

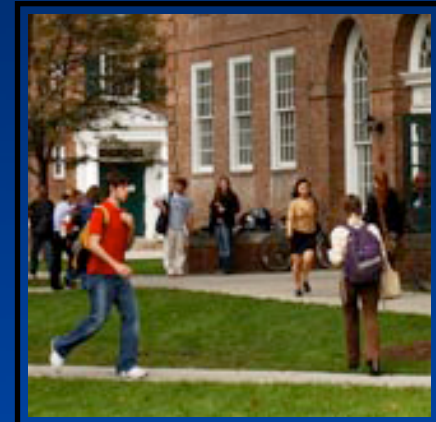
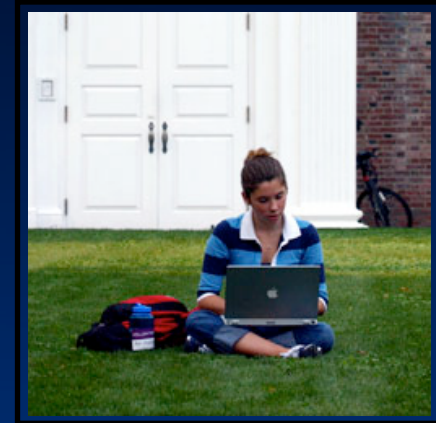
# Extracting a mobility model from real user traces

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April 26, 2006

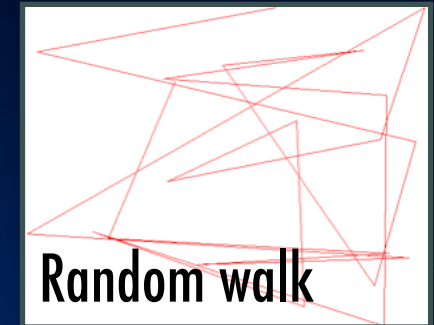
# Simulating user mobility

- Wireless-network usage is increasing
  - ▶ Mobile systems or applications need be aware of people's mobility
  - ▶ Not feasible to test in real environment
  - ▶ Thus, resort to simulations
- To simulate people's movements
  - ▶ Trace-driven: limited parameter space
  - ▶ Model-based: no realistic models



# Need a new mobility model

- Current models aren't realistic
  - ▶ Variation of random-walk models
  - ▶ Based on intuition of designer
- Goal: Develop mobility model using **real traces**
- Mobility traces
  - ▶ Physical mobility traces aren't available
  - ▶ Use network mobility traces: syslog
  - ▶ Why syslog? Easy to collect, readily available



# Syslog traces

- Dartmouth has campus-wide wireless network
  - ▶ Around 560 access points, on 1km<sup>2</sup> main campus
- Access points (APs) collect syslog traces
  - ▶ Record client events (associate, authenticate,...)
  - ▶ Each entry: time stamp, AP, client, event type
- Two types of models can be developed
  - ▶ Model of AP-association patterns
  - ▶ Model of **physical mobility** ← *Our goal*

# Focus on always-on devices

- On-and-off devices
  - ▶ Laptops
- Always-on devices
  - ▶ Vocera communicators
  - ▶ Cisco VoIP phones
- Usage patterns are different
  - ▶ Not enough path information for laptops
  - ▶ Focus on **always-on devices**

