6.1820/MAS.453: Mobile and Sensor Computing

aka IoT Systems

https://6mobile.github.io/

Lecture 9: The Pothole Patroll

Course Staff

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Announcements

1. PSet 1 due tonight
2. Lab 2 due next Tuesday, March 11
3. Shared project ideas and inventory list. Start forming teams!

The Two Lecture Series

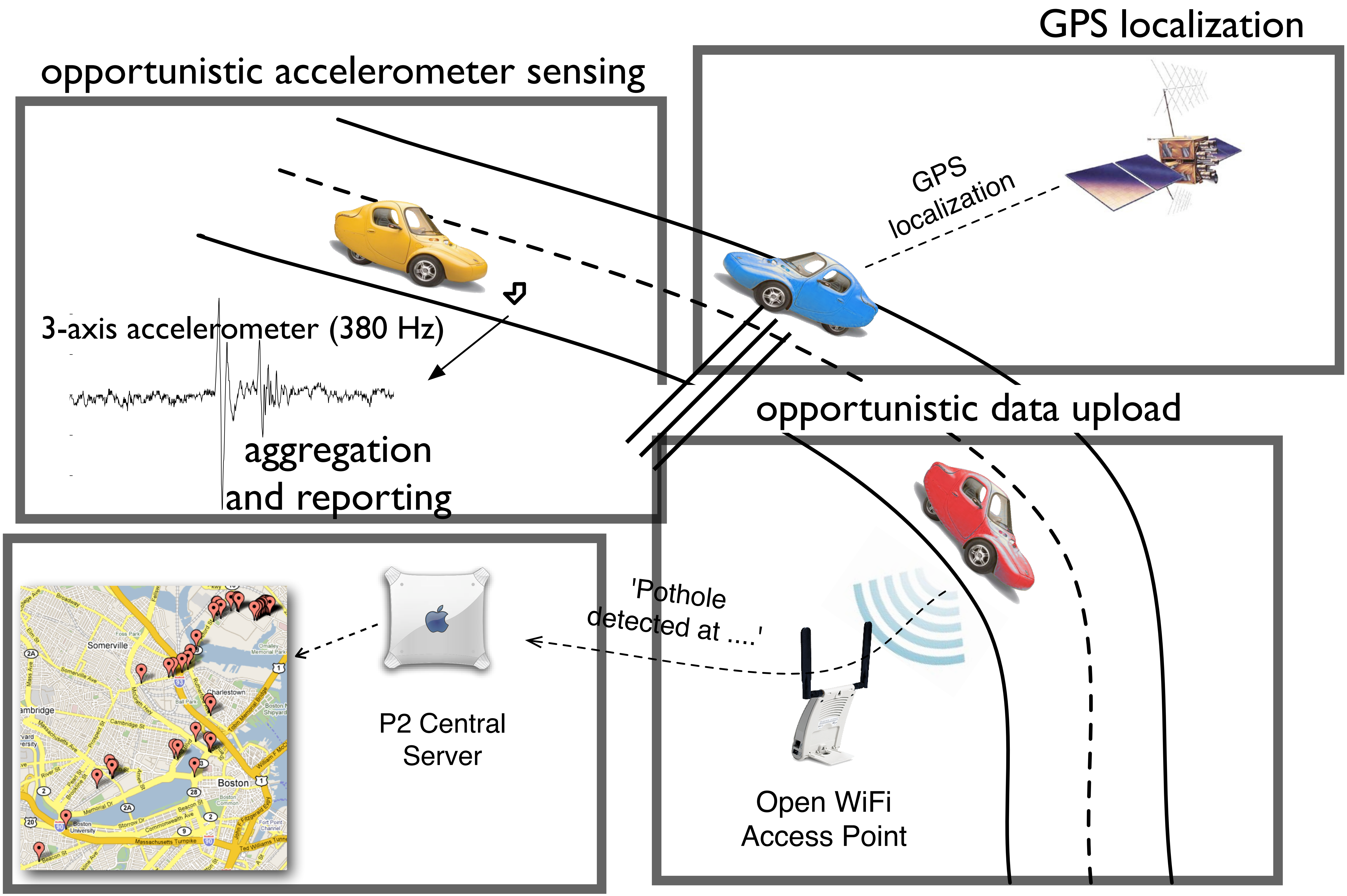
Fundamentals & Applications of Inertial Sensing

1. What are the fundamentals of inertial sensing? ✓
2. How does dead-reckoning work? And how do strap-down navigation systems operate? ✓
3. Case-study based application of inertial sensing: Pothole patrol
4. Practical approaches to combating sensory noise in real-world settings

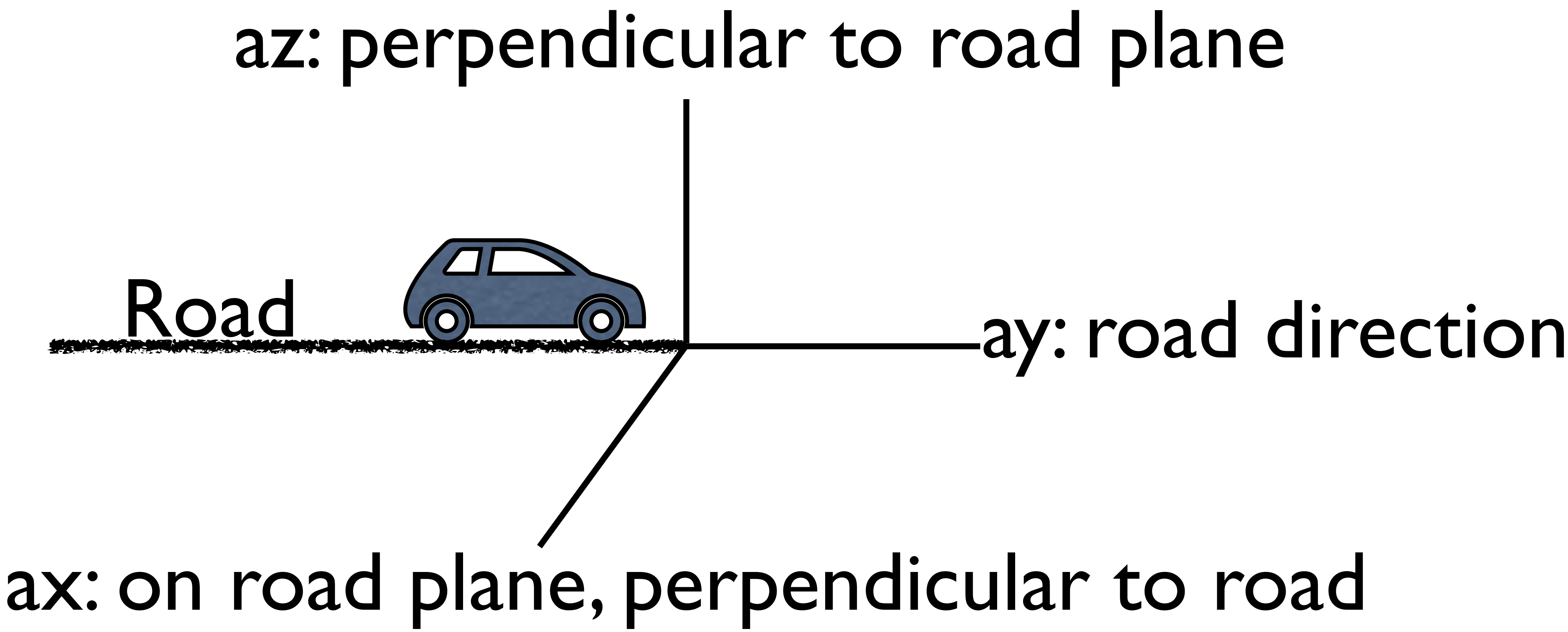
this lecture

- road decay unavoidable, hard to predict
- current monitoring methods costly/ineffective

