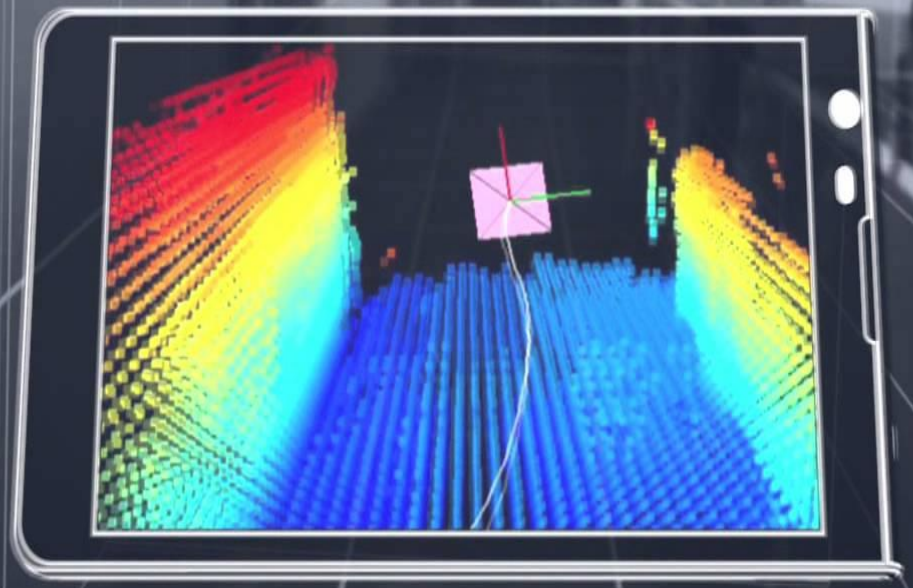
室内定位4.0
Indoor Localization 4.0



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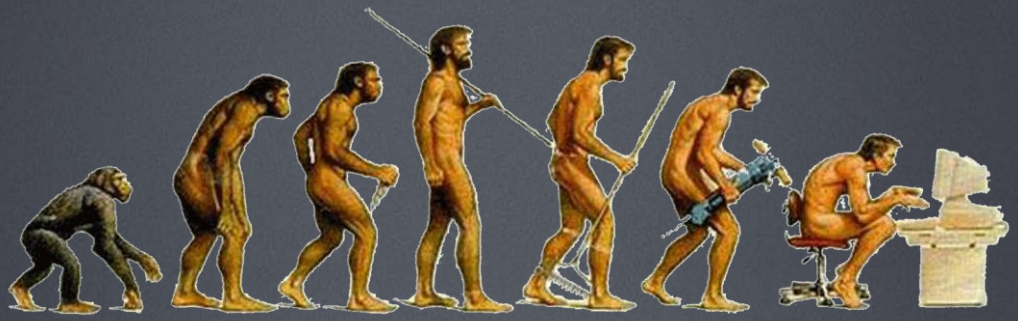
个人简介

- 清华大学软件学院副教授
- 入选国家“万人计划”青年拔尖人才、北京市科技新星计划
- 国家优秀青年基金获得者
- 获得国家自然科学二等奖
- 研究方向：无线网络、移动计算、普适计算
- 发表CCF推荐A类论文 60 余篇，中英文专著各 1 部

1. BACKGROUND

What we talk about when we talk about positioning technology?



WHO ARE YOU,

WHERE ARE YOU GOING,

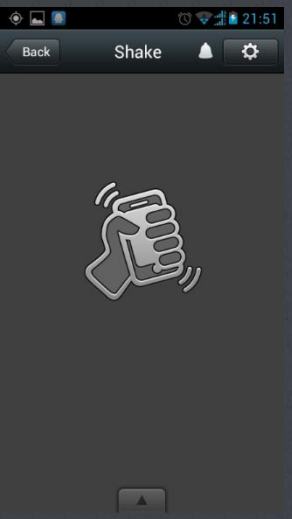
WHERE HAVE YOU BEEN?

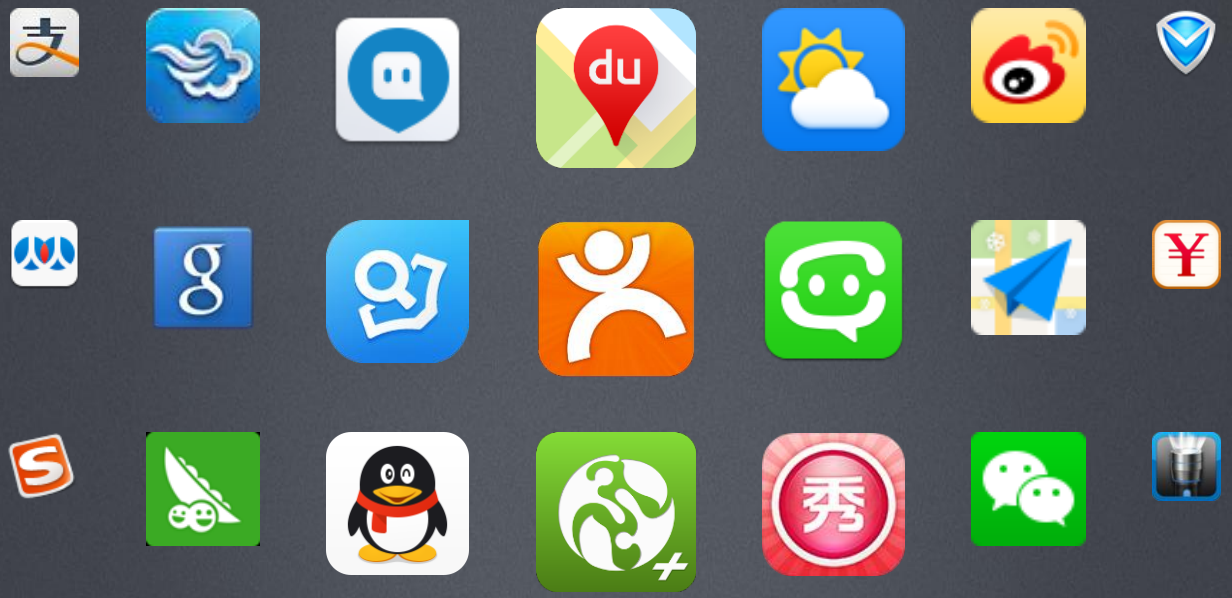
LOCATION

A long story…









Almost all Apps request location..

WIRELESS LOCALIZATION

Past, Present & Future

“Localization” ≈ GPS

~~31 satellites / 3m~~ 2014

2015 GPS III

A-GPS 2004

2001 In-car navigation

Final deactivation of selective availability 2000

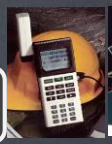
Worldwide use FREE 1994

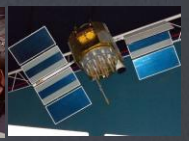
1999 Benefon Esc

~~Civilian use~~ 1983

NAVSTAR 1974

1989-94 Block II satellite Hand-held RX

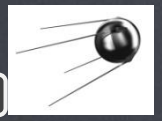




Transit 1959

1978-85 Block I Satellite

1957 Sputnik



Sorry, the GPS signals NOT found!

Mainly due to the blockage of walls
Giving birth to INDOOR LOCALIZATION

GLOBAL VS. INDOOR POSITIONING SYSTEM

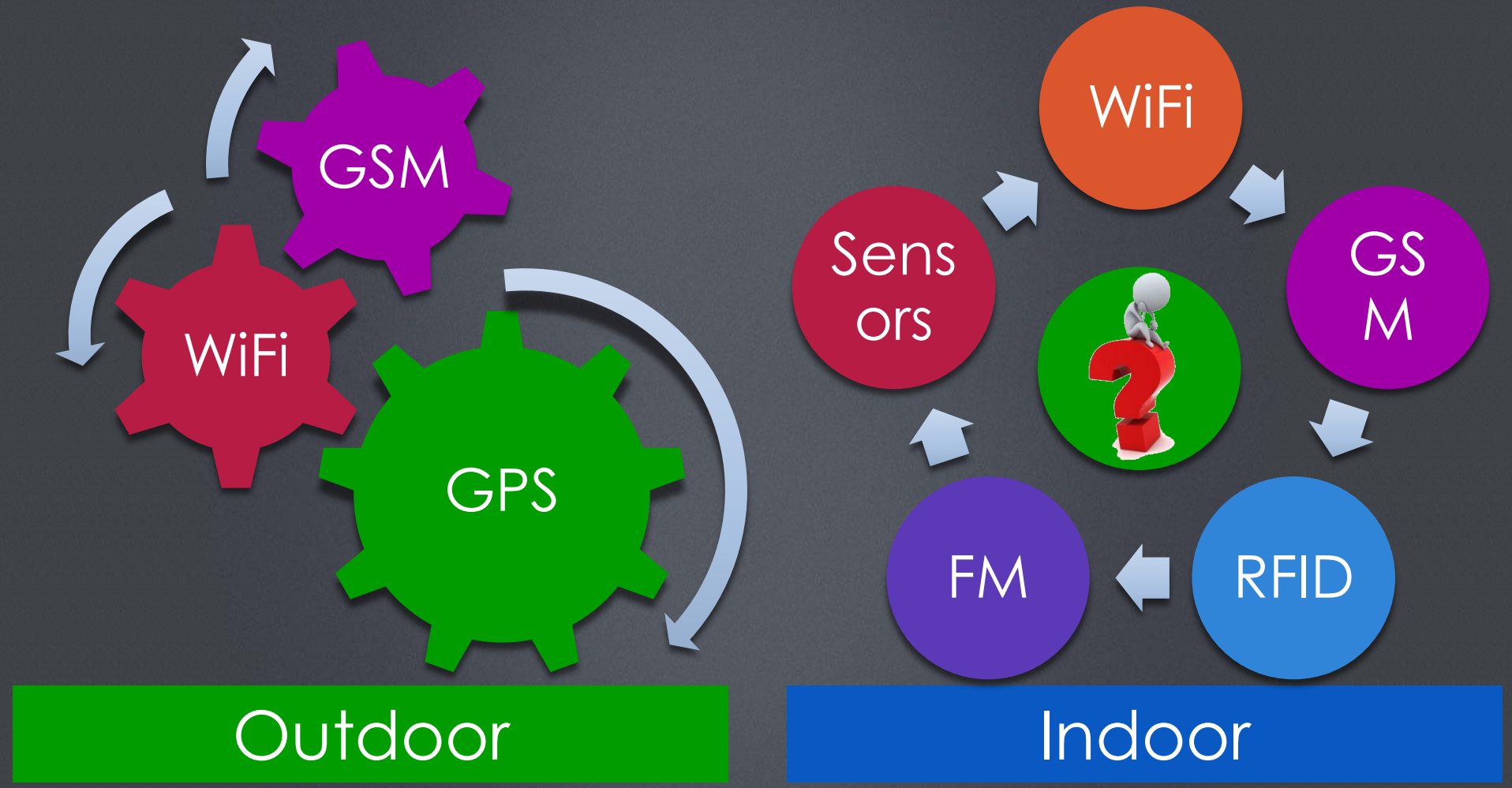
GPS dominates outdoor positioning.

IPS is of great importance and huge demand.

INDOOR LOCALIZATION EVERYWHERE

Numerous location-based applications in our daily life.

GLOBAL VS. INDOOR POSITIONING SYSTEM

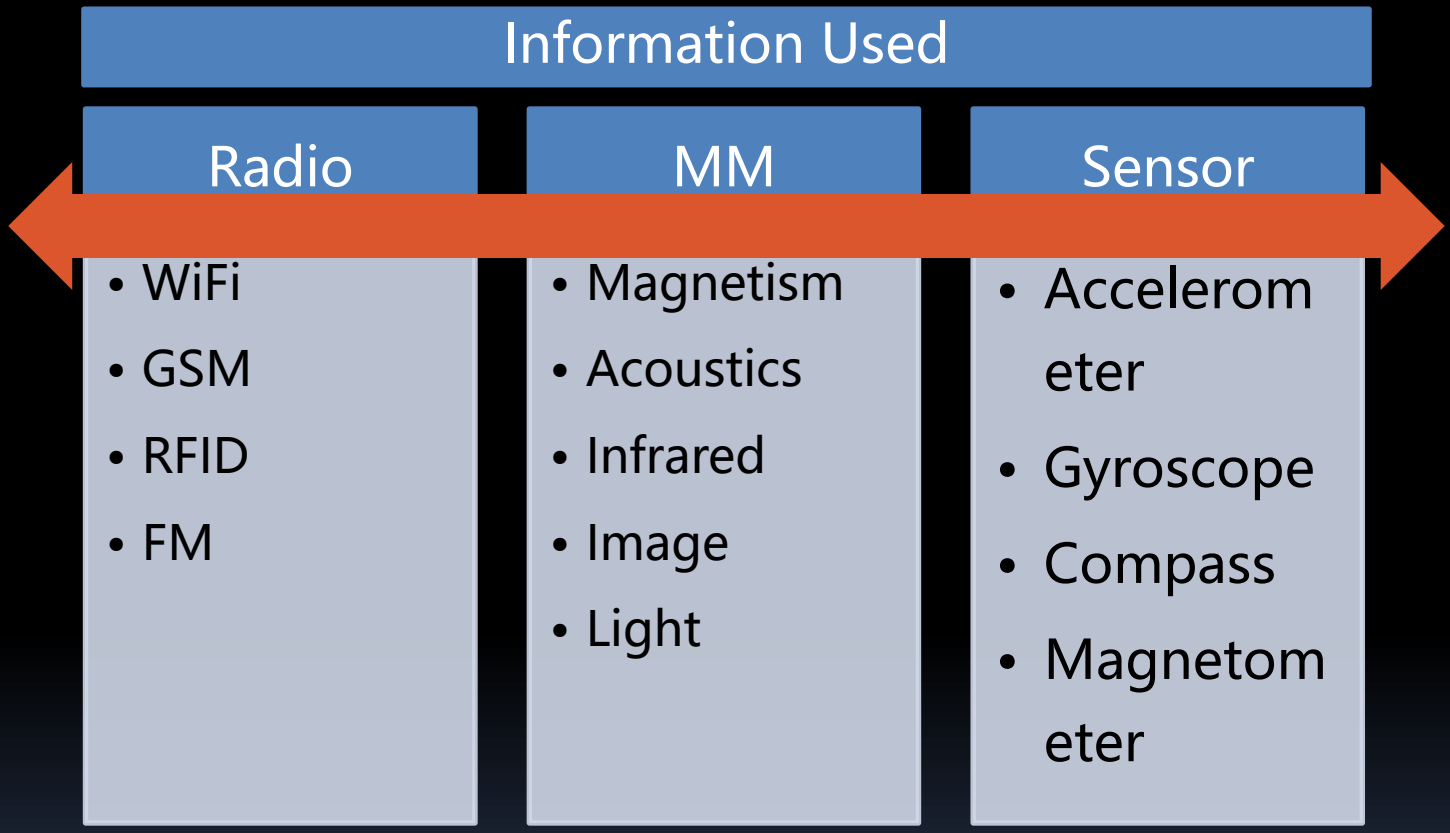


Many techniques have been proposed for indoor localization

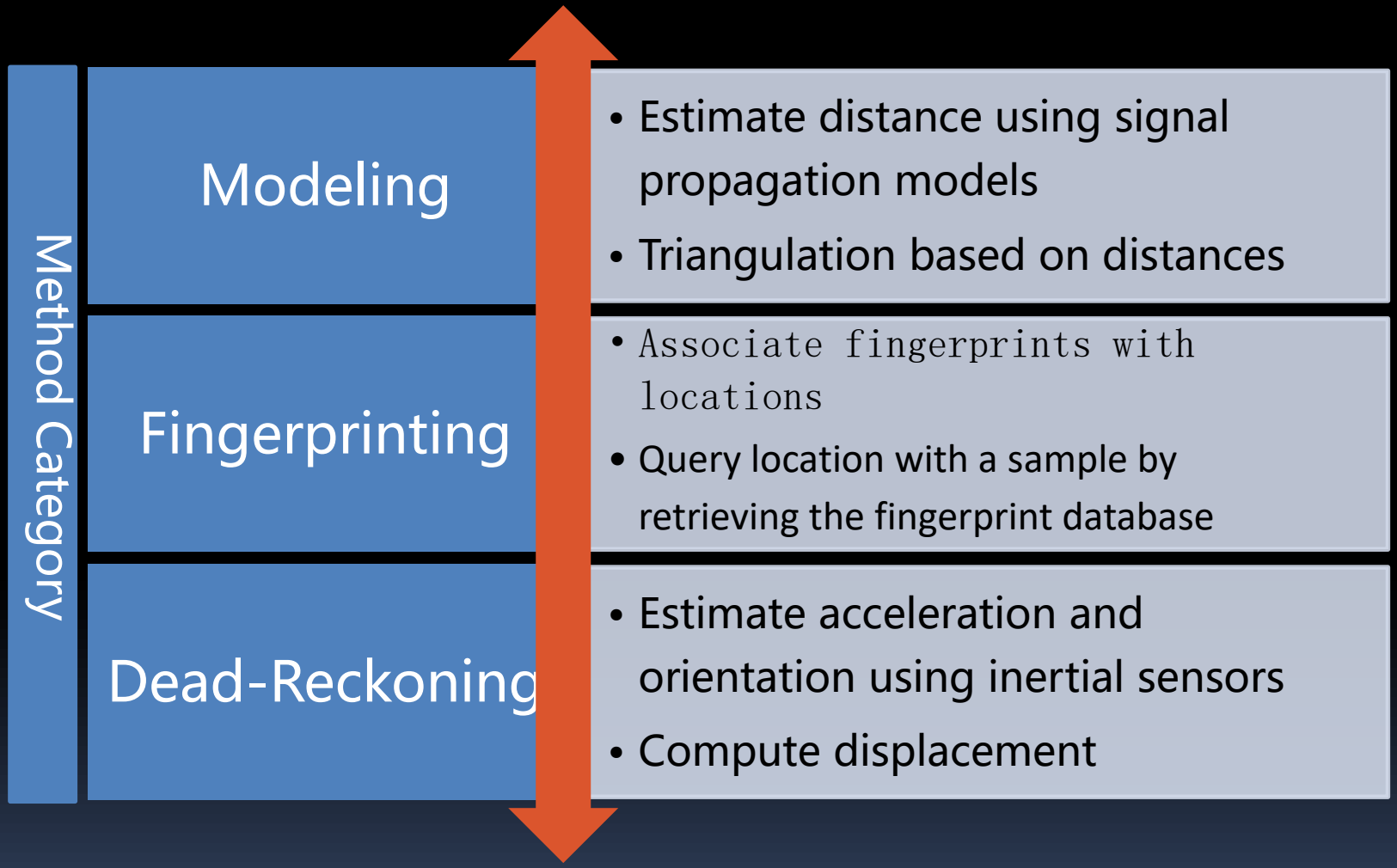
2. Location Computation

How to figure out locations?