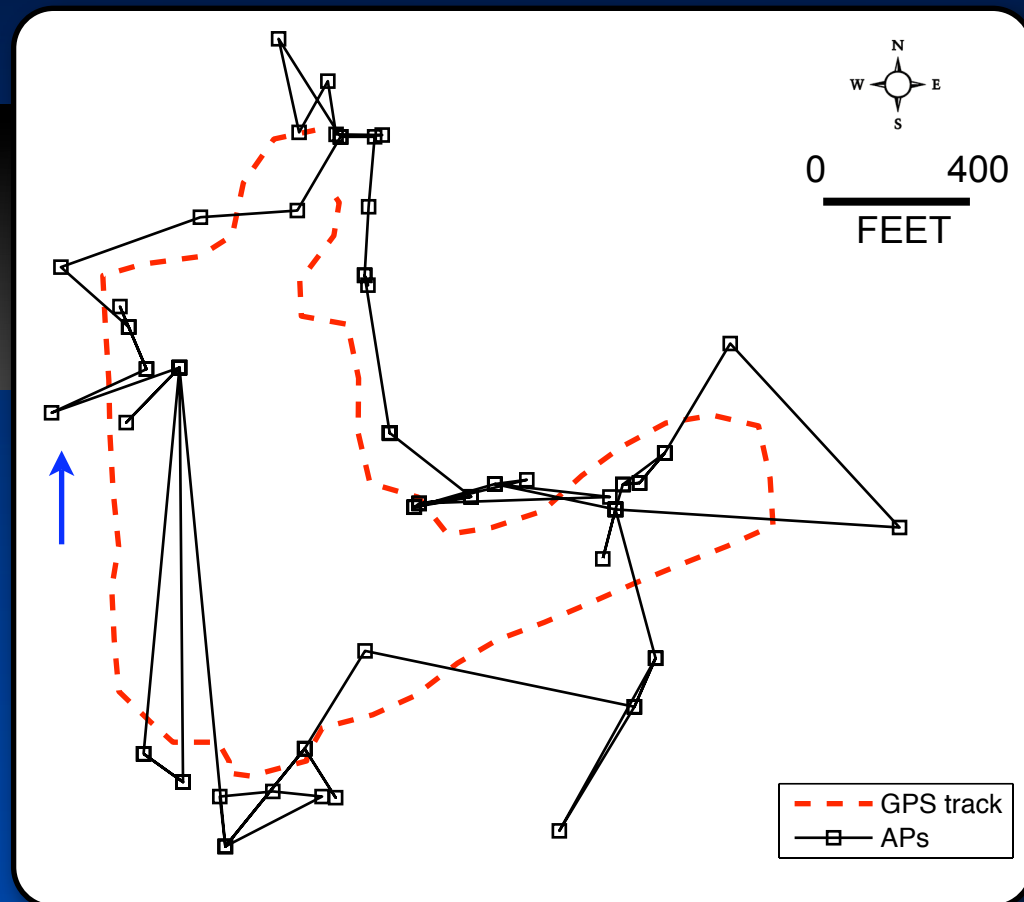


# Estimating physical location

- Problem: Syslogs don't contain users' physical location, only sequence of AP locations
- Challenge: How to estimate physical location?

## Sample walk

*User walked for 20 min,  
carrying GPS and Vocera*



# Estimating physical location

- Estimate physical location using filters

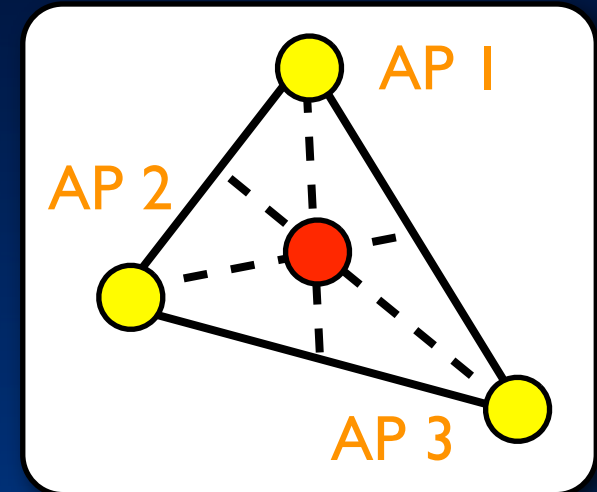
- ▶ Centroid filters

- Triangle centroid

- use three associations

- Time-based centroid

- use associations within 60s



- ▶ Kalman filter: estimate position given knowledge on system's behavior and measurements with noise
- Kalman filter performed the best

# Extracting pause time

- Problem: Syslogs have only association time stamps
- Challenge: Separate time into travel and pause
- For given distance, expected travel time is known
  - ▶ If elapsed time is longer than expected, user probably paused and then moved

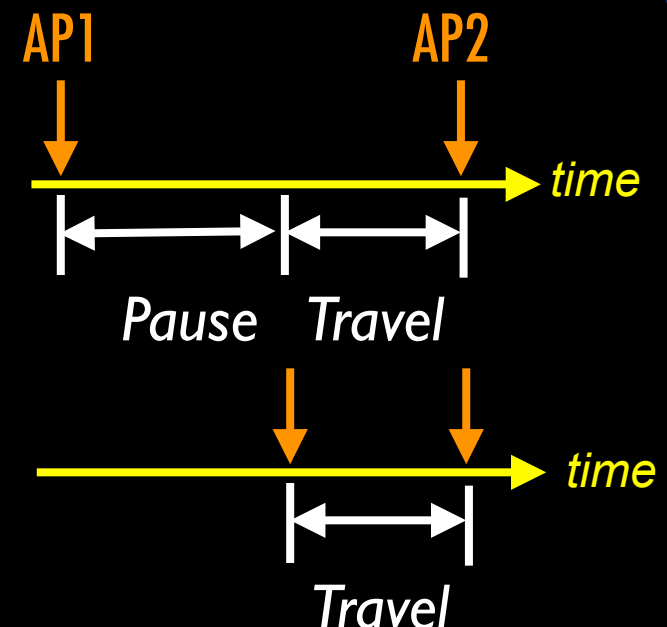
Let  $s = \text{distance} / \text{elapsed}$

