Growing an Organic Indoor Location System

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CSAIL
MIT COMPUTER SCIENCE AND ARTIFICIAL INTELLIGENCE LABORATORY
Nokia Research Center

Applications of Location Information

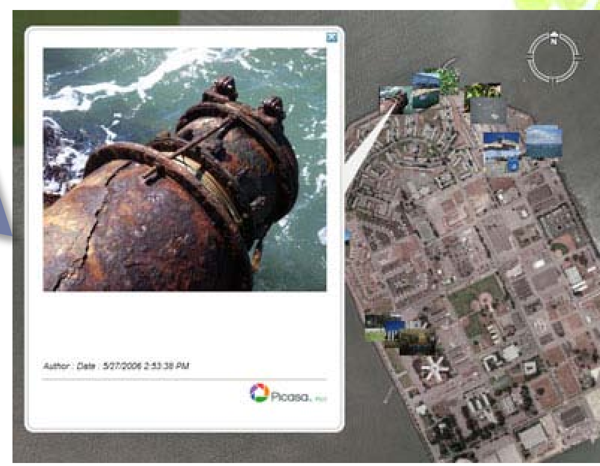
Location-based recommendation

yelp

Location information

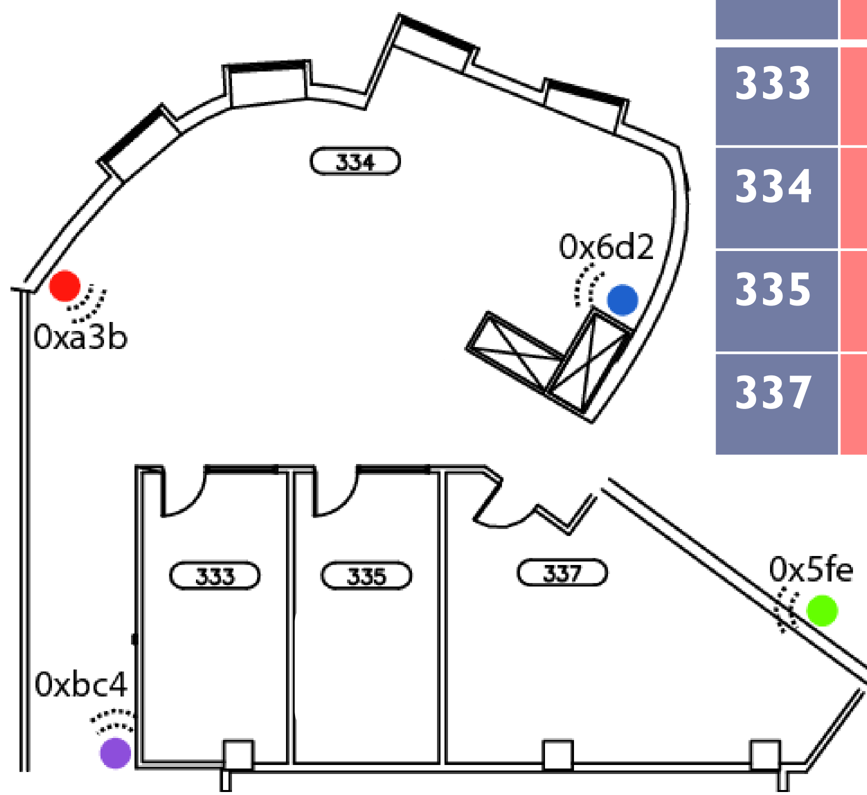
Friend-finding

Geotagging



WiFi Localization: Survey Phase

- Survey environment to build WiFi fingerprint database



Signal strength

	0xa3b	0x5fe	0xbc4	0x6d2
333				
334				
335				
337				

WiFi Localization: Survey Phase

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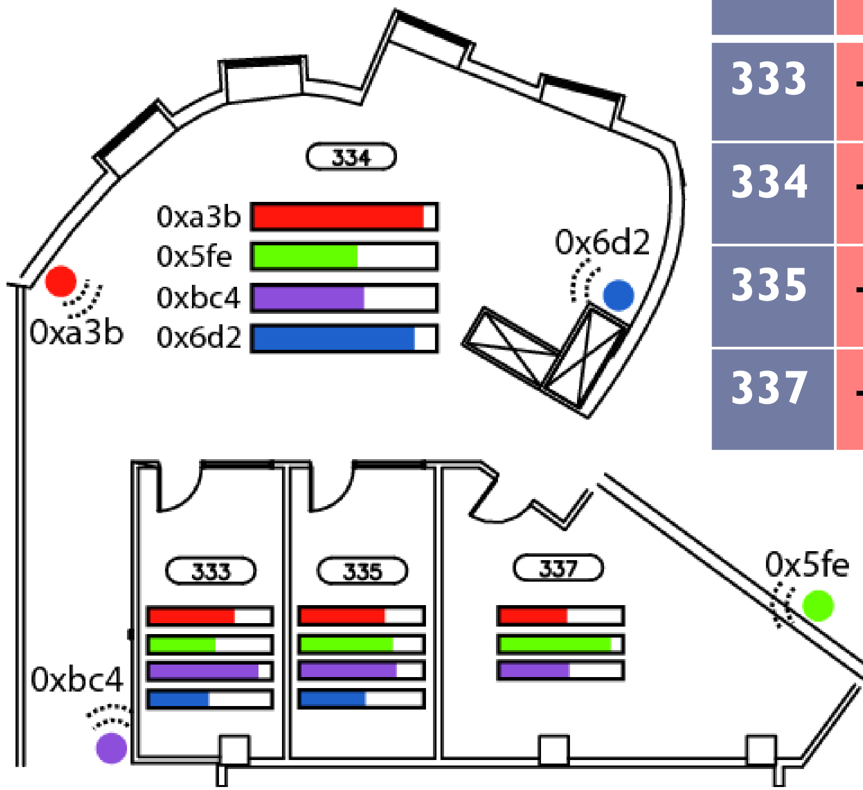
Expert surveyor



Signal strength (dBm)

	0xa3b	0x5fe	0xbc4	0x6d2
333	-55	-82	-39	-85
334	-30	-65	-63	-45
335	-60	-55	-50	-73
337	-72	-31	-73	N/A