The state of the art



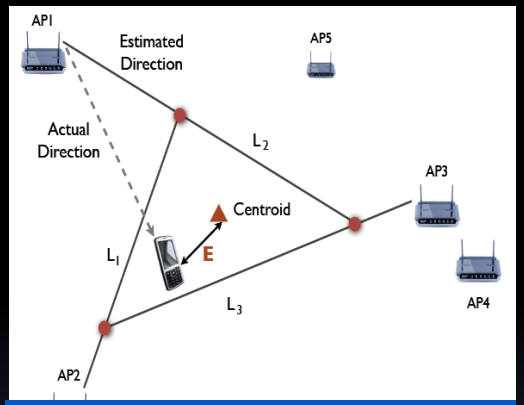
The state of the art



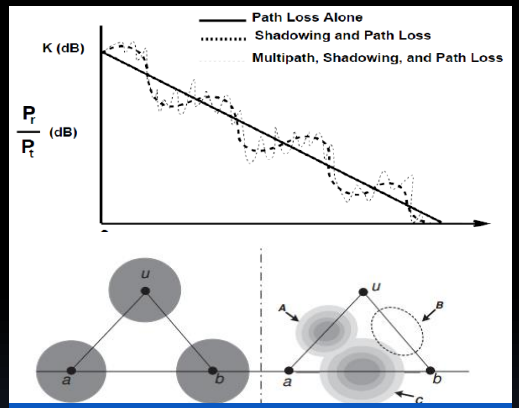
Modeling

- Wireless signal propagation model
- RSS vs. propagation distance
- Determine model parameters

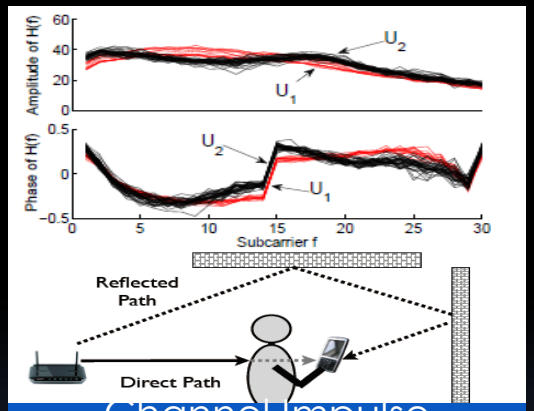
Complex Indoor Environment



Ranging by models



Log distance path loss



Channel Impulse Response

Madigan et al. InfoCom'05

Lim et al. InfoCom'06

ARIADNE MobiSys'06

EZ MobiCom'10

SpinLoc HotMobile'12

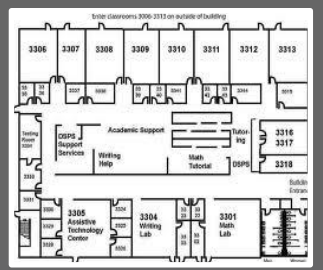
FILA InfoCom'12

Idealized model, low ranging accuracy

Fingerprinting

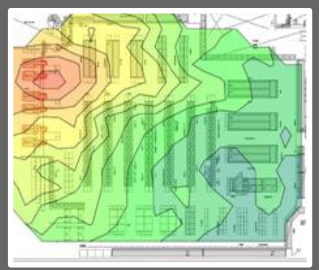
- Locations have fingerprints: distinctive and stable
- Associate fingerprints with locations.
- Constructing fingerprint database

Time-consuming and labour-intensive

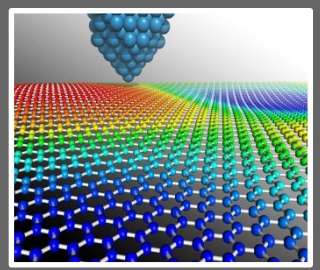


Floorplan

Site survey



Radio map



Localization

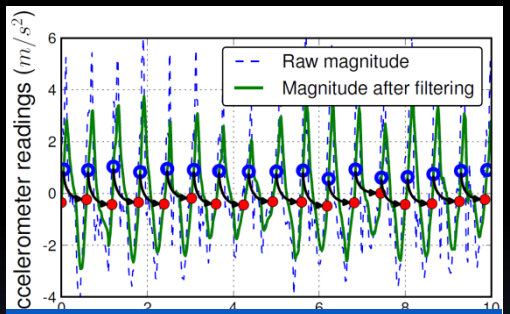
RADAR	Horus	LANDMARC	PlaceLab	OIL	Batphone	PinLoc	LiFS
InfoCom'00	InfoCom'04	Wire. Net.'04	PerCom'05	MobiSys'10	MobiSys'11	MobiSys'12	MobiCom'12

High labor cost, limited accuracy, susceptibility to environment changes

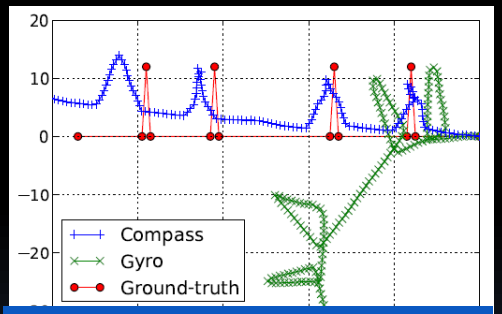
Dead-Reckoning

- Proliferation of smartphones with various built in sensors.
- Capture user mobility using inertial sensors
- Mapping user paths under the constraints of indoor maps

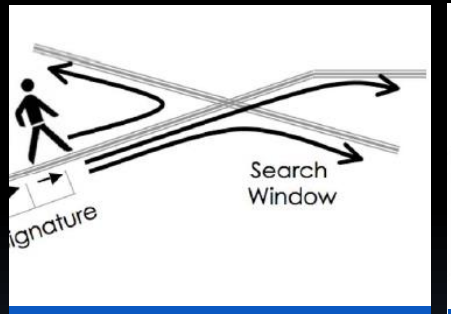
Accumulated error and limited information



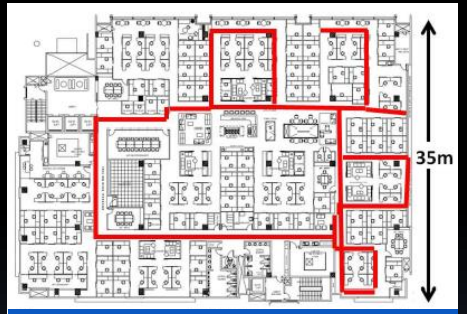
Acc: Step counting



Gyros: Direction



Path construction



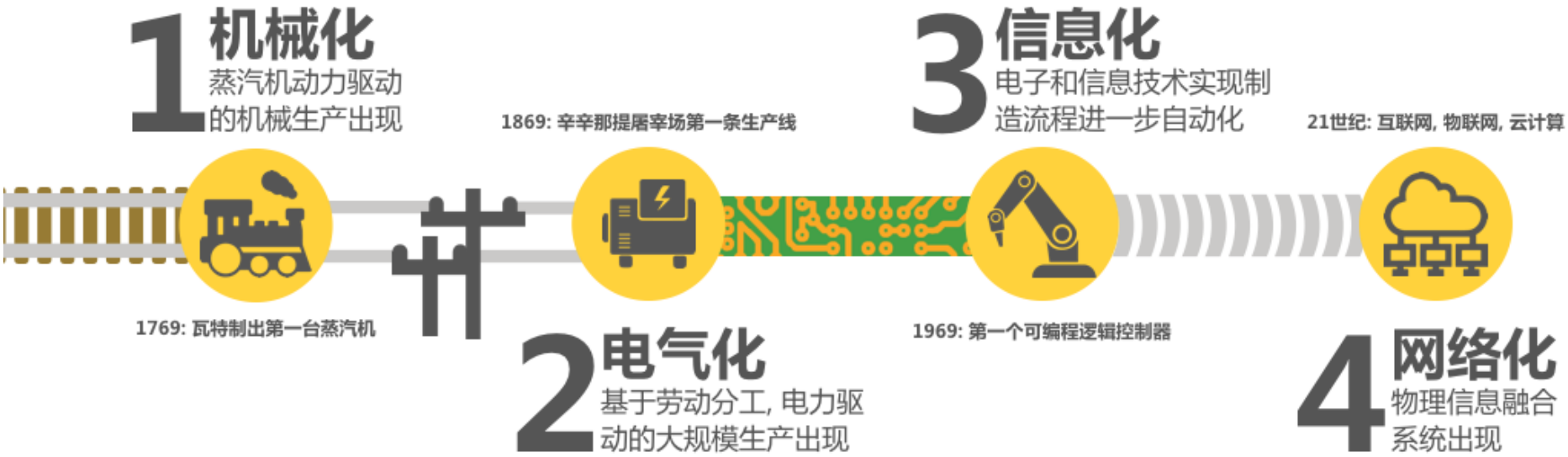
Path mapping

SLAM	CompAcc	SurroundSense	Escort	UnLoc	LiFS	Zee
ToRA'01	InfoCom'10	MobiCom'09	MobiCom'10	MobiSys'12	MobiCom'12	MobiCom'12

Sensor resolution, Low accuracy, User behavior

3. Localization Technology

工业4.0


1
机械化
蒸汽机动力驱动的机械生产出现
1769: 瓦特制出第一台蒸汽机
1869: 辛辛那提屠宰场第一条生产线
2
电气化
基于劳动分工, 电力驱动的大规模生产出现
3
信息化
电子和信息技术实现制造流程进一步自动化
1969: 第一个可编程逻辑控制器
21世纪: 互联网, 物联网, 云计算
4
网络化
物理信息融合系统出现

室内定位4.0

室内定位1.0

鸿蒙初辟：专用信号、专用设备

室内定位2.0

一枝独秀：以WiFi为代表的商用移动设备

室内定位3.0

欣欣向荣：智能手机的多模态传感器数据

室内定位4.0

返璞归真：无线与CV的结合在定位技术中大浪淘沙始见金

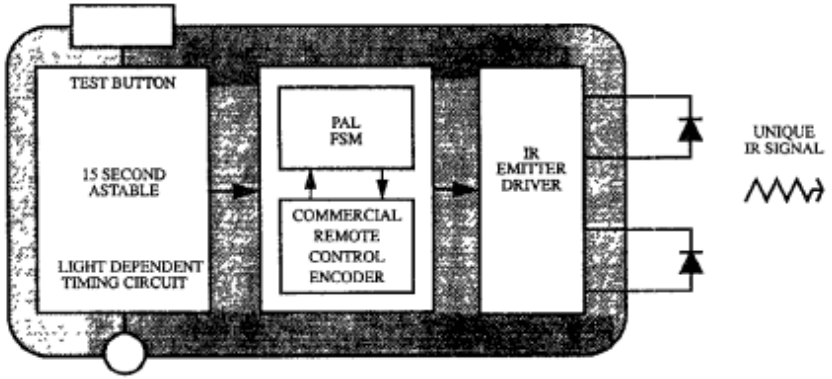
室内定位4.0

时代	特点	典型系统
室内定位1.0（鸿蒙初辟）	专用设备、专用信号	ActiveBadge, Bat, Cricket, LANDMARC
室内定位2.0（一枝独秀）	以WiFi为代表的商用移动设备	RADAR, Horus, LiFS
室内定位3.0（欣欣向荣）	智能手机的多模态传感器数据	Luxapose, SurroundSense
室内定位4.0（返璞归真）	无线+计算机视觉	JIGSAW, Trivi-Navi, **ClickLoc**, **Argus**

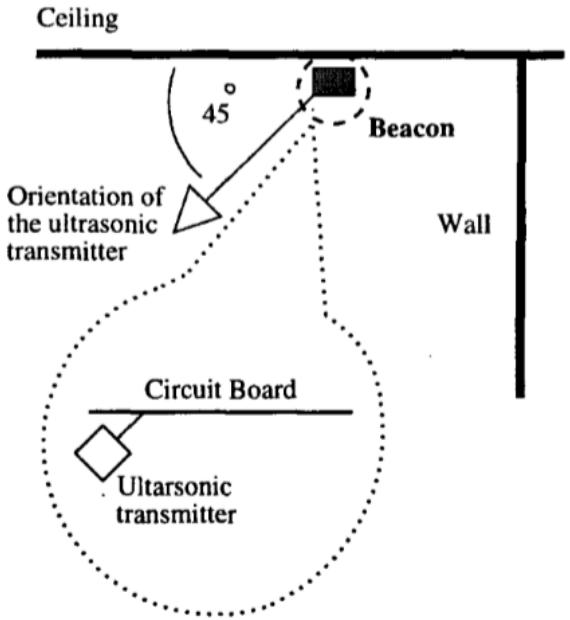
大纲

- **室内定位1.0：鸿蒙初辟**
  - **专用设备与专用信号**
- 室内定位2.0：一枝独秀
  - 以WiFi为代表的普适移动设备定位
- 室内定位3.0：欣欣向荣
  - 利用商用移动设备上的多模态传感器数据
- 室内定位4.0：返璞归真
  - 无线与CV的结合在实践中大浪淘沙始见金
  - Enhancing WiFi-based Localization with Visual Clues (UbiComp 2015)
  - Indoor Localization via Multi-Modal Sensing on Smartphones (UbiComp 2016)

Specific Devices and Signals



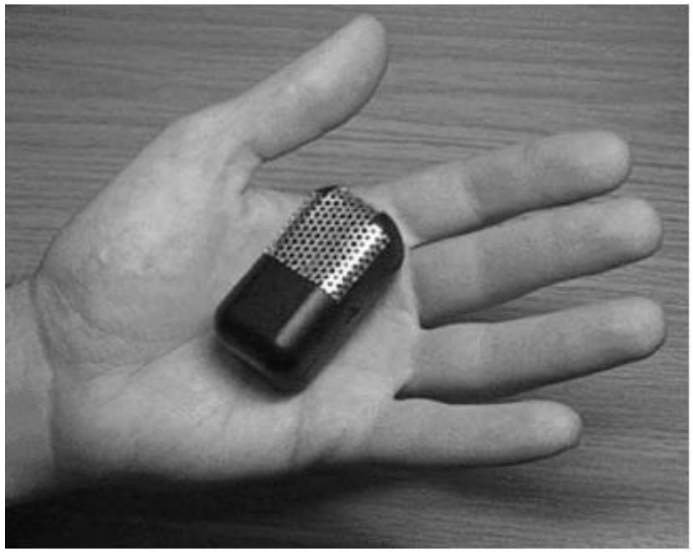
An Active Badge



Cricket Ultrasonic Transmitter

1. Want R, Hopper A, Falcao V, et al. The active badge location system. ACM TOIS, 1992.
2. Priyantha N B, Chakraborty A, Balakrishnan H. The cricket location-support system. ACM MobiCom 2000.

Specific Devices and Signals



A Bat unit

Top View and Bottom View of Receiver

HARTER, A., HOPPER, A., STEGGLES, P., WARD, A., AND WEBSTER, P. The Anatomy of a Context-Aware Application. MobiCom 1999.

