LAST MILE NAVIGATION USING SMARTPHONES

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ACM MobiCom
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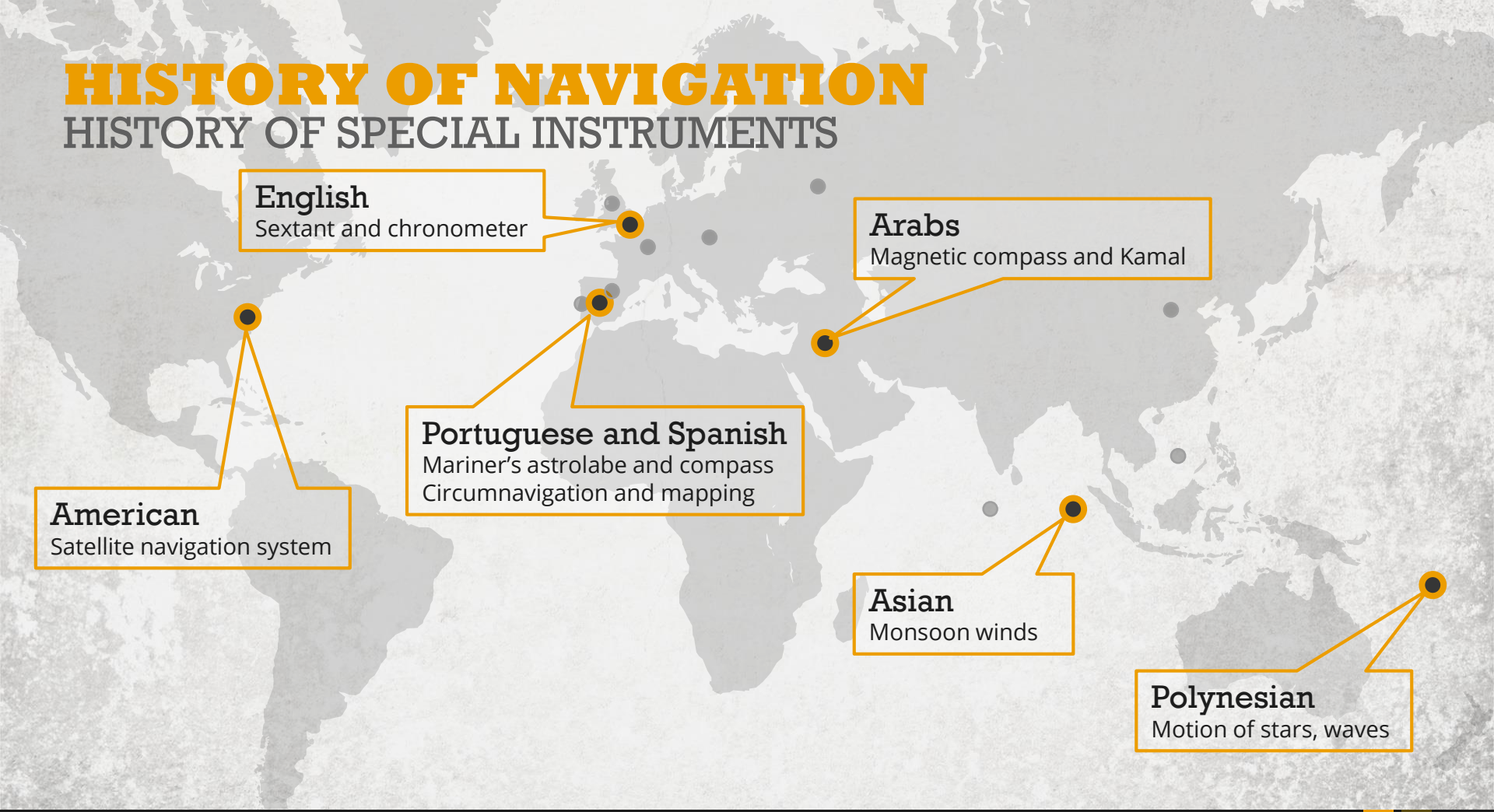
NAVIGATION
THE ACT OF FINDING THE WAY TO GET TO A PLACE

https://studioartofficial.wordpress.com/2014/08/19/vintage-tuesday-6

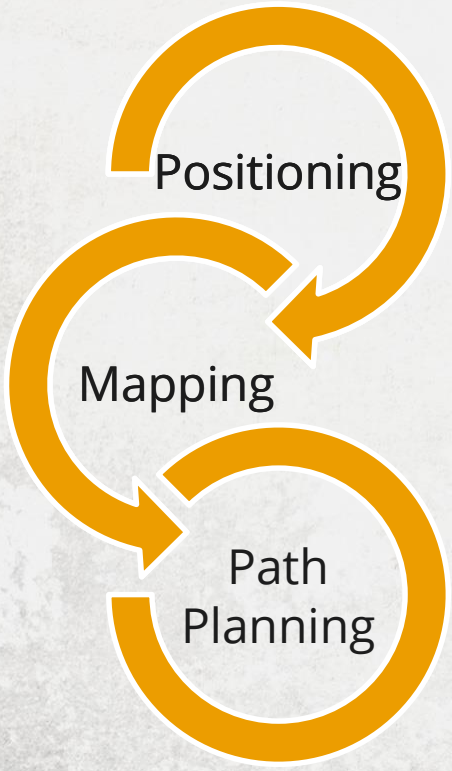
http://www.hipi.info/2014/07/7-cool-airplane-twitter-header-1500x500.htm