WiFi Localization: Positioning Phase

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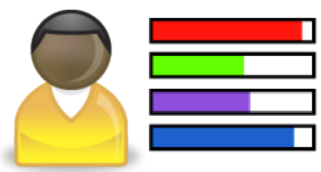
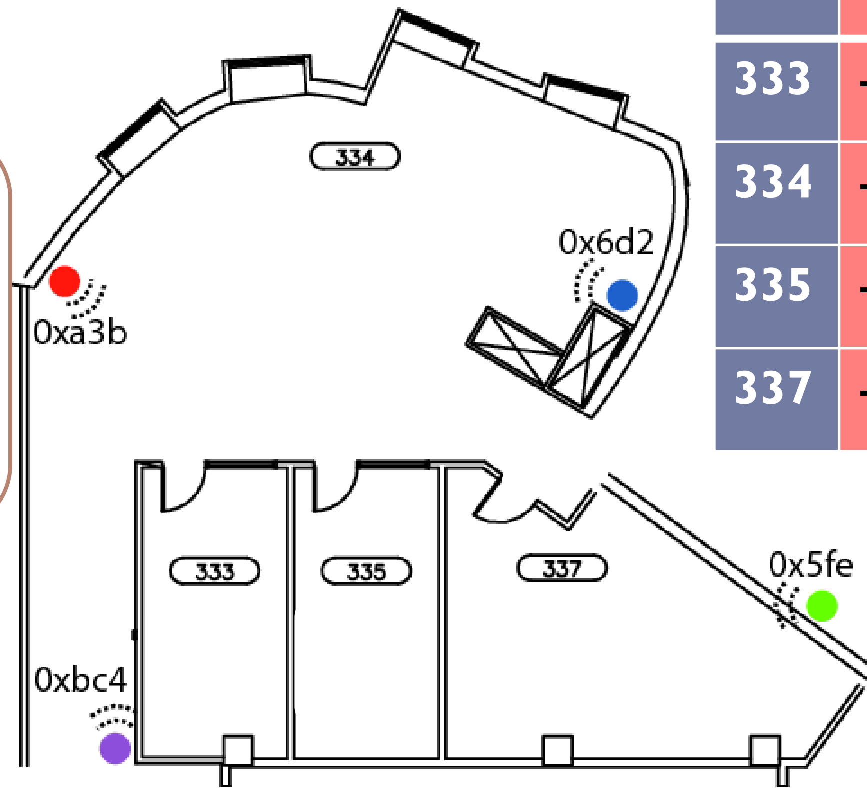


(-31, -66,-60,-40) dBm

“Where am I?”



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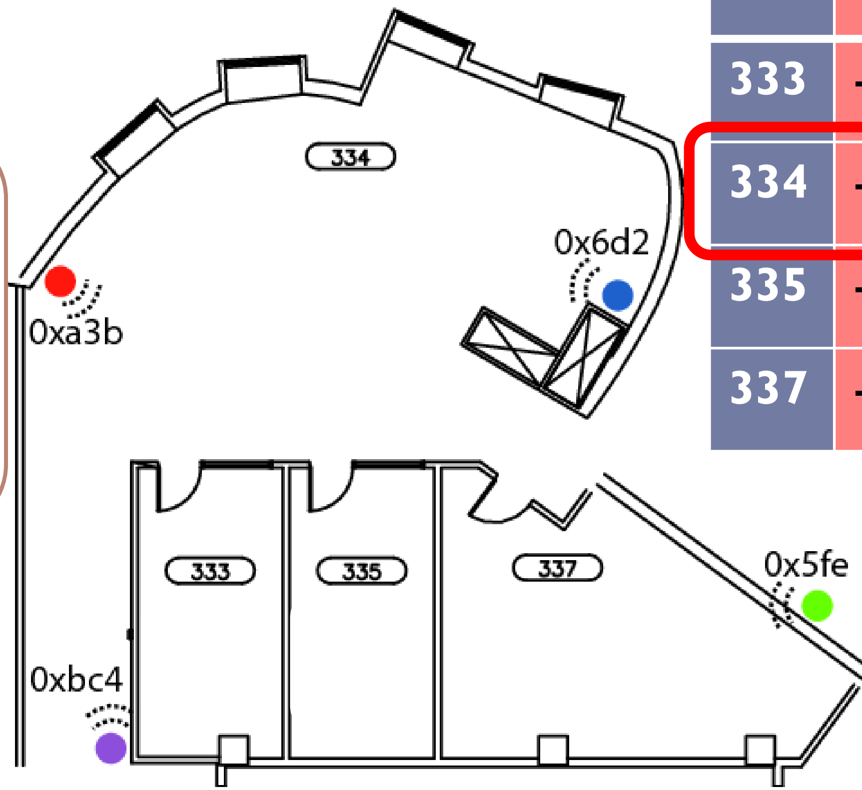
WiFi Localization: Positioning Phase

- Survey environment to build WiFi fingerprint database

(-31, -66,-60,-40) dBm
"Room 334"



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Organic Indoor Localization: Motivation

- Who makes the location fingerprints?
  - Survey requires skilled technicians.
  - Survey is expensive and labor-intensive.
  - "I don't want strangers in my room."
  - Surveyed data may become outdated.

