Experiences with eNav: A Low-power Vehicular Navigation System

Shaohan Hu, Lu Su, Shen Li, Shiguang Wang, Chenji Pan, Siyu Gu, Md Tanvir Amin, Hengchang Liu, Suman Nath, Romit Roy Choudhury, Tarek F. Abdelzaher


3:28 PM
100%
0.8 mi
80
Bay Bridge
Then
17th St
Mariposa St
18th St
101
433A
Potrero Ave
Hampshire St
Vermont St
19th St
POTRERO HILL
20th St
Kansas St
Rhode Island St
Carolina St
Wisconsin St
De Haro St
22nd St
San Francisco
General Hospital
24th St
10 min
1.8 mi · 3:39 PM

Keeping Charger in Car?

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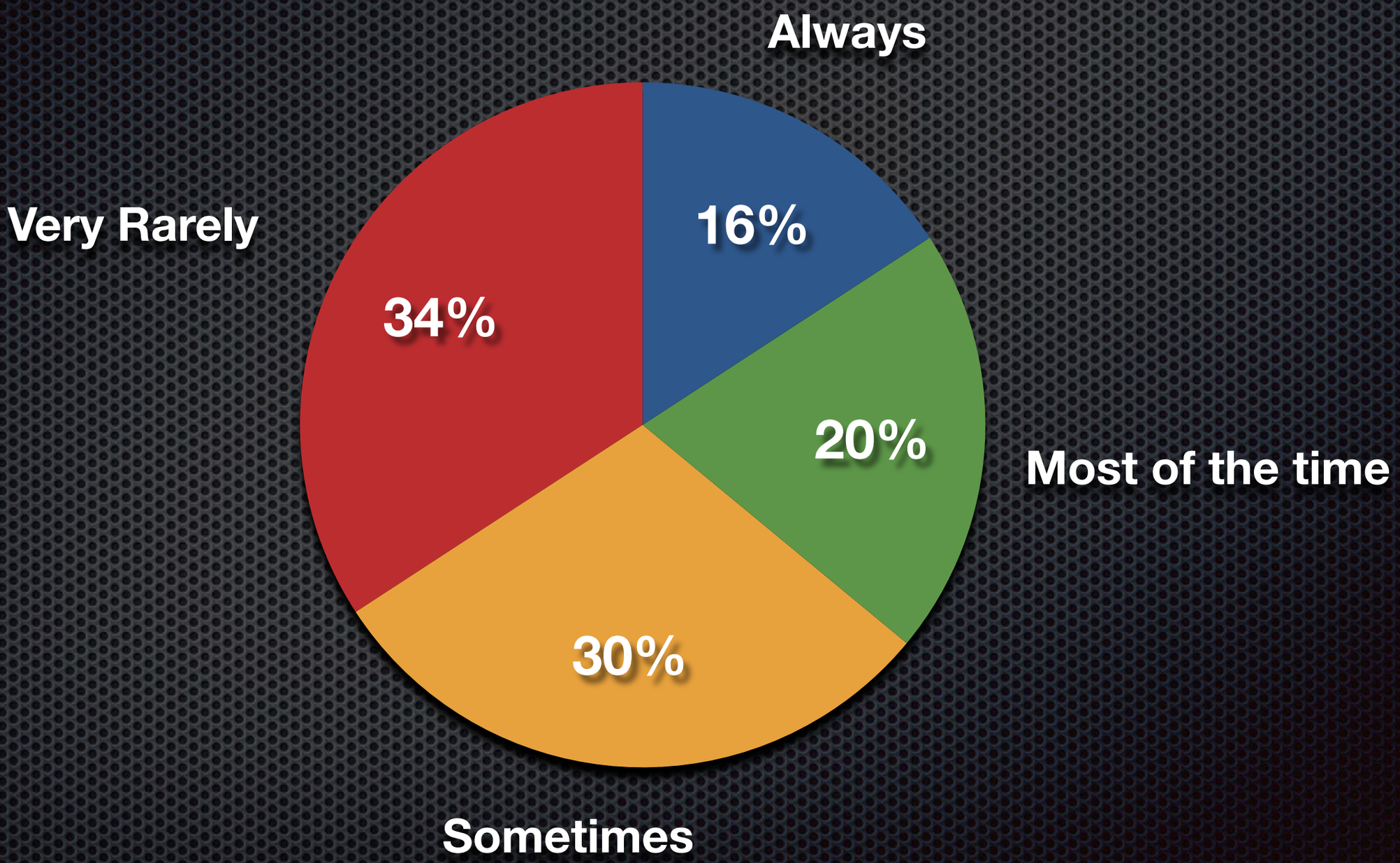
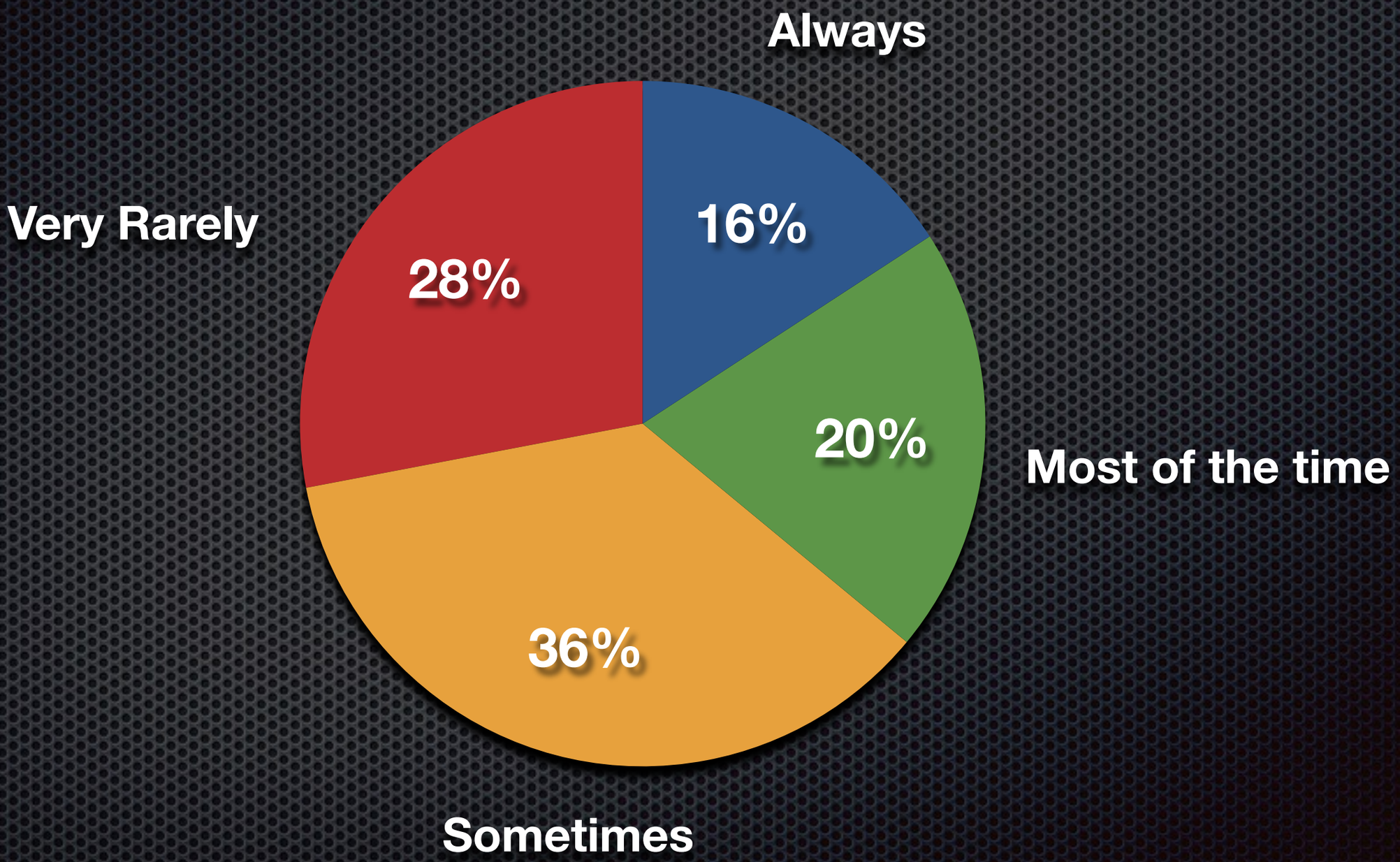


Plug-in Phone during Navigation?



Energy-Efficient Navigator: Useful?