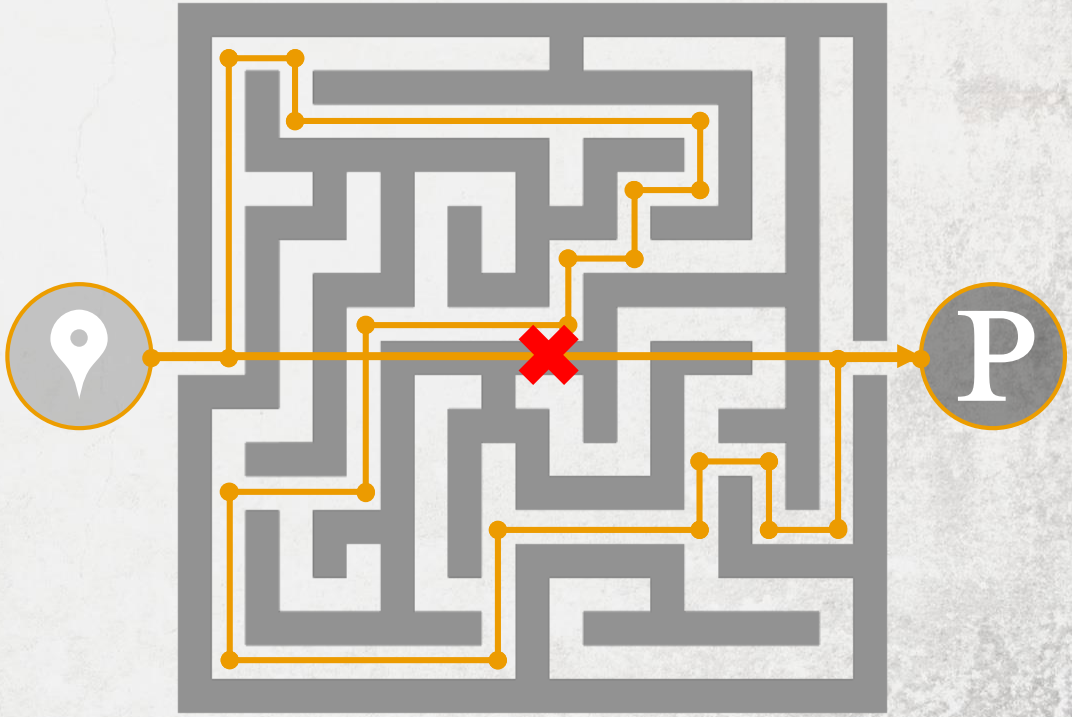
HISTORY OF NAVIGATION

HISTORY OF SPECIAL INSTRUMENTS



MODERN NAVIGATION SYSTEMS
WORKING PRINCIPLE





MODERN NAVIGATION SYSTEMS
STATE-OF-THE-ART

- Positioning
  - Outdoor: satellite-based, meter-level positioning accuracy.
  - Indoor: WiFi, geomagnetism, IMU, Bluetooth, FM [Youssef'05, Yoon'13, Xiong'13].

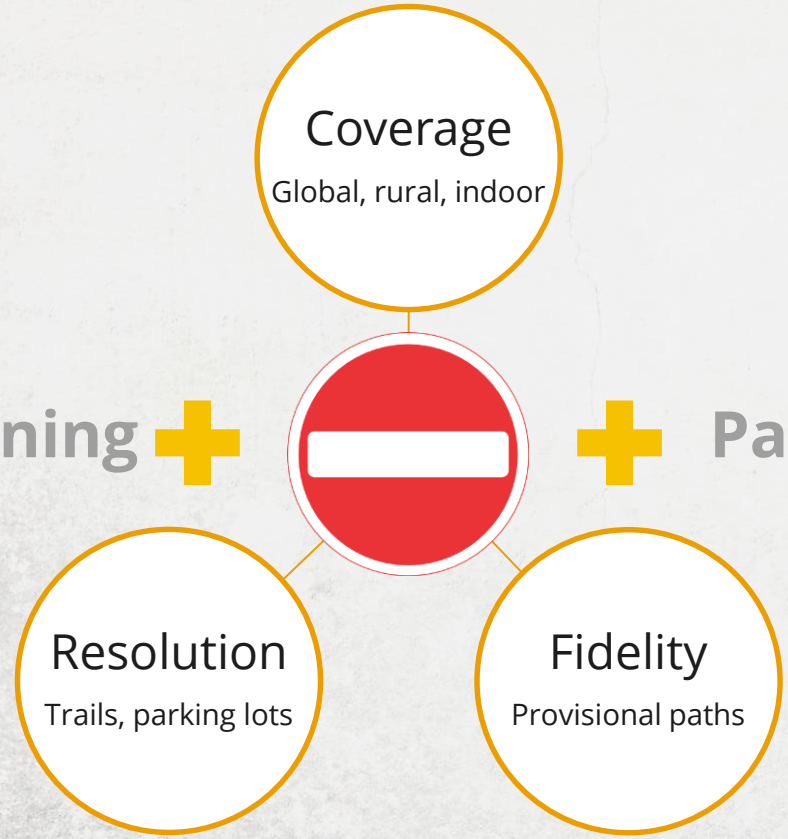
- Mapping
  - We need a map.
    - Satellite mapping, war-driving, floorplan mapping etc.

Does this suffice?

- Path Planning
  - Extensively studied in robotics and mathematics.

LACK OF MAP INFORMATION

BOTTLENECK OF NAVIGATION SYSTEMS

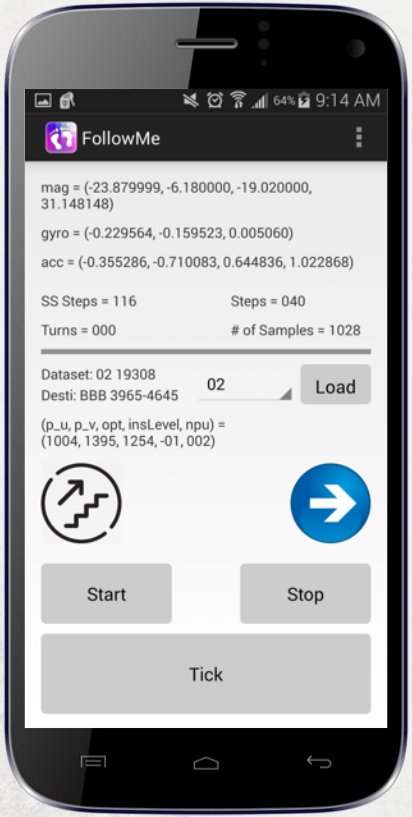


Positioning + + Path Planning ≠ Navigation


MICHIGAN

LAST MILE NAVIGATION PROBLEM

Navigates one to the vicinity of destination tens of miles away, but fails to find a feasible path from there to final destination



- Plug-and-play
- Lightweight
- Smartphone-based
- Last mile navigation

FollowMe

BASIC IDEA
OF FOLLOWME

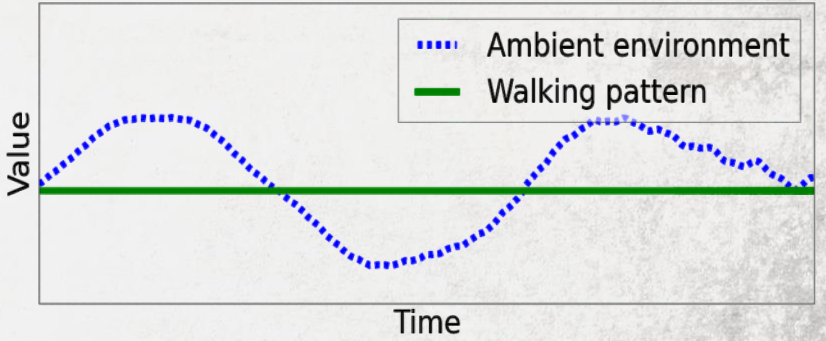
- Exploits “scents/crumbs” left behind by the previous travelers.