the Pothole Patrol



Acceleration vector



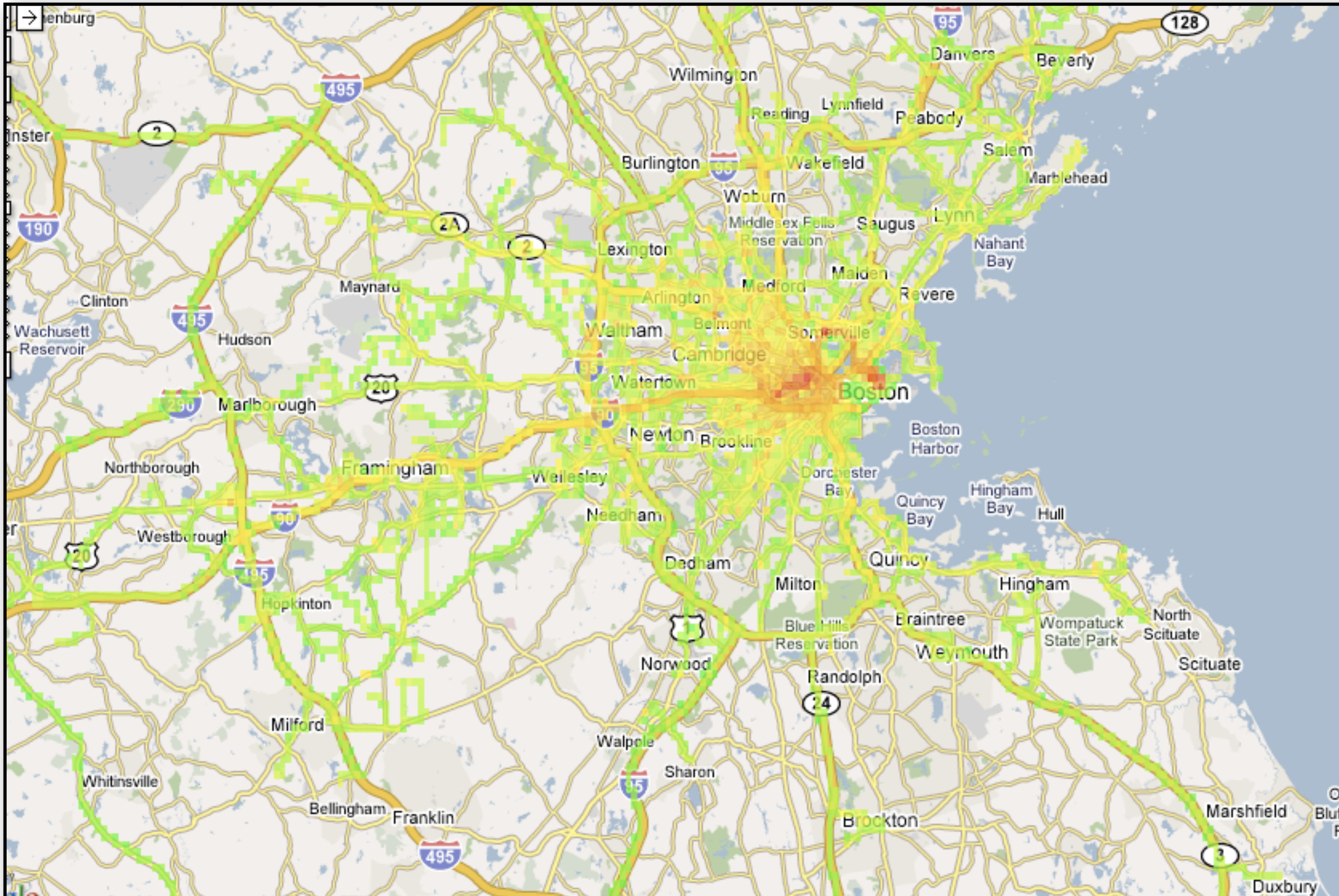
experimental platform

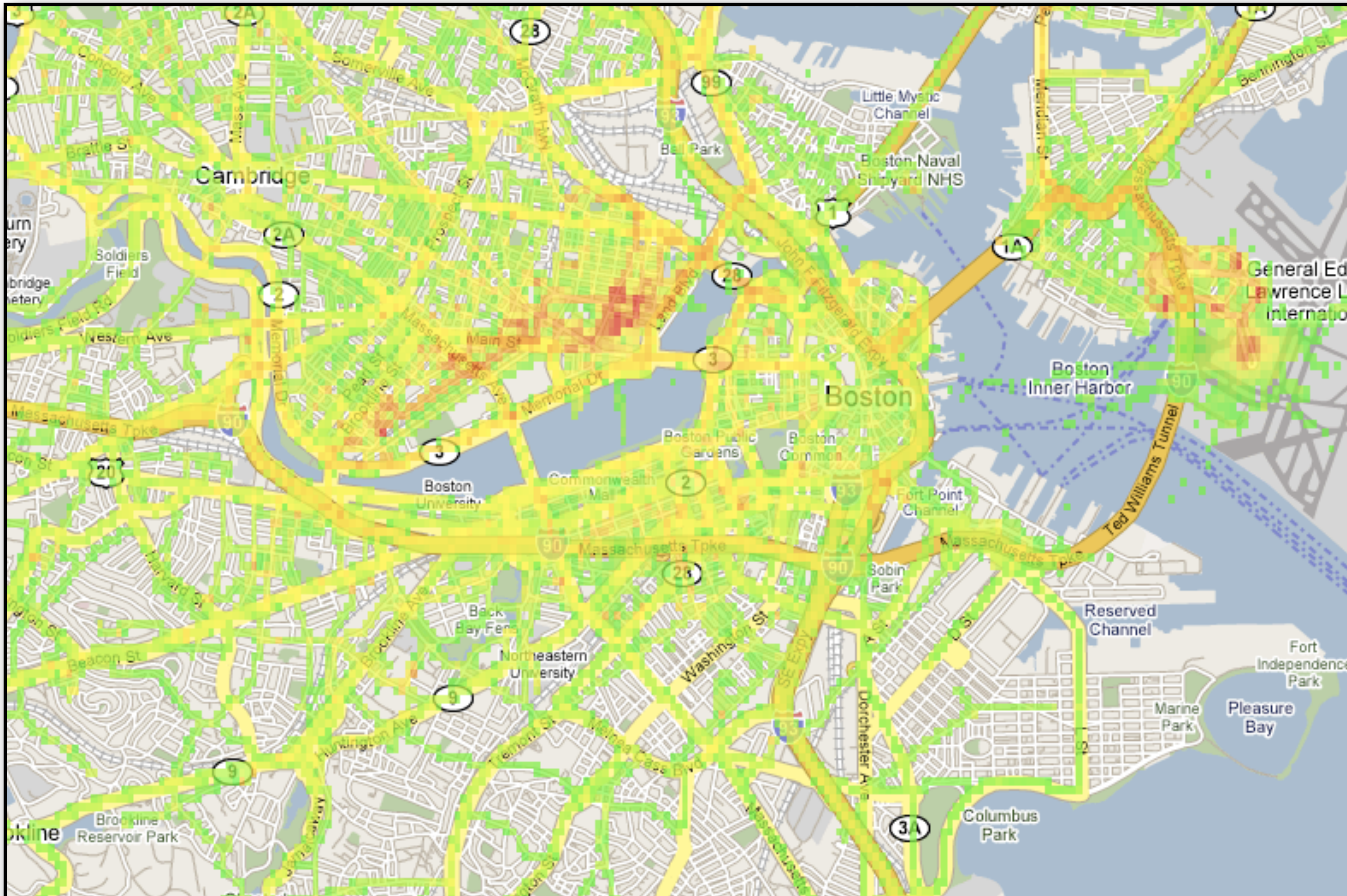
- 7 Boston/Cambridge taxis
- small computer in glove box
- 380 Hz 3-axis accelerometer
- 802.11a/b/g wireless interface
- GPS receiver on roof
- <time,location,heading,speed,ax,ay,az>

When was iPhone released?