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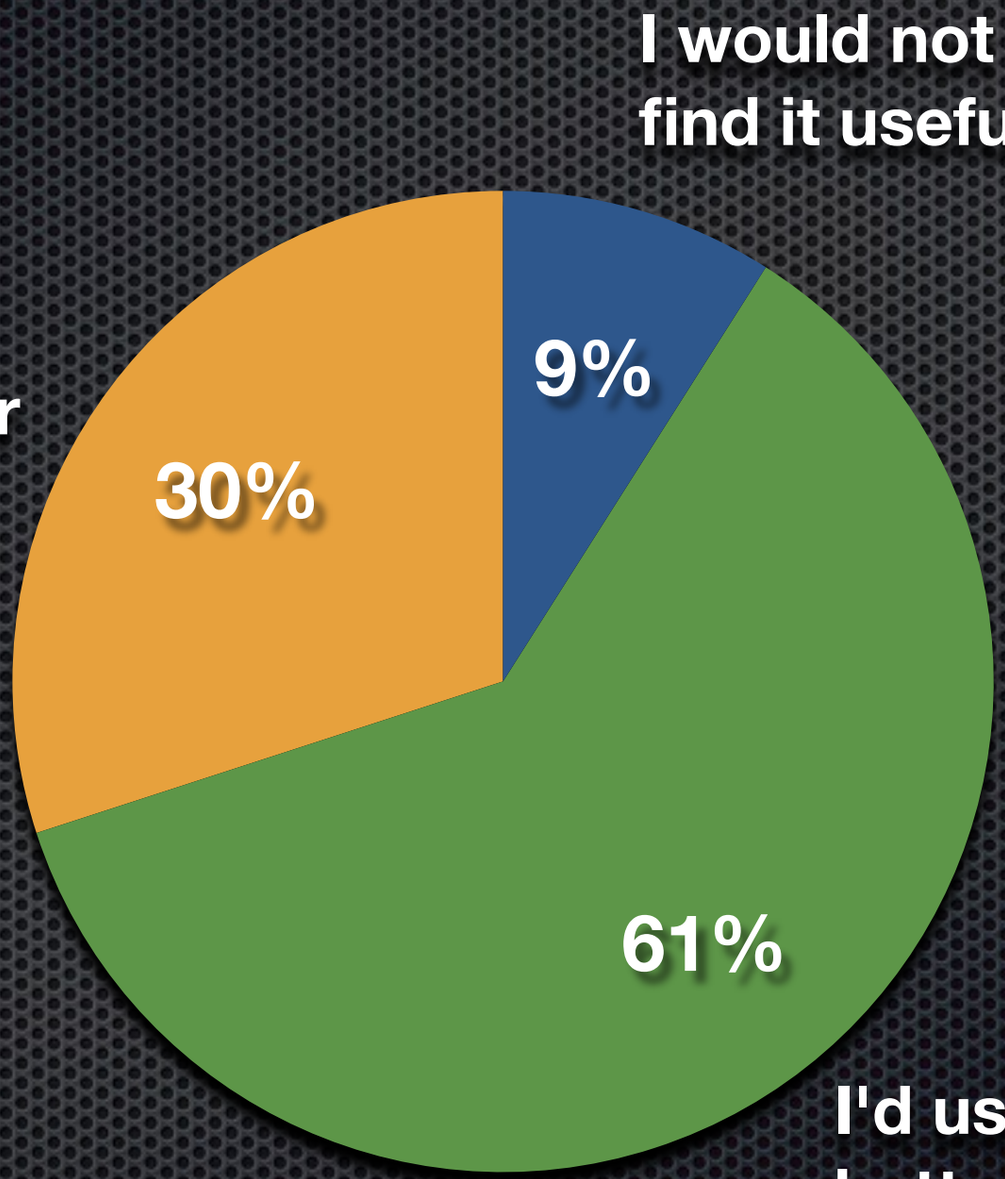
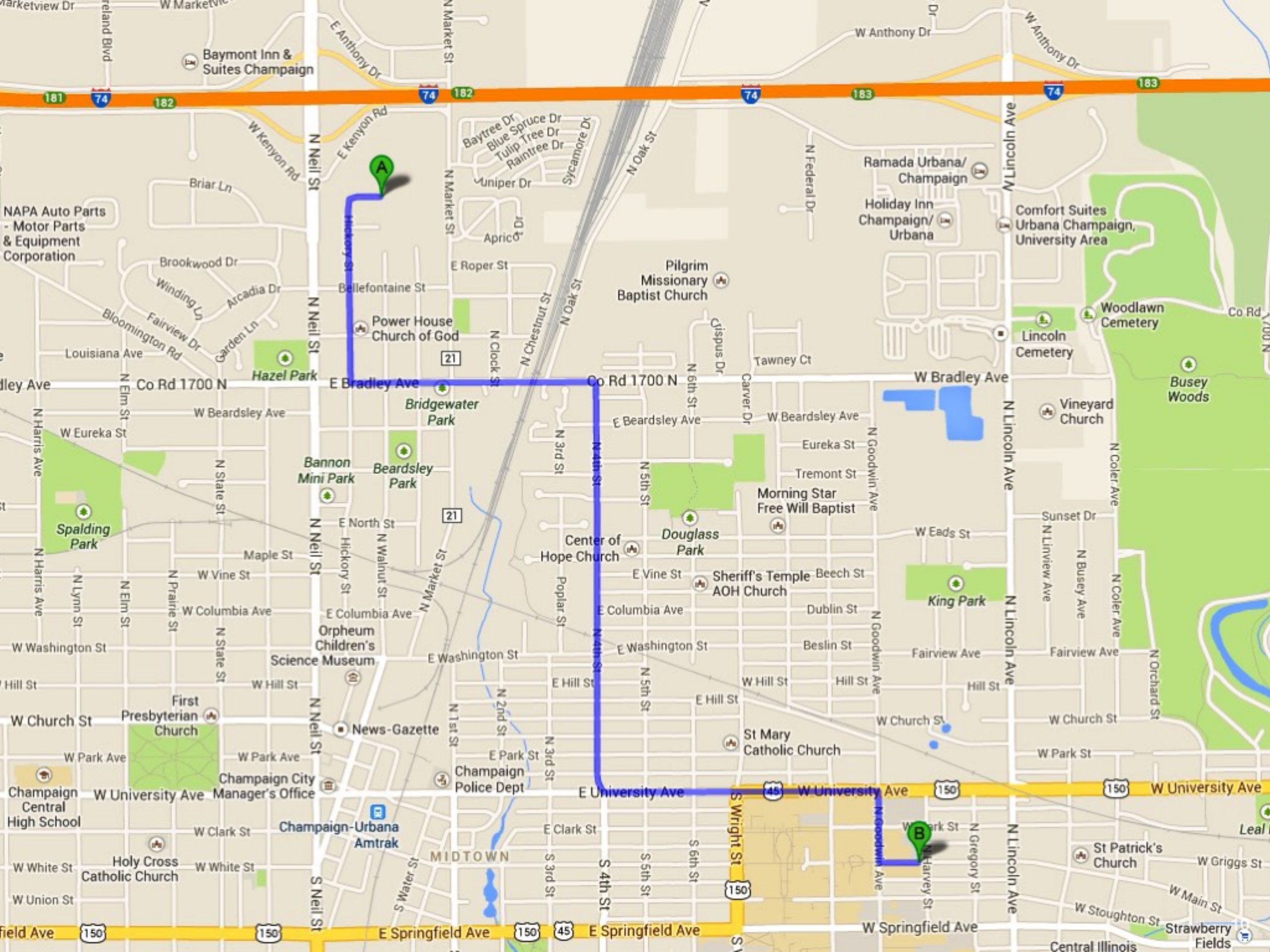


Intuition


A
B
Baymont Inn & Suites Champaign
NAPA Auto Parts - Motor Parts & Equipment Corporation
Power House Church of God
Hazel Park
Bridgewater Park
Bannon Mini Park
Beardsley Park
Spalding Park
Douglass Park
King Park
Pilgrim Missionary Baptist Church
Ramada Urbana/ Champaign
Holiday Inn Champaign/ Urbana
Comfort Suites Urbana Champaign, University Area
Lincoln Cemetery
Woodlawn Cemetery
Busey Woods
Vineyard Church
Morning Star Free Will Baptist
Center of Hope Church
Sheriff's Temple AOH Church
Orpheum Children's Science Museum
First Presbyterian Church
News-Gazette
Champaign Police Dept
Champaign City Manager's Office
Champaign Central High School
Champaign-Urbana Amtrak
Holy Cross Catholic Church
St Mary Catholic Church
St Patrick's Church
Strawberry Fields
MIDTOWN
E Bradley Ave
Co Rd 1700 N
W Bradley Ave
E University Ave
W University Ave
E Springfield Ave
W Springfield Ave
N Neil St
N Market St
N Oak St
N Lincoln Ave
W Anthony Dr
E Anthony Dr
E Kenyon Rd
W Kenyon Rd
E Roper St
Bellefontaine St
Briar Ln
Brookwood Dr
Arcadia Dr
Winding Ln
Fairview Dr
Garden Ln
Bloomington Rd
Louisiana Ave
Baytree Dr
Blue Spruce Dr
Tulip Tree Dr
Raintree Dr
Sycamore Dr
Juniper Dr
Apricot Dr
N Federal Dr
Tawney Ct
Cispus Dr
N Chestnut St
N Clock St
N 6th St
Carver Dr
E Beardsley Ave
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Eureka St
Tremont St
Sunset Dr
W Eads St
Beech St
Dublin St
Beslin St
Fairview Ave
Hill St
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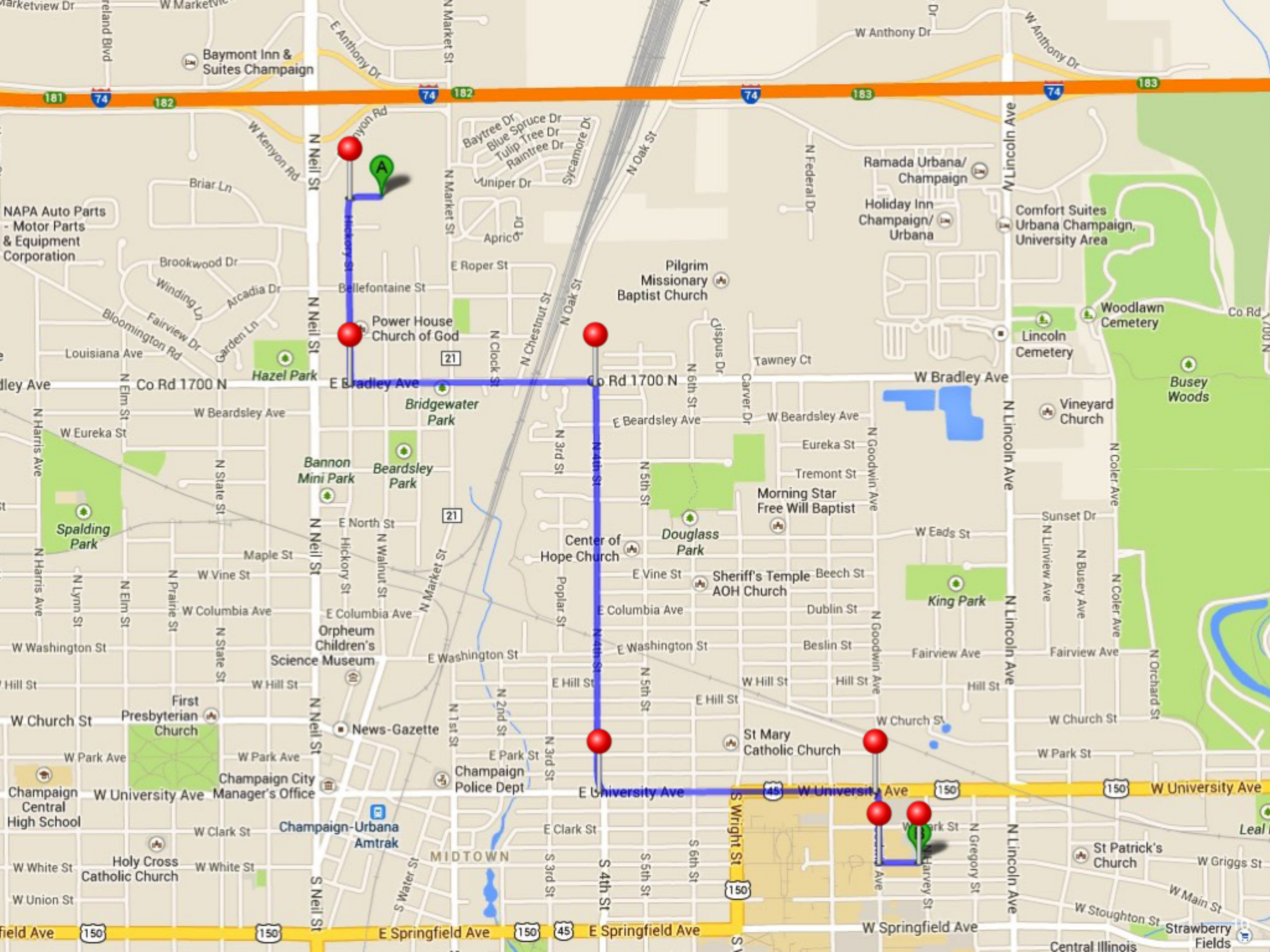
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Poplar St
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W University Ave
E University Ave
E Springfield Ave
W Springfield Ave
W Clark St
E Clark St
W White St
W Union St
W Griggs St
W Main St
W Stoughton St
Strawberry Fields
Central Illinois
181
74
182
183
21
150
45