Ice Age: Scrat's Continental Crack-Up

BASIC IDEA
OF FOLLOWME

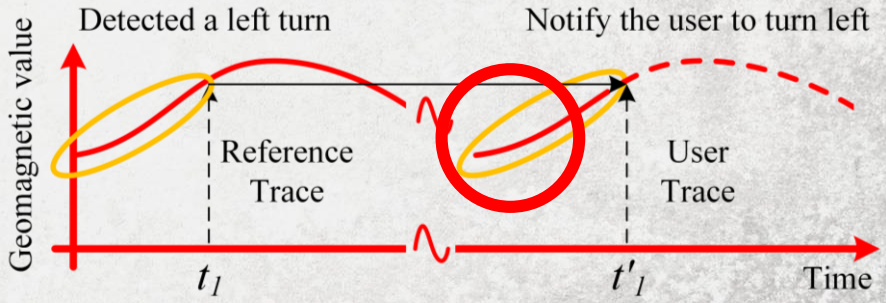
(leader's)

Trace-collection phase



(follower's)

Navigation phase

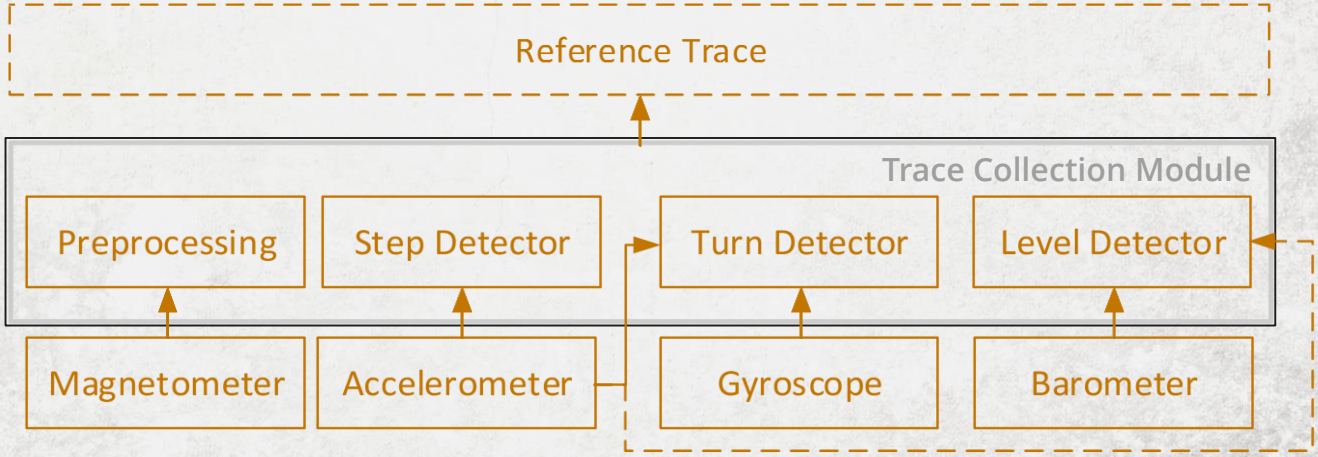


USE CASES
OF FOLLOWME