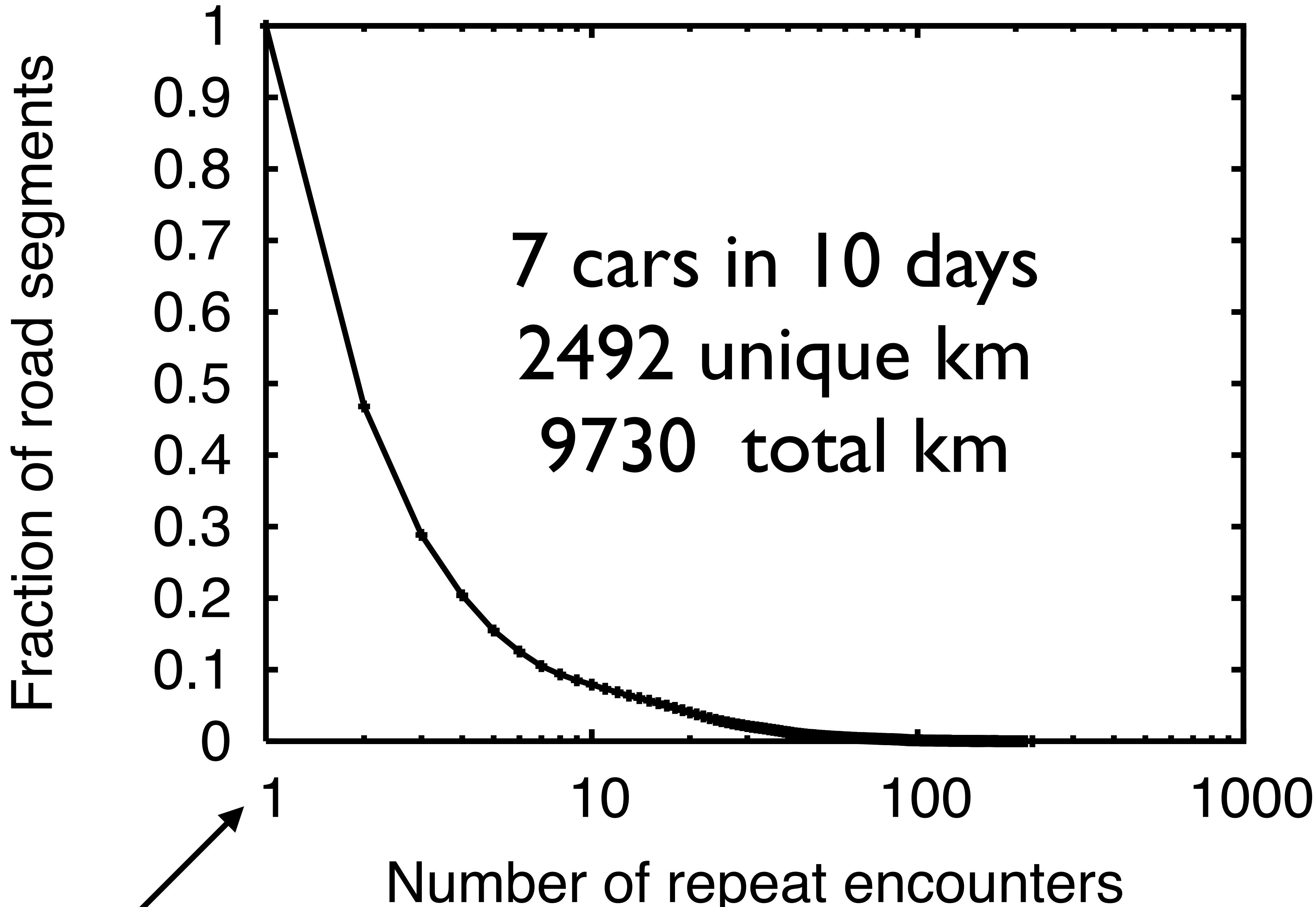
June 2007 (this paper was published 2008)