Navigator Design Sketch

Navigator Design Sketch

- GPS - **accurate localization** only when approaching way-points

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- ACC - **roughly estimation** driving progress

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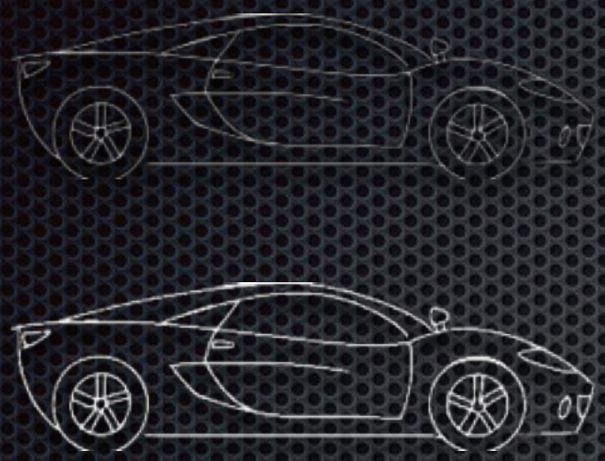
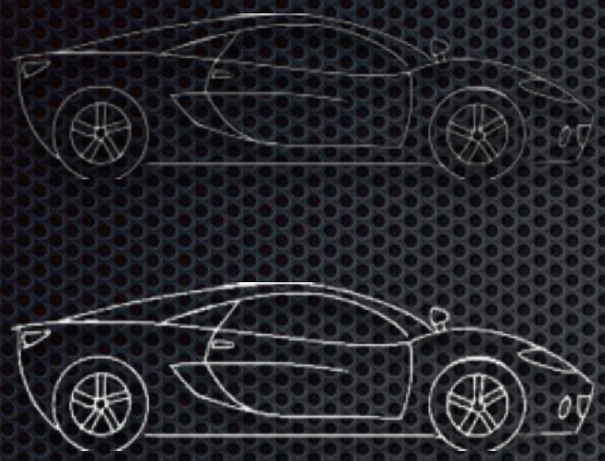
  - Under-estimation results in way-point misses

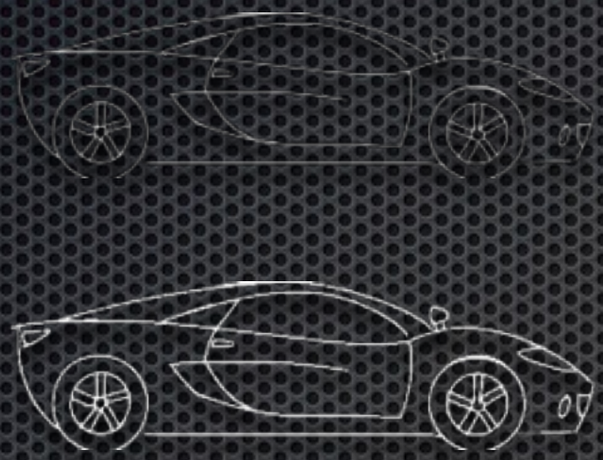
Navigator Design Sketch

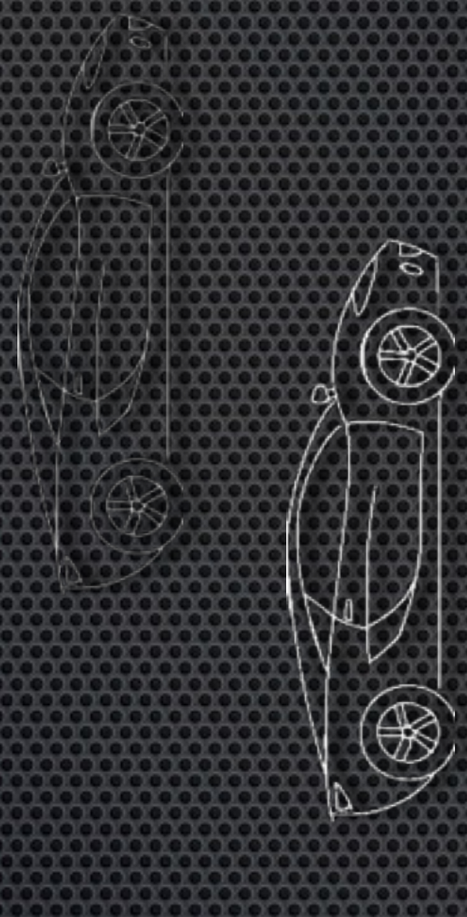
- GPS - **accurate localization** only when approaching way-points
- ACC - **roughly estimation** driving progress
  - Under-estimation results in way-point misses
  - We want **over-estimation**

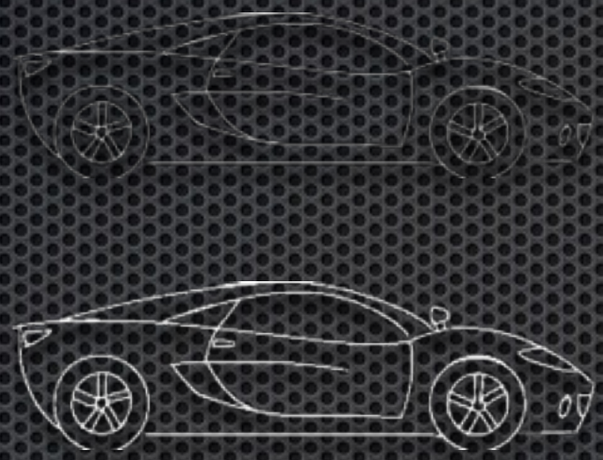


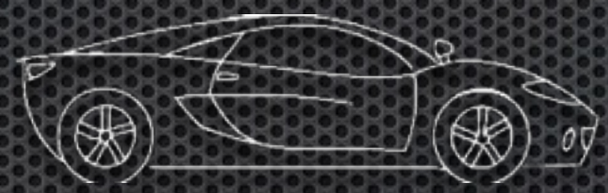
missed :(

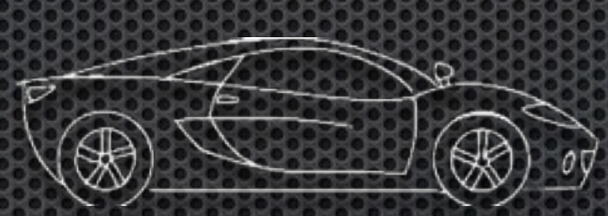






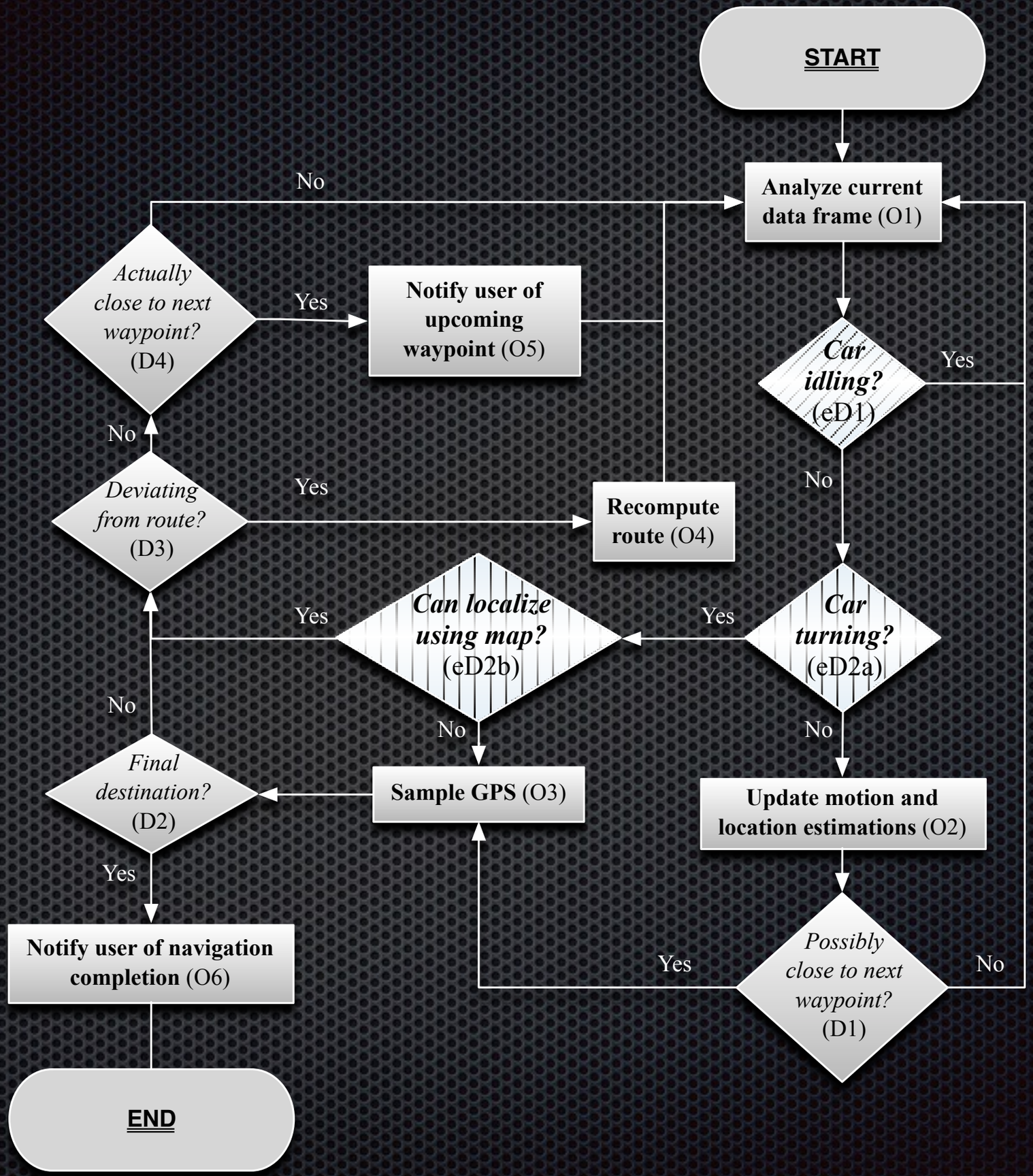






Also, In Practice…

- PCA-based driving direction extraction
- Car-turning detection
- Car-idling detection