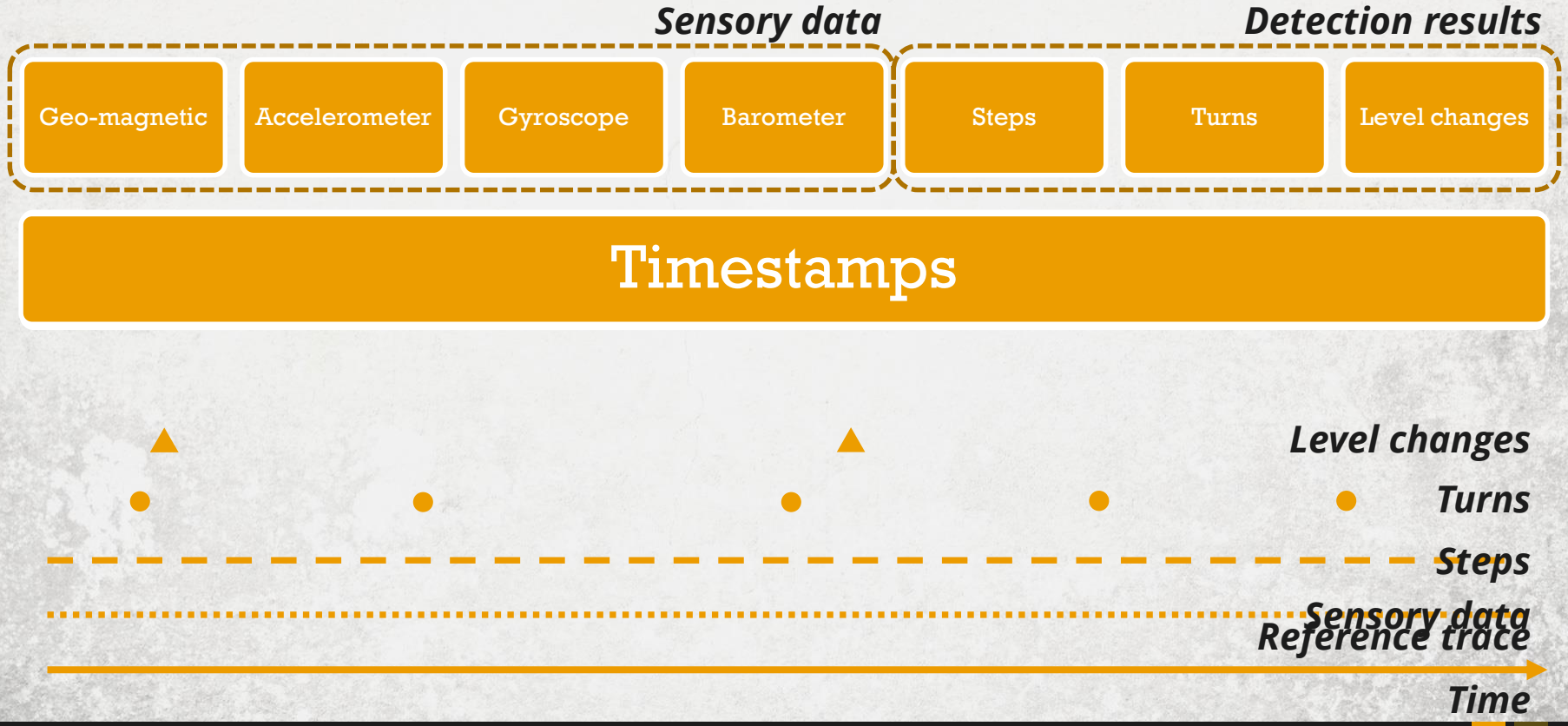
DESIGN

Trace Collection & Real-time Navigation

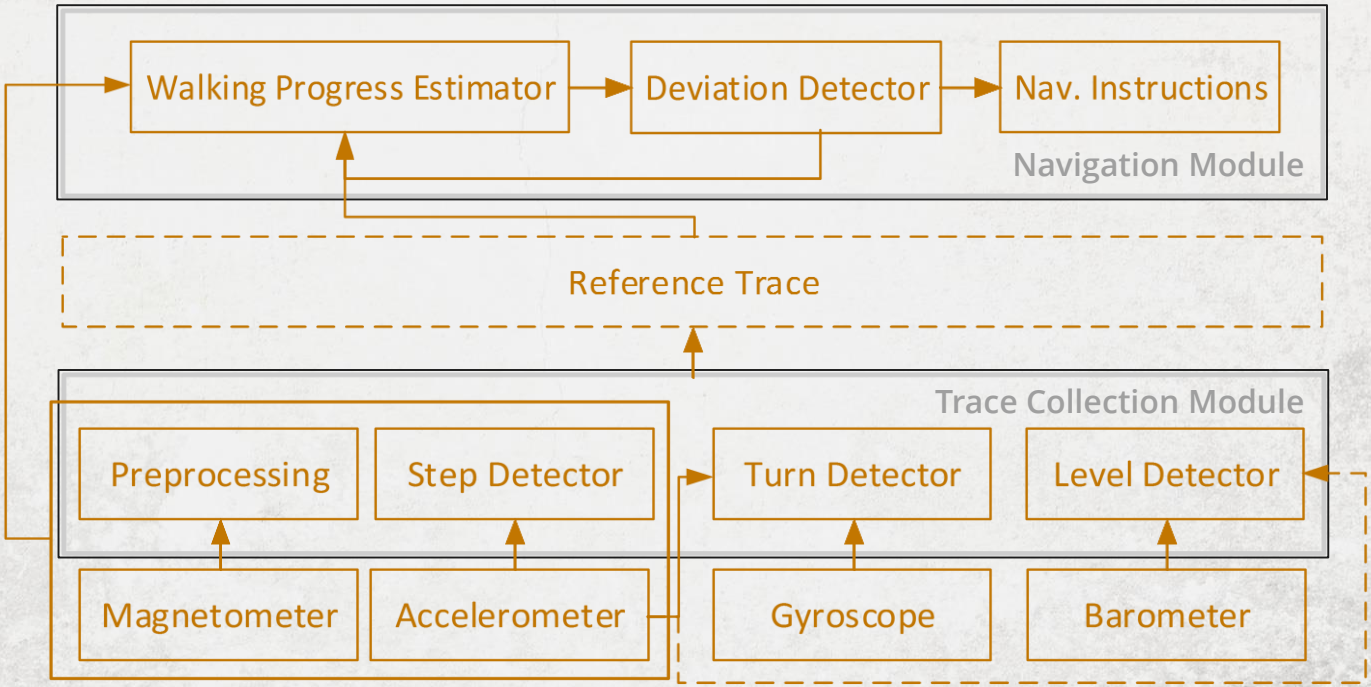
ARCHITECTURE
OF FOLLOWME



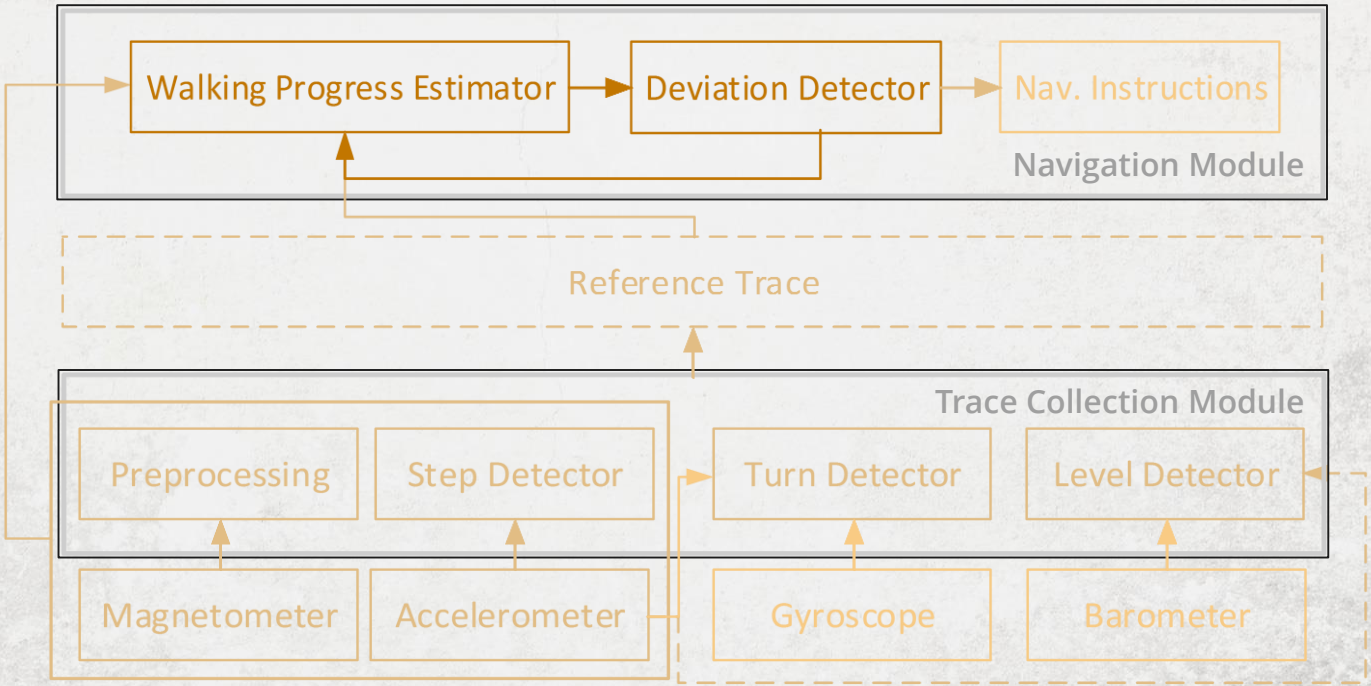
TECHNICAL DESIGN
REFERENCE TRACE CONSTRUCTION