Organic Indoor Localization: Motivation

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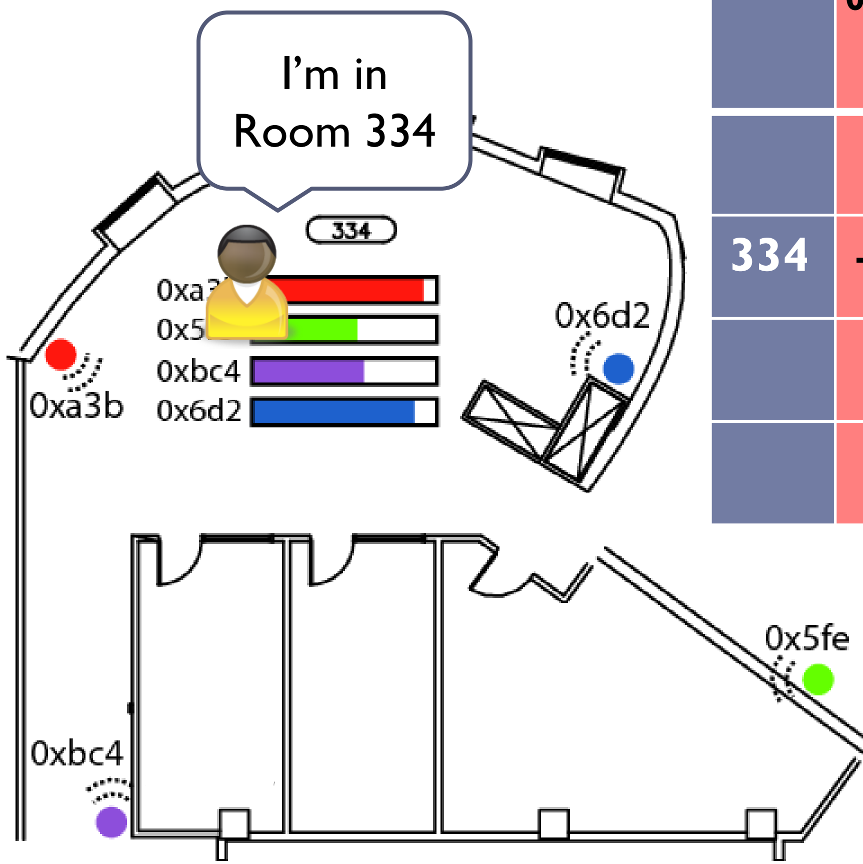
- Our approach
  - Have users collect survey data
  - System facilitates sharing on-line.

- User-generated, or *organic* localization system

Organic Indoor Localization



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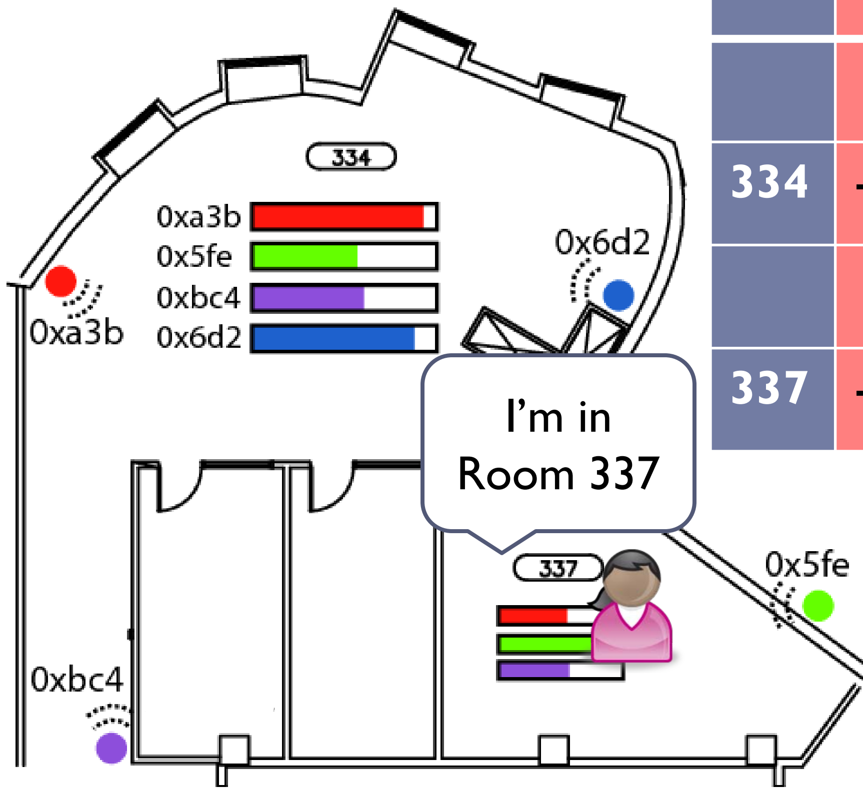

Signal strength (dBm)

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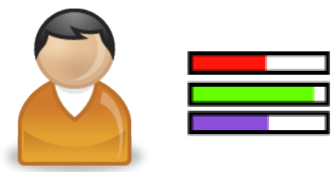
Organic Indoor Localization



(-75, -30,-70,N/A) dBm
"Room 337"

- ~5 meter avg. distance error
- Wikipedia-like Pareto principle in user-contribution

Signal strength (dBm)