wide-area sensing



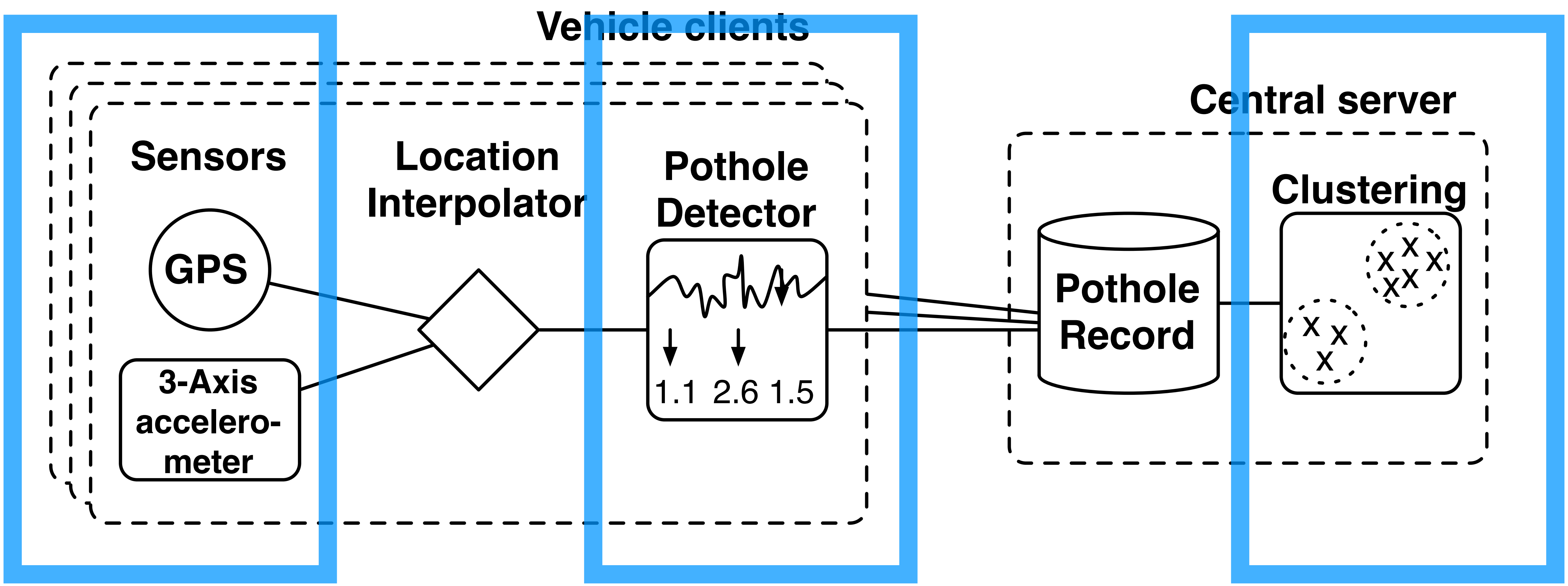


Cambridge
Soldiers Field
Brattle St
Concord Ave
Mass Ave
Somerville Ave
McGrath Hwy
Prospect St
Western Ave
Memorial Dr
Main St
Massachusetts Ave
Massachusetts Tpke
Land Blvd
Little Mystic Channel
Boston Naval Shipyard NHS
Meridian St
Bennington St
John F Fitzgerald Expy
Boston
Boston Inner Harbor
Ted Williams Tunnel
Boston Public Gardens
Boston Common
Commonwealth Mall
Fort Point Channel
Boston University
Reserved Channel
Fort Independence Park
Pleasure Bay
Marine Park
Columbus Park
Harvard St
Beacon St
Brookline Ave
Back Bay Fens
Northeastern University
Huntington Ave
Tremont St
Washington St
SE Expy
Dorchester Ave
Melnea Cass Blvd
D St
Brookline Reservoir Park



appear at least once

P^2 architecture



sensor placement

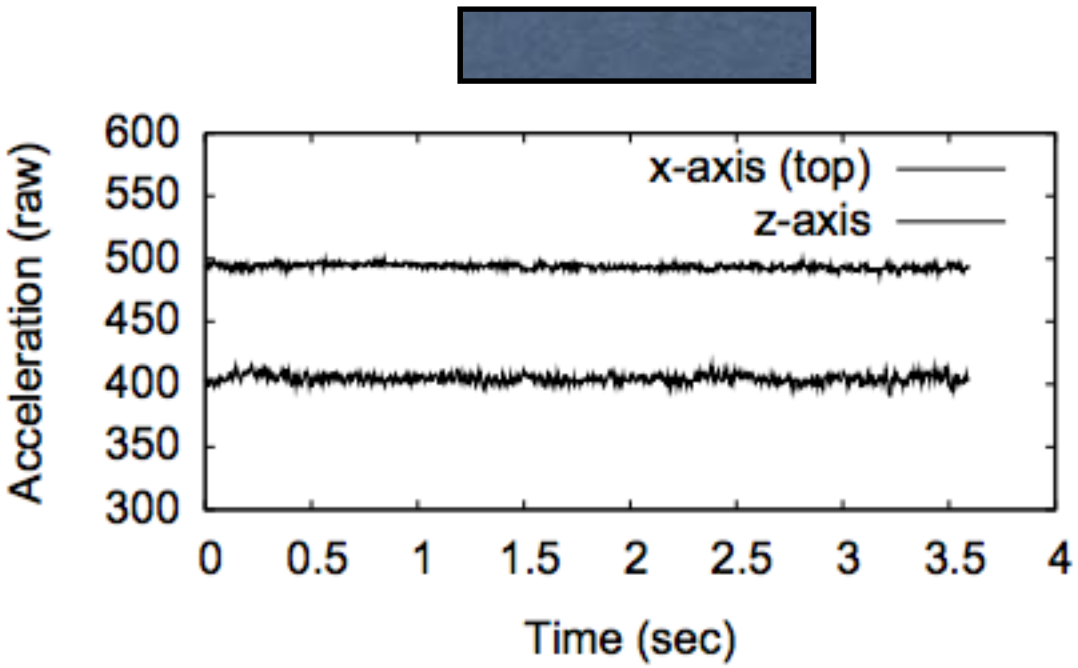
WINDSHIELD?

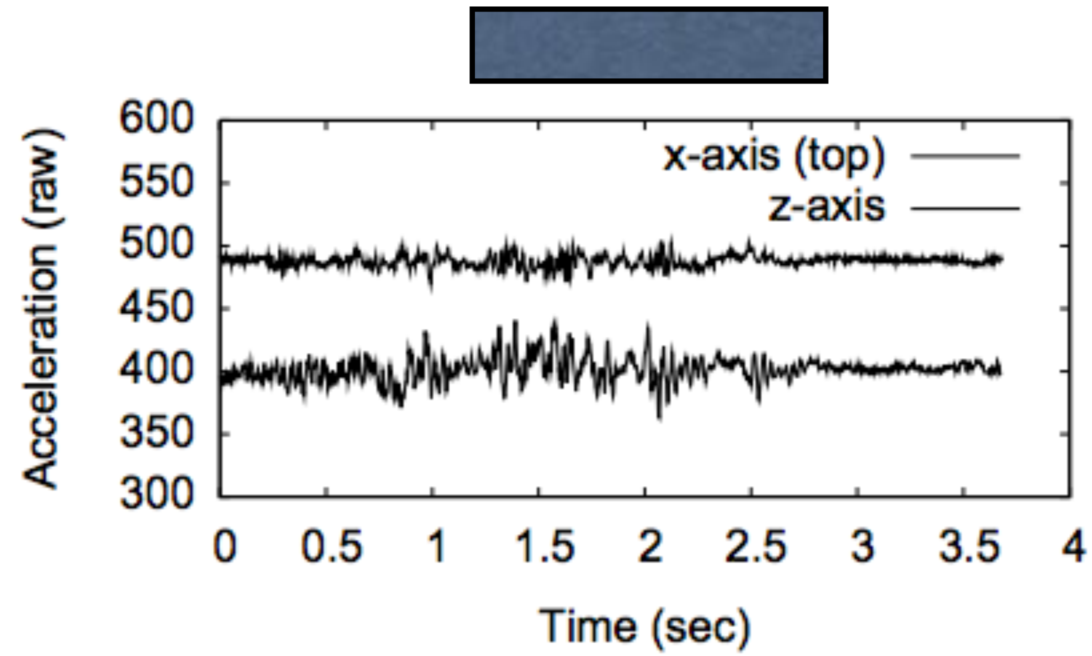
DASHBOARD?

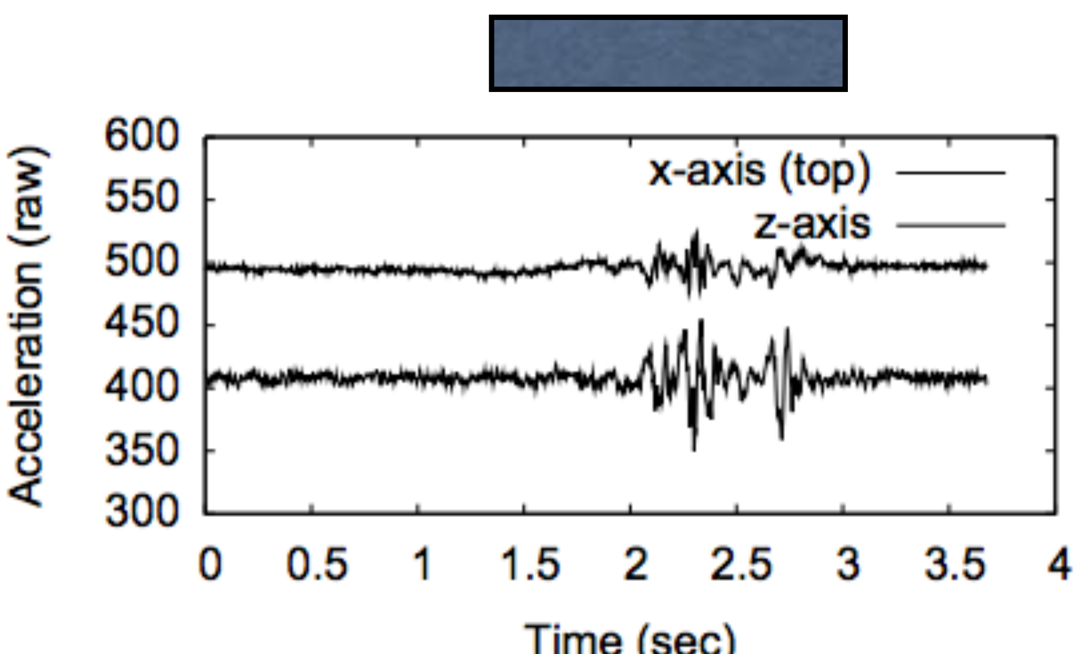
ATTACHED TO PC?