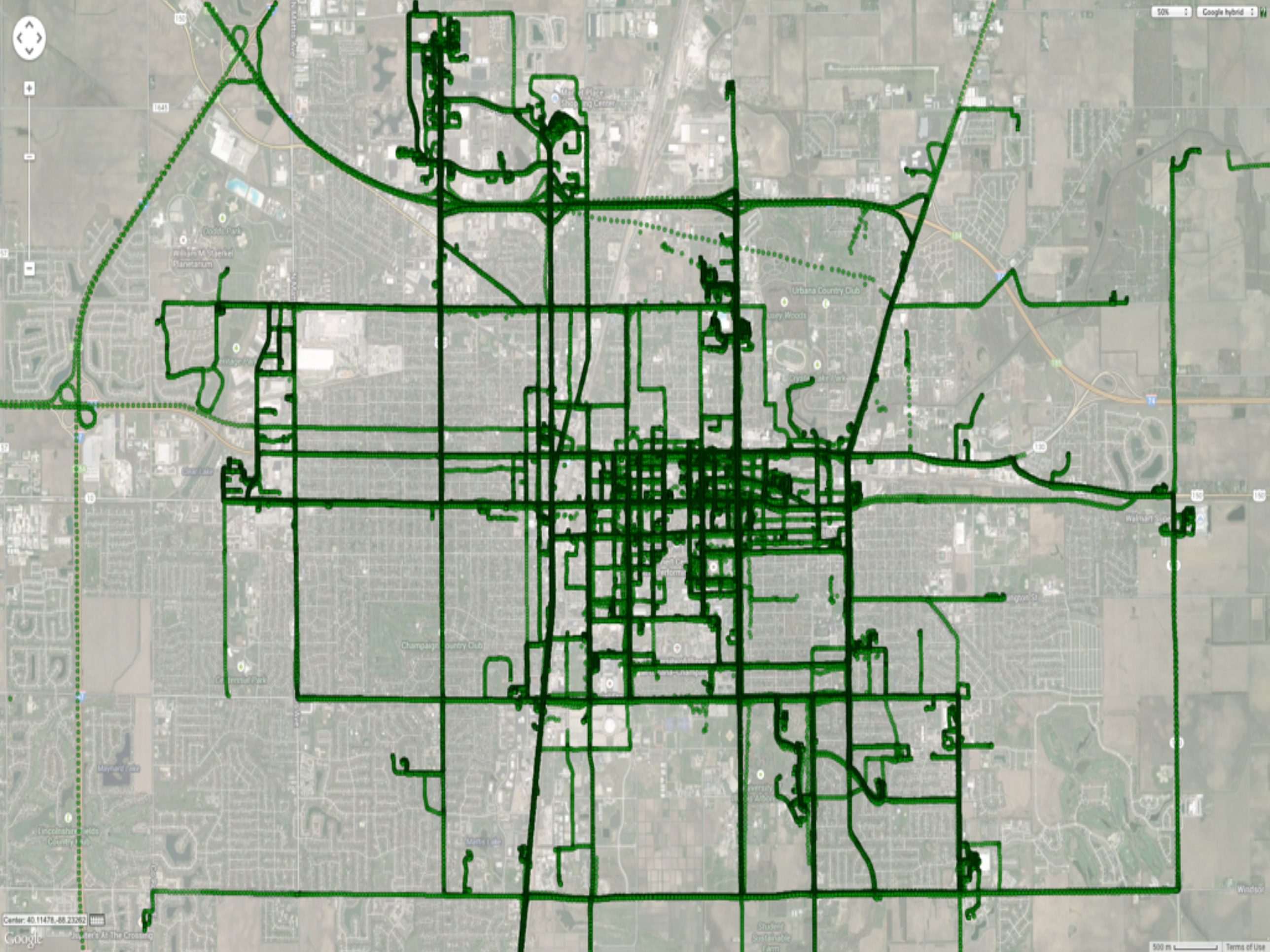

START
Analyze current data frame (O1)
Car idling? (eD1)
Yes
No
Car turning? (eD2a)
Yes
No
Can localize using map? (eD2b)
Yes
No
Possibly close to next waypoint? (D1)
Yes
No
Update motion and location estimations (O2)
Sample GPS (O3)
Final destination? (D2)
No
Yes
Deviating from route? (D3)
No
Yes
Recompute route (O4)
Actually close to next waypoint? (D4)
No
Yes
Notify user of upcoming waypoint (O5)
Notify user of navigation completion (O6)
END

User Study

- 33 external volunteer participants
- Various road/traffic/weather/time-of-day conditions
  - urban, rural
  - rush hour, quiet hour
  - daytime, nighttime
  - sunny, rainny, snowy

Phase I - Trace Analysis

- Participants asked to drive as they wished
- GPS+ACC traces logged by vehicle-resident phones
- 2 months total, 3 weeks per participant
- 6,000 km driving data


Google hybrid
Urbana Country Club
Champaign Country Club
Google
500 m
Terms of Use

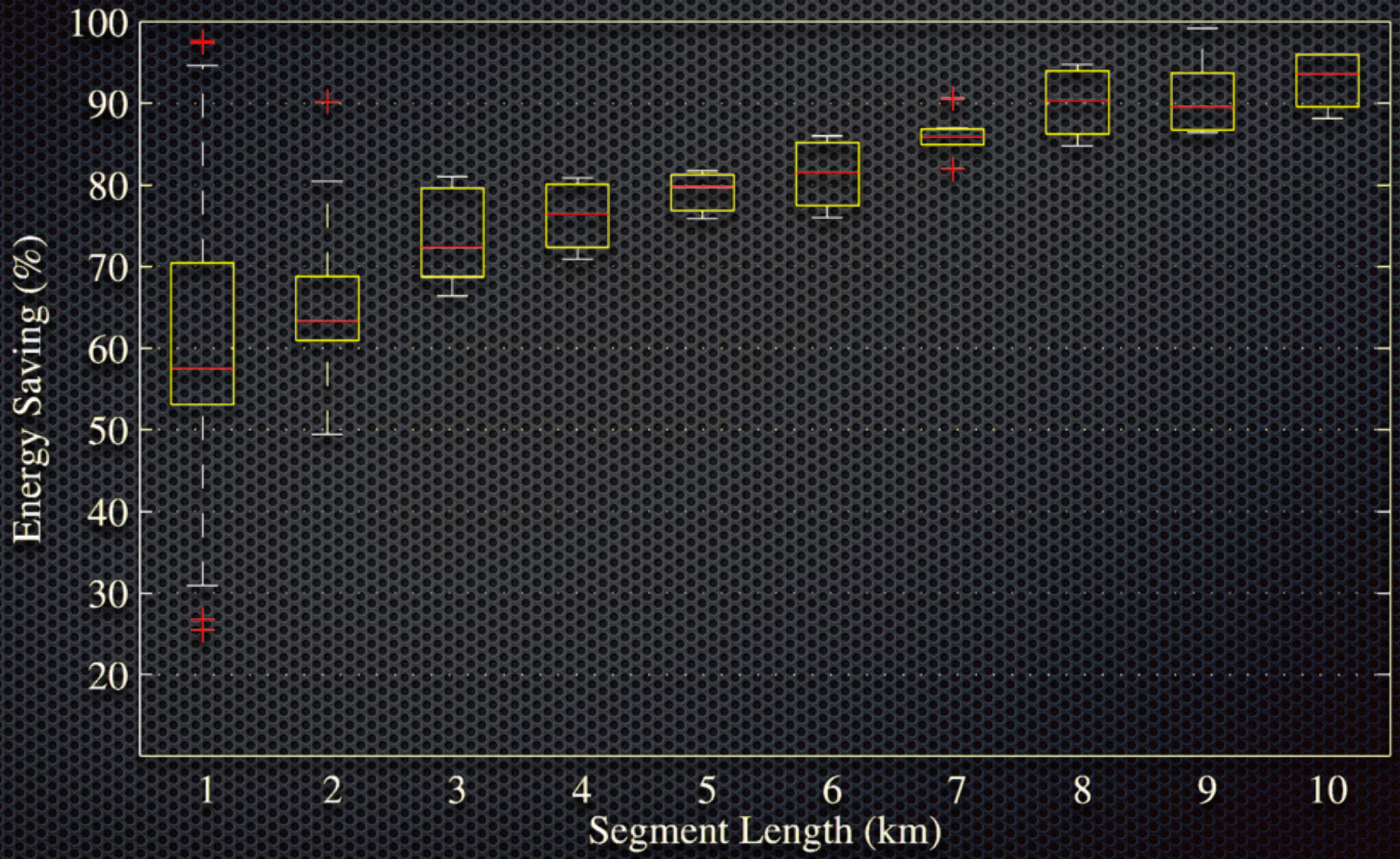

~78.4%

0 way-point misses

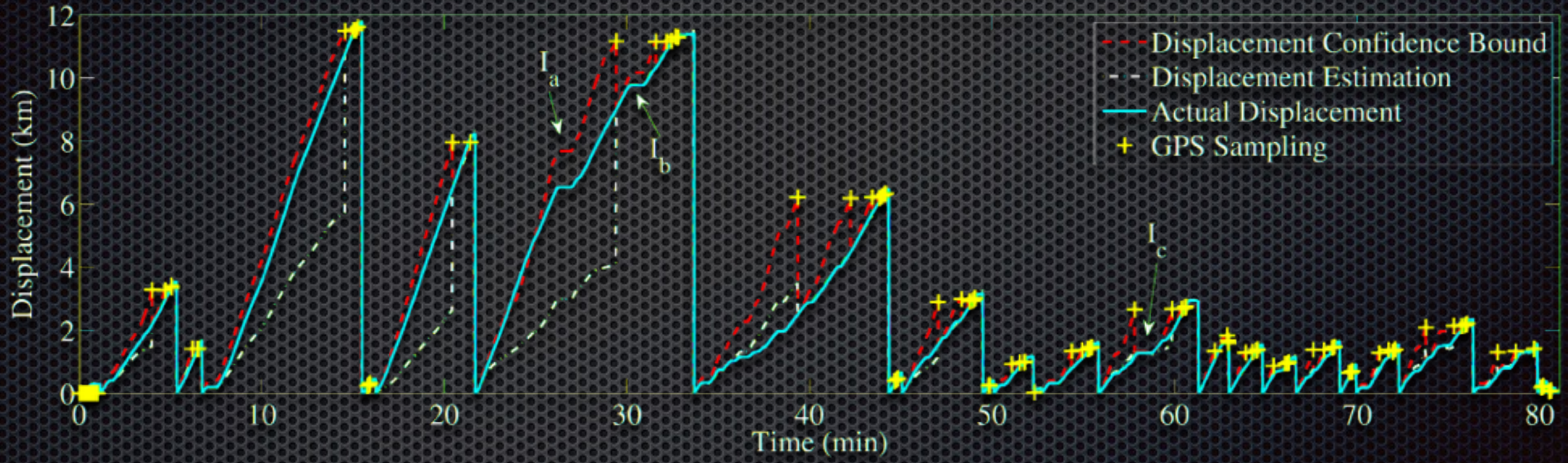
What if: simply down-sample GPS?

- Sampling period: 1s -> **83s**
- Missing **83.2%** waypoints!