Qualitative Comparison

System	Accuracy	User Privacy	Cost	Deployment	Decentralized
Bat	~10cm	No	High	Difficult, requires matrix of sensors	No
Active Badge	Room Level	No	High	Difficult, requires matrix of sensors	No
Cricket	>1m	Yes	High	Easy	Yes

大纲

- 室内定位1.0：鸿蒙初辟
  - 专用设备与专用信号
- **室内定位2.0：一枝独秀**
  - **以WiFi为代表的普适移动设备定位**
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  - 无线与CV的结合在实践中大浪淘沙始见金
  - Enhancing WiFi-based Localization with Visual Clues (UbiComp 2015)
  - Indoor Localization via Multi-Modal Sensing on Smartphones (UbiComp 2016)
- 未来展望

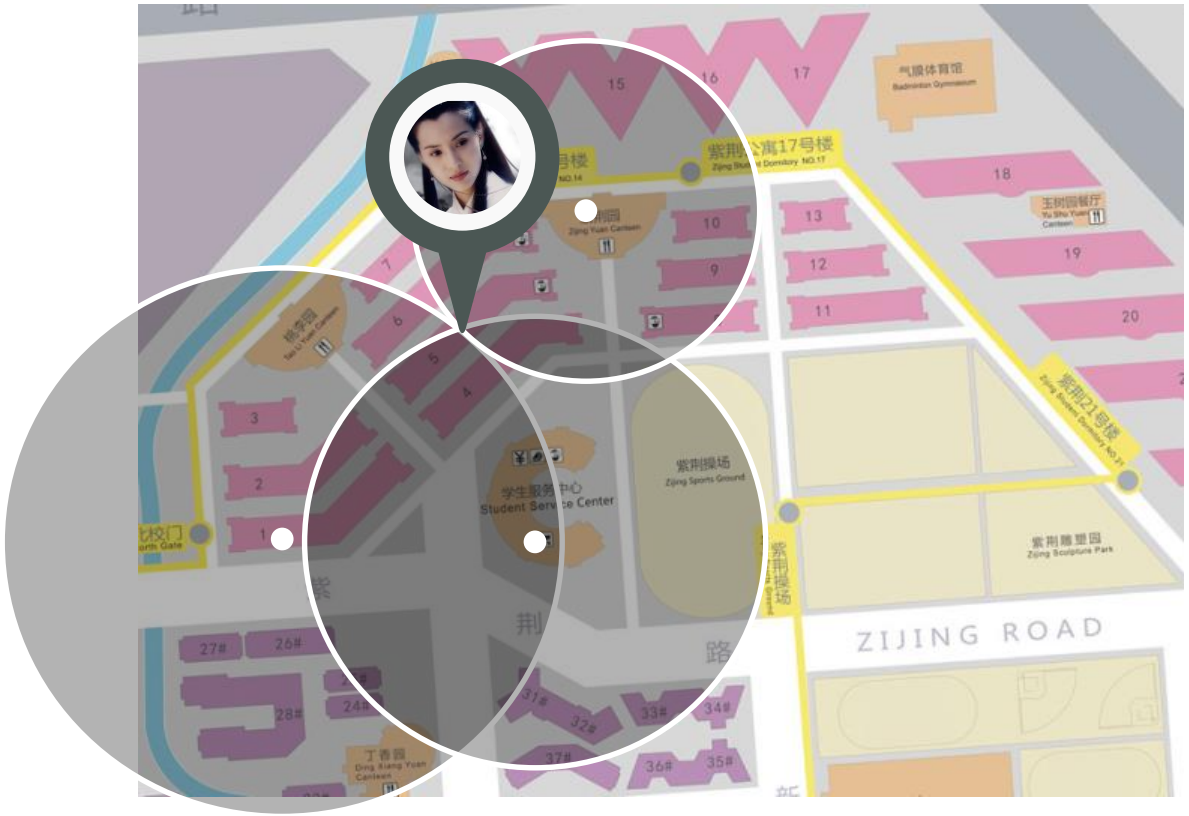
WiFi is the Most Promising Solution to Ubiquitous Localization Service

WiFi is everywhere, and it is the most convenient way to get access to the internet.

Using WiFi!

RANGING	Derive distances from received signals
FINGERPRINTING	Signal features as location fingerprints

WiFi based ranging



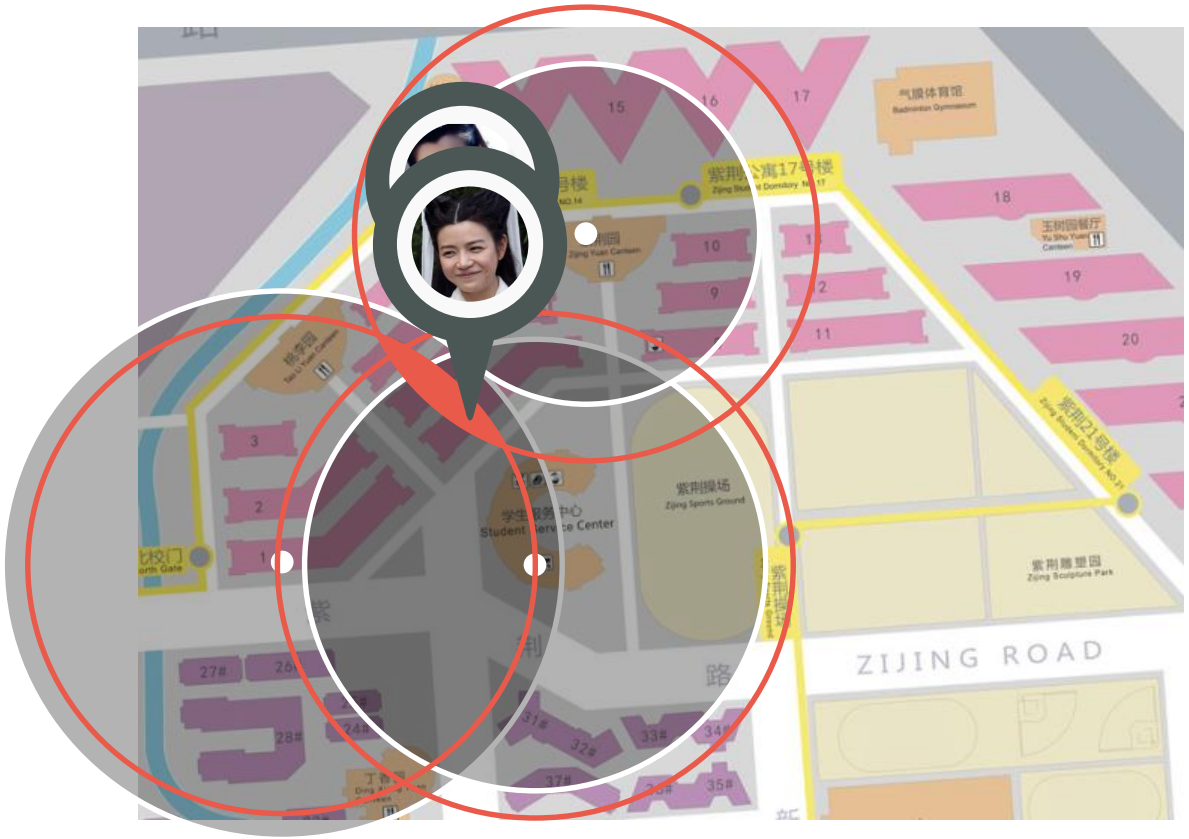
RANGING

Signal strengths decays logarithmically over distance

Estimate distance using signal propagation models

Localization by triangulation

WiFi based ranging



RANGING

Signal strengths decays logarithmically over distance

Estimate distance using signal propagation models

Localization by triangulation

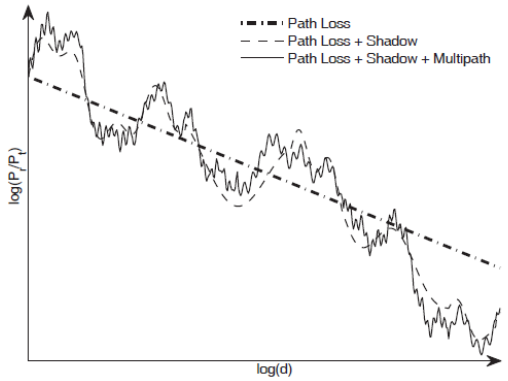
Inaccurate ranging

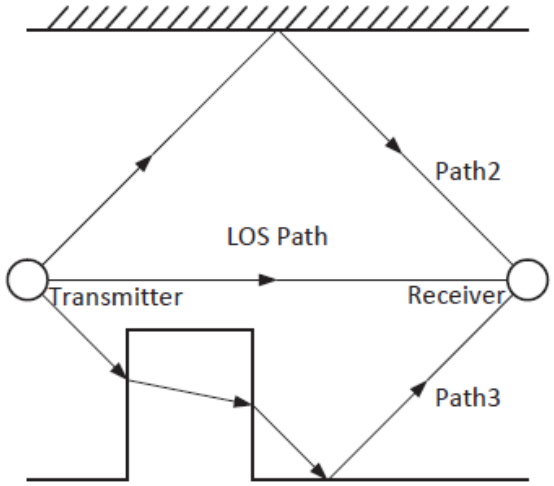
INACCURATE

Inaccurate model parameters

Ideal models unsuitable in complex indoor environments

Multipath effects

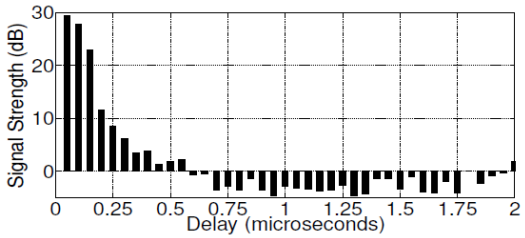




Improve ranging

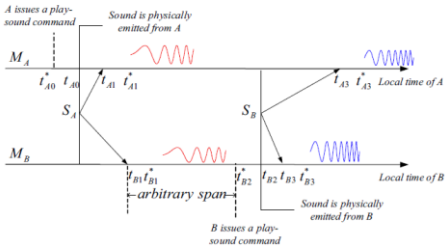
Avoiding multipath

PHYsical Layer: Channel state information



Acoustic ranging

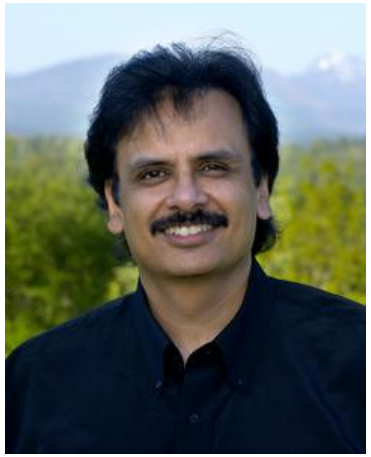
Ranging by microphones & speakers in smartphone



Classical Fingerprint-based systems

RADAR

The first fingerprint-based system
Leading a new epoch / 2000



Paramvir /
Victor Bahl

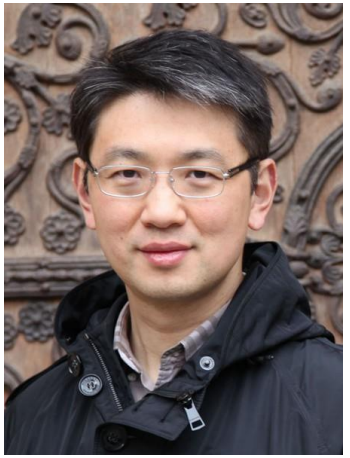
HORUS

Improved upon RADAR
/ 2004

Moustafa
Youssef

LANDMARC

First RFID Fingerprinting System
/ 2004

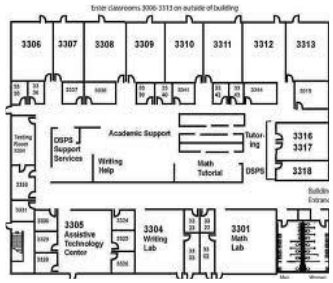


Yunhao Liu

WiFi based Fingerprinting

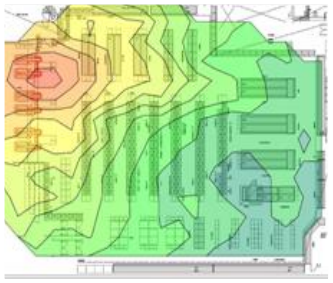
FINGERPRINTING

RSS as unique feature of a physical location
Build fingerprint database of RSS-location records
Estimate location by finding best-matched item

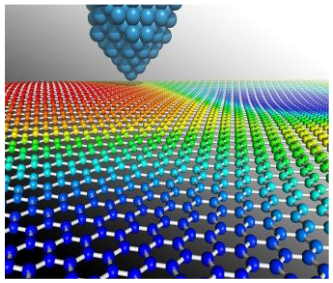


Floor plan

Site survey



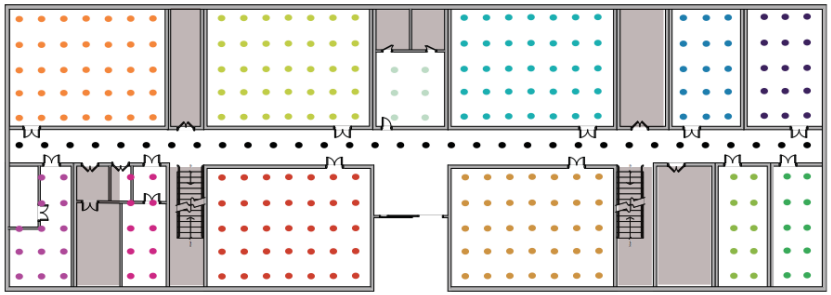
Radio map



Localization

WiFi Fingerprinting-based Localization

Training Phase



Construct a Radio Map

Operating Phase

$$\textbf{Minimize} \quad \left| f_i - \sum_{j \in \mathbb{N}(i)} W_{ij} f_i^{\mathbb{N}(j)} \right|$$

$$\textbf{Subject to} \quad \sum_{j \in \mathbb{N}(i)} W_{ij} = 1$$

Determine User Location based on RSS and Radio Map

1. Bahl P, Padmanabhan V N. RADAR: An in-building RF-based user location and tracking. IEEE INFOCOM 2000.
2. Youssef M, Agrawala A. The Horus WLAN location determination system. ACM MobiSys 2005.

Fundamental issues

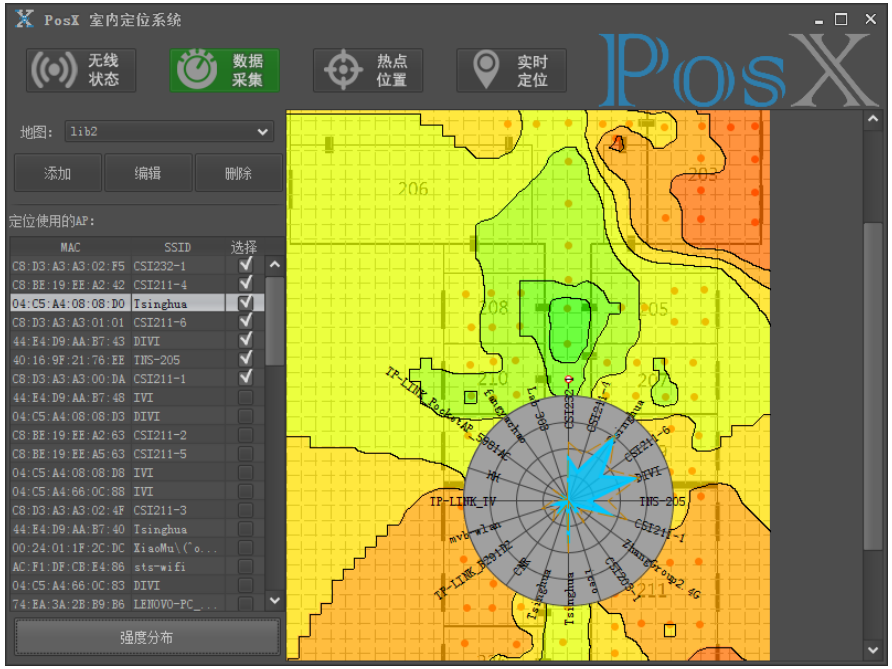
Fingerprints What types of information?
What types of feature?

Site survey How to calibrate the fingerprint database?
How to adapt to the environment dynamics?

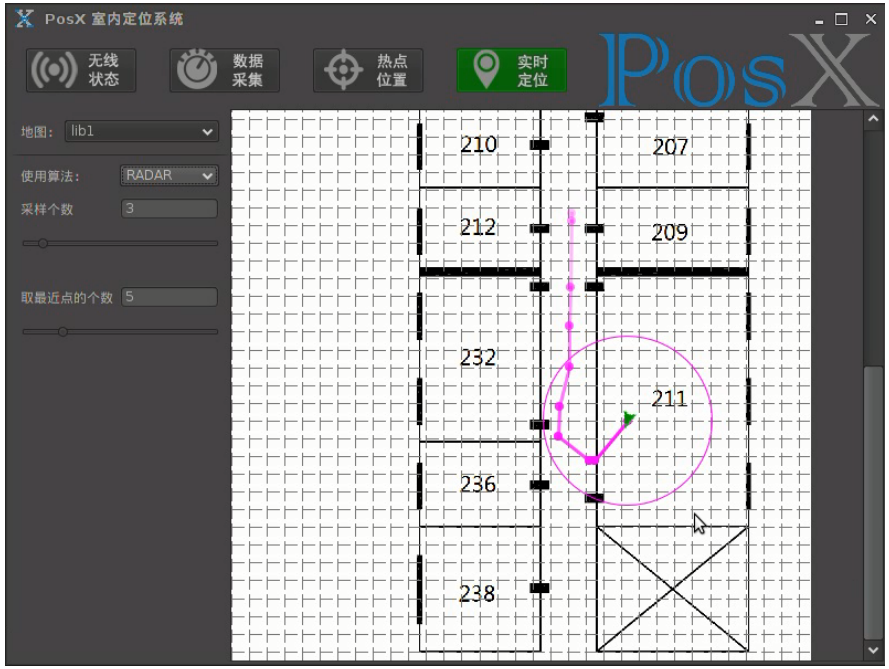
Matching What algorithms for fingerprint matching?