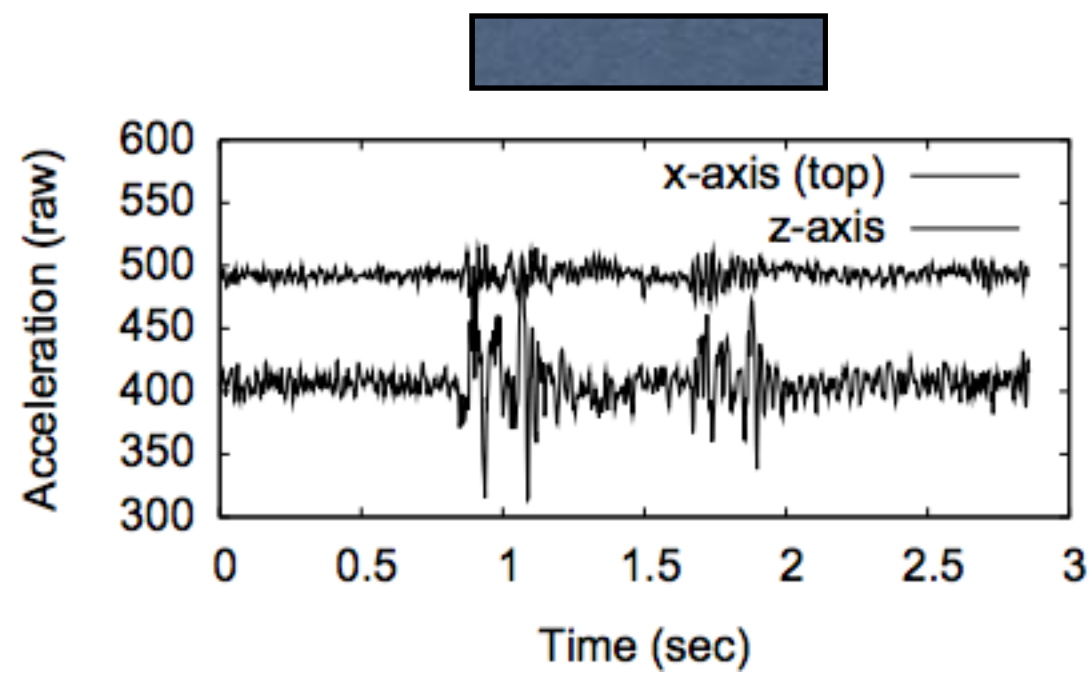
pothole v. not pothole

challenge: “pothole” v. “not pothole”

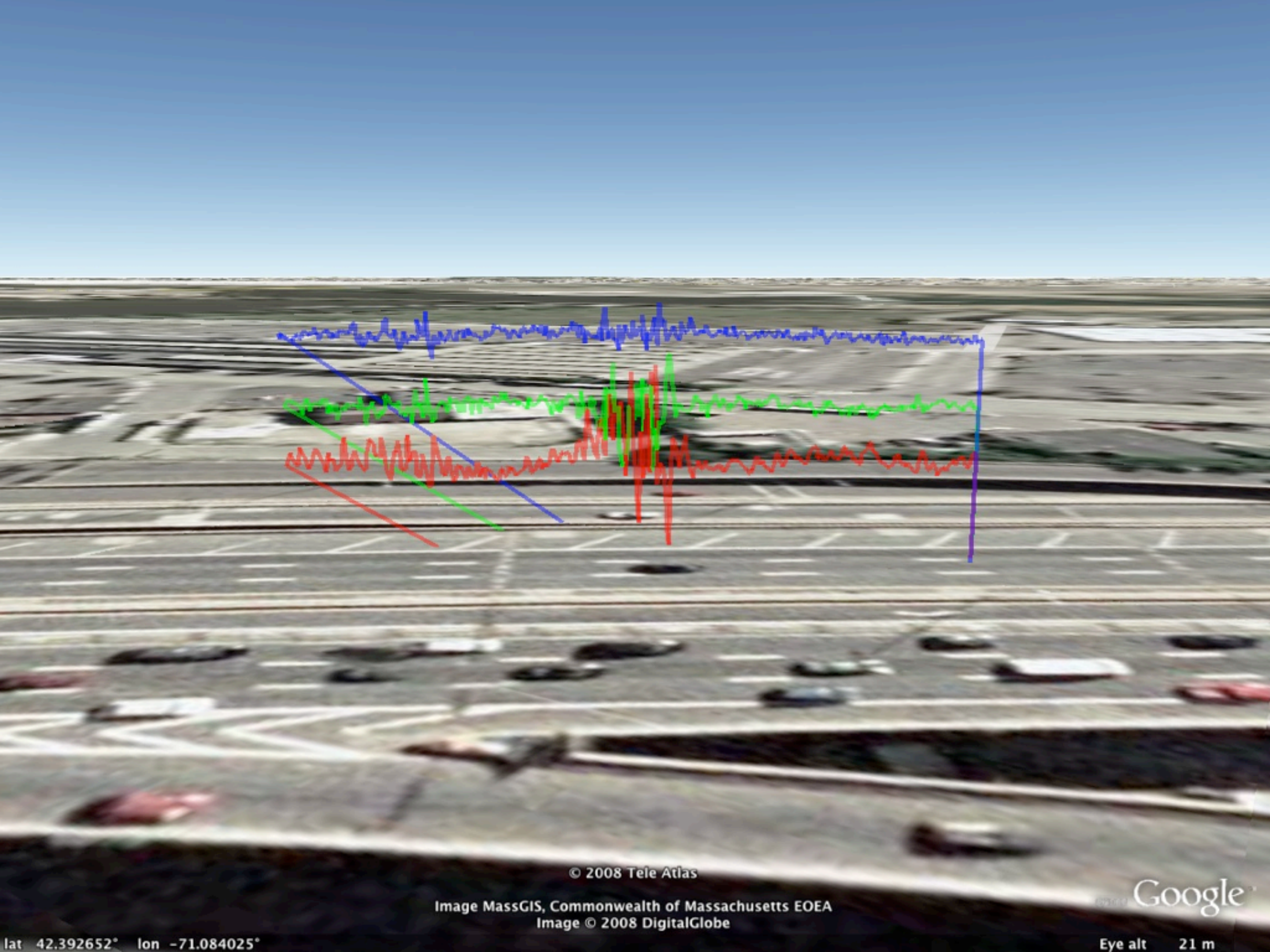








How do we identify pothole vs others?