If  $s < 0.5 \text{m/s}$

user paused and then moved

If  $s$  is in normal range  $[0.5 - 10 \text{m/s}]$

user didn't pause

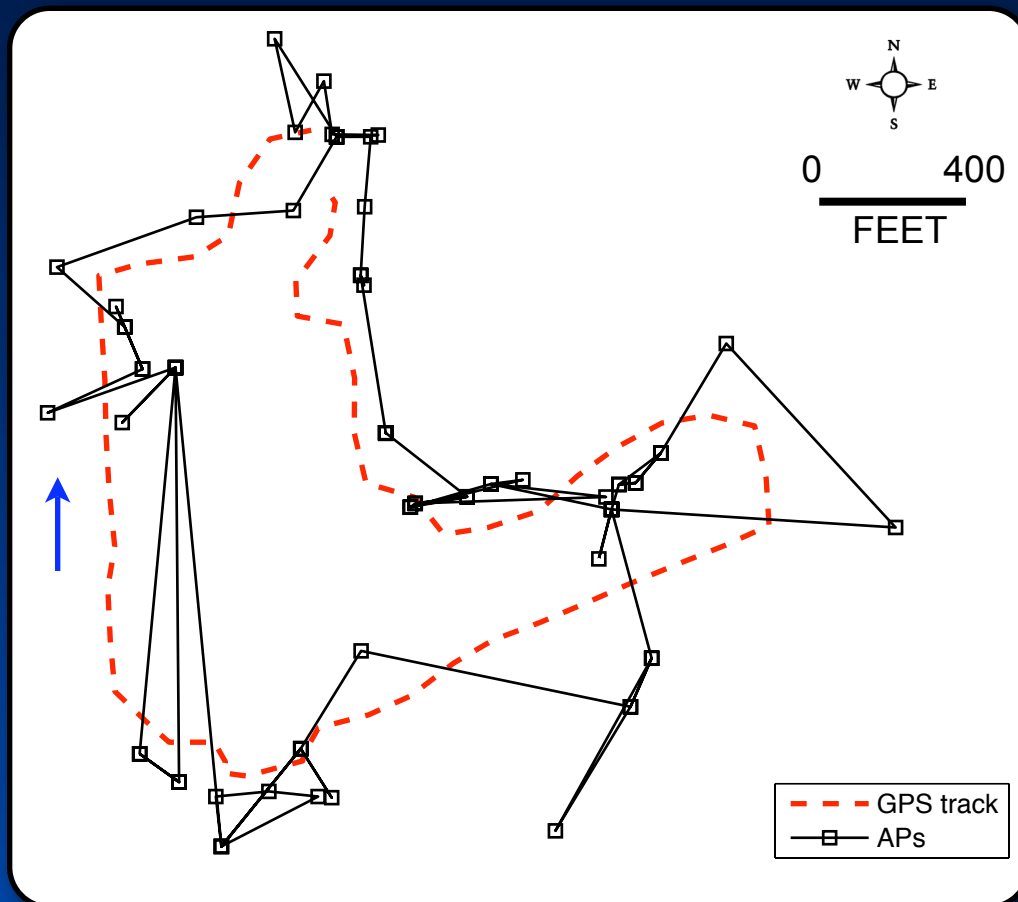




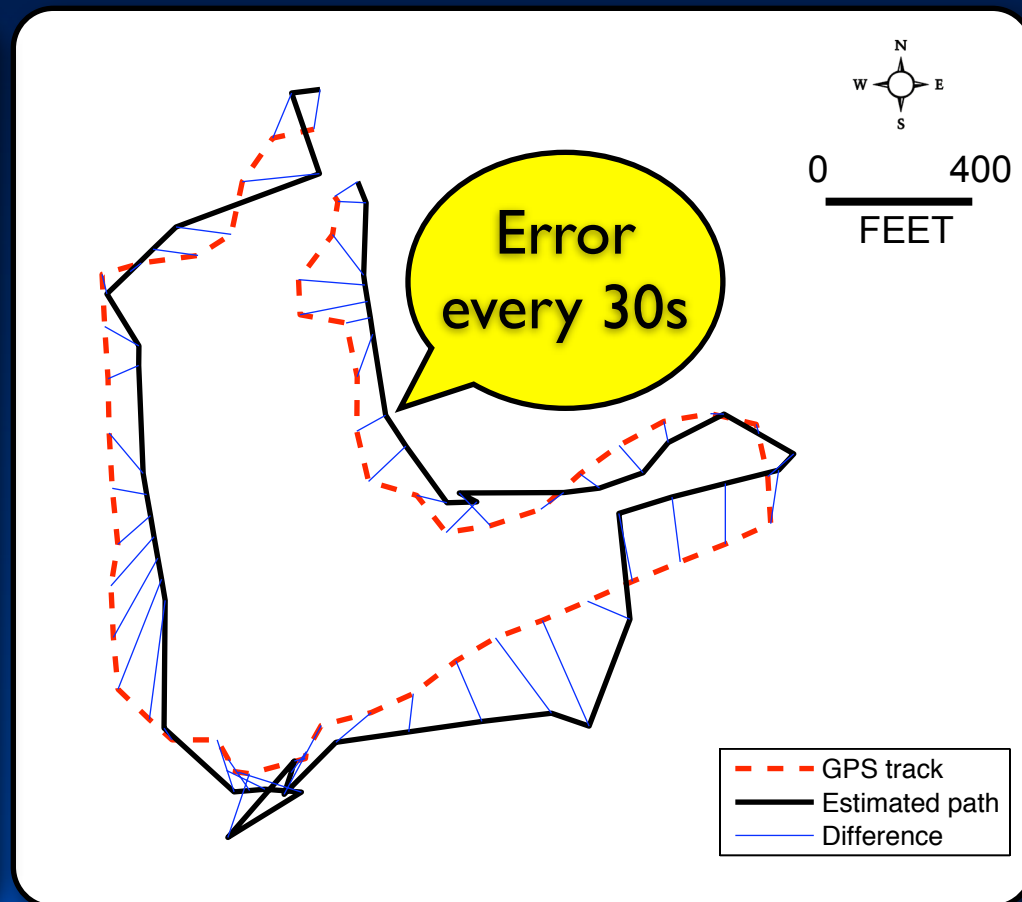
# Evaluation method

- Four people walked, carrying GPS, Vocera, and Cisco phone
  - ▶ Each walk lasted 30 min with a 10 min pause
  - ▶ Four Vocera traces, four Cisco traces