PosX: Indoor Positioning System

Training Phase



Operating Phase



Posx: http://tns.thss.tsinghua.edu.cn/PosX/

Demo Video

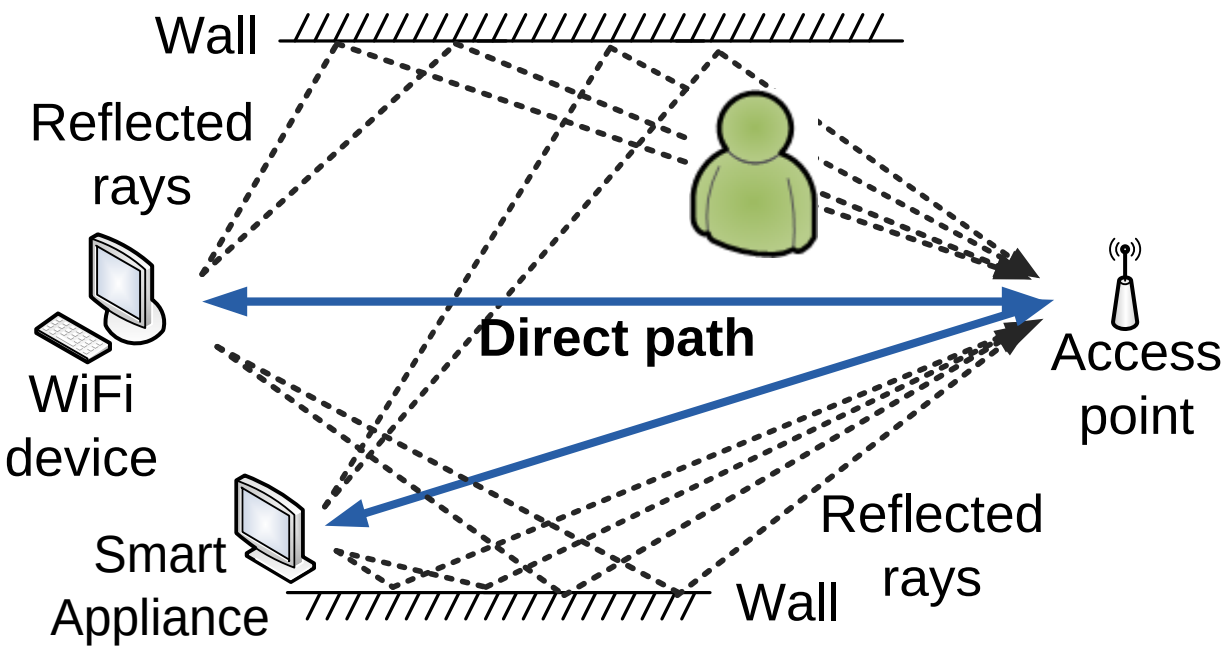
Posx: http://tns.thss.tsinghua.edu.cn/PosX/

WiFi Localization: Summary

- **Applications:**
  - Indoor Localization and navigation
  - Healthcare Monitoring
  - Intelligent Logistics
- **Benefits:**
  - Simultaneous Communication & Localization
  - Without Wearable Sensors
  - Widespread deployment

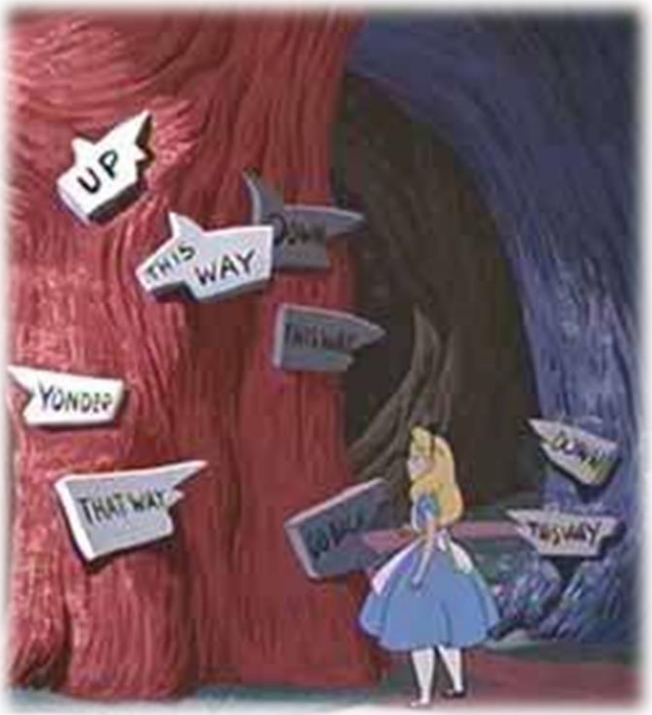
A **Gap** between Fantasy and Reality

Fantasy: WiFi is Enough



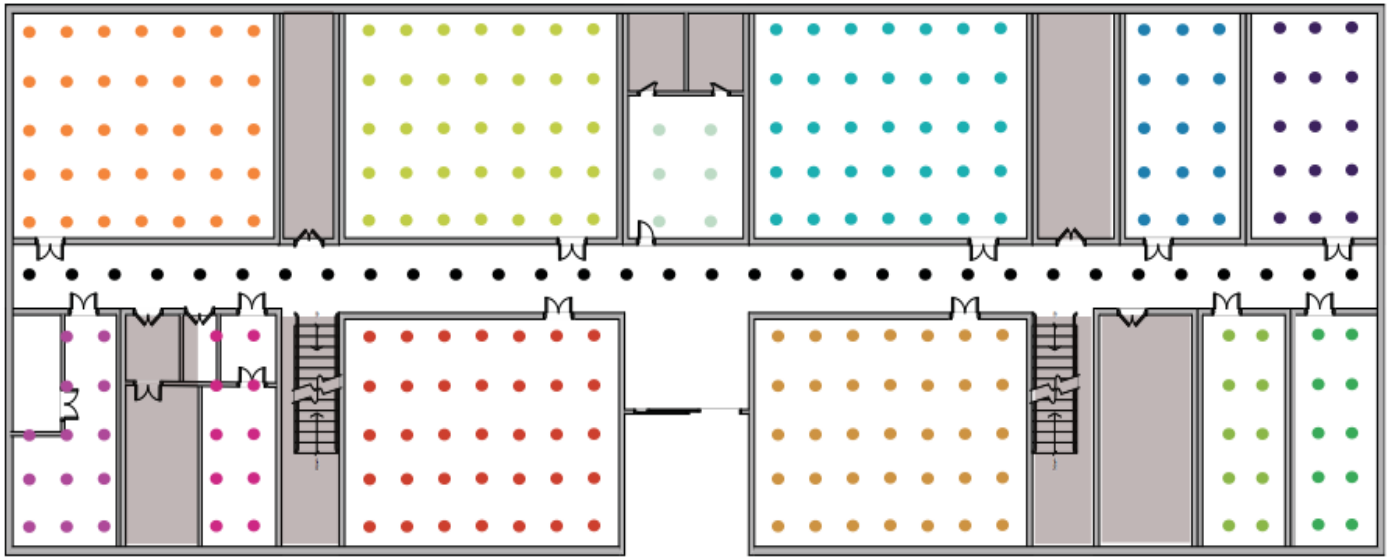
Reality: Large Localization Error roots in rich Multi Path Propagation Indoors

Fantasy: WiFi is Enough



Reality: Lack Location Context which is More Valuable and Meaningful

Fantasy: WiFi is Enough



Reality: Huge Overhead during Database Construction and Maintenance

Qualitative Comparison

System	Accuracy	Context	Cost	Deployment
Radar	3~5m	No	High	War-driving
Horus	<1m	No	High	War-driving
LiFS	~5m	No	Low	Crowdsourcing
Zee	~3m	No	Low	Crowdsourcing

大纲

- 室内定位1.0：鸿蒙初辟
  - 专用设备与专用信号
- 室内定位2.0：一枝独秀
  - 以WiFi为代表的普适移动设备定位
- **室内定位3.0：欣欣向荣**
  - **利用商用移动设备上的多模态传感器数据**
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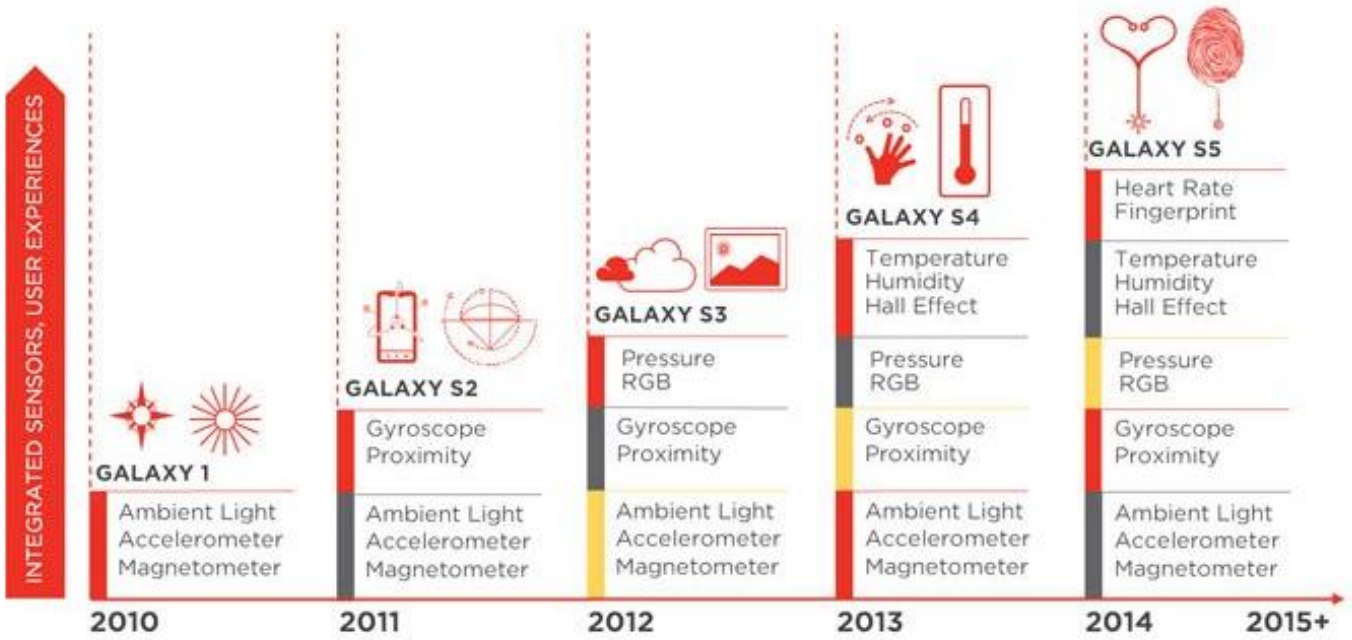
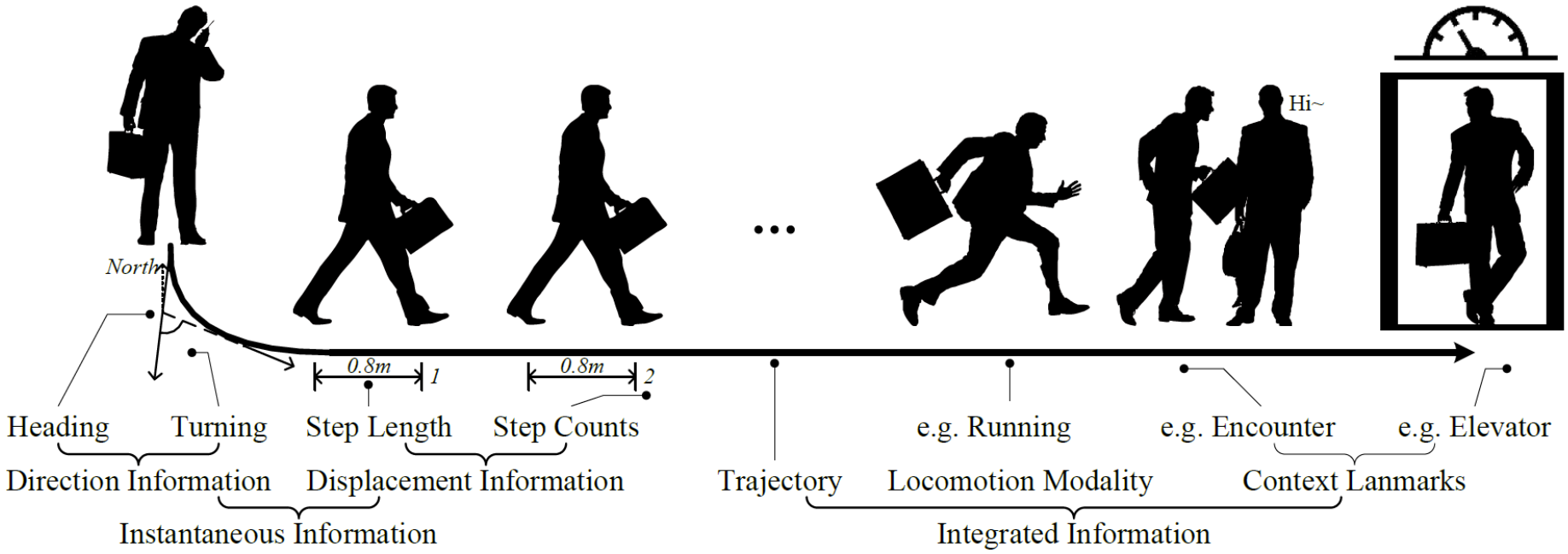
  - 无线与CV的结合在实践中大浪淘沙始见金
  - Enhancing WiFi-based Localization with Visual Clues (UbiComp 2015)
  - Indoor Localization via Multi-Modal Sensing on Smartphones (UbiComp 2016)

A New Dawn



How to exploit **Multiple Sensors** and Boost Indoor Localization?

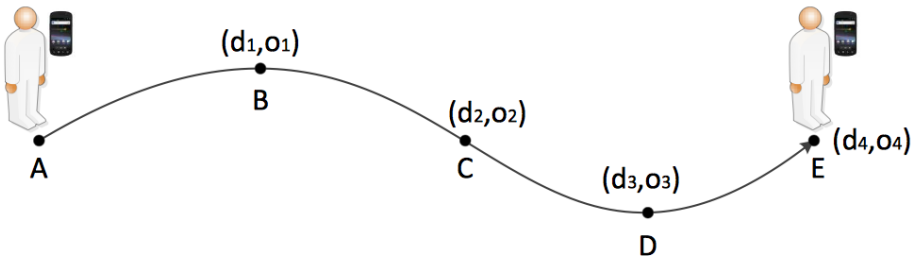
Sensors Recognize Human Activity



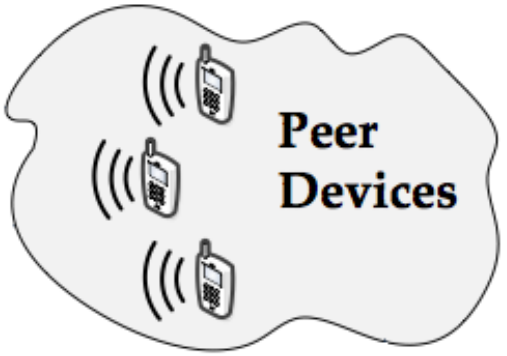
Zheng Yang, et al., "Mobility Increases Localizability: A Survey on Wireless Indoor Localization using Inertial Sensors", ACM Computing Surveys

Sensors Help Solve Fingerprint Ambiguity

Motion-assisted Localization



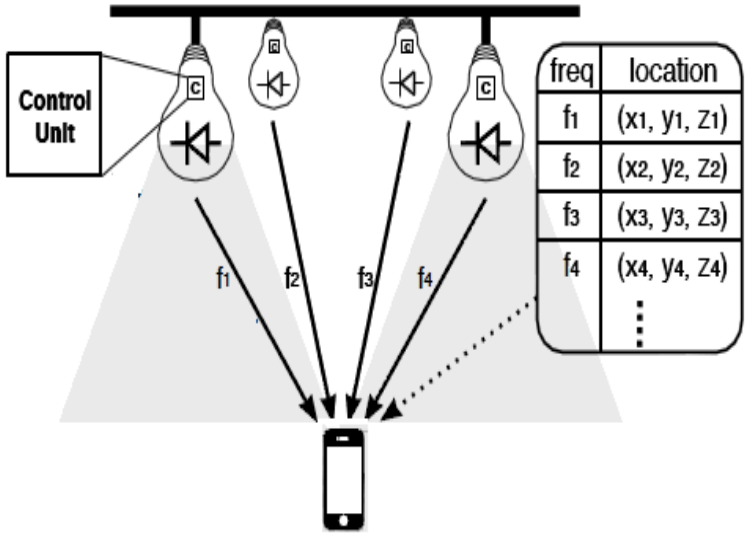
Peer-assisted Localization



1. Sun Wei, et al. Moloc: On distinguishing fingerprint twins. ICDCS 2013.
2. Liu, H., et al. Push the limit of wifi based localization for smartphones. MobiCom 2012.