Energy Savings Break-down



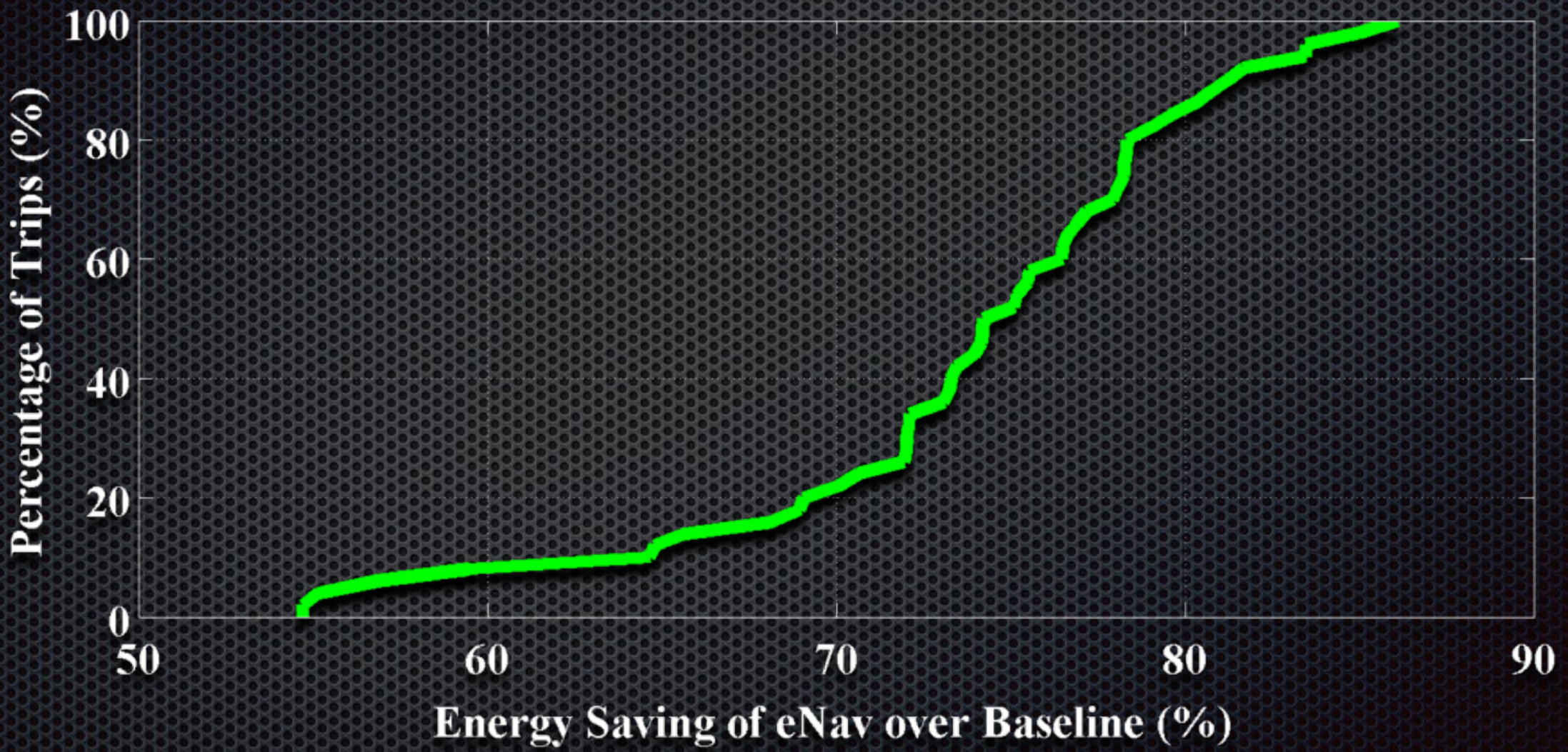
An Example Trace



Phase II - eNav Navigation

- Participants asked to drive w/ eNav for navigation
- 3 routes (with strange destinations) per participant
- 2,000 km

Energy Savings E-CDF

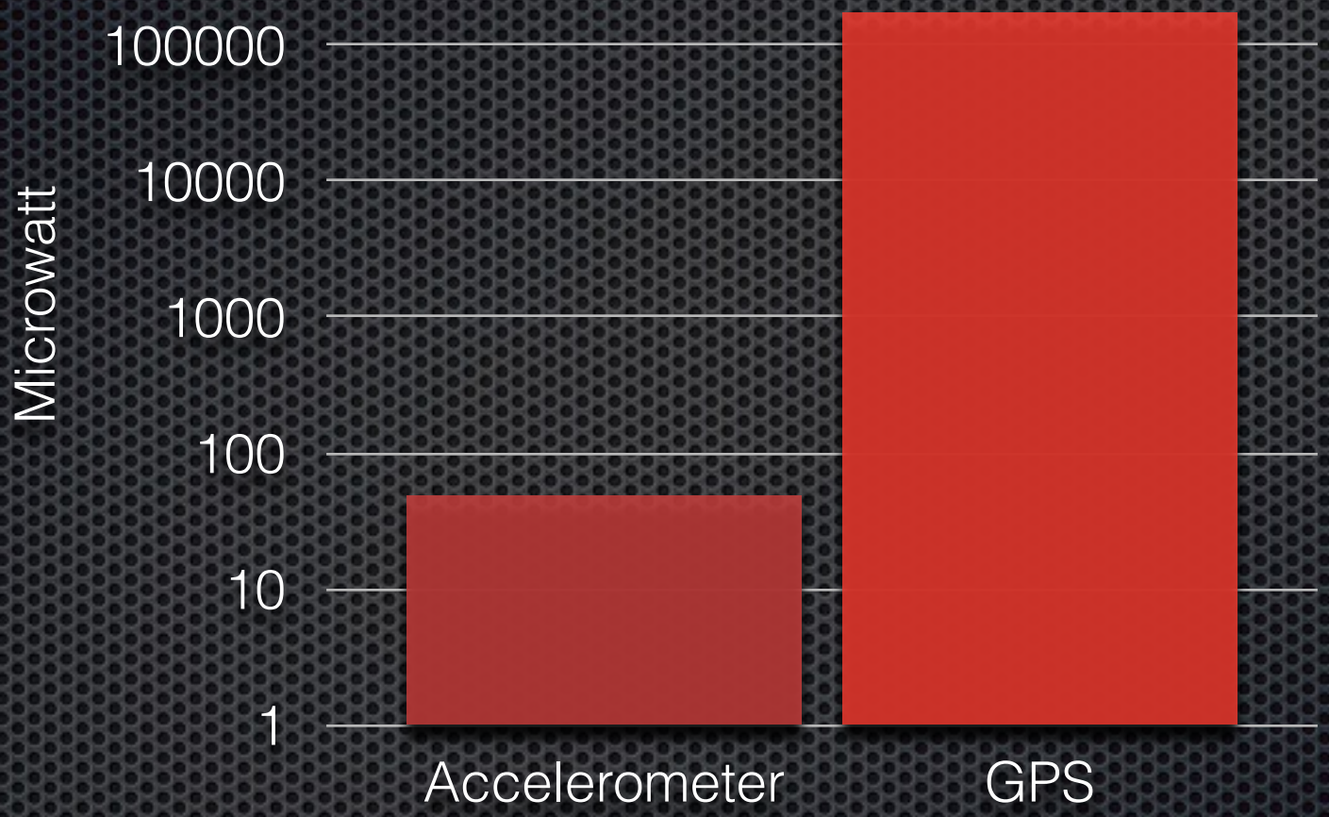


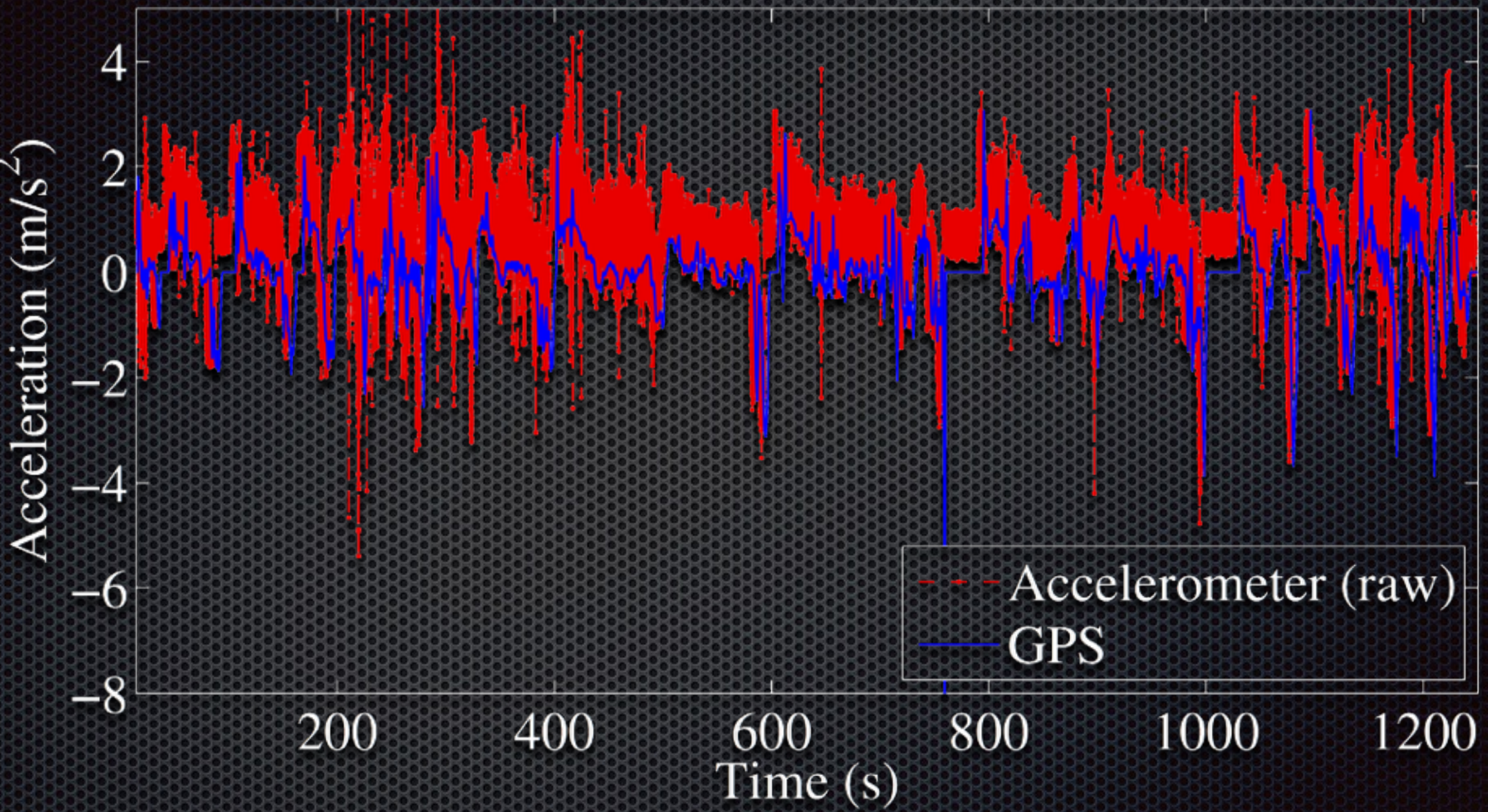
“It’s hard to tell the difference between your service and real GPS!”