## Raw AP associations



## Filtered user path



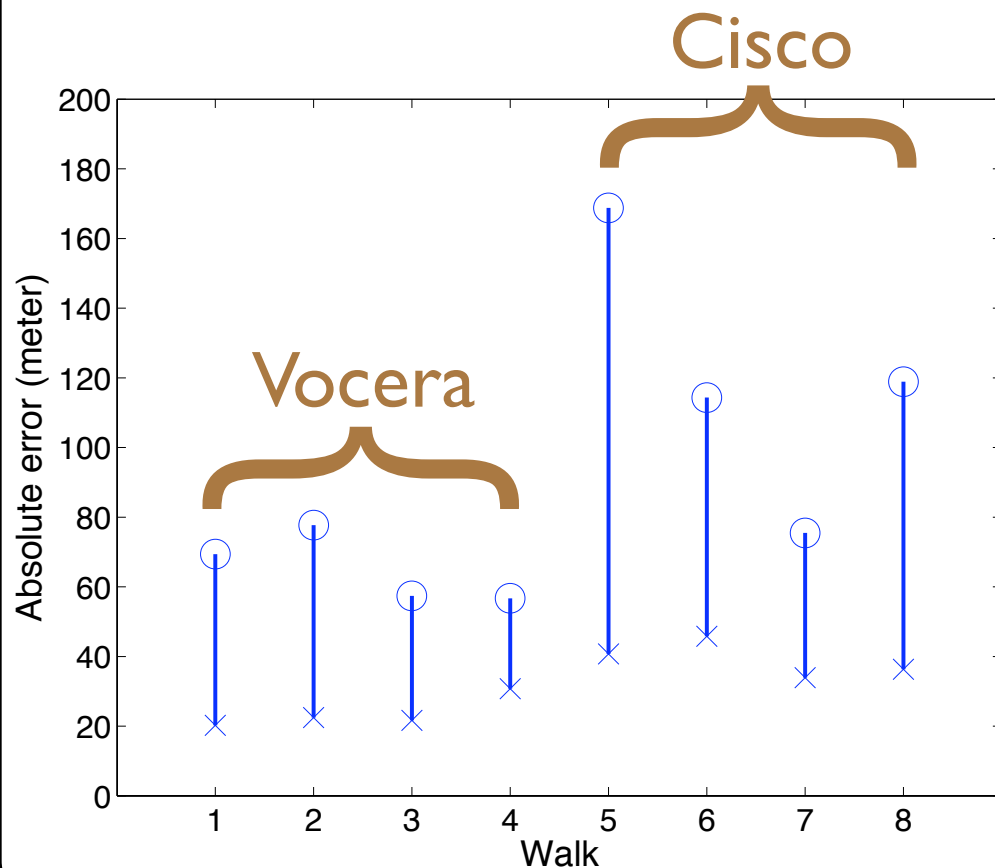
# Evaluation result

## Path extractor (Kalman filter)

Error computed every 30s per walk

Ground truth: GPS

Median error: 20m - 46m

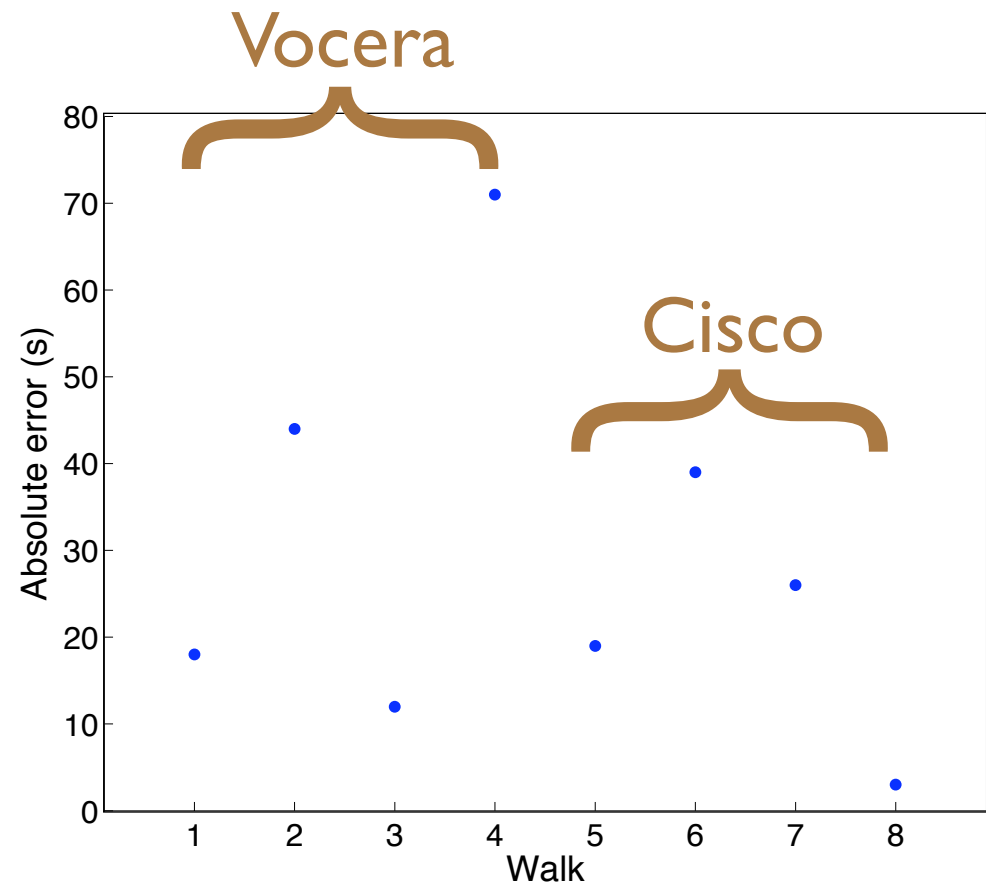


## Pause extractor

Error computed for a 600s pause

Ground truth: user recorded

Error: 3s - 71s



# Network traces

- June 2003 - June 2004
- 198 always-on devices (existing users)
- To remove diurnal effects, considered 8am-6pm