Sensors add New Dimension

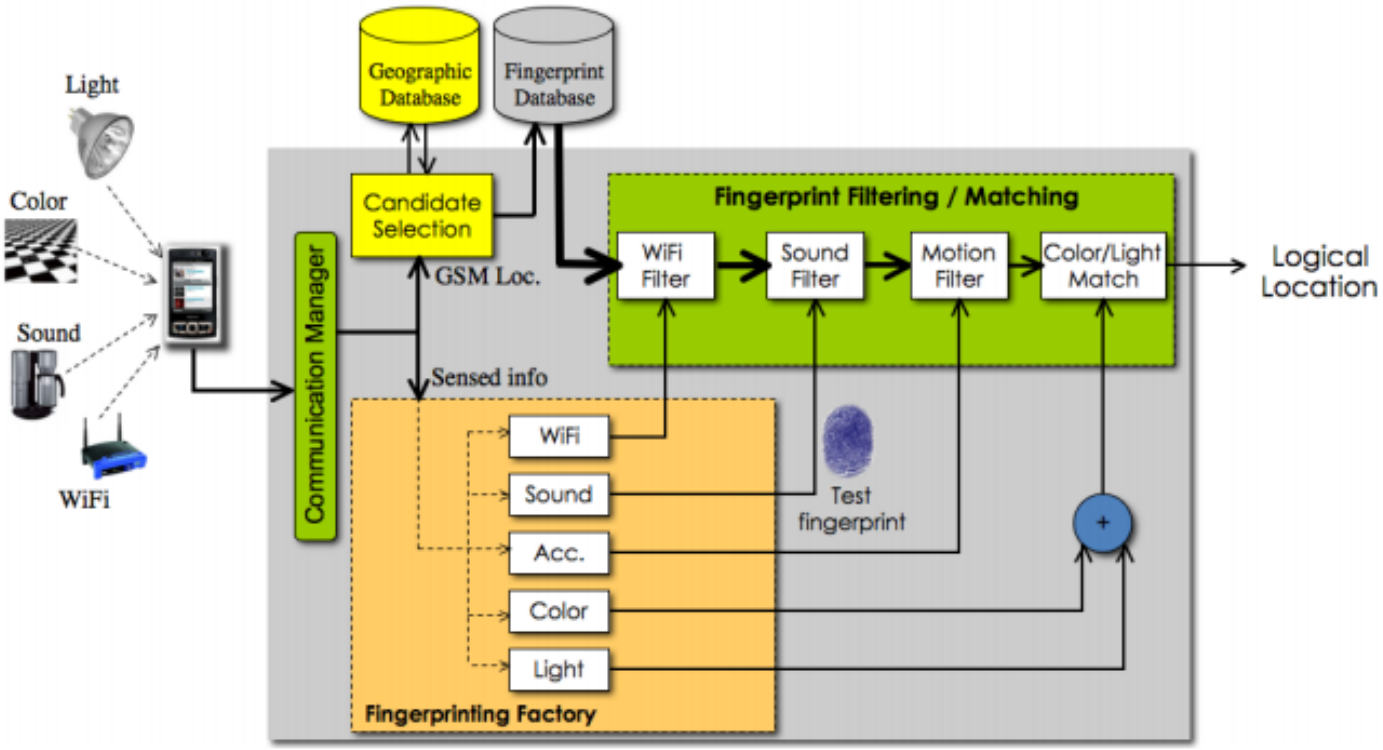
Barometer-based Application



Visible Light Communication

1. Sankaran K, Zhu M, Guo X F, et al. Using mobile phone barometer for low-power transportation context detection. SenSys 2014.
2. Ye-Sheng Kuo, Pat Pannuto, Ko-Jen Hsiao, and Prabal Dutta. Luxapose: Indoor Positioning with Mobile Phones and Visible Light. MobiCom 2014.

Sensors lead to New Fingerprint



Azizyan M, Constandache I, Roy Choudhury R. SurroundSense: mobile phone localization via ambience fingerprinting. ACM MobiCom 2009.

Sensors lead to New Fingerprint

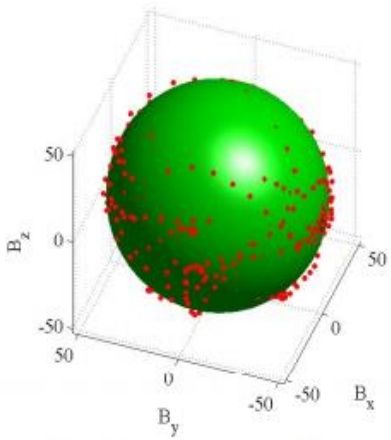


Figure 1. Locus of magnetic readings with the optimum ellipsoidal fit superimposed.

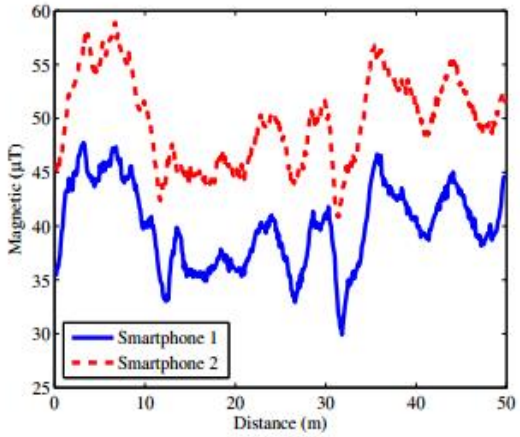


Figure 2. Magnetic readings captured by two smartphones along a 50-meter corridor.

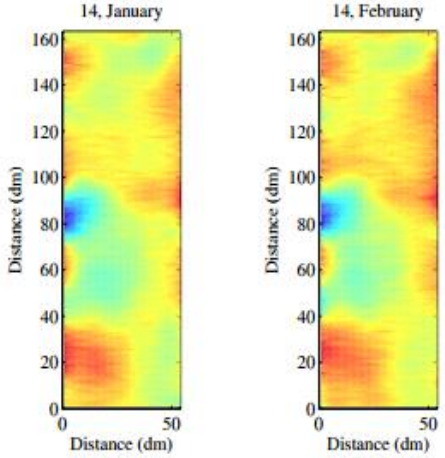


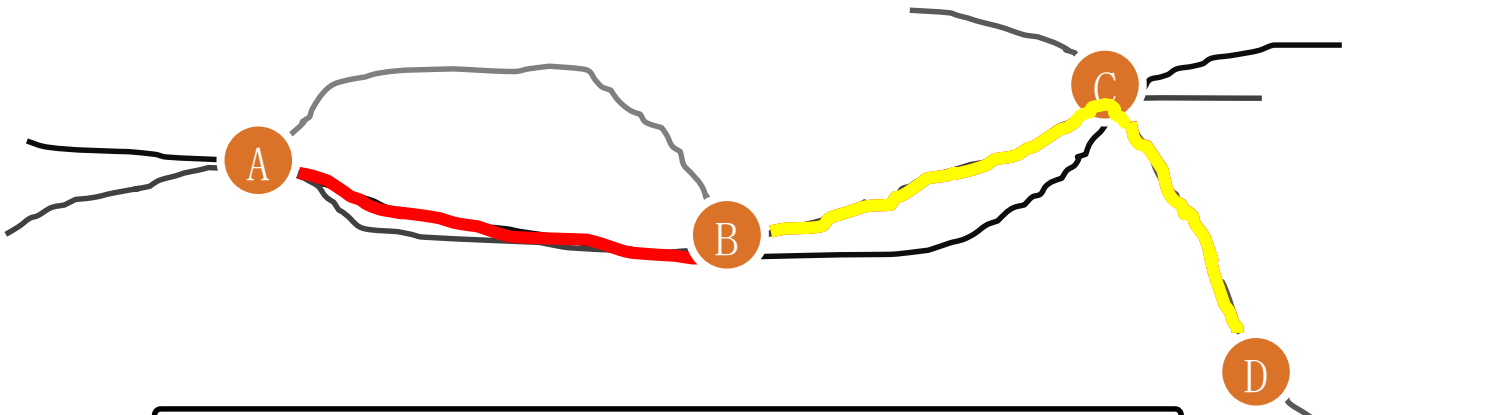
Figure 3. Magnetic field map captured by smartphones over one month.

Xie H, Gu T, Tao X, et al. MaLoc: a practical magnetic fingerprinting approach to indoor localization using smartphones. UbiComp 2014.

Sensors Cut off Site Survey

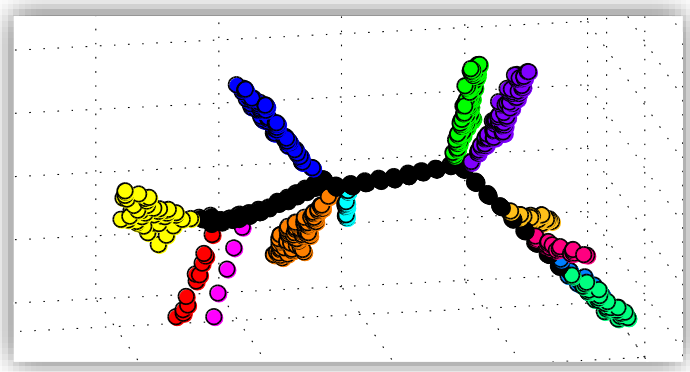
Crowdsourcing the site-survey by mobile users.

- Collect mobility information from users' routine work and life and, on this basis, form a fingerprint space by associating the originally separated fingerprints

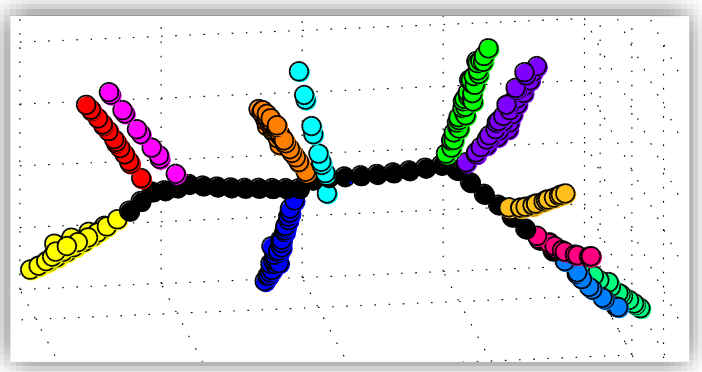


User moving paths connect fingerprints

Sensors Cut off Site Survey



Fingerprint space constructed from user mobility



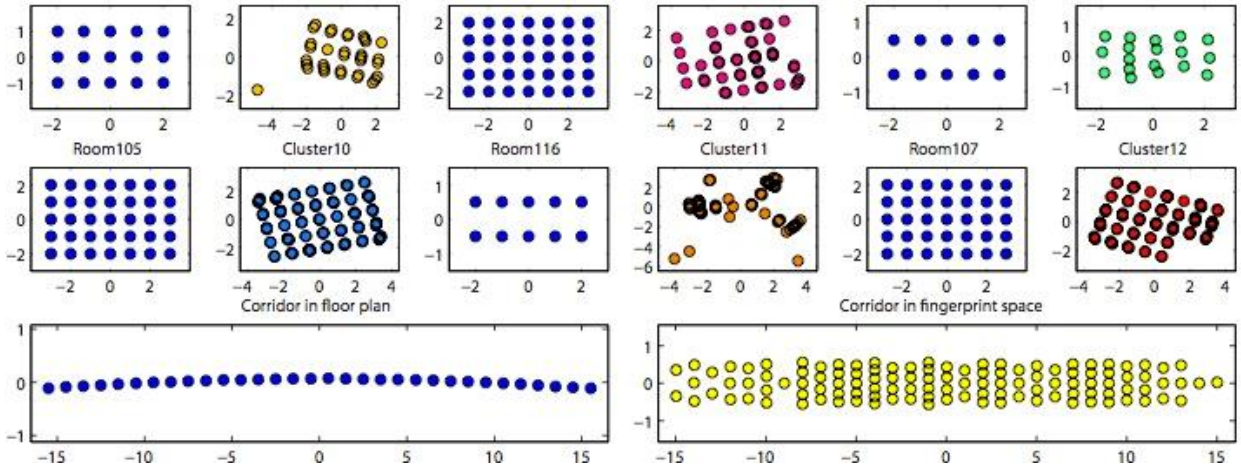
Transform common floor plan into stress-free floor plan

Associate the fingerprints to their physical locations by the spatial similarity between these two graphs.

The task can be only finished by site survey before

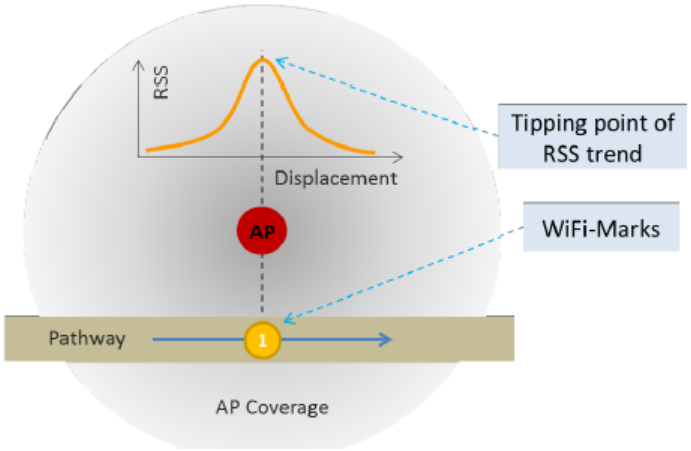
Sensors Cut off Site Survey

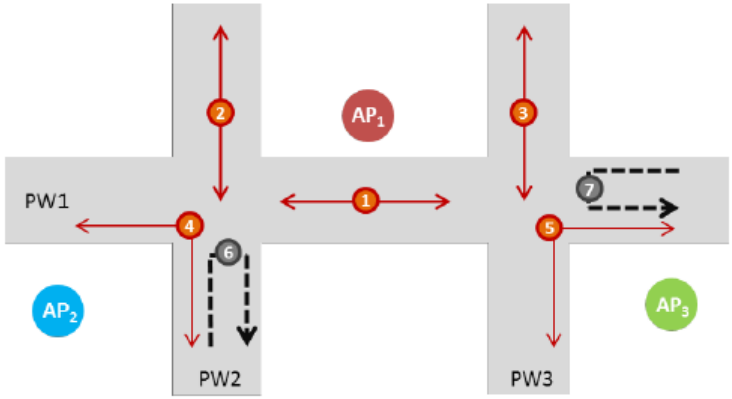
- A system base on the thinking of crowdsourcing:
  - No need to site survey
  - No extra infrastructure or hardware
  - No prior knowledge of networks
  - No explicit participations on users.



"Locating in Fingerprint Space: Wireless Indoor Localization with Little Human Intervention", ACM MobiCom 2012

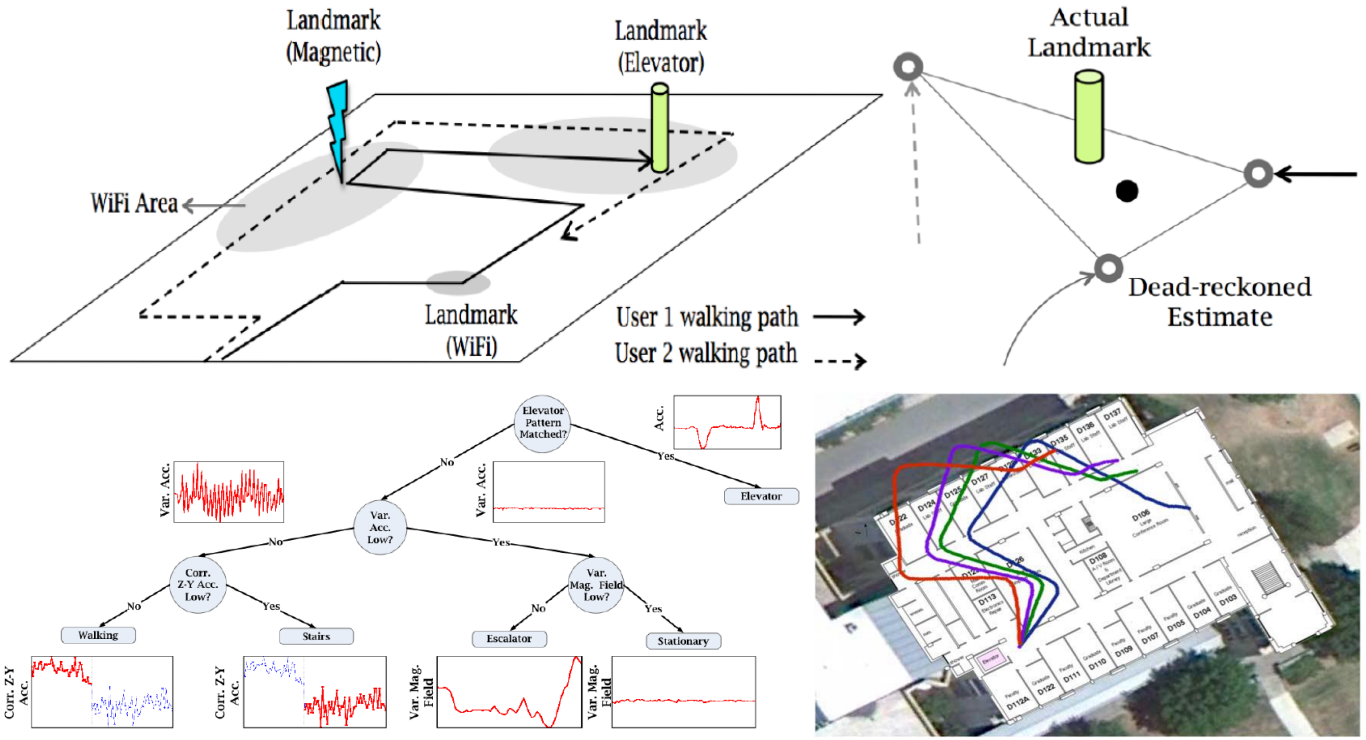
Avoiding site survey: Walkie-Markie





"Walkie-Markie: Indoor Pathway Mapping Made Easy," NSDI'13

Avoiding site survey: Unloc



H. Wang et al, "No need to war-drive: unsupervised indoor localization," MobiSys'12.

Qualitative Comparison

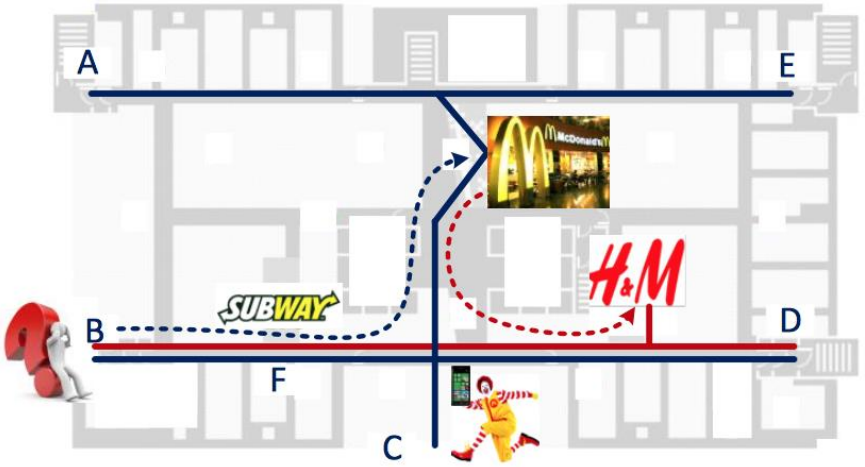
System	Accuracy	Context	Cost	Deployment	Sensors
MoLoc	m	No	Low	War-driving	Inertial Sensors
Liu, H., et al.	~2m	No	Low	Ad-hoc	Microphone
Sankaran, K., et al.	>90%	Yes(Idle, walking, vehicle)	Low	Digital Map	Barometer
Luxapose	<10cm	No	High	Light bulbs	Camera
Surround Sense	~87%	Yes(Room Functionality)	Low	War-driving	Microphone, WiFi, Inertial, Light, Color
Maloc	1~2.8m	No	Low	War-driving	Magnetic