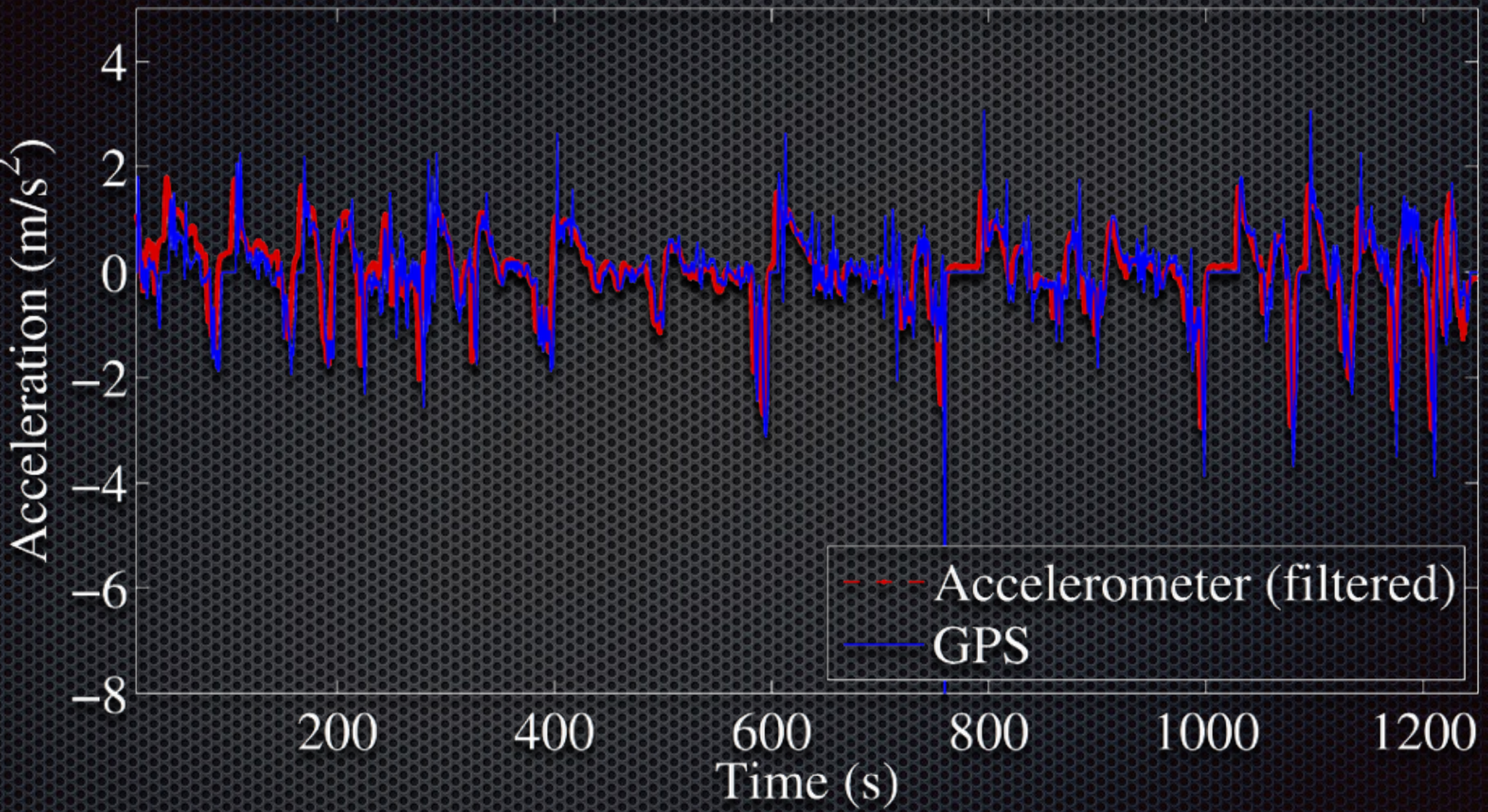
Thanks

backups

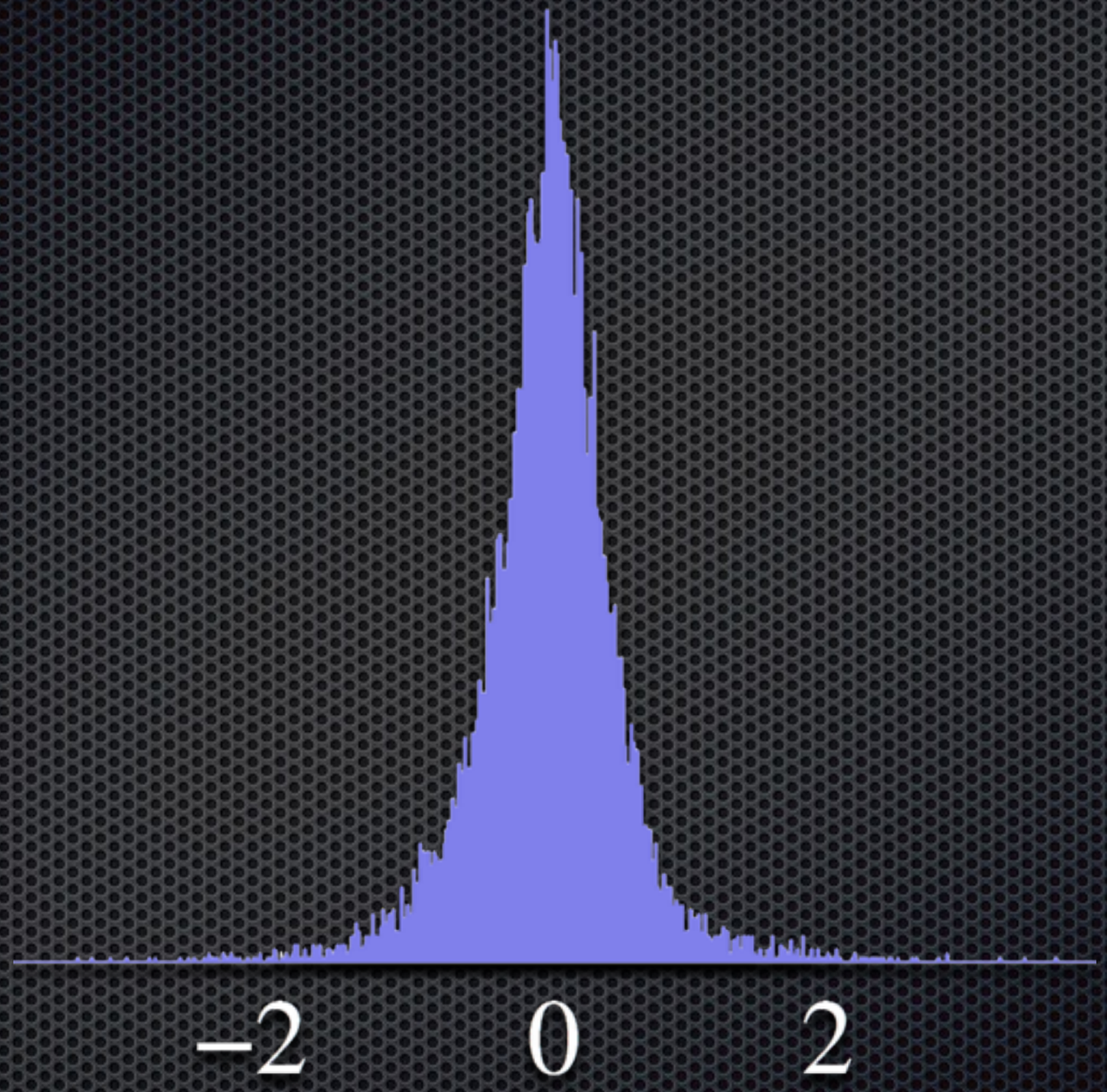
Accelerometer?


100000
10000
1000
100
10
1
Microwatt
Accelerometer
GPS


Acceleration (m/s^2)
4
2
0
−2
−4
−6
−8
200
400
600
800
1000
1200
Time (s)
Accelerometer (raw)
GPS


Acceleration (m/s^2)
4
2
0
−2
−4
−6
−8
200
400
600
800
1000
1200
Time (s)
Accelerometer (filtered)
GPS

Acc Estimation Error



ACC estimation error (m/s^2)

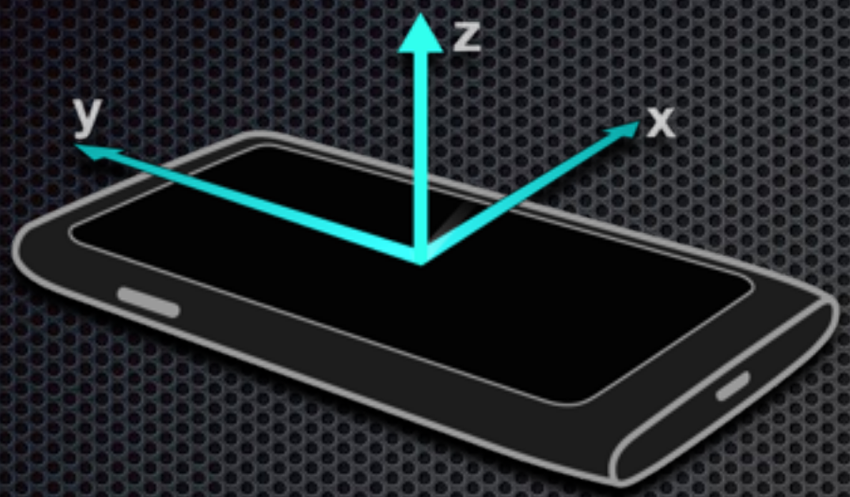
Deviations

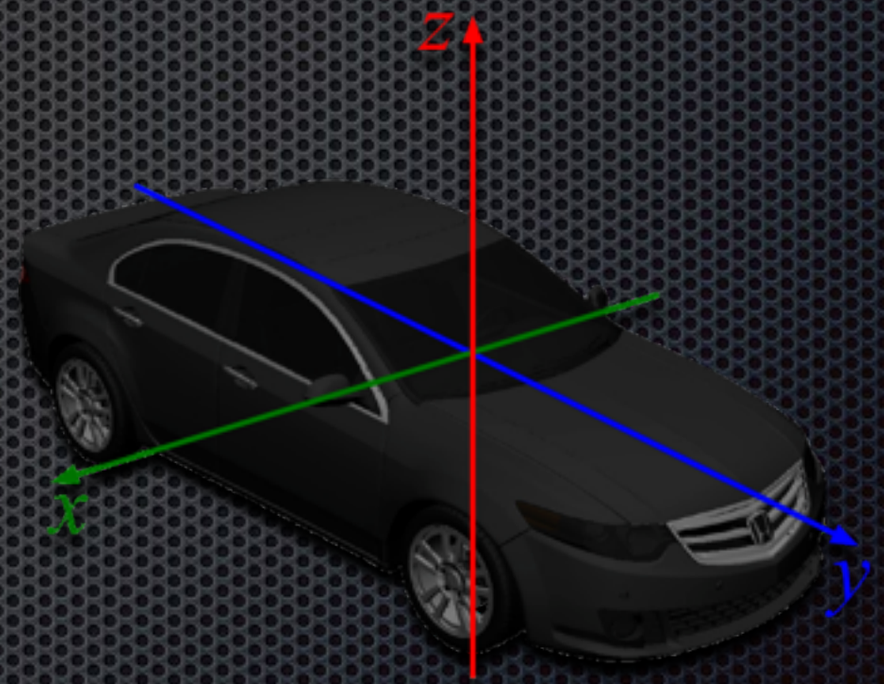
- User makes a turn too early
- User makes a turn too late
- User fails to make a turn and keeps driving