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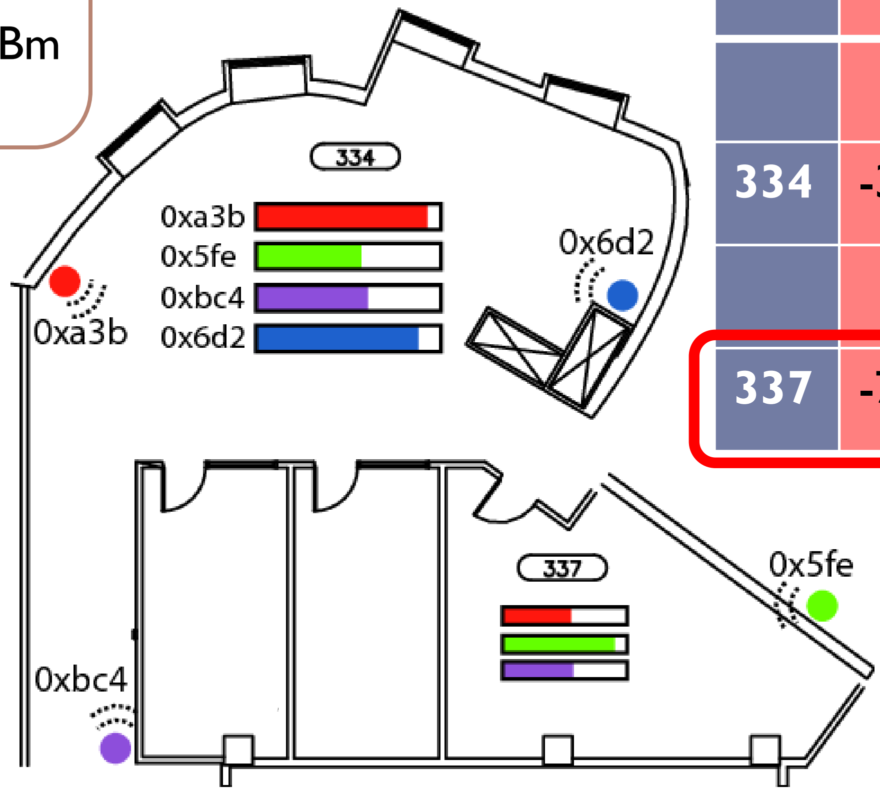
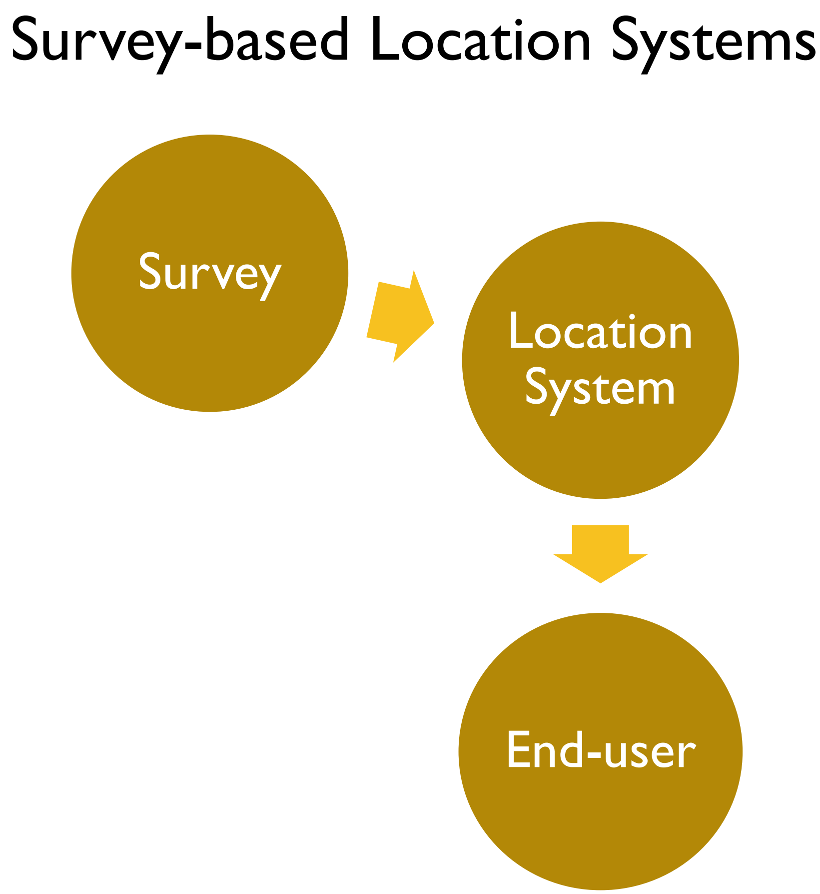
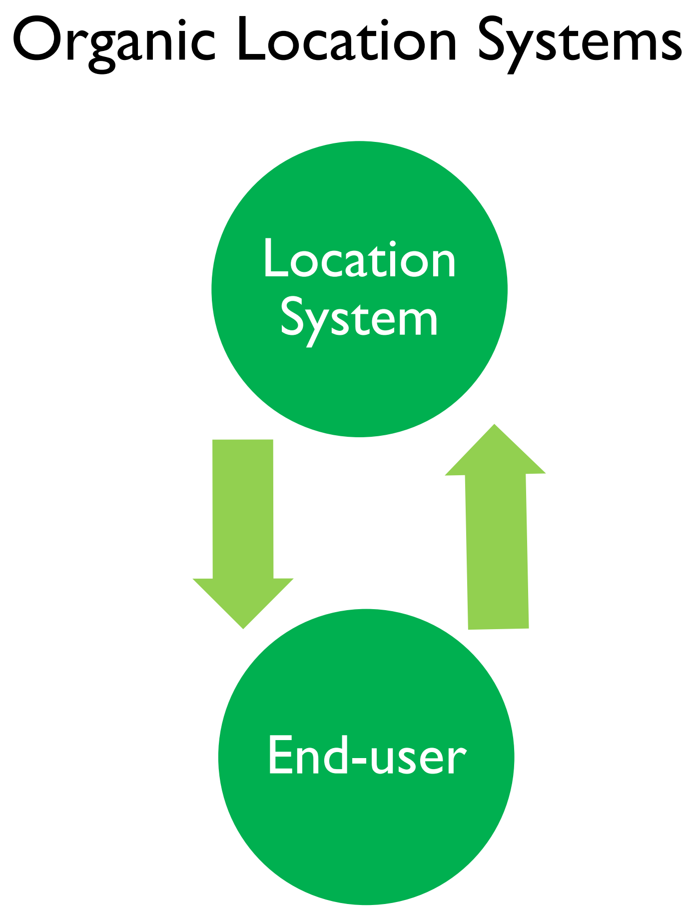


See e.g.: Teller et. al., *Organic Indoor Location Discovery*, Griswold et. al., *ActiveCampus*, Boliger et. al., *Redpin*, Barry et. al., *Long-duration study of user-trained 802.11 localization*