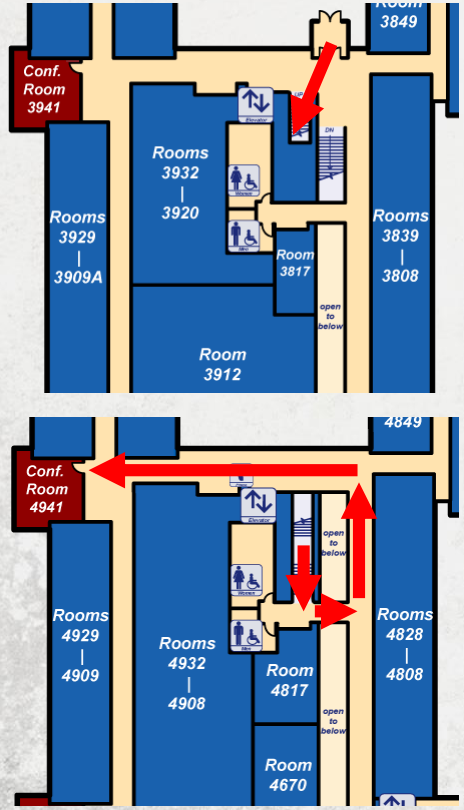
ARCHITECTURE
OF FOLLOWME

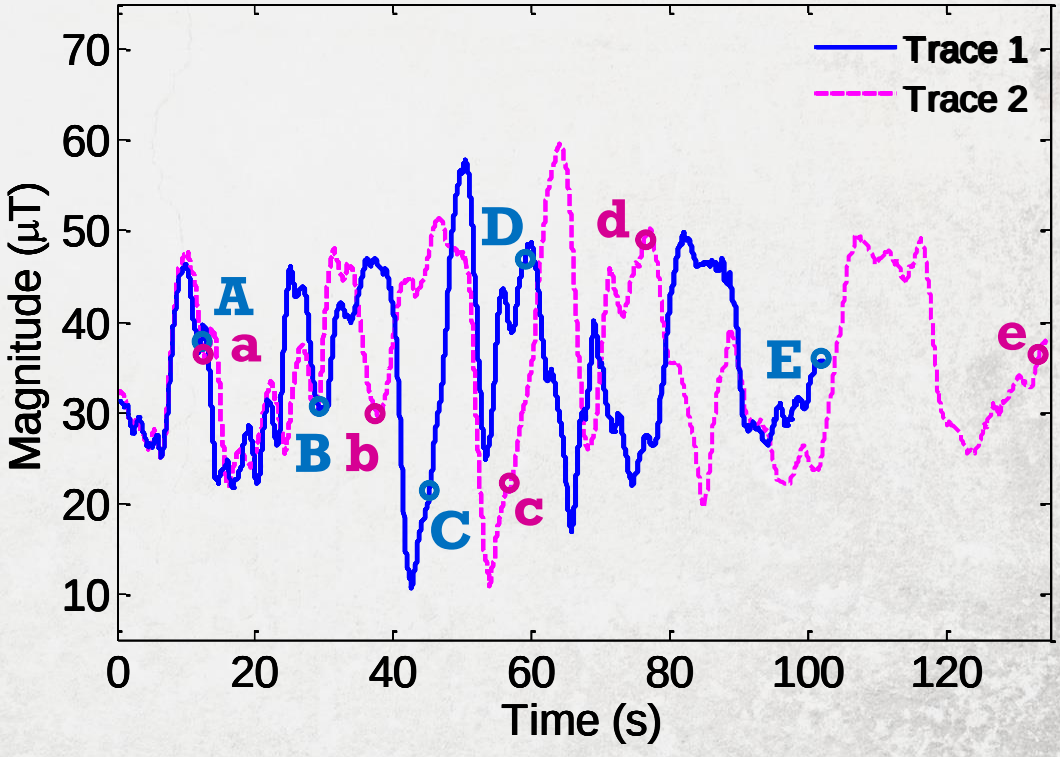


ARCHITECTURE
OF FOLLOWME



A NAVIGATION EXAMPLE

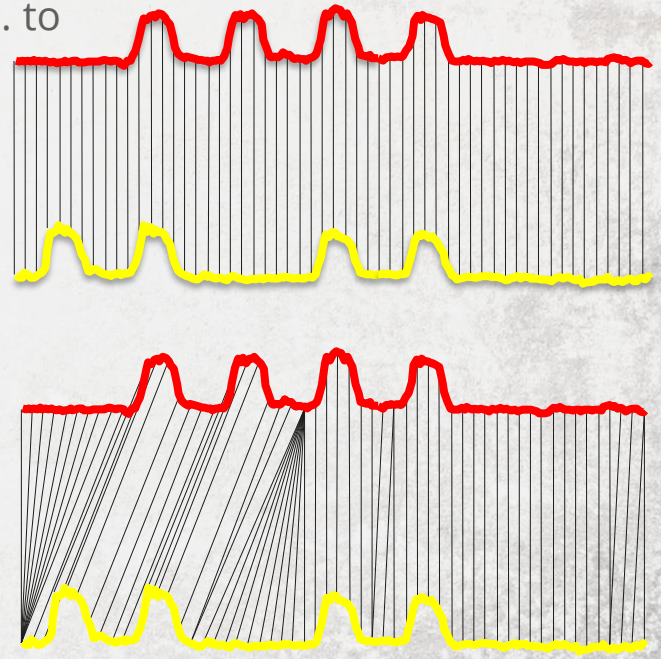




TECHNICAL DESIGN
WALKING PROGRESS ESTIMATION

- Step-constrained trace synchronization algorithm
  - Filter out high-freq. mag. and utilize differential info. to handle device and usage diversity
  - Sync. based on legacy dynamic time warping (DTW)

$$Given\ S_a = S_a[i], i = 1, \dots L_a\ and\ S_b = S_b[i], i = 1, \dots L_b,$$
$$DTW\ aims\ to\ find\ a\ monotonic\ mapping\ function$$
$$f : I[1, L_a] \rightarrow I[1, L_b]\ between\ S_a\ and\ S_b\ such\ that$$
$$minimize: \sum_{i=1}^{L_a} (S_a[i] - S_b[f(i)])^2$$
$$where\ I[1, L_a]\ is\ the\ integers\ from\ 1\ to\ L_a.$$



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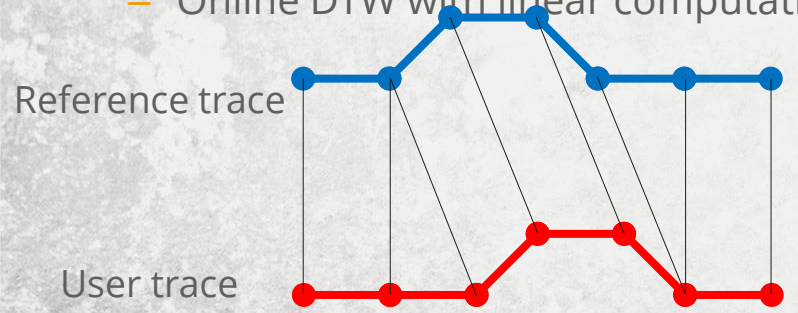
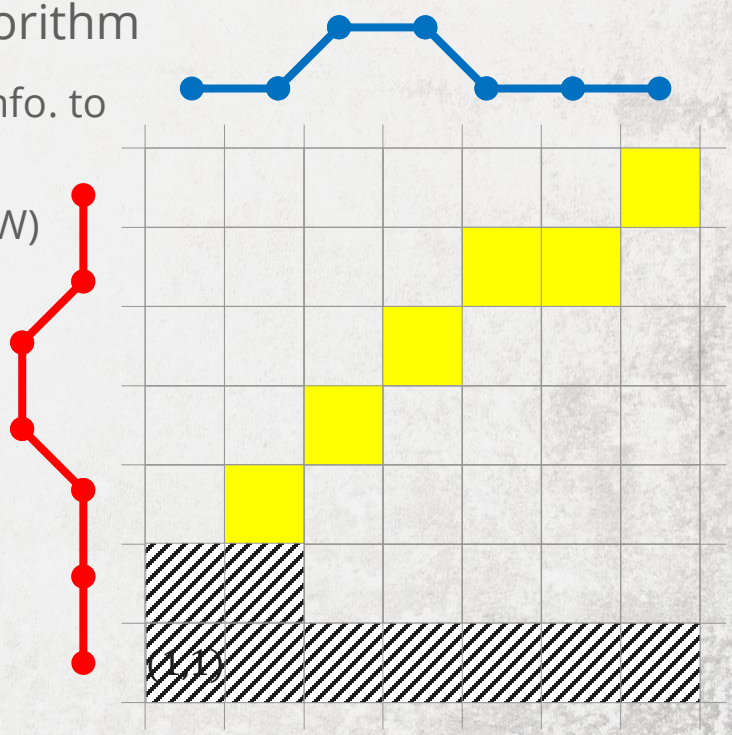
    - Full knowledge of traces
    - Quadratic computational complexity
  - Online DTW with linear computation overhead