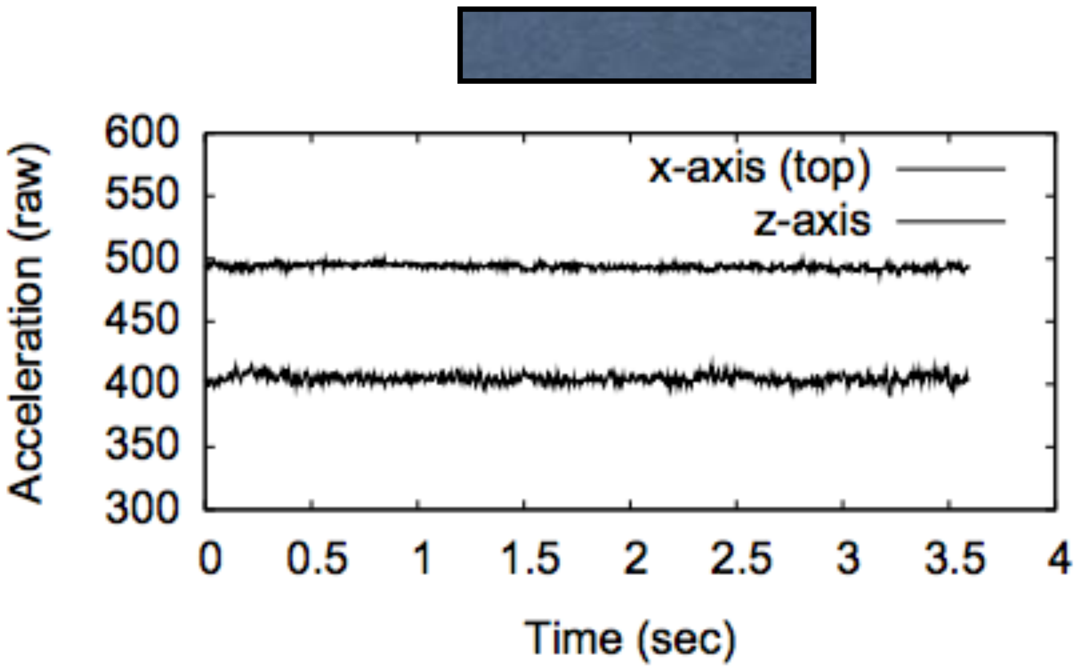

© 2008 Tele Atlas
Image MassGIS, Commonwealth of Massachusetts EOEA
Image © 2008 DigitalGlobe
Google
lat 42.392652° lon -71.084025°
Eye alt 21 m