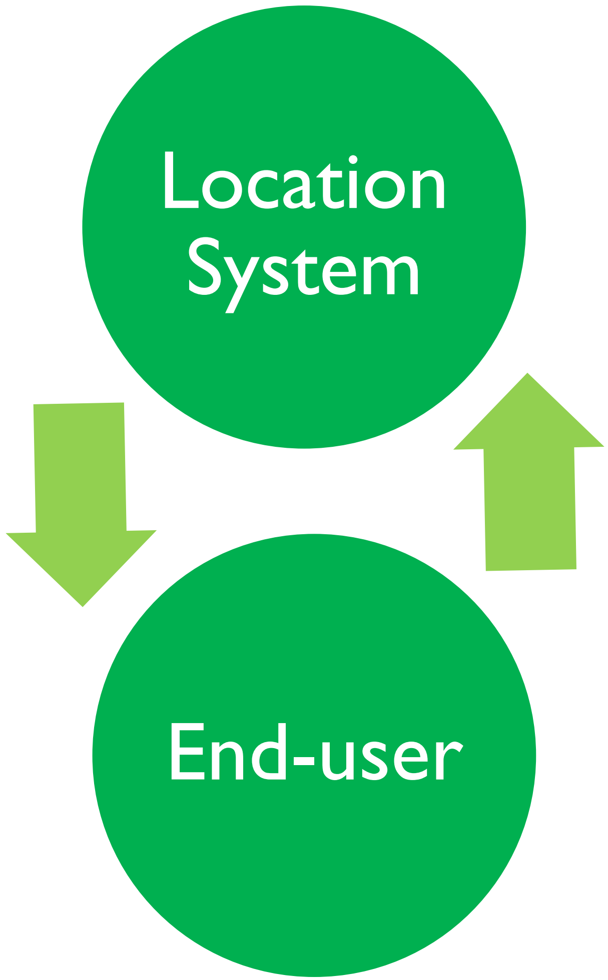
Organic Indoor Location System





Growing an Organic Indoor Location System

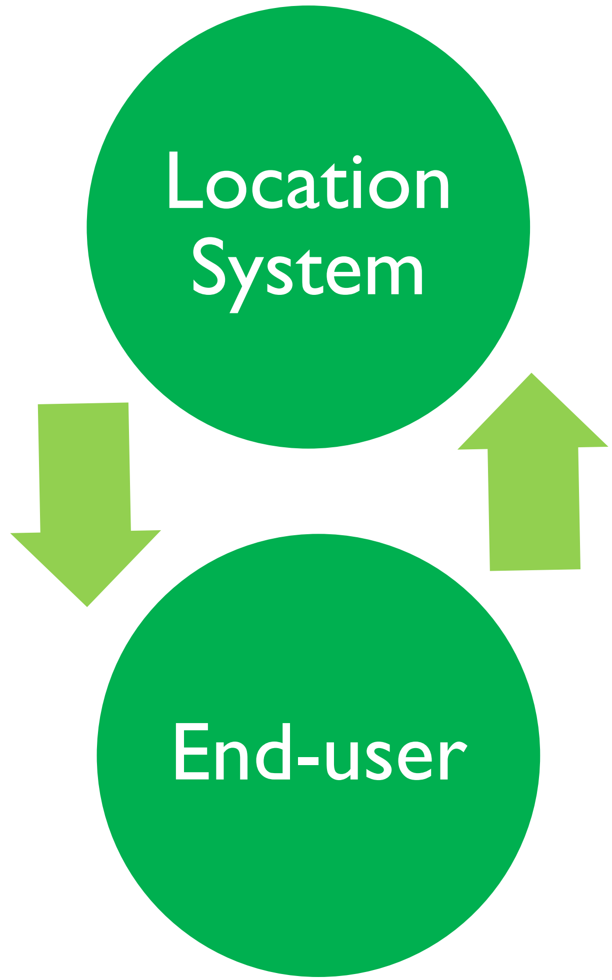
Facilitating organic growth
of location database



Weeding out
erroneous user-inputs

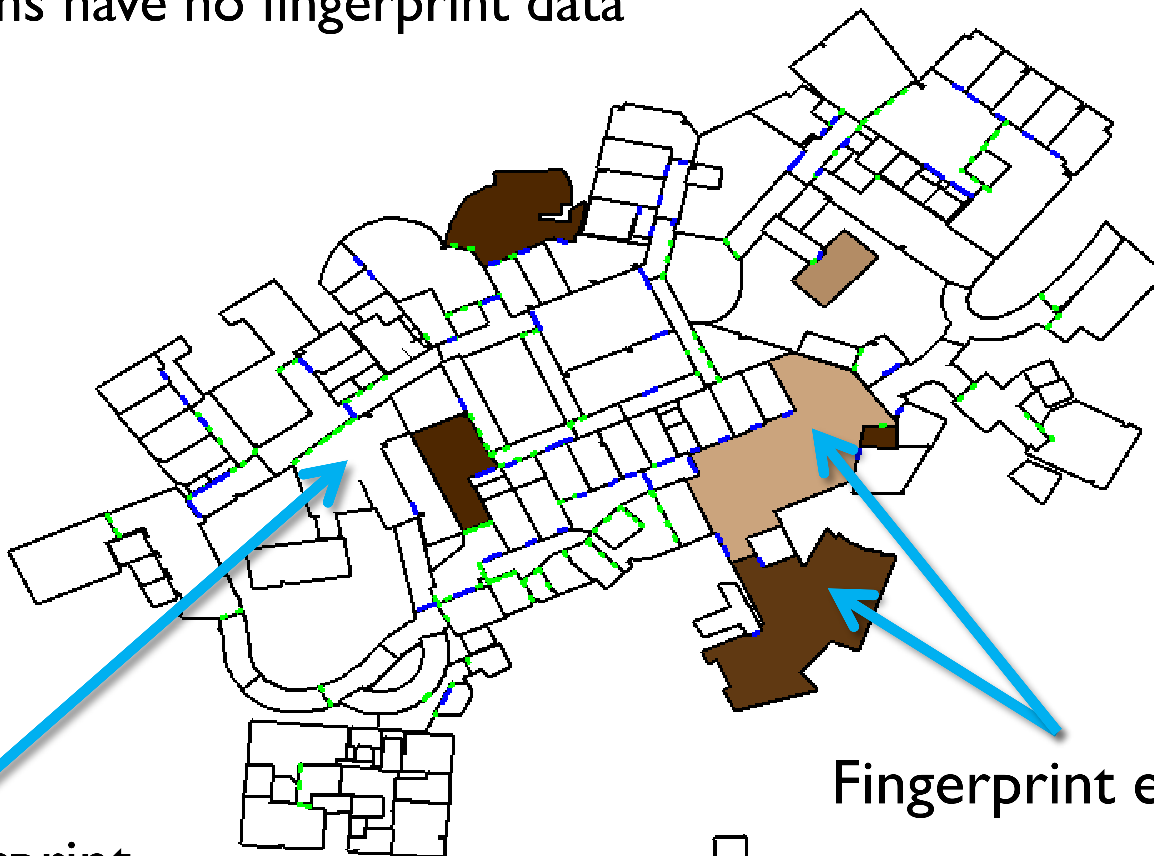
Growing an Organic Indoor Location System