$$D[i][j] = \min(D[i-1][j-1], D[i-1][j], D[i][j-1]) + dist(i,j)$$

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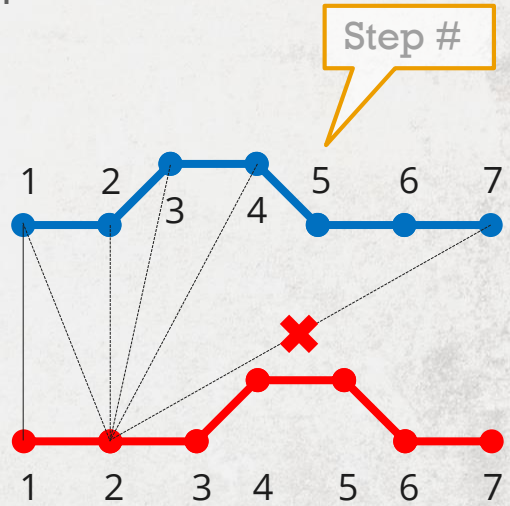
    - Step-constrained search space

$$\text{If } < m_i > \in < s_j > \rightarrow < \hat{m}_{i'} > \in < \hat{s}_{j'} >, \text{ and } < m_{i+1} > \in < s_k > \rightarrow < \hat{m}_{i''} > \in < \hat{s}_{j''} >, \text{ then } |(\hat{s}_{j''} - \hat{s}_{j'}) - (s_k - s_j)| > c$$

    - Dynamically changing search band



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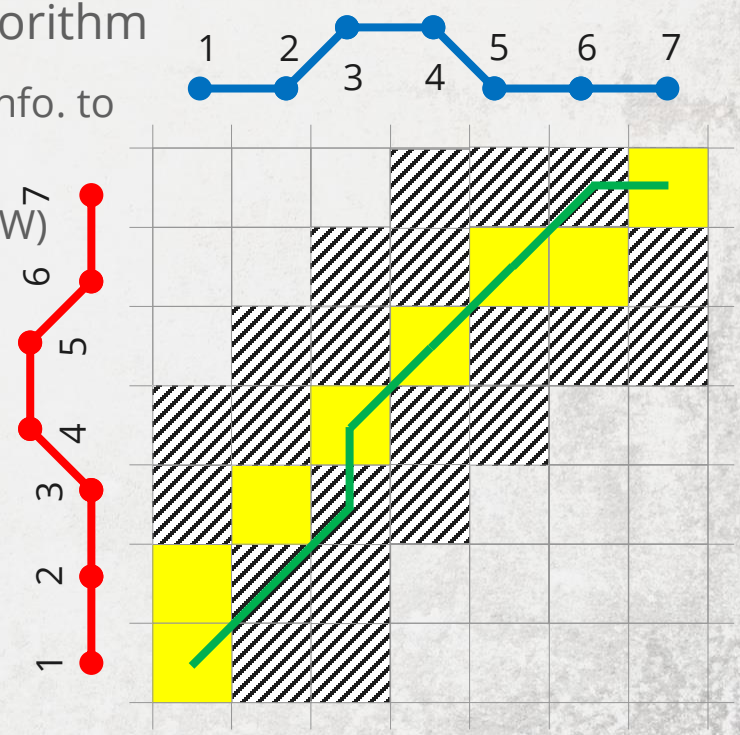
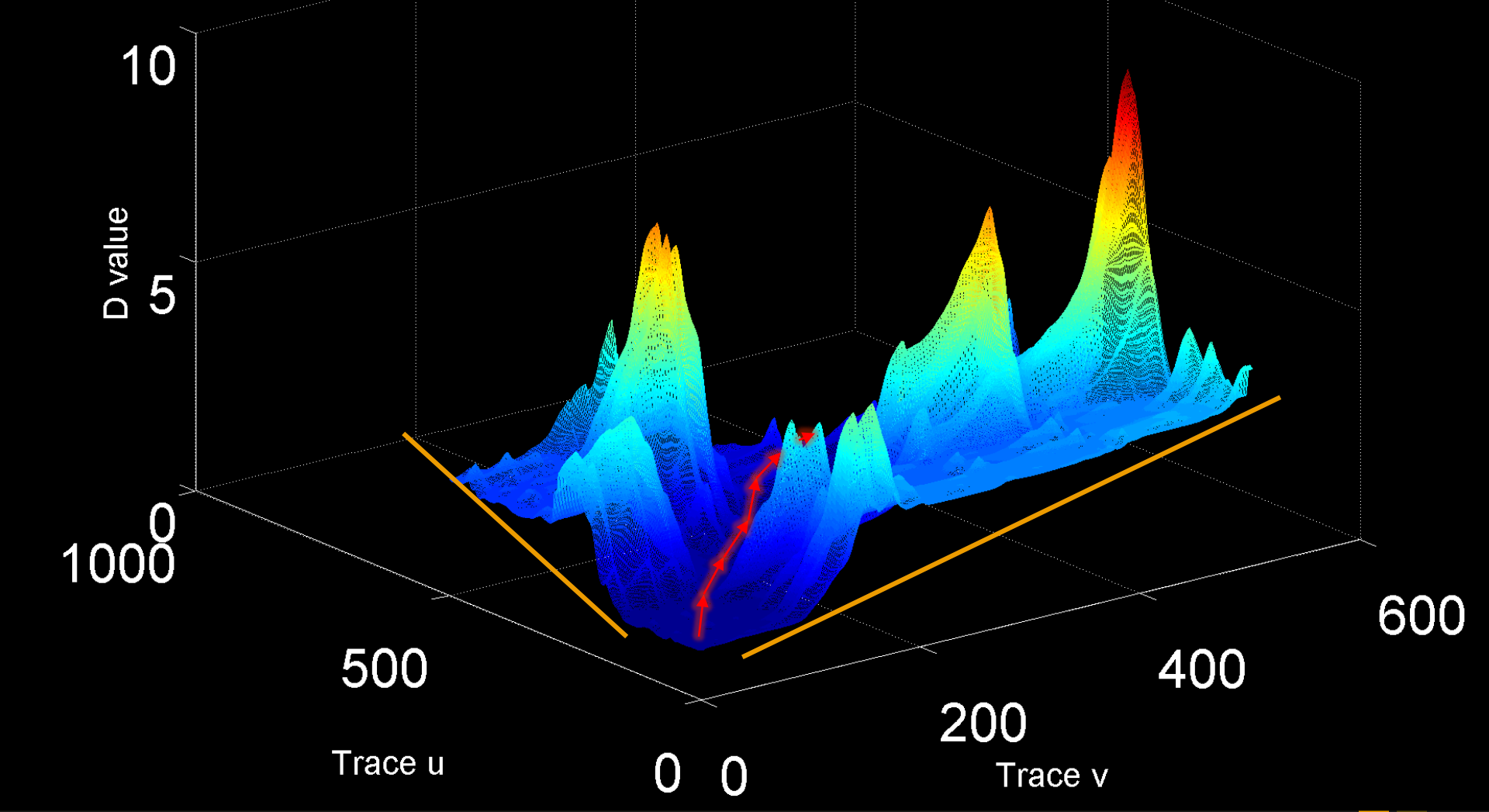
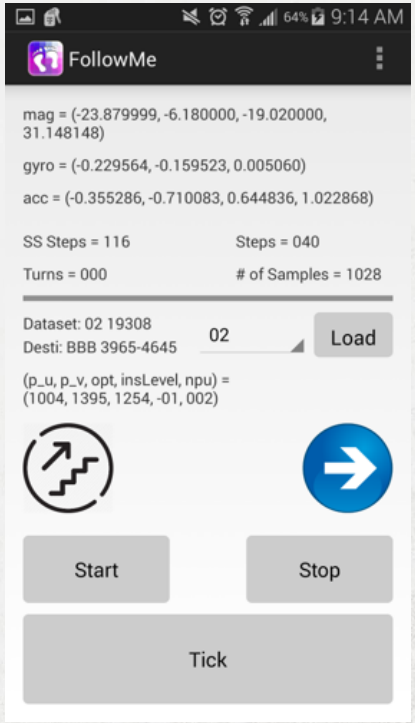
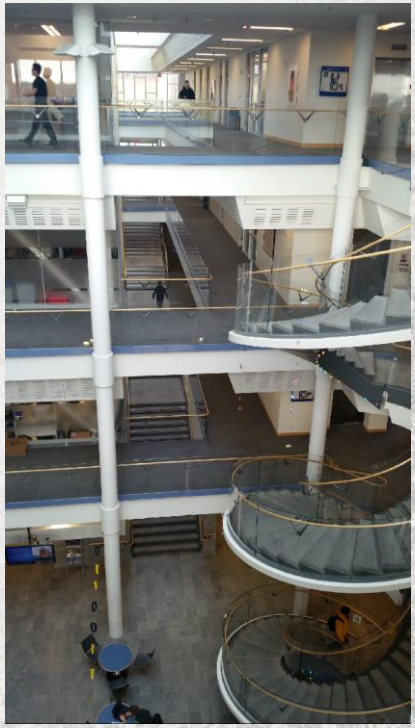