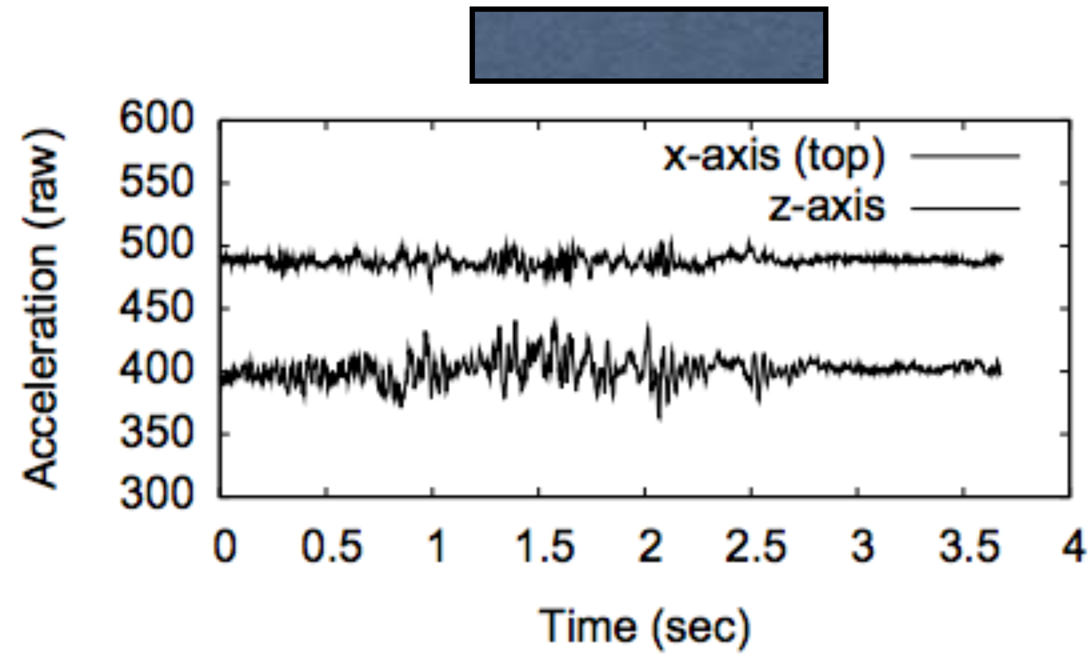
P^2 detector

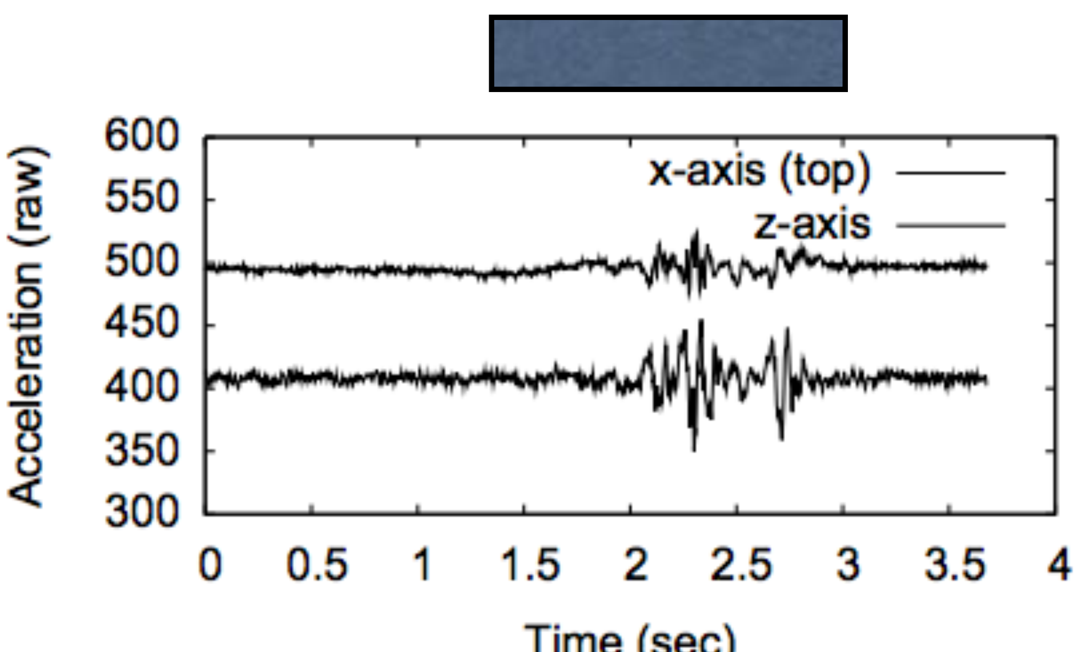
256-sample
windows

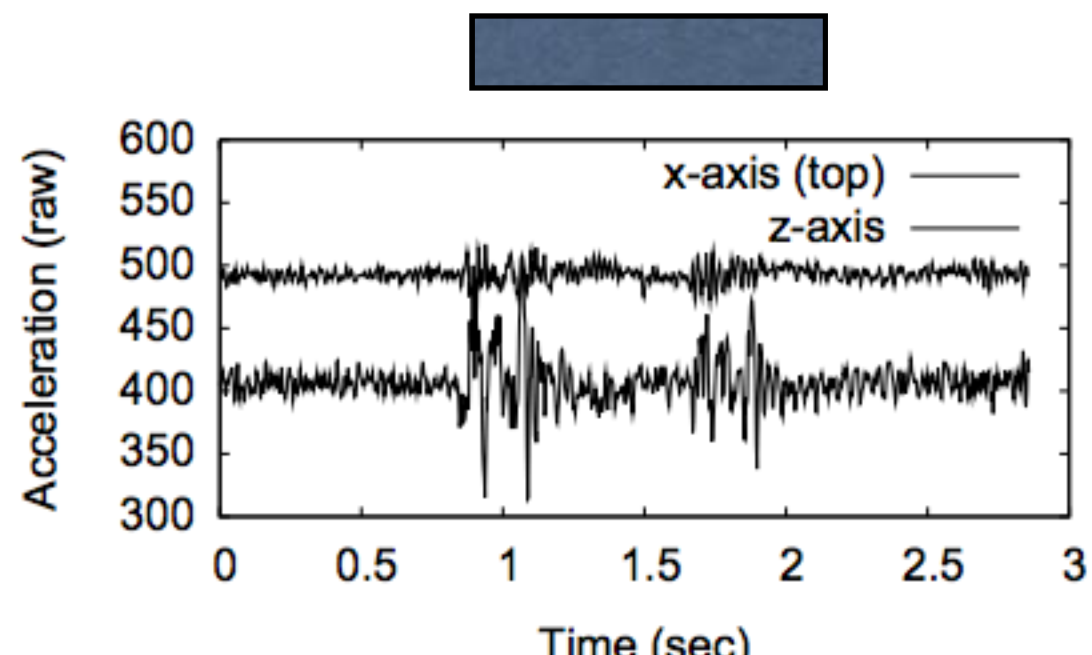
Events usually of much shorter duration than 256 samples

challenge: "pothole" v. "not pothole"









How do we identify pothole vs others?

hand-labeled training data

- **Smooth road (SM)**: Segments of road surface that are considered smooth.
- **Crosswalks and Expansion Joints (CWEJ)**: Crosswalks using extra-thick paint, brick, strips of pavers, or raised dots. Metal expansion joints in bridges and overpasses.
- **Railroad Crossing (RC)**: Train tracks. Such crossings can be jarring, and are sometimes confused for a disturbed road surface.
- **Potholes (PH)**: Missing chunks of pavement, severely sunk in or protruding manhole covers, other significant road surface anomalies.
- **Manholes (MH)**: Manhole covers and other equipment in the road that are nearly flush with the road surface. Moderate cracking, sinking or bulging.
- **Hard Stop (ST)**: A rapid deceleration, sometimes with the familiar jerk at the end.
- **Turn (TU)**: Turning a corner. This sometimes exhibits a rather violent acceleration profile.

training the detector

- manually label training samples

Type	Count	Percentage
Smooth road (SM)	64	23%
Potholes (PH)	63	23%
Manholes (MH)	59	21%
Railroad Crossing (RC)	18	6%
Crosswalk/Exp. Joint (CWEJ)	76	27%

loosely-labeled training

- needed to avoid over-training with unrepresentative manually curated data

- under-samples "smooth" roads

  - **Storrow Dr.** Heavily used four-lane parkway on the Boston side of the Charles River with several bridges, some potholes.
  - **Memorial Dr.** Heavily used four-lane parkway on the Cambridge side of the Charles River, good condition.
  - **Binney St.** A two-lane street with many sunk-in manholes and sealed cracks, one pothole.
  - **Hwy I-93** An 8 lane interstate highway that cuts through the center of Boston in good condition.
  - **Beacham St** A heavily trafficked back road in very poor condition.

training the detector

- pick an objective function

$$s(\mathbf{t}) = corr - incorr^2$$

$$s(\mathbf{t}) = corr - incorr^2_{labeled} - \max(0, incorr_{loose} - count_r).$$

- optimize over 3 threshold parameters
  - z-peak
  - xy-ratio
  - speed vs. z-ratio

detector performance

Among the segmented reported as potholes by the algorithm

After training on loosely labeled data

Class	before	after
Pothole	88.9%	92.4%
Manhole	0.3%	0.0%
Exp. Joint	2.7%	0.3%
Railroad Crossing	8.1%	7.3%

E.g., 7.3% of detected "potholes" are railroad

Note: Actual false positive rate is not 7.6%

Why?