Facilitating organic growth of location database



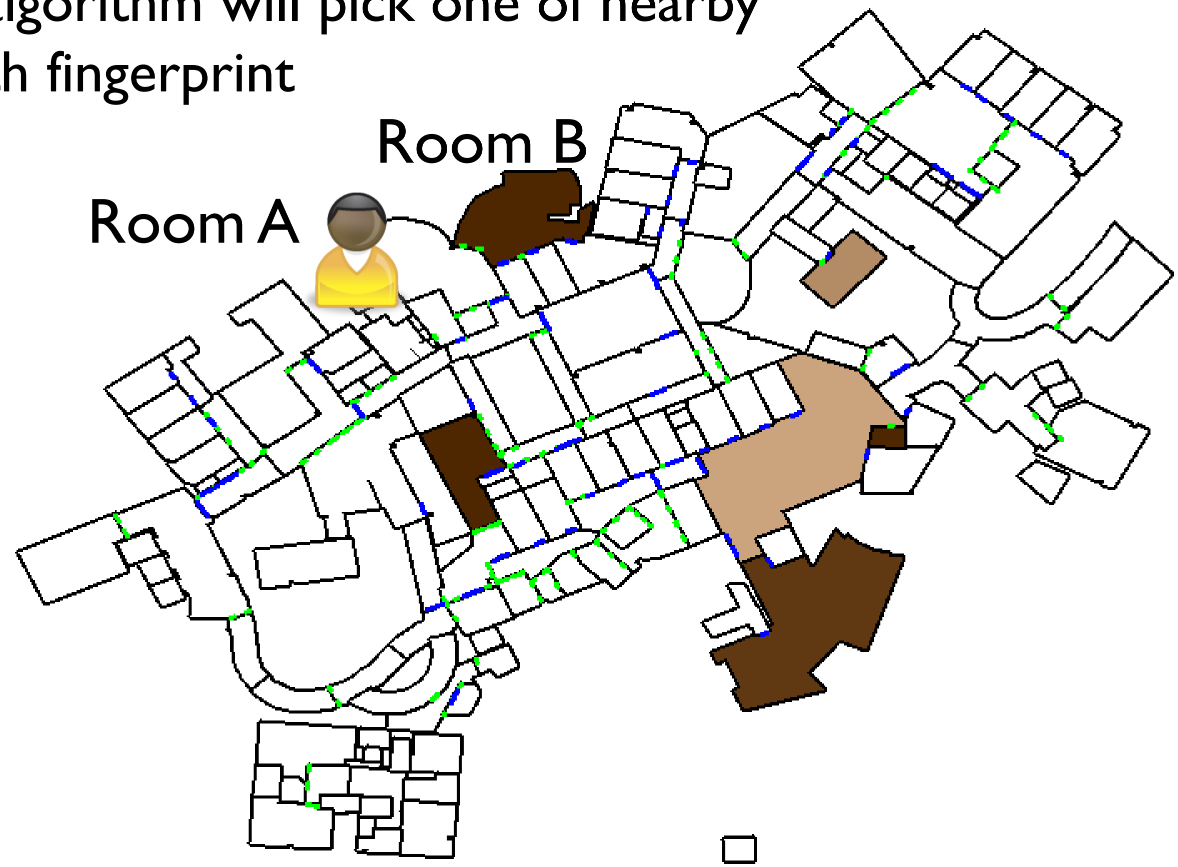
Conveying Spatial Uncertainty to Users

- At early stage of organic localization, some locations have no fingerprint data



Conveying Spatial Uncertainty to Users

- If a user is in a location without fingerprint, localization algorithm will pick one of nearby locations with fingerprint



