^{(t)}_{\text{Apple}}$
$p_{\text{INRIX}} \sim x^{(t)}_{\text{INRIX}}$
$p_{\text{Bing}} \sim x^{(t)}_{\text{Bing}}$

30%
8%
62%
40%
7%
54%
60%
3%
37%
0%
0%
100%
12%
9%
79%

All users of each company “equal” by standards of the company i.e. same (shortest) travel time according to the company, “essentially” Nash.
Example for 3 miles in Pasadena

Let us assume overnight, 15% of users of I210 start using Waze:
- Immediate massive reroute through Pasadena
- Travel time in Pasadena instantaneously goes up by 17%
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Conclusions

Historical perspective
- The years 2007-2012 have brought information to mobility, giving drivers the ability to achieve shortest travel time.
- The years 2010-2016 have seen the impact of these technologies on mobility patterns (changes in modality, routing, behavior)
  - Companies (apps): are “learning”
  - Users are “learning”

Scientific contributions in a “post travel time / optimal control era”
- Under certain conditions, companies working non-cooperatively on user routing might converge to a Nash equilibrium.
- Conditions of this convergence depends on the assumptions on the model of these companies
- Practical implementations on “humans” reveals convergence to Nash equilibria

Public policy perspective
- Today, in many regions of the world, traffic “[non]-equilibrium” is probably worse than Nash equilibrium
- Apps probably contribute to steering system towards Nash
- While Nash is probably still better than current situation globally, it redistributes congestion, leading to increased congestion in sub-urban areas
Other mobile sensors and data points

**NestSense**
- Using Android & SmartWatches to monitor Alzheimer’s patients at their homes
- Deployment of technology on cohort of 300 patients through collaboration with UCSF hospital
Other mobile sensors and data points

iShake project (with Steve Glaser, Jon Bray, Richard Allen)
- One of the first shake monitoring apps on the iPhone (2010)
- SeismoLab scaled it up
- Deployment in the T-Mobile / DT app store, several 100K downloads
Other mobile sensors and data points

**Floating sensor network**

- Starting summer 2012: deployment of 100 floating / submersible units in the San Francisco Bay / Sacramento Delta, DWR
- Stillwater, OK, rapid levee breech repair demo, DHS
Other mobile sensors and data points

**Inverse modeling, data assimilation, inference, estimation**
- Real-time, online (with streaming data)
- Running two dimensional shallow water models (LBNL REALM)
- Using Ensemble Kalman Filtering, statistical inference methods
- Running on 500 nodes of the Magellan / NERSC cluster at LBNL
Other mobile sensors and data points
Floating Sensor Network
Distributed Learning Dynamics
Convergence in Routing Games.

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