estimating false +ve rate

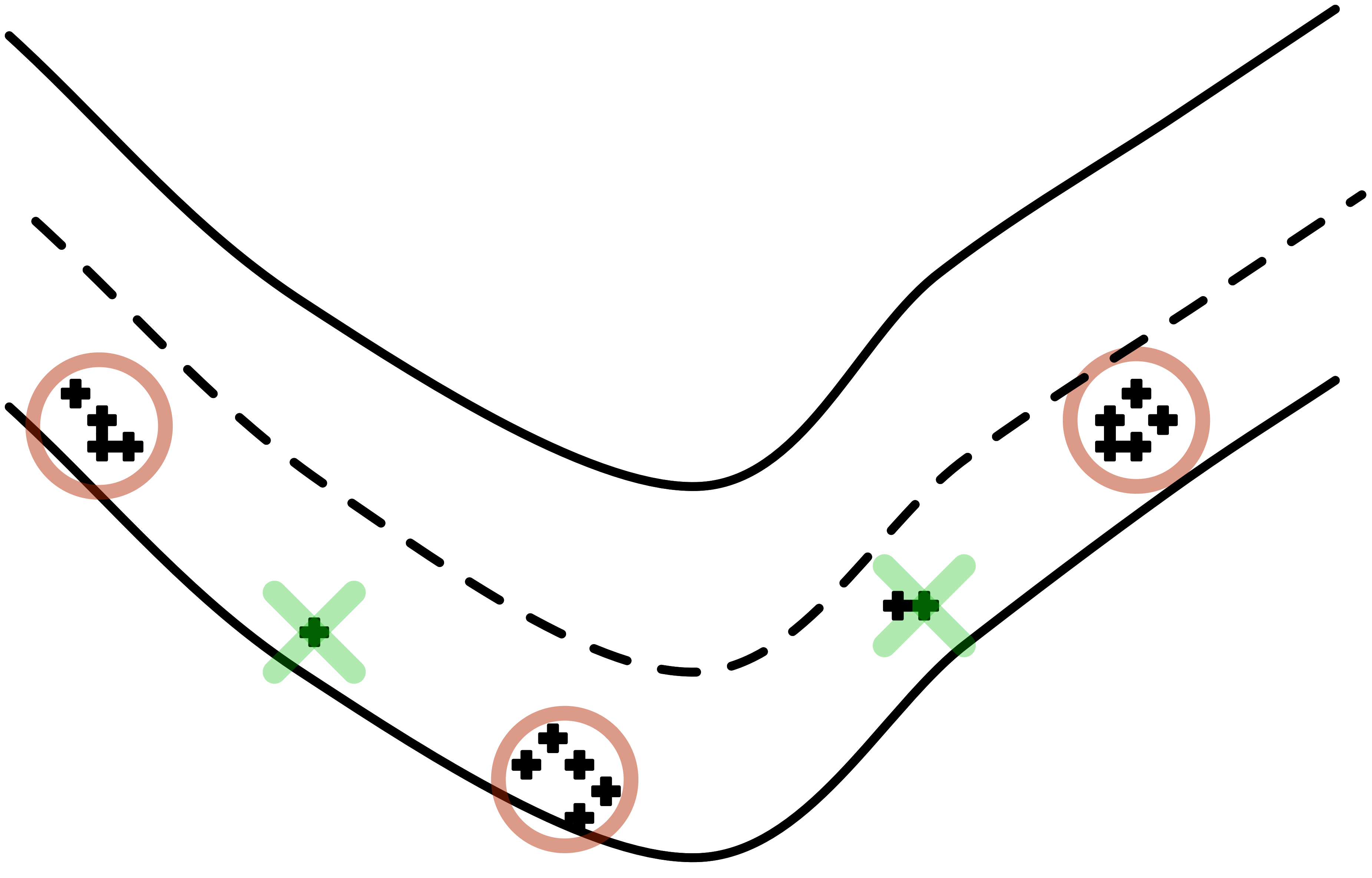
of sample windows

# of detections/ # windows

Road	# potholes	#win	#det.	rate
Storrow Dr.	few	1865	3	0.16%
Memorial Dr.	few	1781	2	0.12%
Hwy I-93	few	2877	5	0.17%

upper bound on FPs

clustering

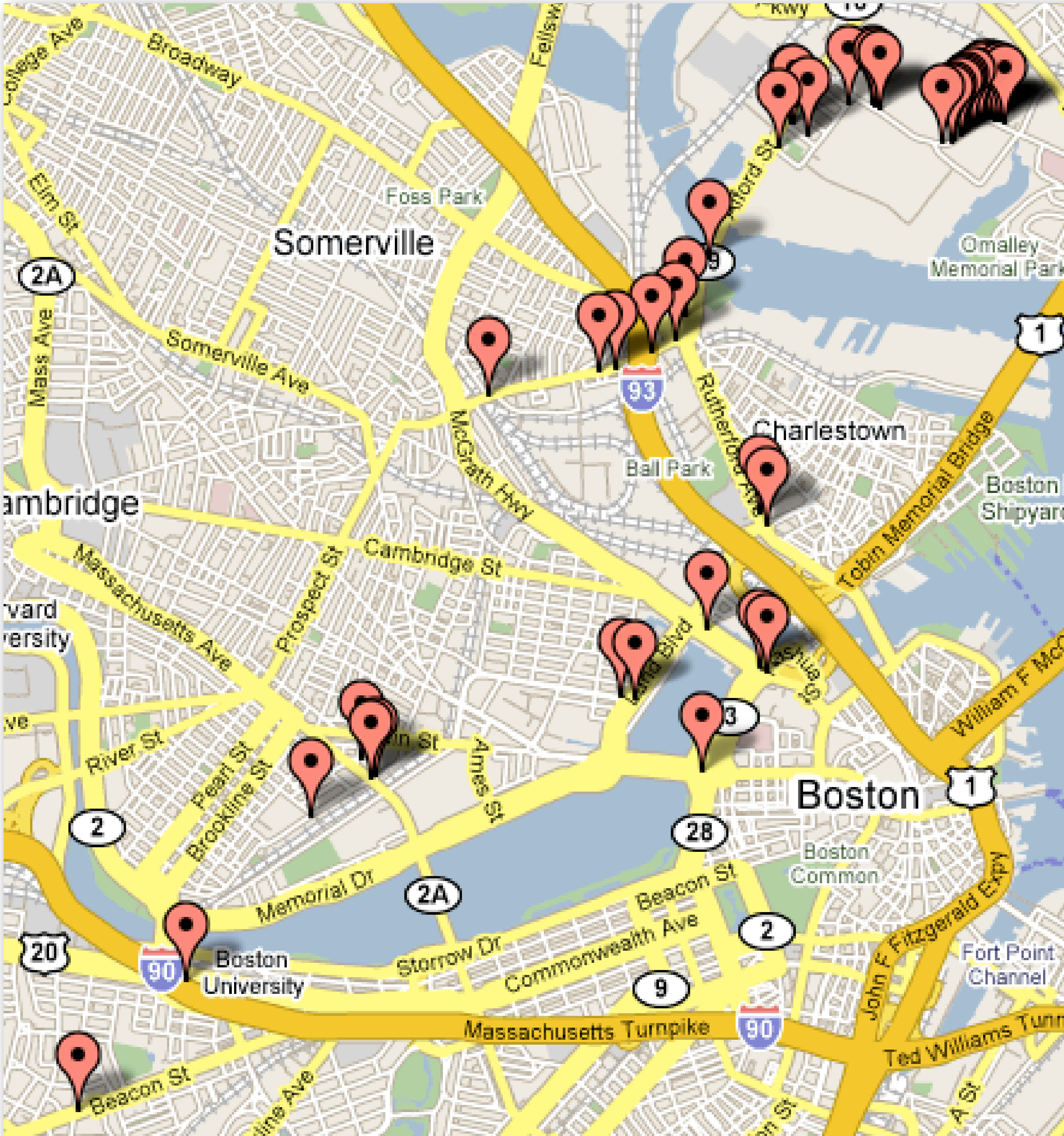


experiments

- 7 taxis over 10 days
- 9730 total km of road covered
- 2492 unique km of road covered
- 1.4 million sample windows
- 4131 severe detections
- **2709** unique locations (after clustering)

48 spot-checks

potholes	39
sunk-in manholes	3
railways and exp. joints	4
undetermined	2


Somerville
Foss Park
Broadway
College Ave
Elm St
Mass Ave
Somerville Ave
ambridge
Cambridge St
Massachusetts Ave
Prospect St
McGrath Hwy
Ball Park
Charlestown
Rutherford Ave
Tobin Memorial Bridge
Omalley Memorial Park
Boston N Shipyard
William F McCl
Boston
Boston Common
Fort Point Channel
John F Fitzgerald Expy
Ted Williams Tunne
Massachusetts Turnpike
Commonwealth Ave
Storrow Dr
Beacon St
Memorial Dr
Ames St
River St
Pearl St
Brookline St
Boston University
Beacon St
rvard ersity
2A
93
1
2
28
20
90
9

P^2: the Pothole Patrol

- automatic wide-area road-quality monitoring
- use of opportunistic mobility
  - mobile sensing w/ delay-tolerant communication
  - machine learning classifier with labeled and loosely-labeled data
  - Data collection and curation is hard!
- low-cost approach to help solve a costly problem

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Projects

Students have most fun & learn most from the projects

- All projects must involve system implementation
- Ideal group size: 3
- We suggested project ideas; feel free to choose your own projects

Timeline (per 6.1820 web site):

Will provide instructions on all deliverables & how to prepare for meetings with course staff

- Proposal (1-2 pages): April 1 (Tuesday)
- Meet on April 8 and April 10 (during class) to give feedback
  - May allow updating proposals based on feedback
- Last 3 weeks of classes: dedicated to project meetings
- Title and Abstract due: May 6
- Demos and presentations: May 13