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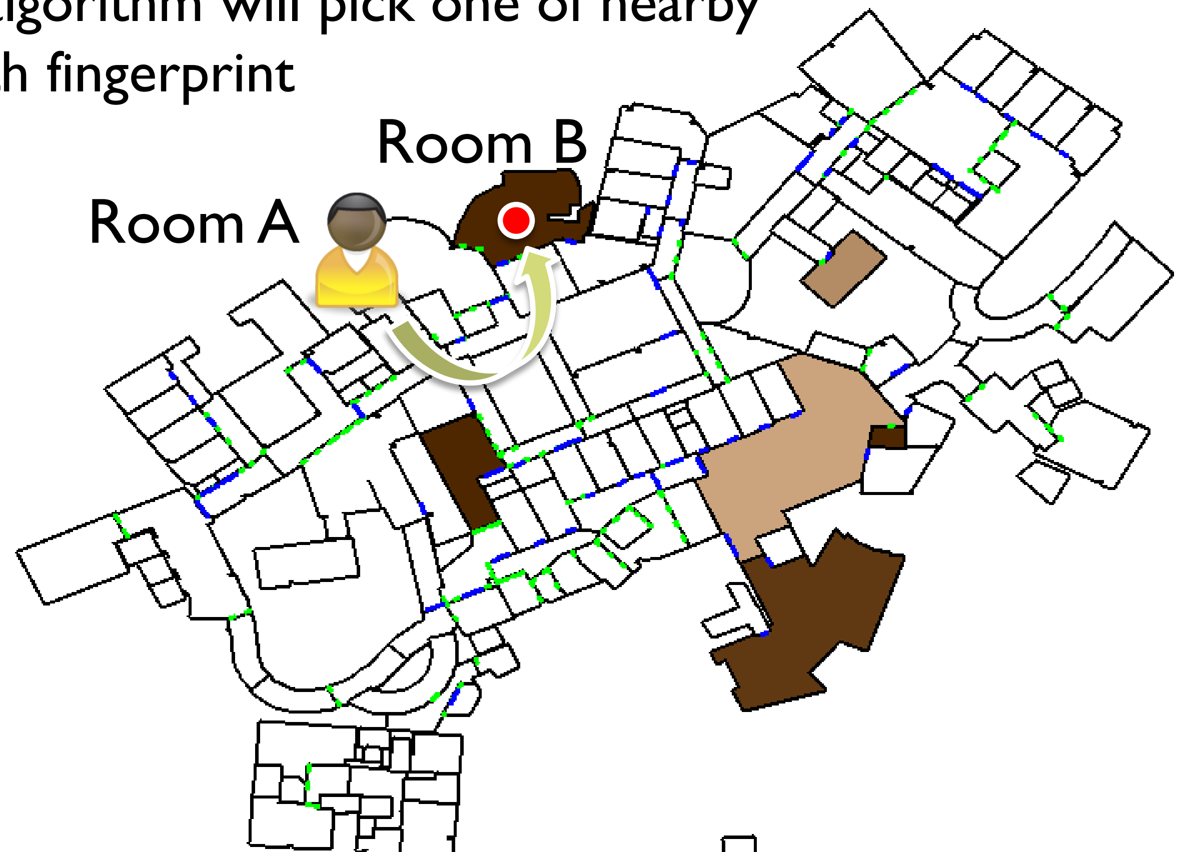
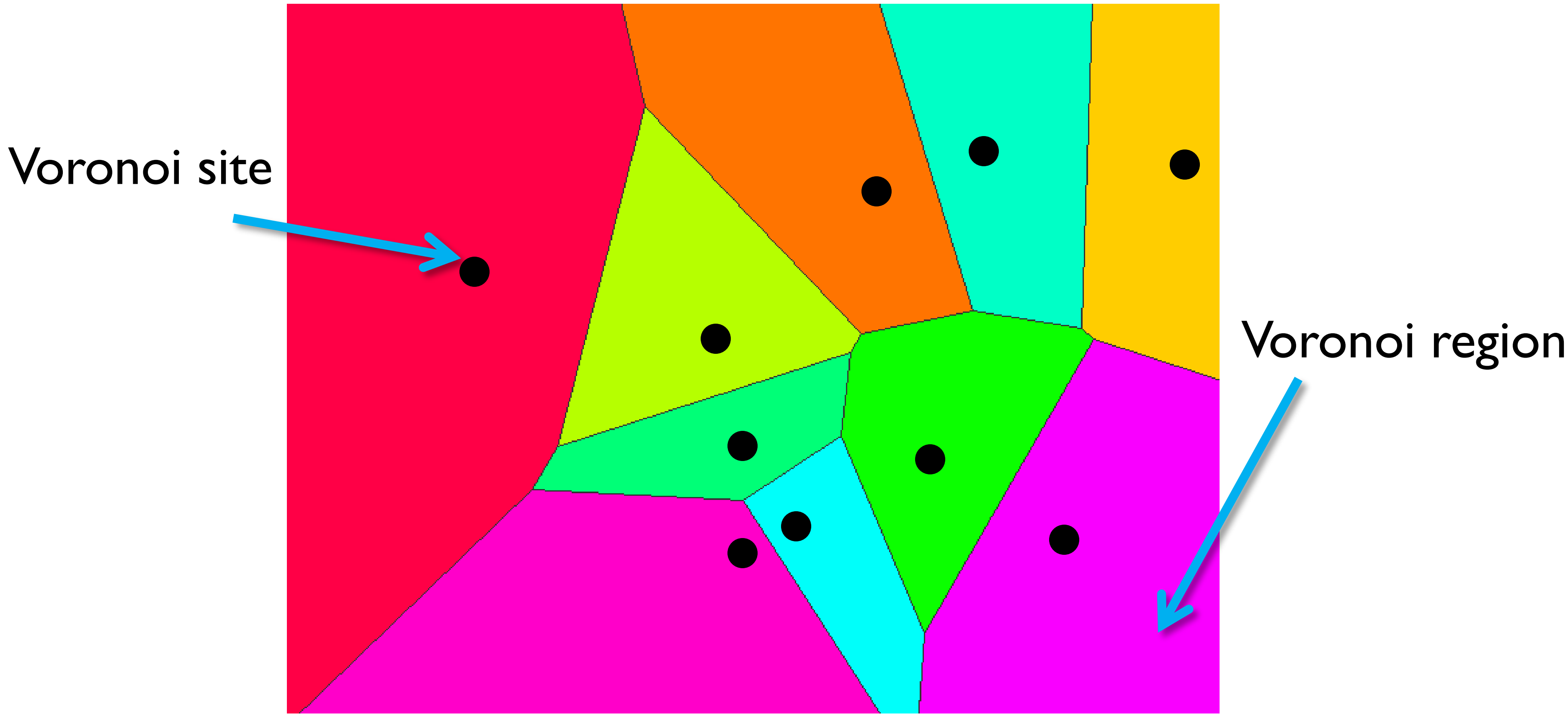
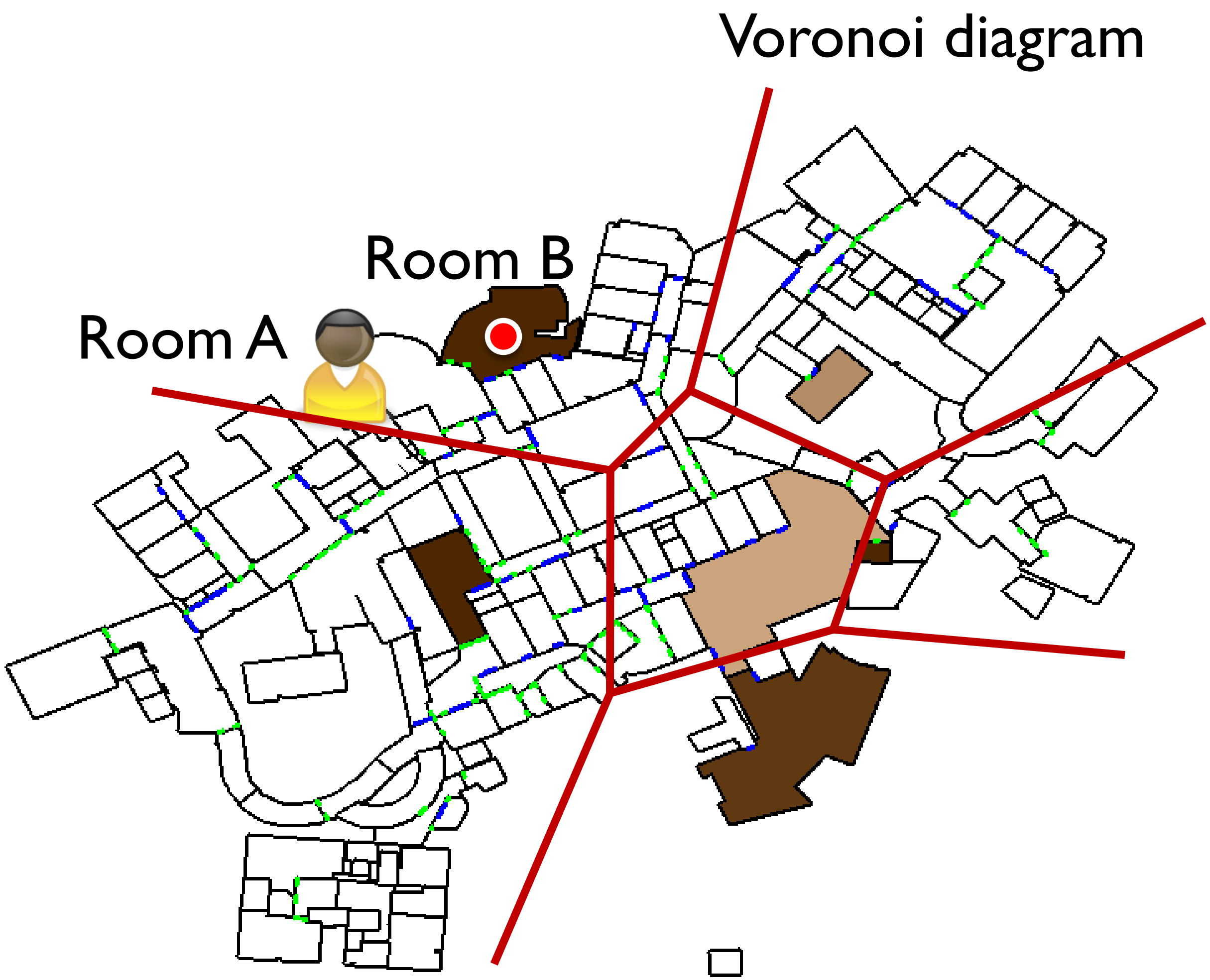