10
D value
5
0
1000
500
Trace u
0
0
200
Trace v
400
600

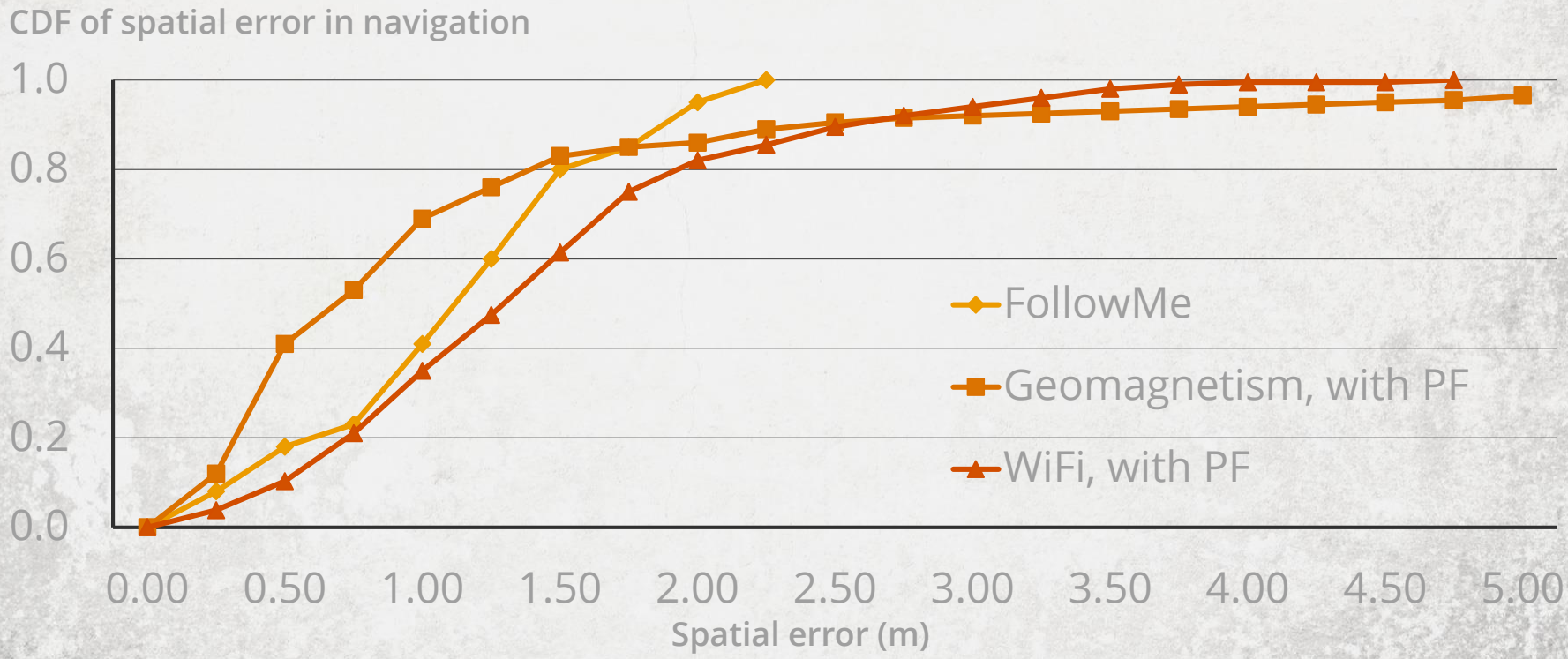
IMPLEMENTATION AND EVALUATION

- Implementation
  - Android 4.4.2, Samsung Galaxy S5
  - Two threads
    - Data collection : *50Hz*
    - Signal processing
  - DTW buffer size: 12s (c = 600)
- Evaluation
  - Four-story campus building
  - 5 participants
  - 10 different reference traces