- Divide workday traces based on
  - ▶ *Diameter*: maximum distance between any two APs visited by user during workday

Set	Diameter	Workdays
Mobile	$\geq 100$ m	3,252 (46%)
Stationary	$< 100$ m	3,876

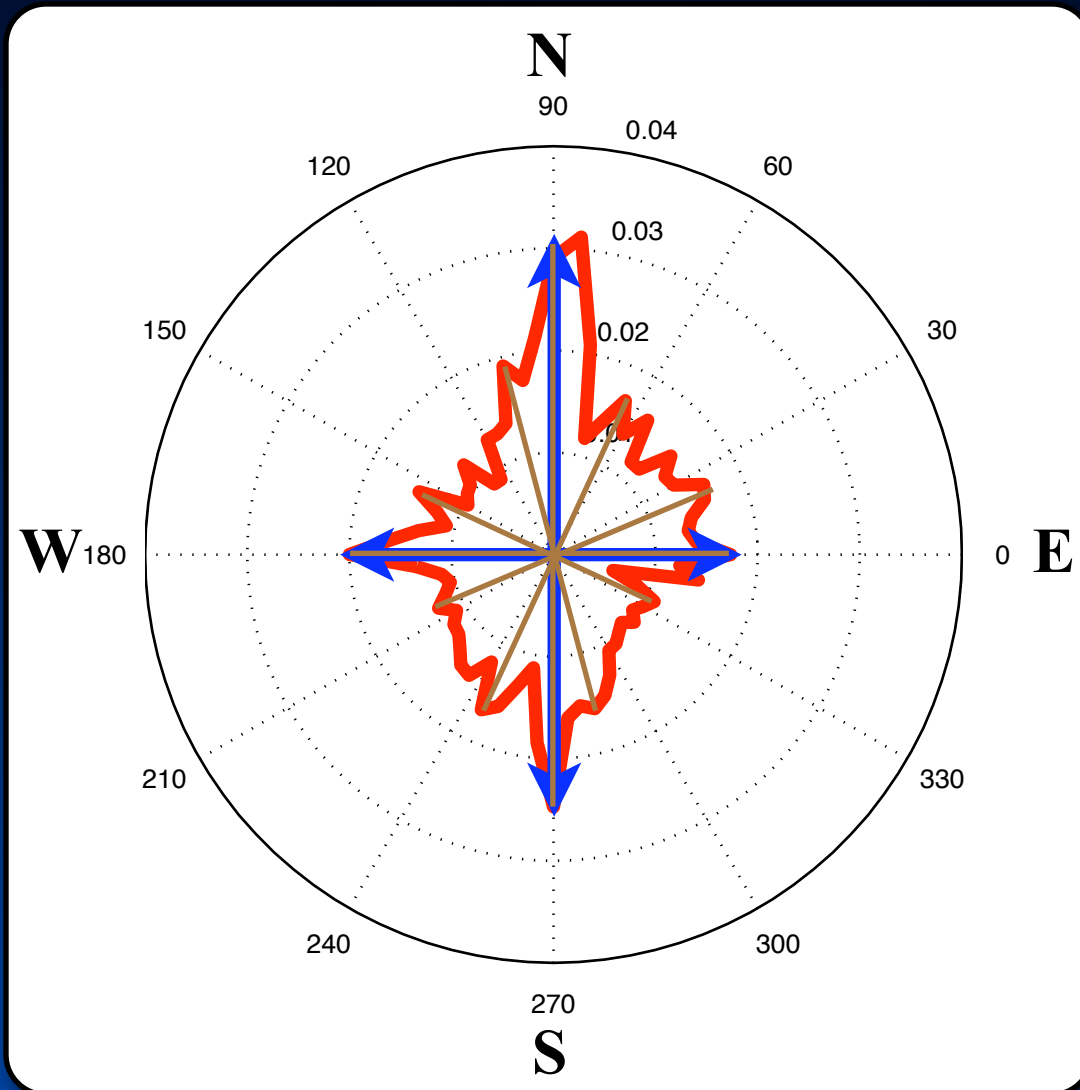
# Temporal characteristics

Characteristic	Distribution	Mean	Median
Pause	log-normal	1,677s	163s
Speed	log-normal	1.65m/s	1.26m/s
Start time 08:00-	exponential	09:54	09:06
End time -18:00	exponential	16:30	17:06