大纲

- 室内定位1.0：鸿蒙初辟
  - 专用设备与专用信号
- 室内定位2.0：一枝独秀
  - 以WiFi为代表的普适移动设备定位
- 室内定位3.0：欣欣向荣
  - 利用商用移动设备上的多模态传感器数据
- **室内定位4.0：返璞归真**
  - **无线与CV的结合在实践中大浪淘沙始见金**
  - Enhancing WiFi-based Localization with Visual Clues (UbiComp 2015)
  - Indoor Localization via Multi-Modal Sensing on Smartphones (UbiComp 2016)

CV-assisted Localization and Navigation

Floor Plan Reconstruction

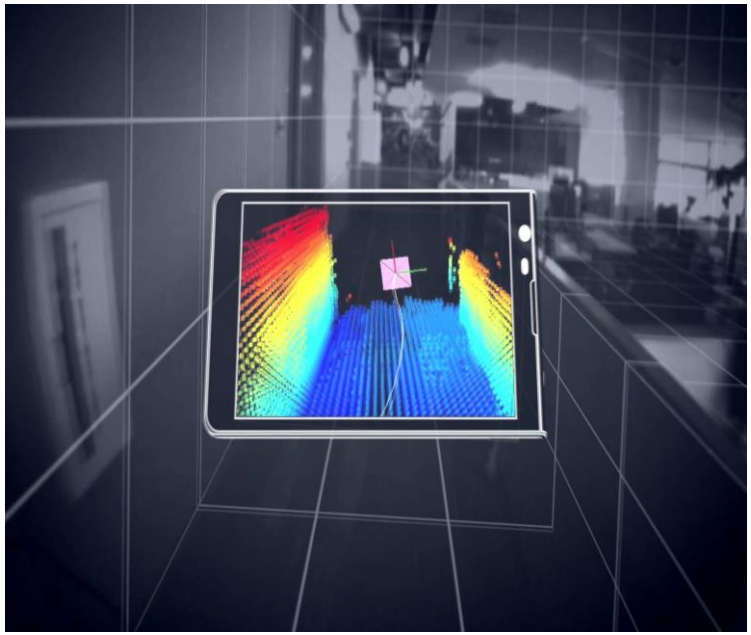


Indoor Navigation

1. Ruipeng Gao, et al. Jigsaw: Indoor Floor Plan Reconstruction via Mobile Crowdsensing. MobiCom 2014.

2. Yuanqing Zheng, et al. Travi-Navi: Self-deployable Indoor Navigation System. MobiCom 2014.

What you see is what you get!



Google Project Tango

Indoor VR and AR

大纲

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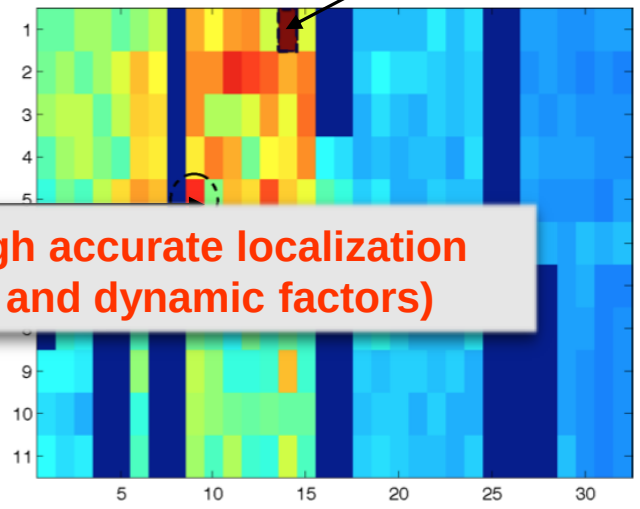
  - 无线与CV的结合在实践中大浪淘沙始见金
  - **Enhancing WiFi-based Localization with Visual Clues (UbiComp 2015)**
  - Indoor Localization via Multi-Modal Sensing on Smartphones (UbiComp 2016)

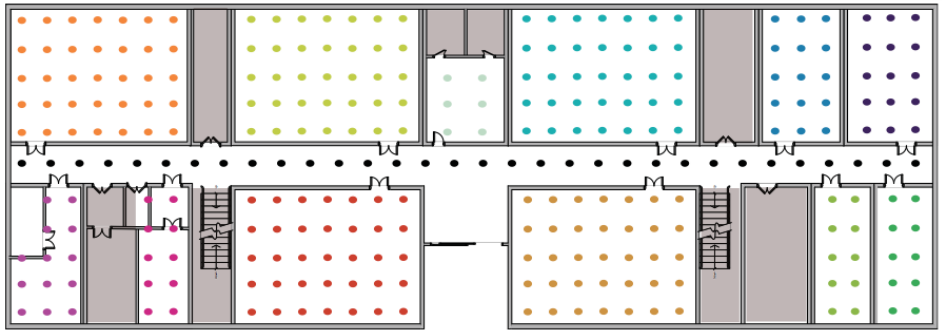
Motivation

Nearest Neighbor is here



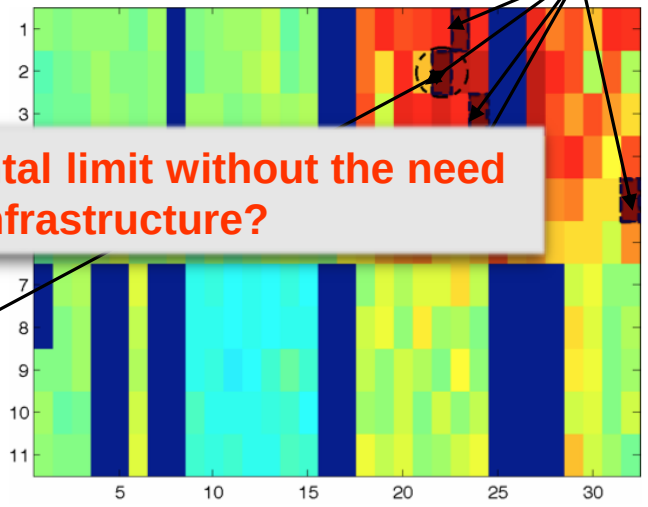
Target is here

WiFi is not a suitable candidate for high accurate localization due to large errors (Both permanent and dynamic factors)



Reference Points on the Floor Plan

Top 5 Nearest Neighbors



Is it possible to address this fundamental limit without the need of additional hardware or infrastructure?

Fingerprint Ambiguity

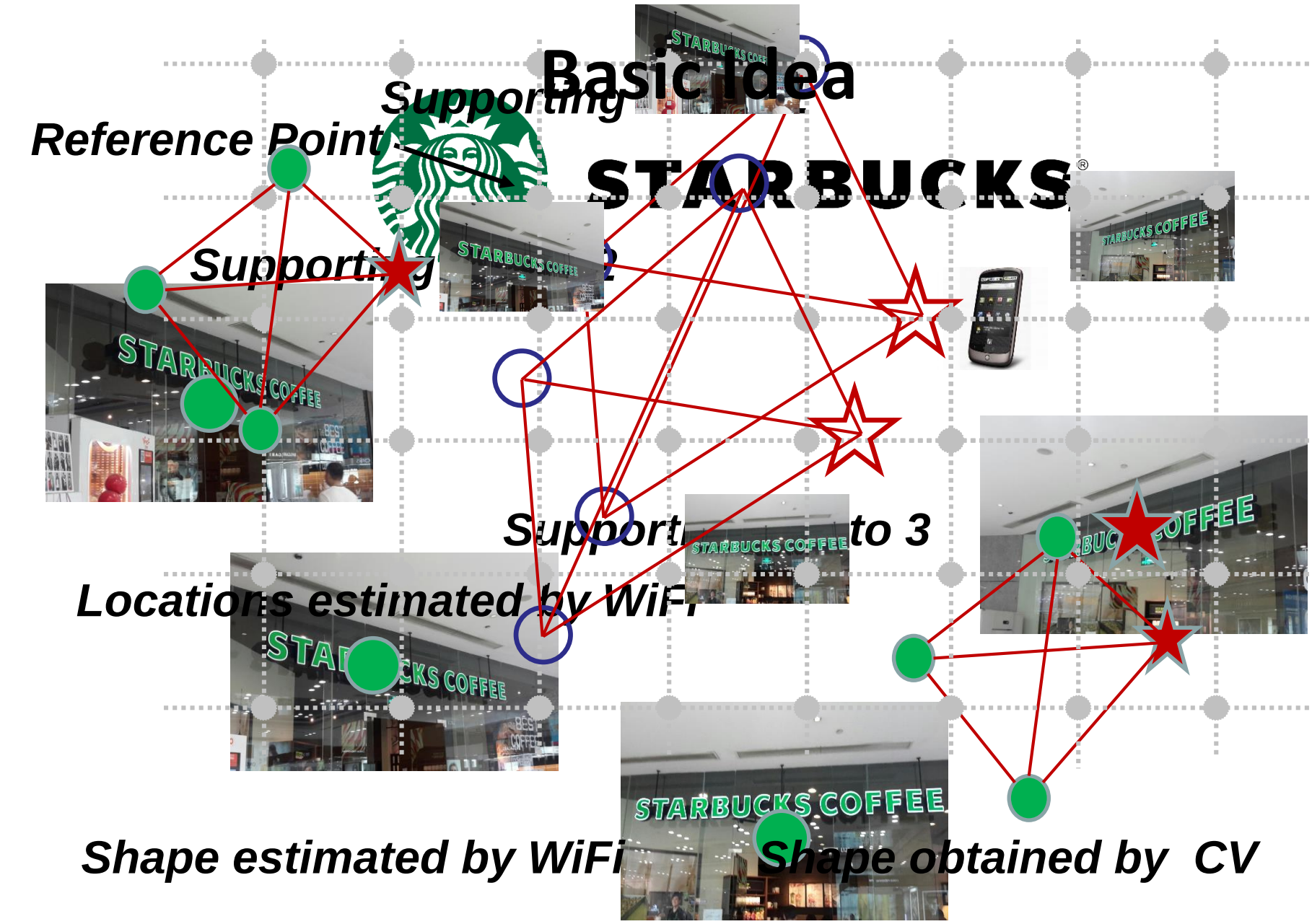
Target is here

One Click Localization?

Enhanced Phone Camera

People take photos everywhere!

Basic Idea


Supporting
Reference Point
Supporting
Support to 3
Locations estimated by WiFi
Shape estimated by WiFi
Shape obtained by CV

System Design Goals and Challenges

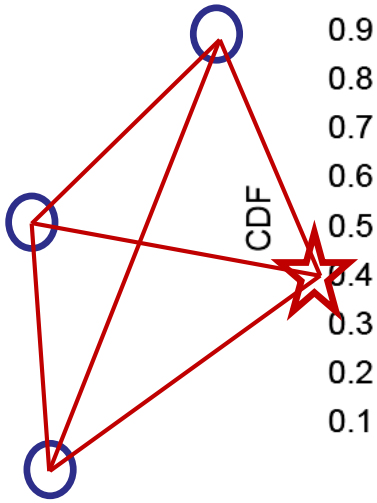
- Efficient and reliable constraint extract
  - How to efficiently extract reliable geometric constraints for accurate localization from crowdsourced images

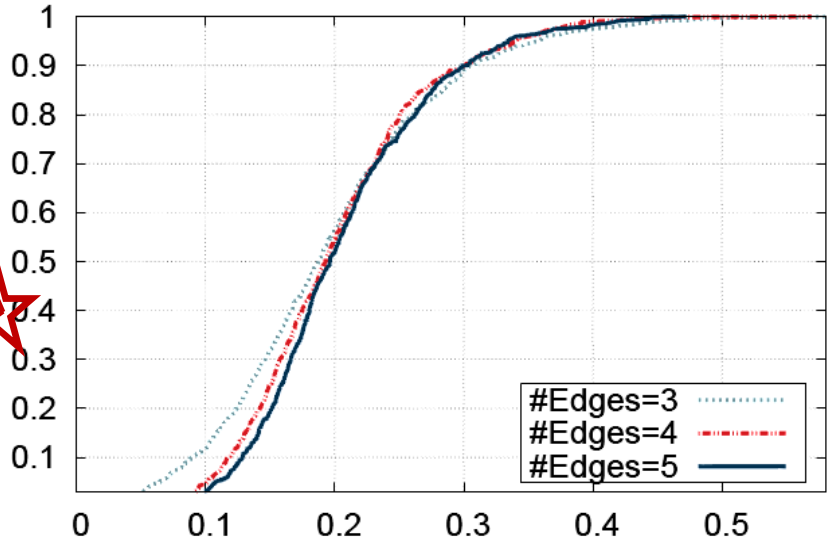
- Image assisted localization
  - Exactly what is the algorithm to search for the best fit position and quantify the similarity so that to reduce large errors?

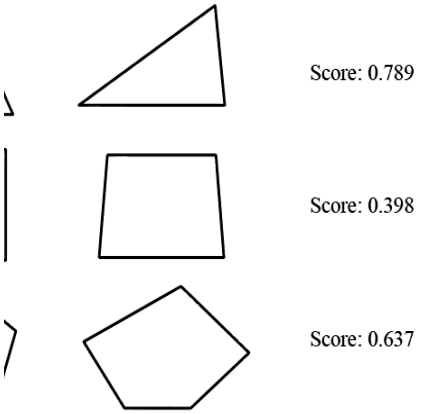
- Lightweight and ease of use
  - Co-exist with the prevalent WiFi infrastructure
  - Not annoy to user regular activity

System Work Flow

Obtaining Geometric Constraints







Polygon generated by SfM

ured Shape Similarity [1]

SfM generated Polygons v.s. Ground Truth Locations

1. Arkin, E. M., Chew, L. P., Huttenlocher, D. P., Kedem, K., and Mitchell, J. S. An Efficiently Computable Metric for Comparing Polygonal Shapes. IEEE Transactions on Pattern Analysis and Machine Intelligence 13, 3 (1991), 209–216..

System Work Flow

☐ Supporting Photo Selection

- ◆ Handling Device Heterogeneity
- ◆ Major Selection Criteria:
  - I. WiFi fingerprints similarity
  - II. Image Similarity
  - III. Polygon Shape Similarity

System Work Flow

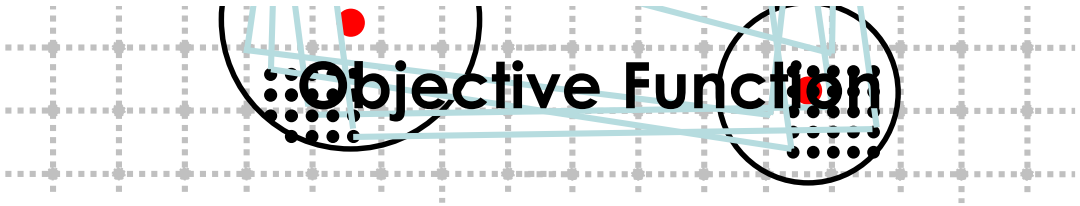
- Joint Location Estimation

Minimize

$$\sum_{\forall i} \left[f\left(a_i\right) - f\left(b_i\right)\right]\left[f\left(a_i\right) - f\left(b_i\right)\right]^T$$

Subject to

$$\forall i,j \quad : \quad (1-\alpha)\frac{|E_{i,j}|}{|E_{1,2}|} \leqslant \frac{|(b_i,b_j)|}{|(b_1,b_2)|} \leqslant (1+\alpha)\frac{|E_{i,j}|}{|E_{1,2}|}$$

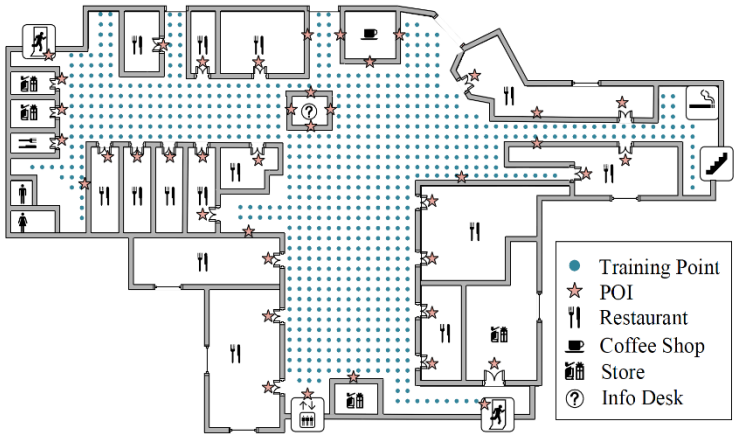


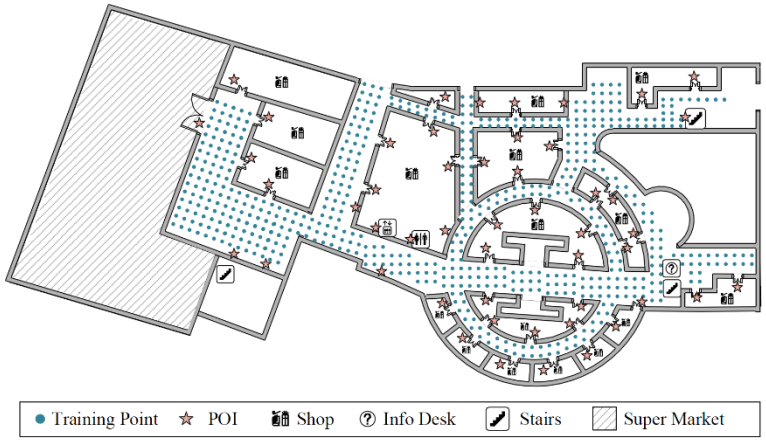
Step 1: Step 2: Step 3:

Experimental Setup

- Device:
  - Google Nexus 5 and Samsung Tablet 10.1
  - Operating in Android 4.4

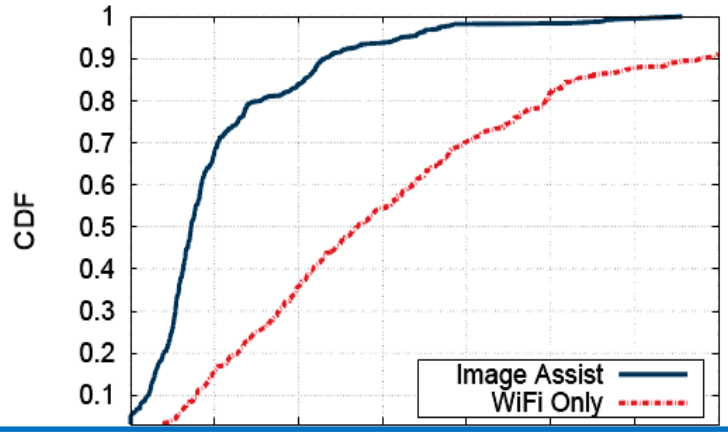
- Scenarios:
  - Food Plaza and Shopping Mall
  - 5-20 photos per POI, in total more than 1200 photos (with 2 volunteers)
  - 10 WiFi samples every 1.8m

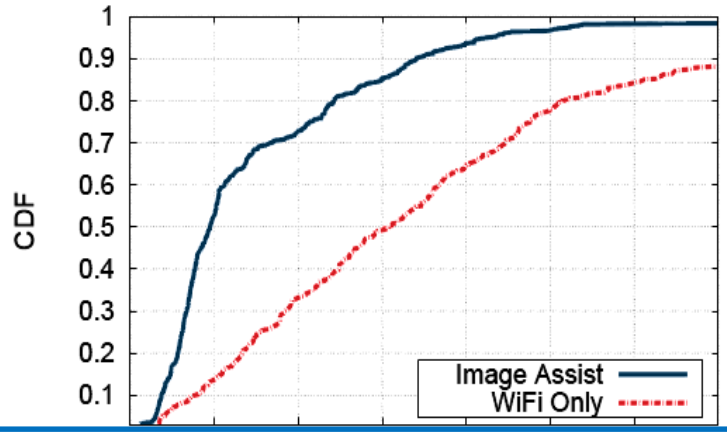




Overall Performance

- 50-percentile error: 2.73m v.s. 0.78m (mall), 3.01m v.s. 0.97m (plaza)
- 80-percentile error: 4.98m v.s. 1.38m (mall), 5.02m v.s. 2.30m (plaza)





Triple the Localization Accuracy than Classic WiFi-based Localization

大纲

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  - 专用设备与专用信号
- 室内定位2.0：一枝独秀
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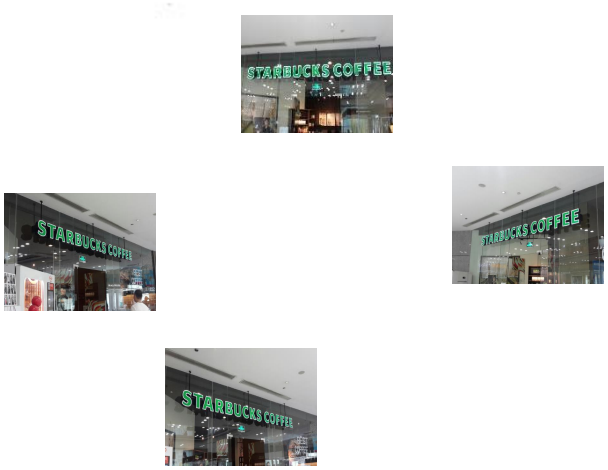
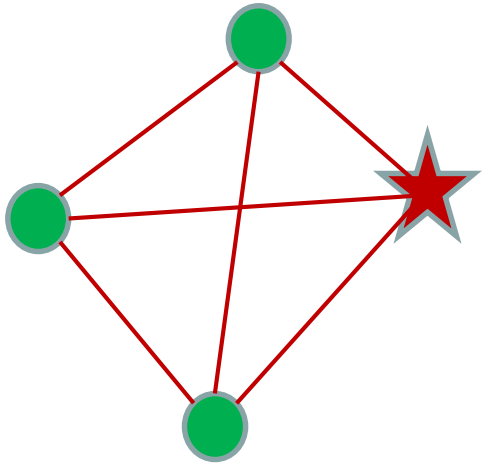
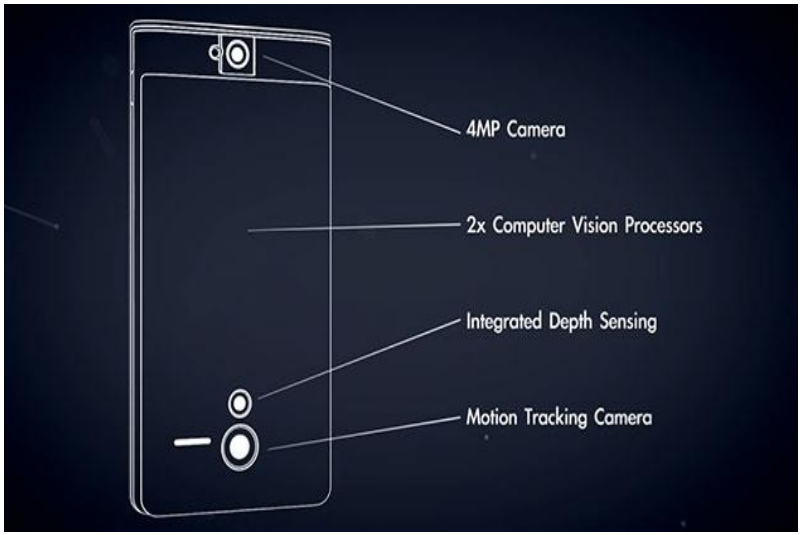
Different Perspective





Two Major Limitations for Image-based Solution in Practice

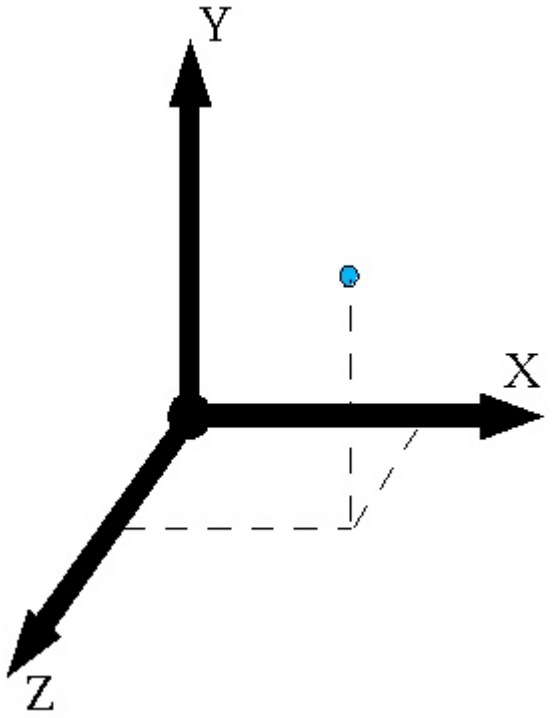
Huge Overhead during Image Database Construction.



The 3D model is relative, extra calibration or device is required.

Transformation from Image Space to Physical Space

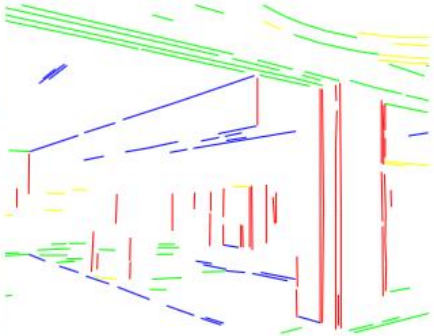
3D Model



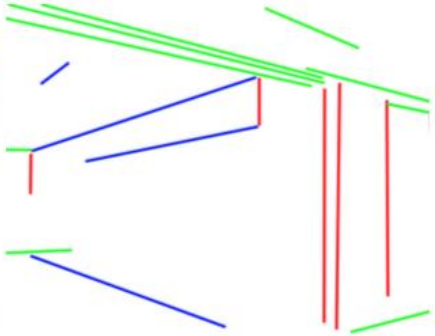
World Coordinates

POIs on the Floor Plan

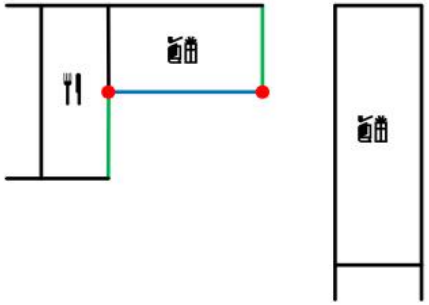
(a) Original Image



(b) Extracted lines



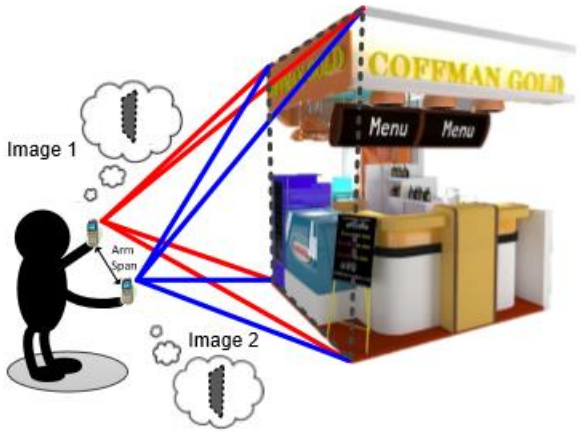
(c) After Processing

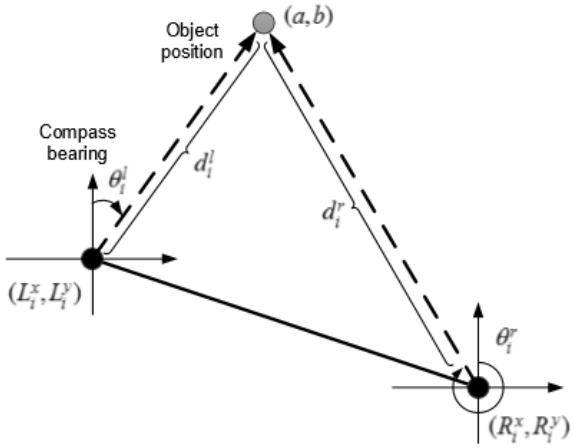


(d) Map to Floor Plan

Estimate Scaling, Rotation, and Translation via **Indoor Geometric Reasoning**.

Estimation of Scaling II





$$\textbf{Minimize} \quad \sum_{\forall i} \left| E_i^l + E_i^r \right|$$

Subject to

$$\forall i \; : \; s_i^2 = \left[-sin\left(\theta_i^l + E_i^l\right) d_i^l + sin\left(\theta_i^r + E_i^r\right) d_i^r \right]^2 + \left[-cos\left(\theta_i^l + E_i^l\right) d_i^l + cos\left(\theta_i^r + E_i^r\right) d_i^r \right]^2$$

$$\forall i \; : \; s_i = s + E_i^s$$

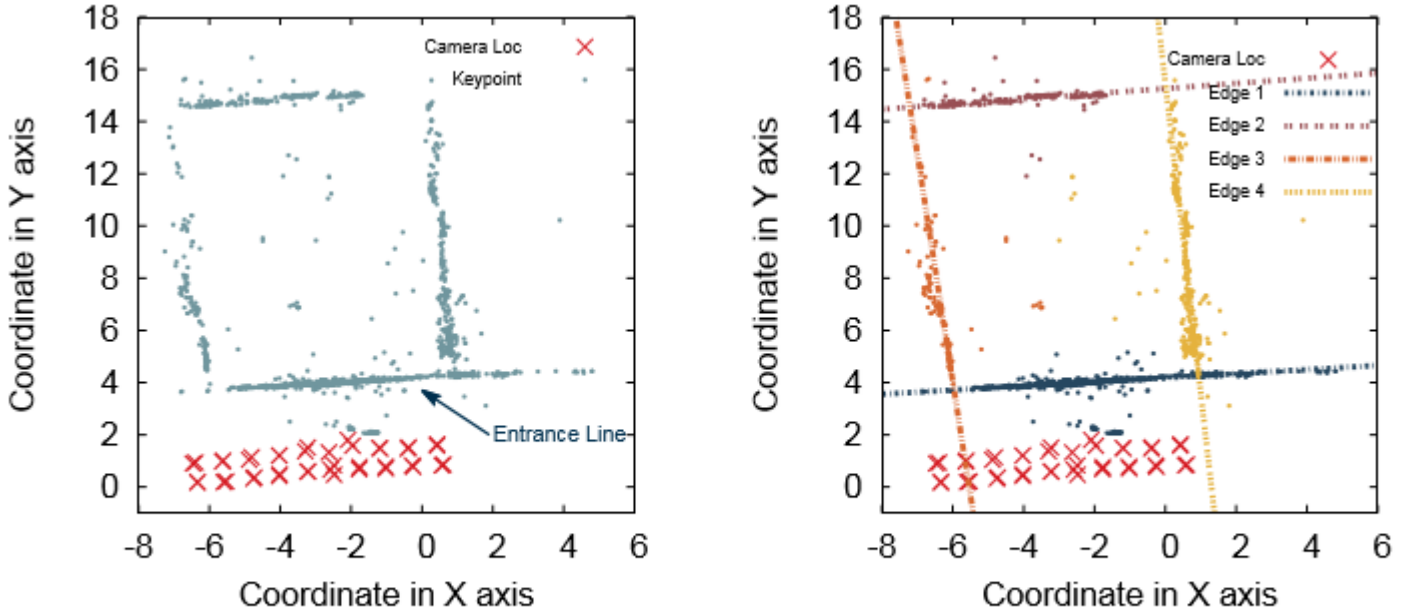
$$\forall i \; : \; d_i^l = \lambda \sqrt{\left(L_i^x - a\right)^2 + \left(L_i^y - b\right)^2}$$

$$\forall i \; : \; d_i^r = \lambda \sqrt{\left(R_i^x - a\right)^2 + \left(R_i^y - b\right)^2}$$

Estimate the Scaling Factor via

Arm Span and Sensor Data.

Estimation of Rotation II

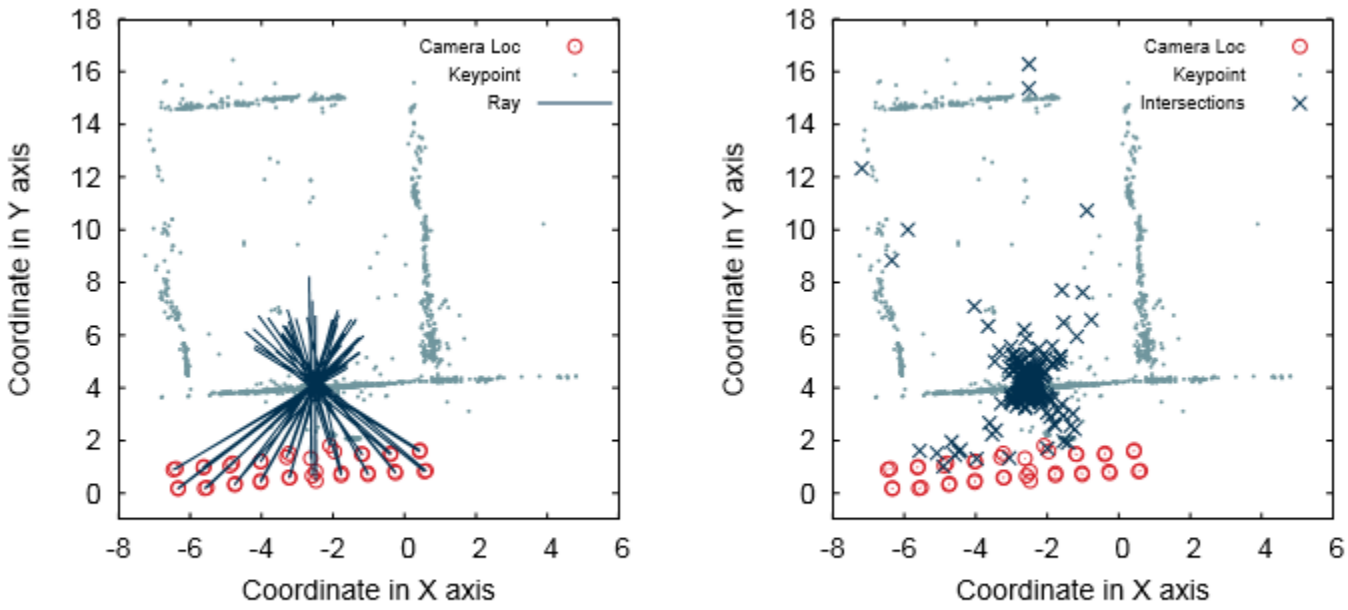


(a) Point cloud and cameras (b) 4 edges found by "K-Edges"

Estimate the Rotation via

Top View Projection and Compass.