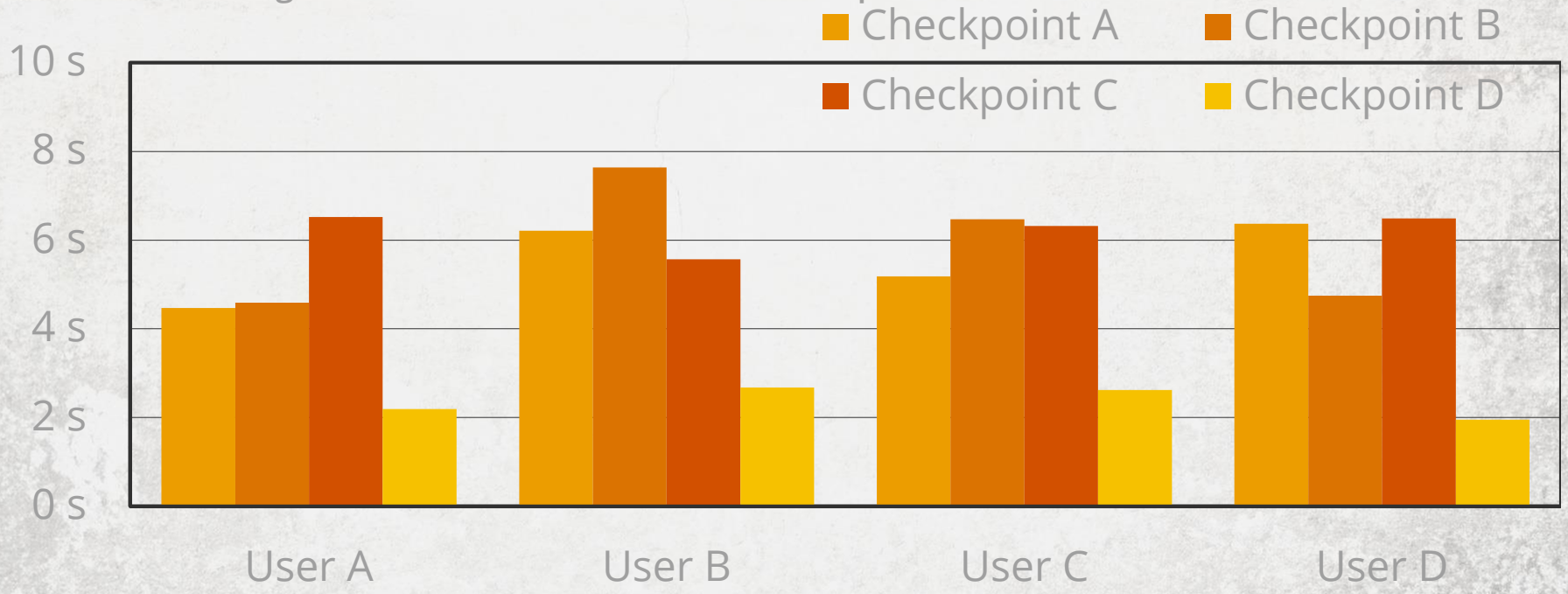


EVALUATION
NAVIGATION ACCURACY



EVALUATION
NAVIGATION ACCURACY

Lead time of navigation instructions at different checkpoints



RELATED WORK

Robotics

Special hardware-based nav.

[Cho'10, Bonin'08]

Complicated humans' locomotion;
Limited energy buffer of smartphones.

Smartphone

Nav. with or w/o infrastructure

[Li'12, Chintalapudi,'10, Rai'12, Xiong"13, Yang'12, Chen'12]

Accumulative error and usage-dependent;
Non-universal (e.g., GPS, WiFi);
High bootstrap effort of fingerprinting.

Geo-magnetic

Anomalies-based local. and nav.

[Glanzer'10, Gozik'11, Chung'11, Grand'12],

Ubiquitous and stable;
Localization-based navigation (map?);
Tedious fingerprint collection.

Leader-follower

Trace-based nav.

[Constandache'10, Riehle'12, Zheng'14]

Customized devices (e.g., robots);
Infrastructure-dependent (e.g., WiFi, beacons);
Constraints imposed on users.

CONCLUDING REMARKS

INFRASTRUCTURE FREE

Cloud-based or Ad-hoc

No need of floor plans (maps)

WiFi/Bluetooth-independent

HIGH EFFICIENCY

Low-power sensors

Low computation

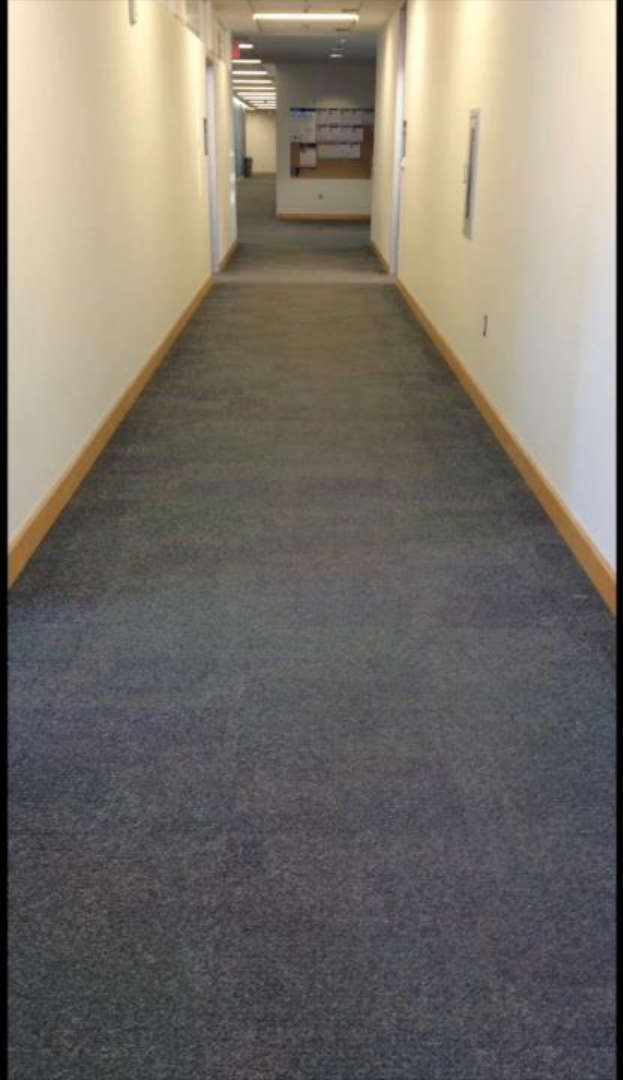
Energy efficient

MINI. USER INVOLVEMENT

Plug-and-play

Fast and easy bootstrapping

No action required during NAV



More info. and updates

FollowMe

THANK YOU

Q&A