\* Human walking speed: 3mile/h = 1.34m/s

# Movement direction

- Histogram with  $5^\circ$  bin weighted by duration of movement



NS, EW are popular

Symmetry across  $180^\circ$

# Hotspots on campus map

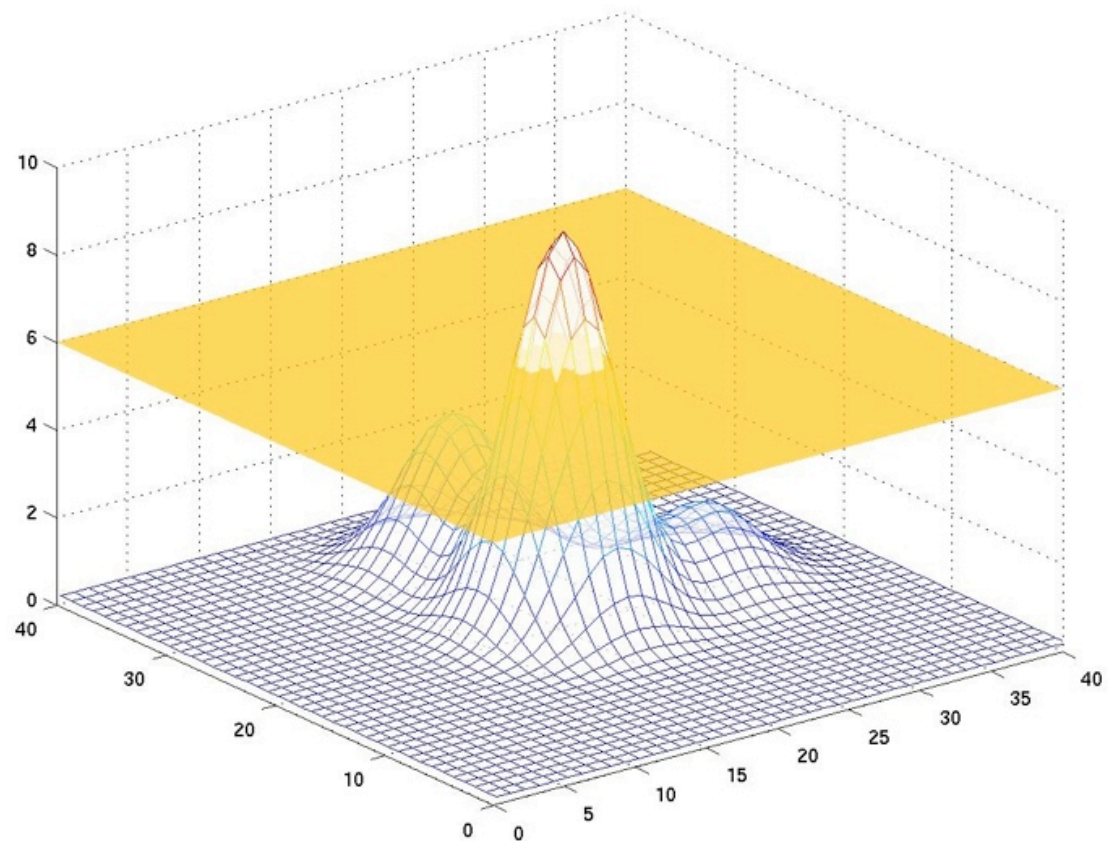
- Problem: Estimated user location, with error
- Challenge: How to define popular regions?