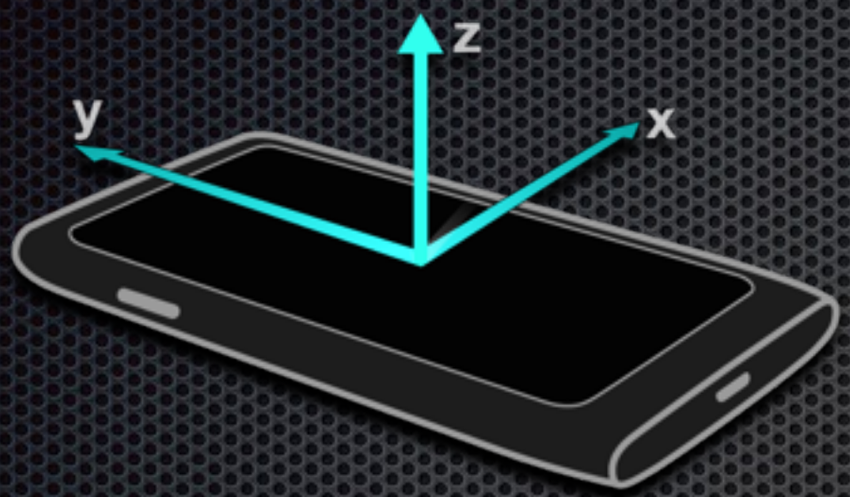
2 Driving Motion Detections

- Turn and Idle detections
- DecisionTree based classifiers
- ~99% accuracies for both

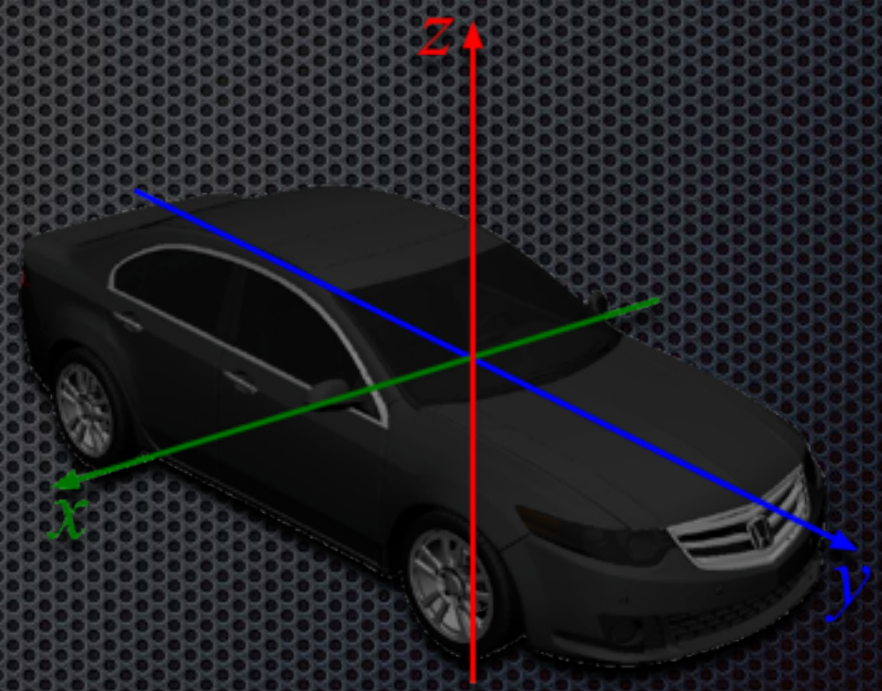
Orientation?