Estimation of Translation II

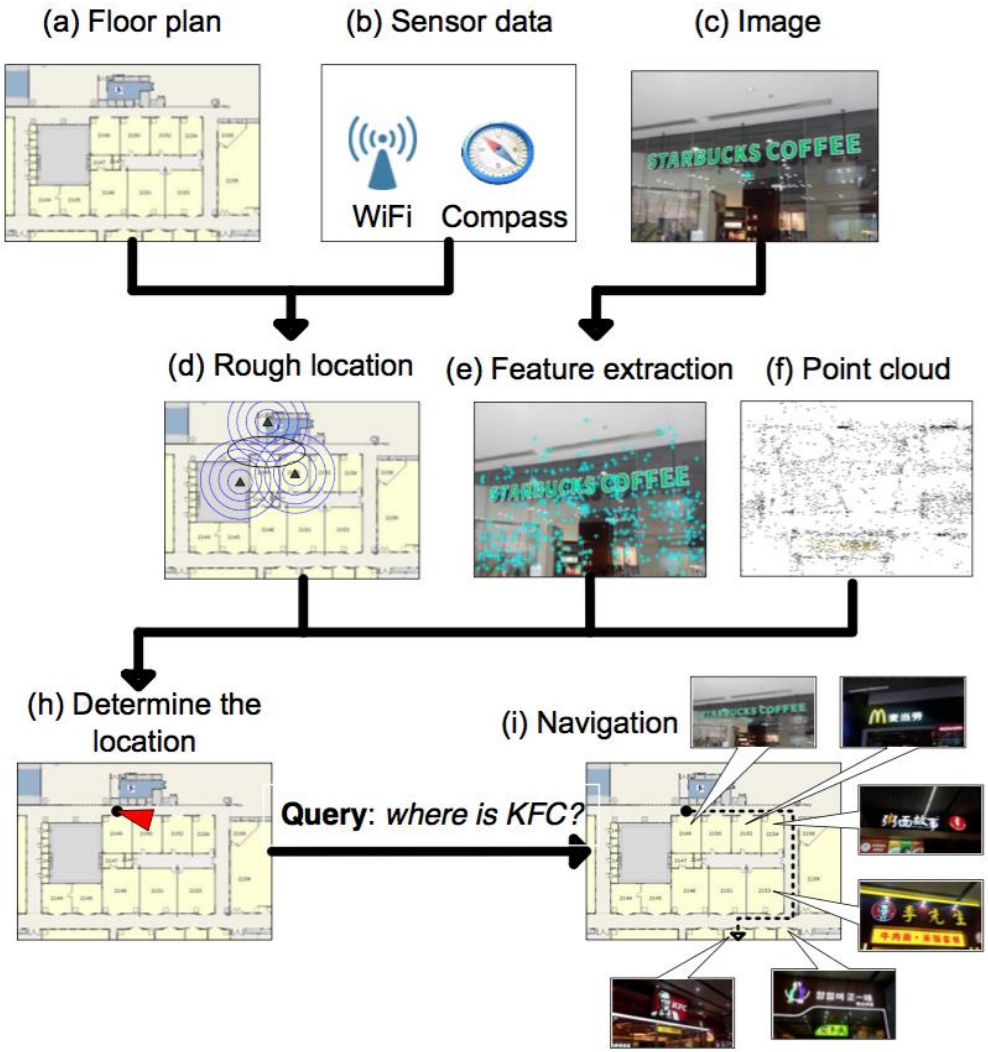


(a) Rays emit from camera centers (b) Intersections of Views

Estimate the Translation via

Finding the Intersection of Views.

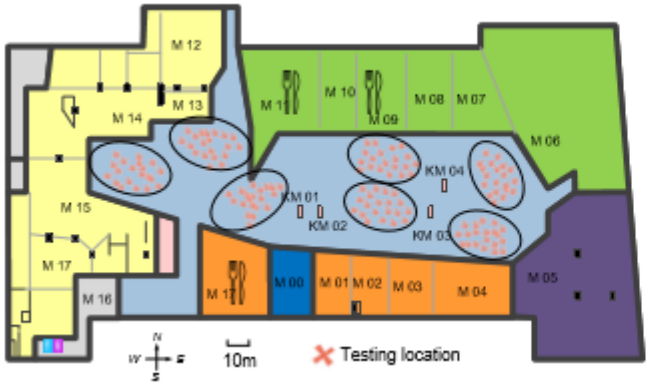
ClickLoc: Image-assisted Localization and Navigation

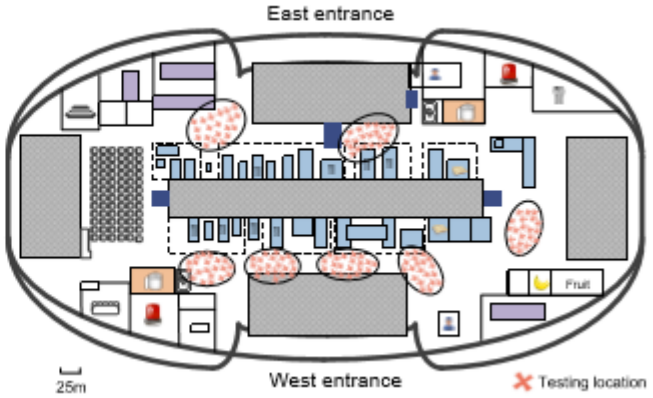


Experimental Setup

- Device:
  - Google Nexus 5 and Samsung Tablet 10.1
  - Operating in Android 4.4

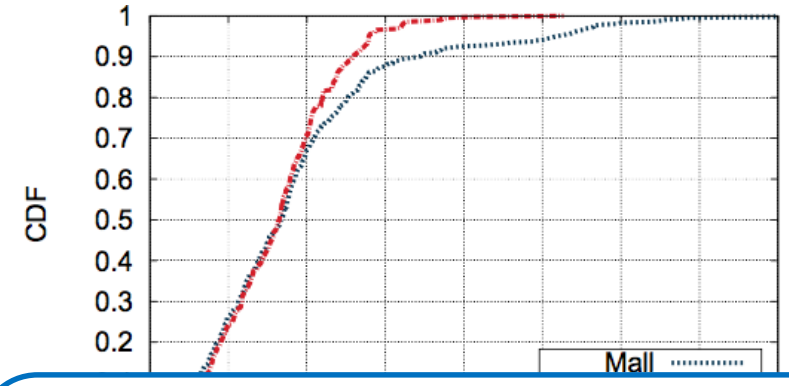
- Scenarios:
  - Shopping Mall and Railway Station
  - 40-120 photos per POI, in total more than 1200 photos
  - ClickLoc v.s. Argus, ClickLoc v.s. Travi-Navi

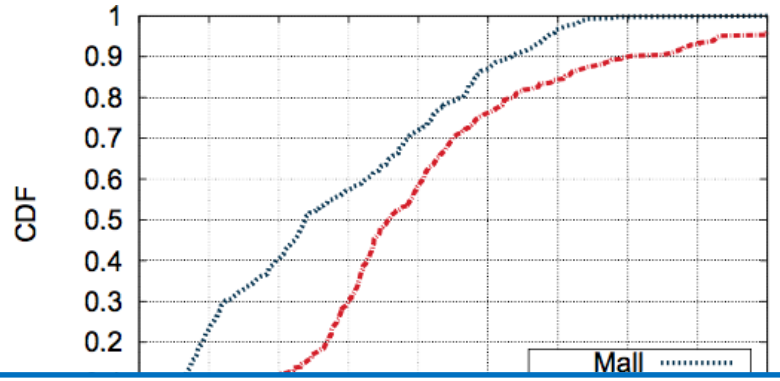




Overall Performance

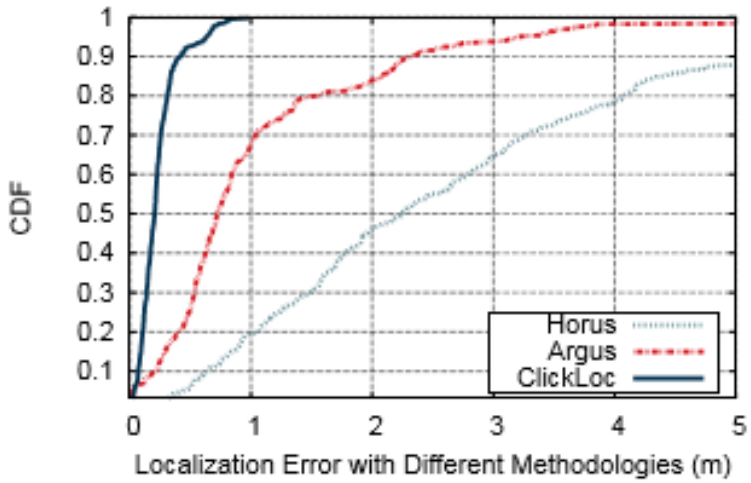
- 50-percentile error: 0.17m (POIs with Desired Properties) v.s. 0.7m (POIs without Desired Properties)
- 80-percentile error: 0.26m (POIs with Desired Properties) v.s. 1m (POIs without Desired Properties)



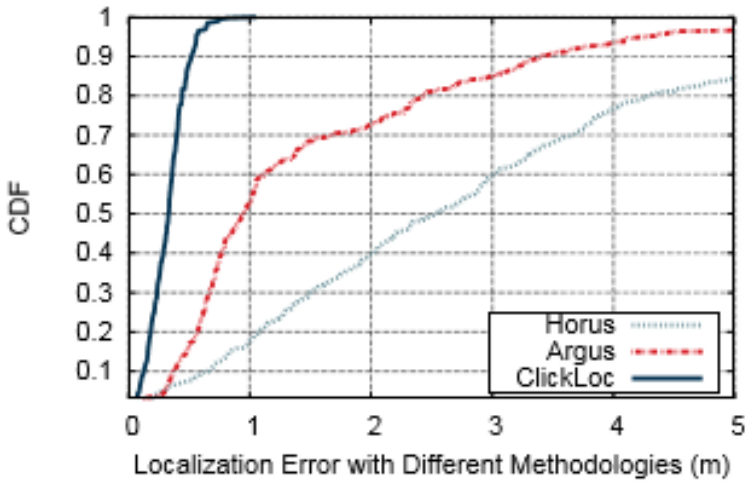


ClickLoc successfully provide
Sub-meter Level Accuracy.

ClickLoc v.s. Argus



(a) Mall*



(b) Plaza

ClickLoc improves Localization Accuracy by **an Order of Magnitude**.

室内定位4.0

时代	特点	典型系统
室内定位1.0（鸿蒙初辟）	专用设备、专用信号	ActiveBadge, Bat, Cricket, LANDMARC
室内定位2.0（一枝独秀）	以WiFi为代表的商用移动设备	RADAR, Horus, LiFS
室内定位3.0（欣欣向荣）	智能手机的多模态传感器数据	Luxapose, SurroundSense
室内定位4.0（返璞归真）	无线+计算机视觉	JIGSAW, Trivi-Navi, **ClickLoc**, **Argus**

4. Voice from Industry

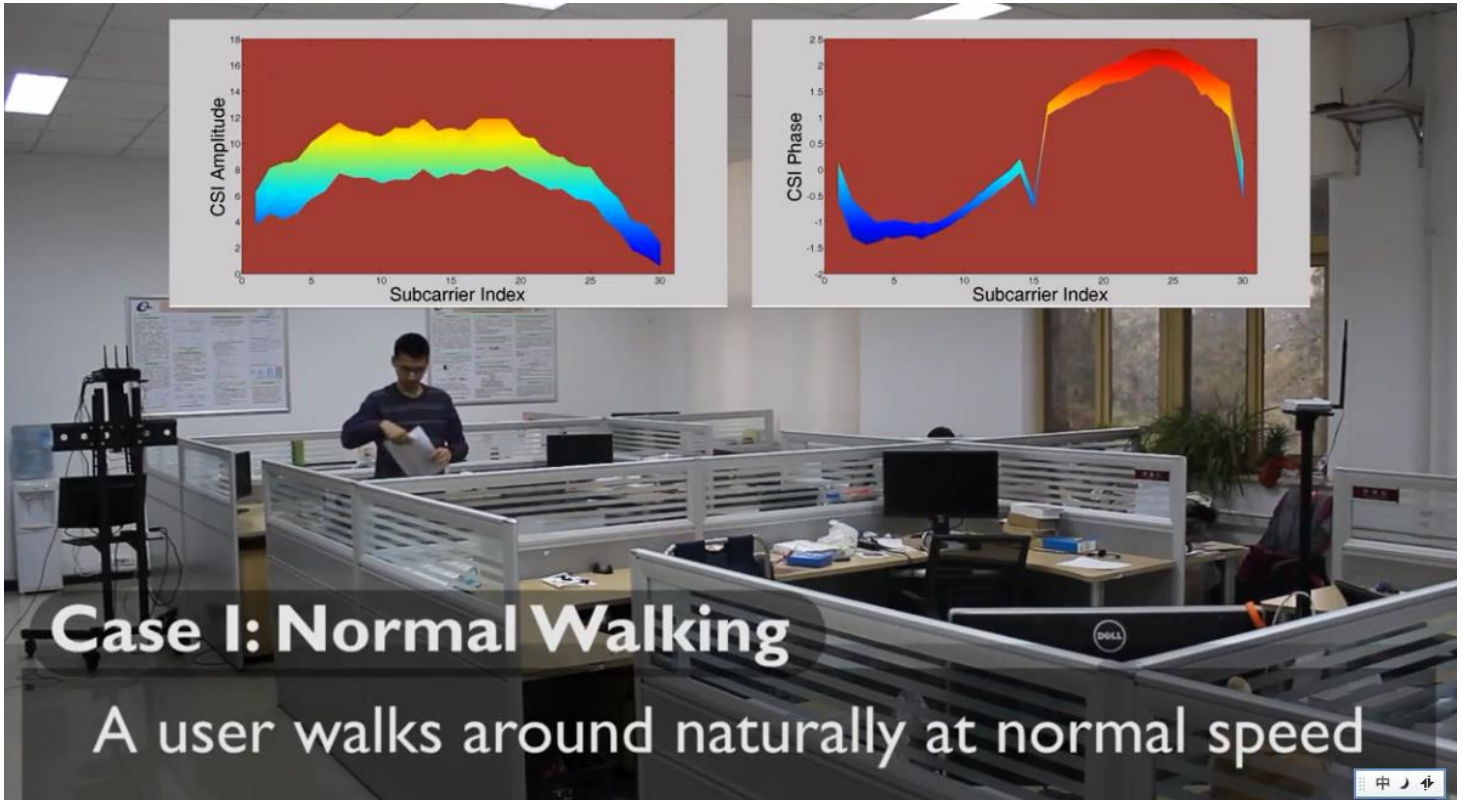
The Voice from the industry

5. Future Trends

定位技术发展趋势

- Positioning Accuracy
  - 我想要定的更准
- Location Context
  - 我想知道你在干什么
- Device-free (Passive) Localization
  - 我想定位“你”

被动式感知与定位：WiFi雷达



Youku：http://v.youku.com/v_show/id_XODQ4MTY3MjY0.html

Youtube: http://youtu.be/As5JexOeOYY

WiFi Radar： http://tns.thss.tsinghua.edu.cn/wifiradar/

6. Conclusion

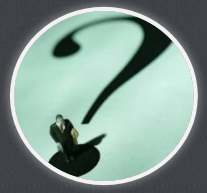
LOCATION

A long way to go..









Localization is a 5A service (Anyone, Anytime, Anywhere, Anyway, Anything).

GPS dominates outdoor positioning. IPS consists of a wide variety of technologies.

Due to WiFi's worldwide deployment, WiFi-based positioning becomes increasingly popular.

"Computer Vision + WiFi" has promising future as the next generation indoor positioning technology.

我听说过一个故事.....

在通讯和定位还不发达的时代，一个年轻女人只身坐火车来到北京与经人介绍的未婚夫见面，两人约在了火车站前的广场。不幸的是，女人等了好几天也没有等到男人，为了维持生计就在火车站前开了个小卖部，一边卖东西一边等。男人失望地没等到女人，想尽一切办法也联系不上女人，最后独自寻到女人老家，可女人在老家也没什么亲人。六年后，男人出差返京错误地在北京前一站丰台就下了火车，正寻思怎么回去，走到一个小卖部买烟。“要火吗？”女人的一句话让对视的两人错愕。

使用定位技术，不再让错过变成过错，不再让空间上的迷失造成心灵上的迷失。这也是我心中定位技术不断发展的驱动力之一。

Reference

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- Zheng Yang, et al., "Mobility Increases Localizability: A Survey on Wireless Indoor Localization using Inertial Sensors", ACM Computing Surveys, Volume 47, Issue 3, Article No. 54, 2015.
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- Chenshu Wu, Zheng Yang, Yunhao Liu, Smartphones based Crowdsourcing for Indoor Localization, IEEE Transactions on Mobile Computing (TMC), Volume 14, Issue 2, 444 – 457, February 2015.
- 杨铮、吴陈沭、刘云浩，《位置计算：无线网络定位与可定位性》，清华大学出版社，2014

我的微信

我的微博

Thanks!

Q&A

欢迎大家交朋友！交流中知不足，交流中进步，交流中创新！

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