**1.** Align the center of unit Gaussian with visit location

**2.** At each location, sum up Gaussian distributions

**3.** Regions above threshold considered as hotspots

Threshold applied





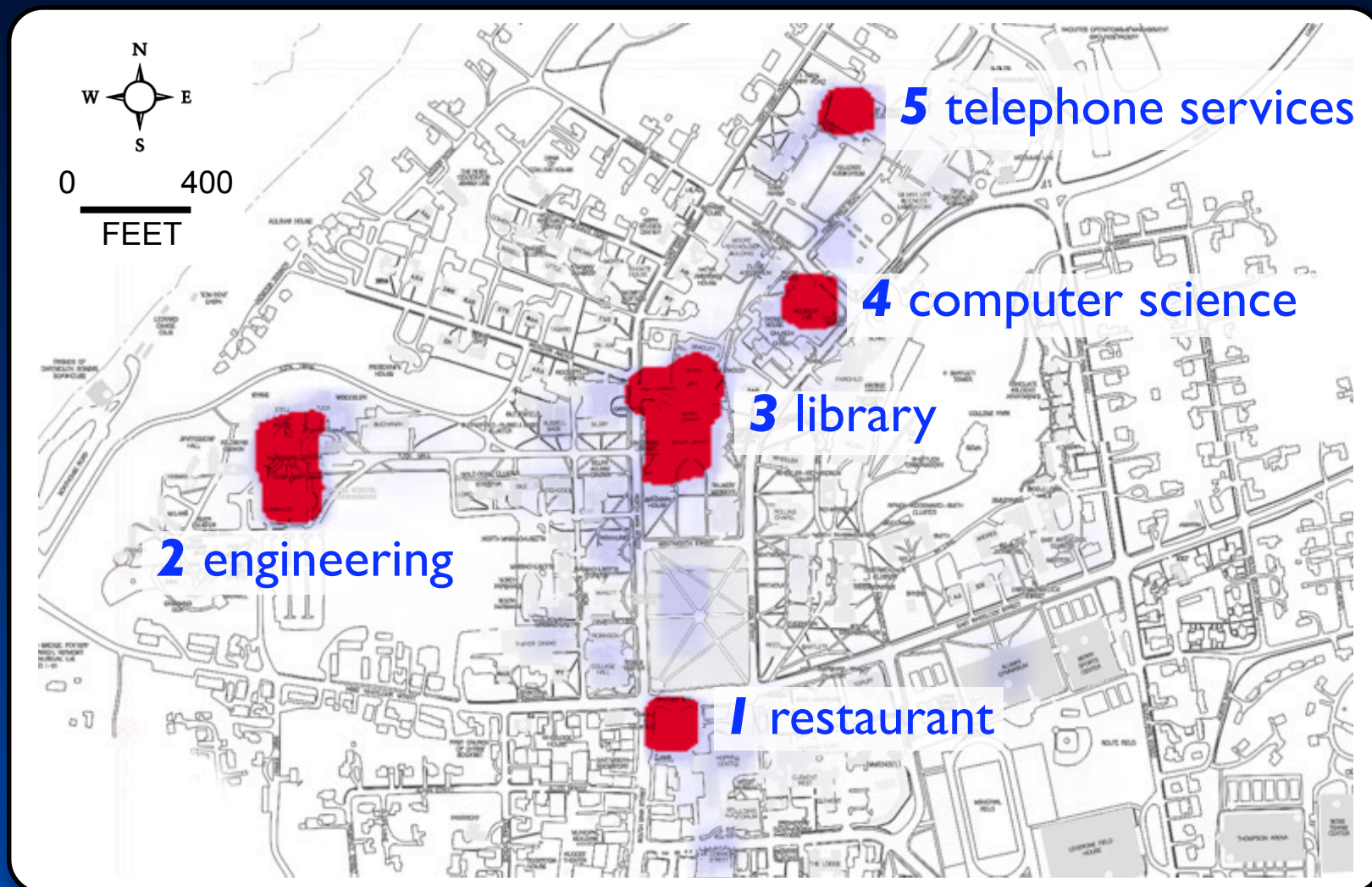
# Gaussian applied

Before cut



# Gaussian applied

After cut



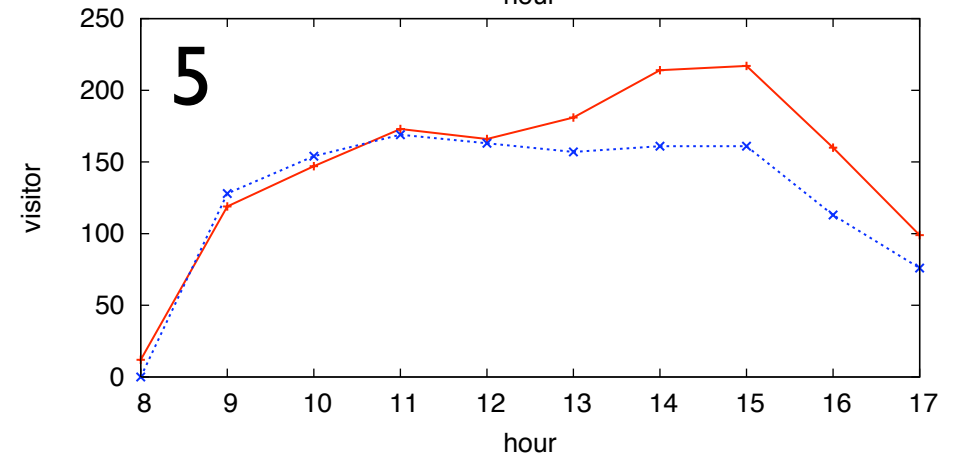
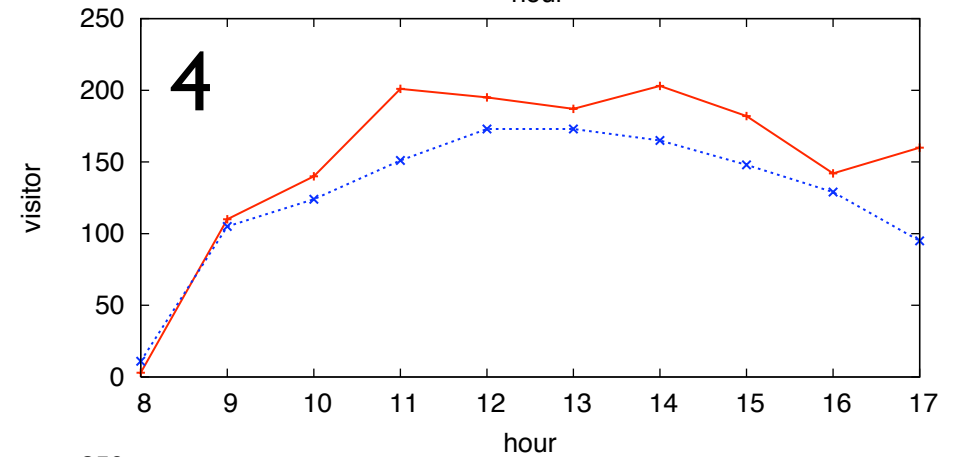
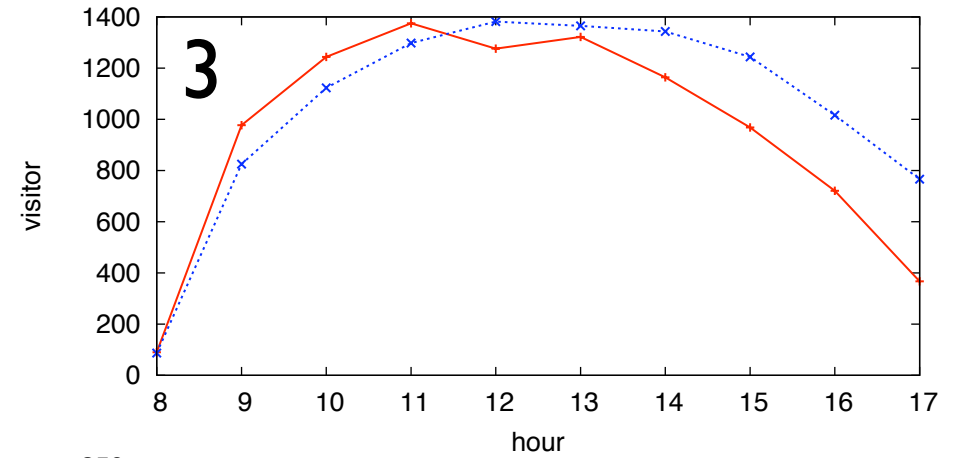
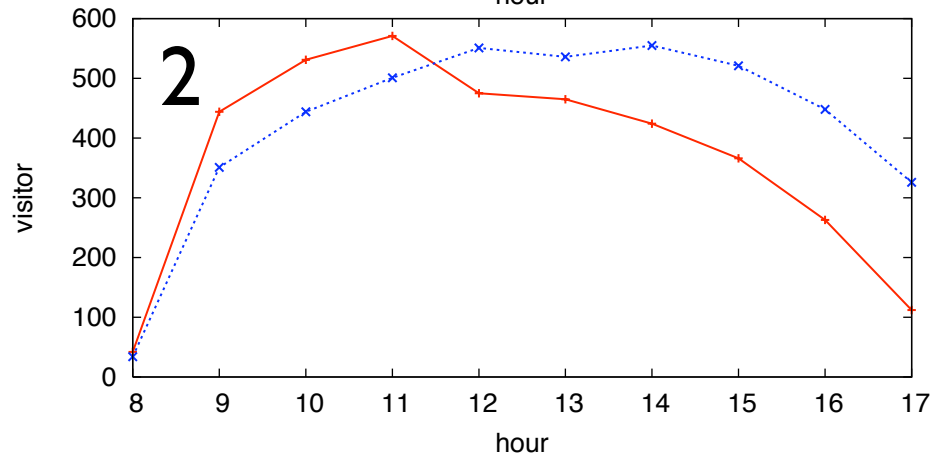
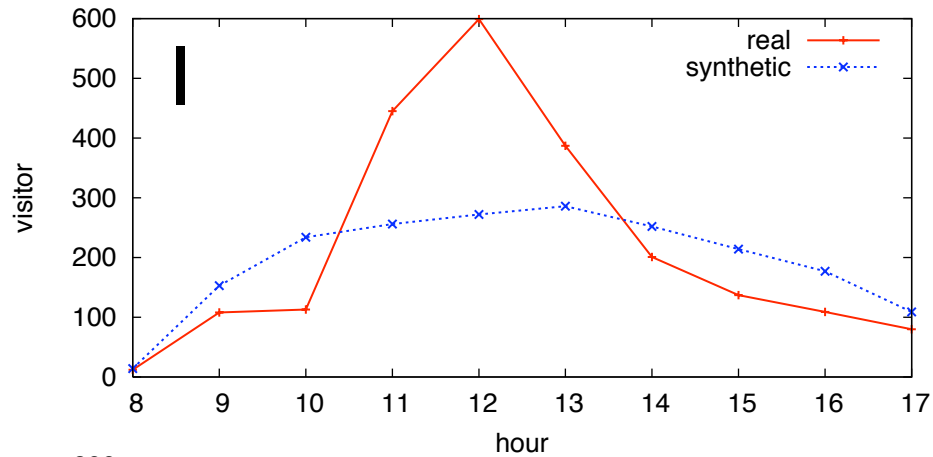


# Mobility model

- Model describes how users move between regions
  - ▶ 5 hotspots, 1 coldspot, 1 offstate
- For each user
  - ▶ Insert a new user using **start time** distribution
  - ▶ Choose start location using **initial region** distribution
- For each movement
  - ▶ Choose destination region using **transition probability** matrix
  - ▶ Choose **speed** and **pause** from distribution

# Model validation

## Hourly visitors



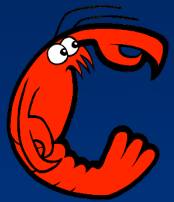
# Conclusion

- In this work, we found that...
  - ▶ We can effectively extracted **physical paths** from syslog traces using Kalman filter
  - ▶ Commonly used mobility assumptions are **incorrect**
  - ▶ Our model generates **realistic movements**
- In the future, we plan to work on...
  - ▶ Time variation over a course of day
  - ▶ Metric for mobility models

# Thank you

For related papers and more info

<http://www.cs.dartmouth.edu/~minkyong/>



For traces used in this paper

<http://crawdad.cs.dartmouth.edu/>



Center for Mobile Computing

<http://cmc.cs.dartmouth.edu/>