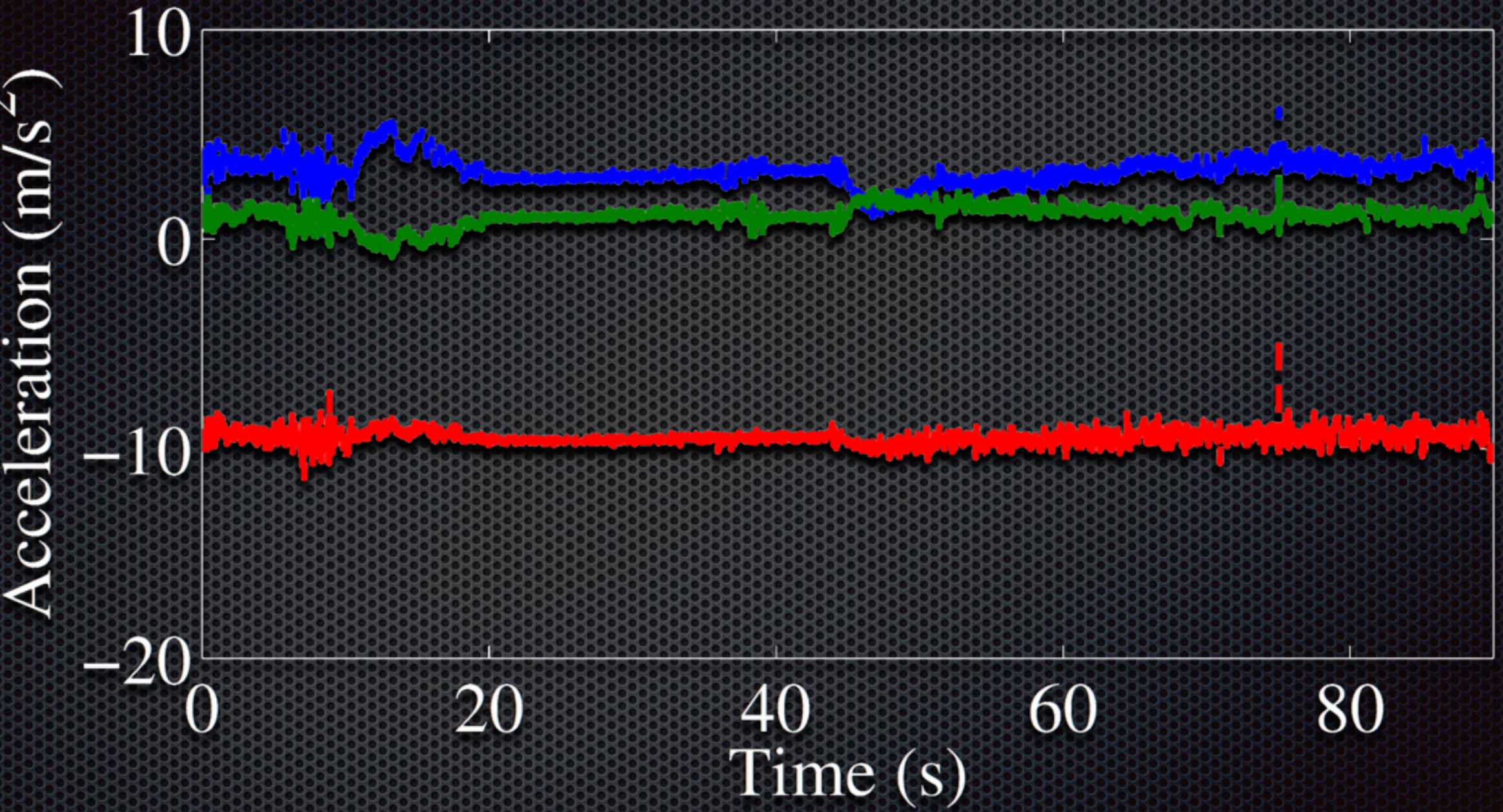

z
y
x

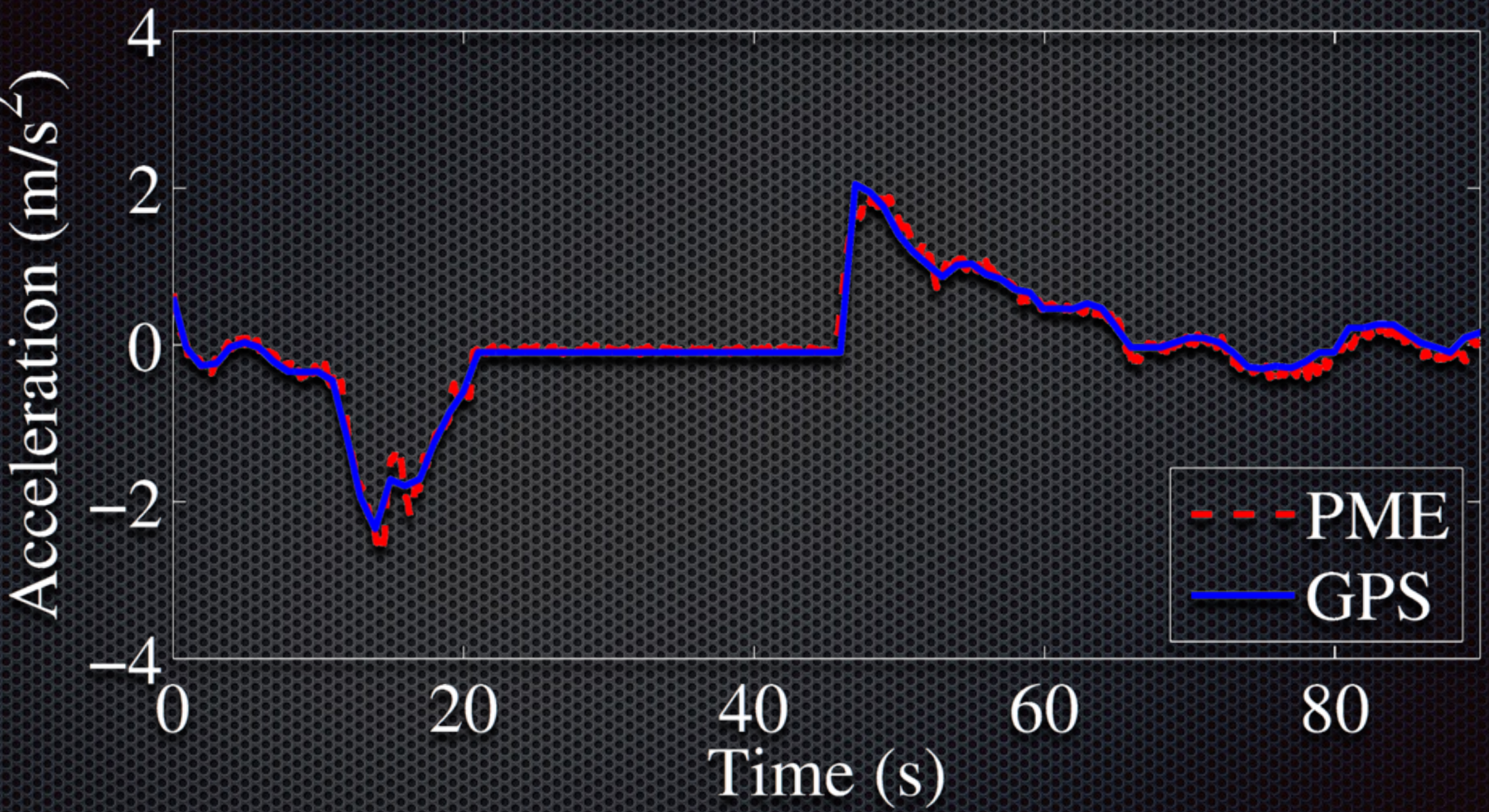

z
x
y



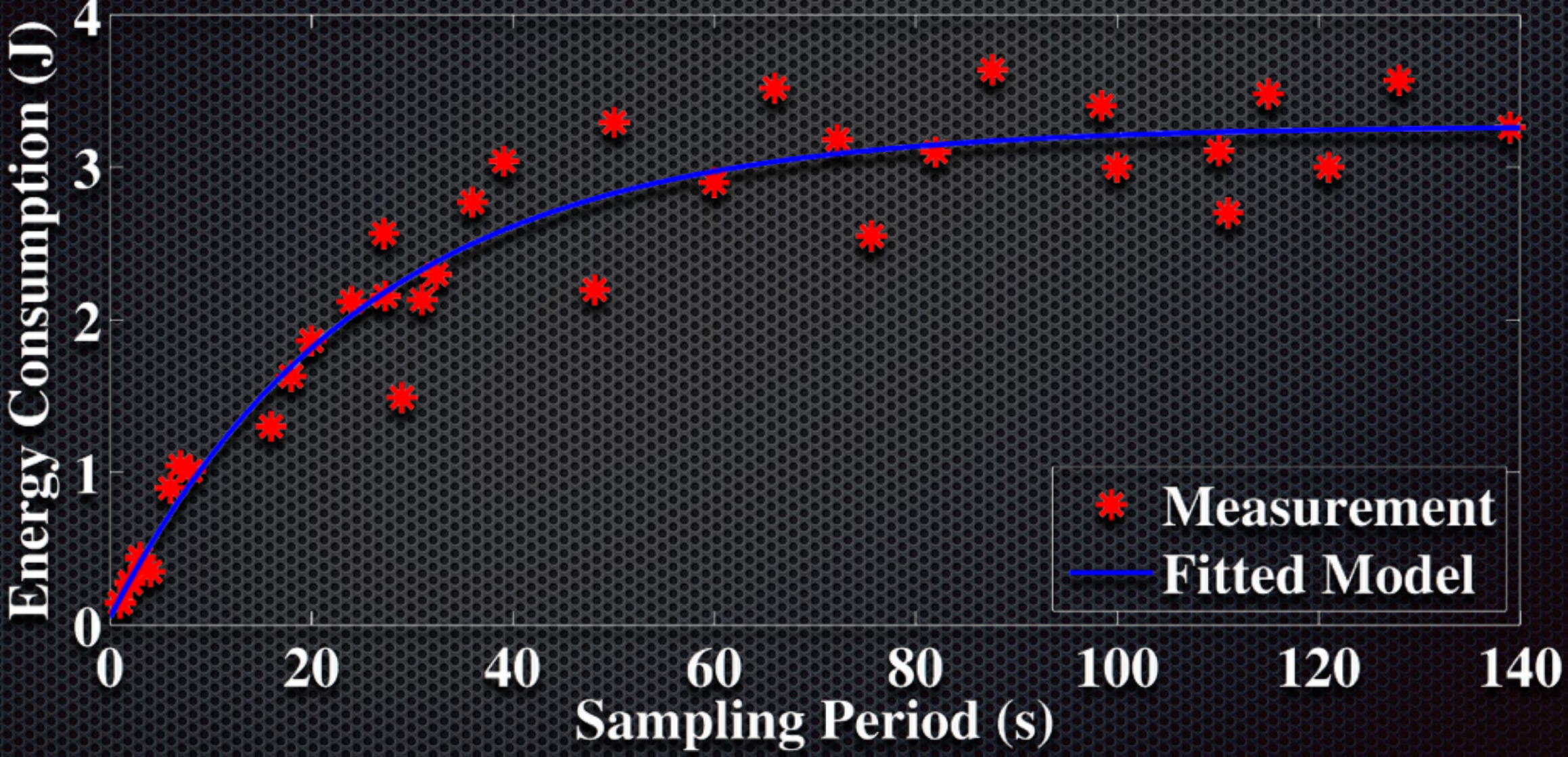
PME




10
0
−10
−20
Acceleration (m/s^2)
0
20
40
60
80
Time (s)

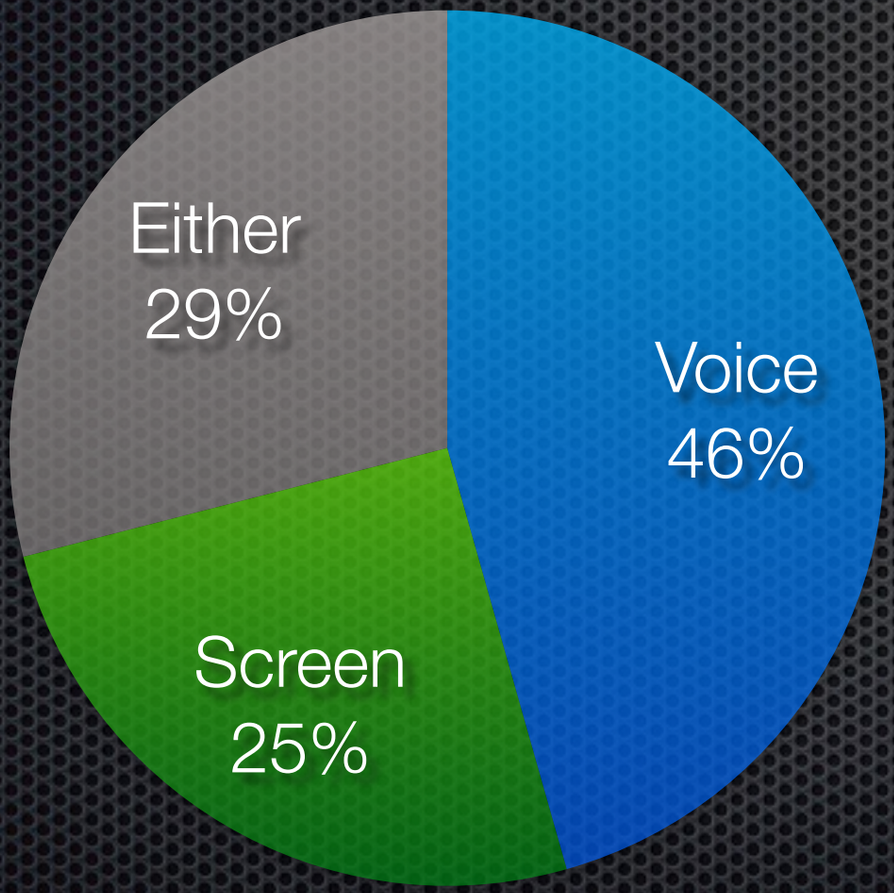

Acceleration (m/s^2)
4
2
0
−2
−4
0
20
40
60
80
Time (s)
PME
GPS

GPS Energy Profiling

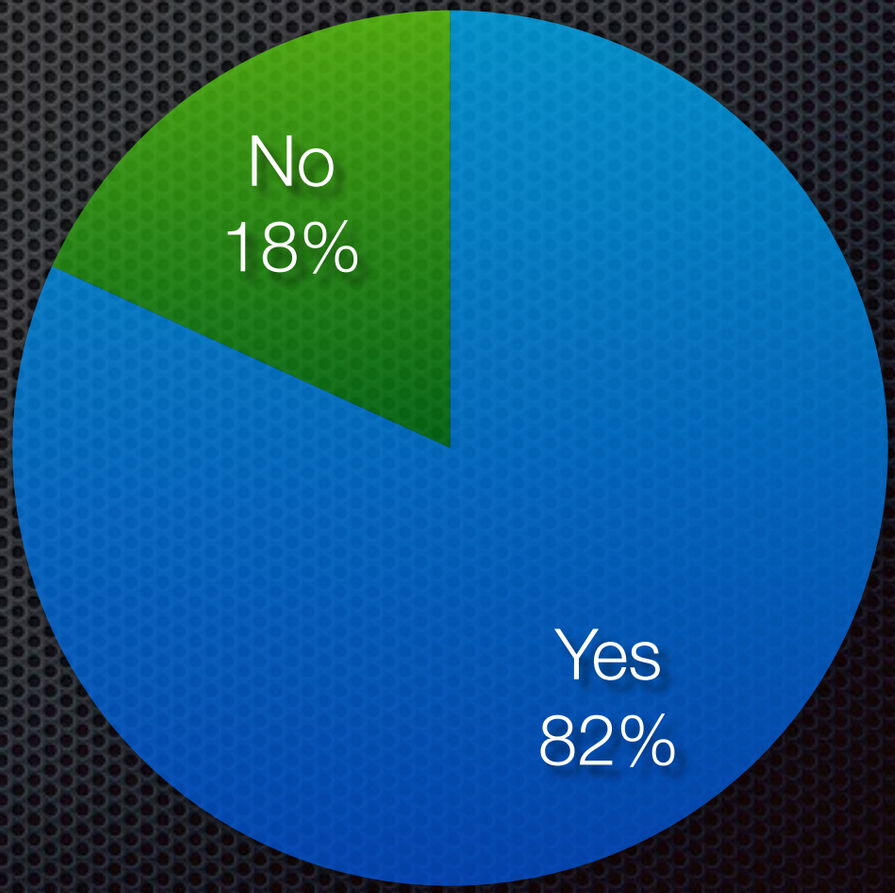


Screen vs Voice Guidance?

Which do you think is more important for GPS navigation?



If battery is running low, would you be willing to rely just on voice guidance



Phase II Screen-On e-CDF