Voronoi Diagrams

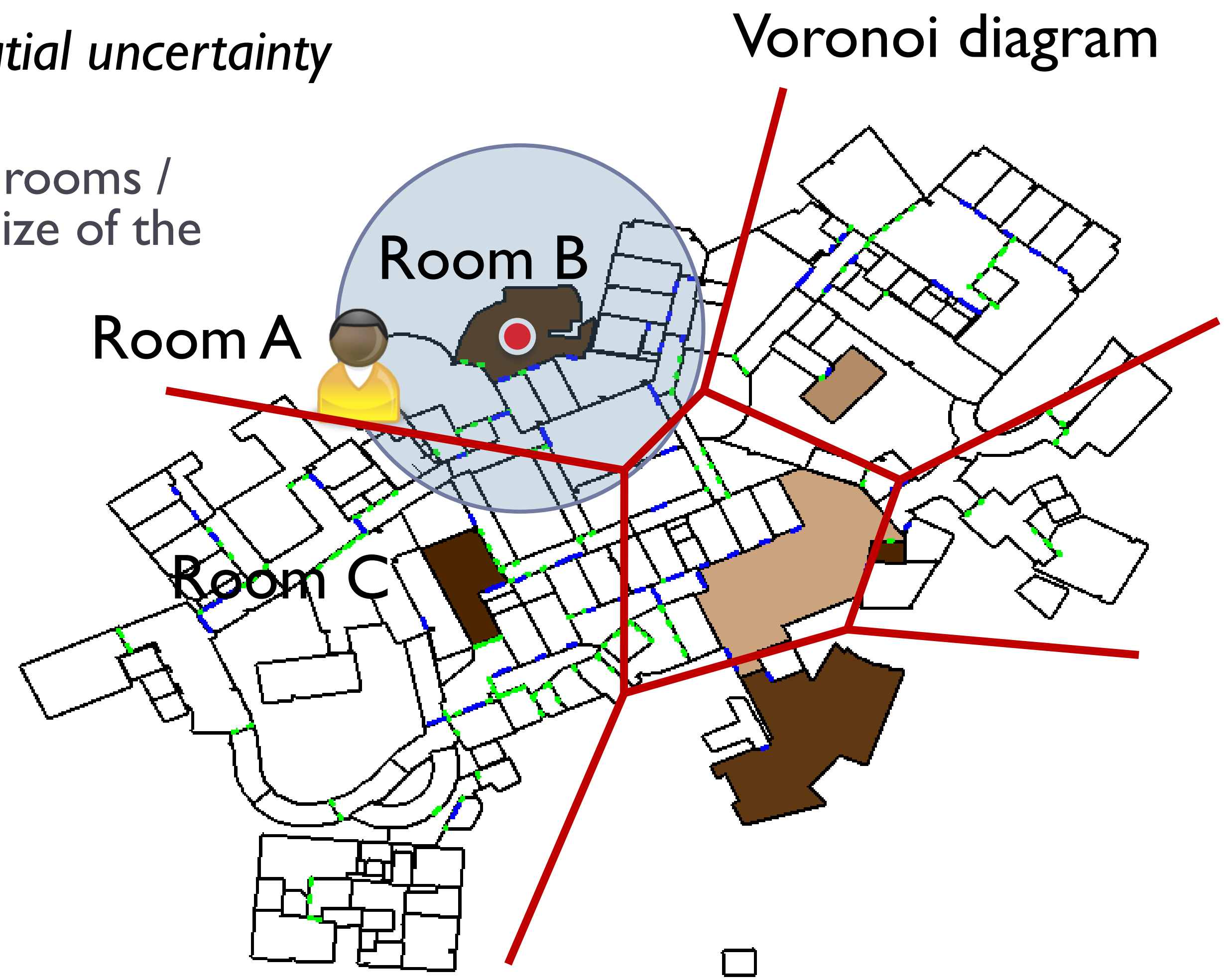


Voronoi Diagrams for Conveying Spatial Uncertainty to Users



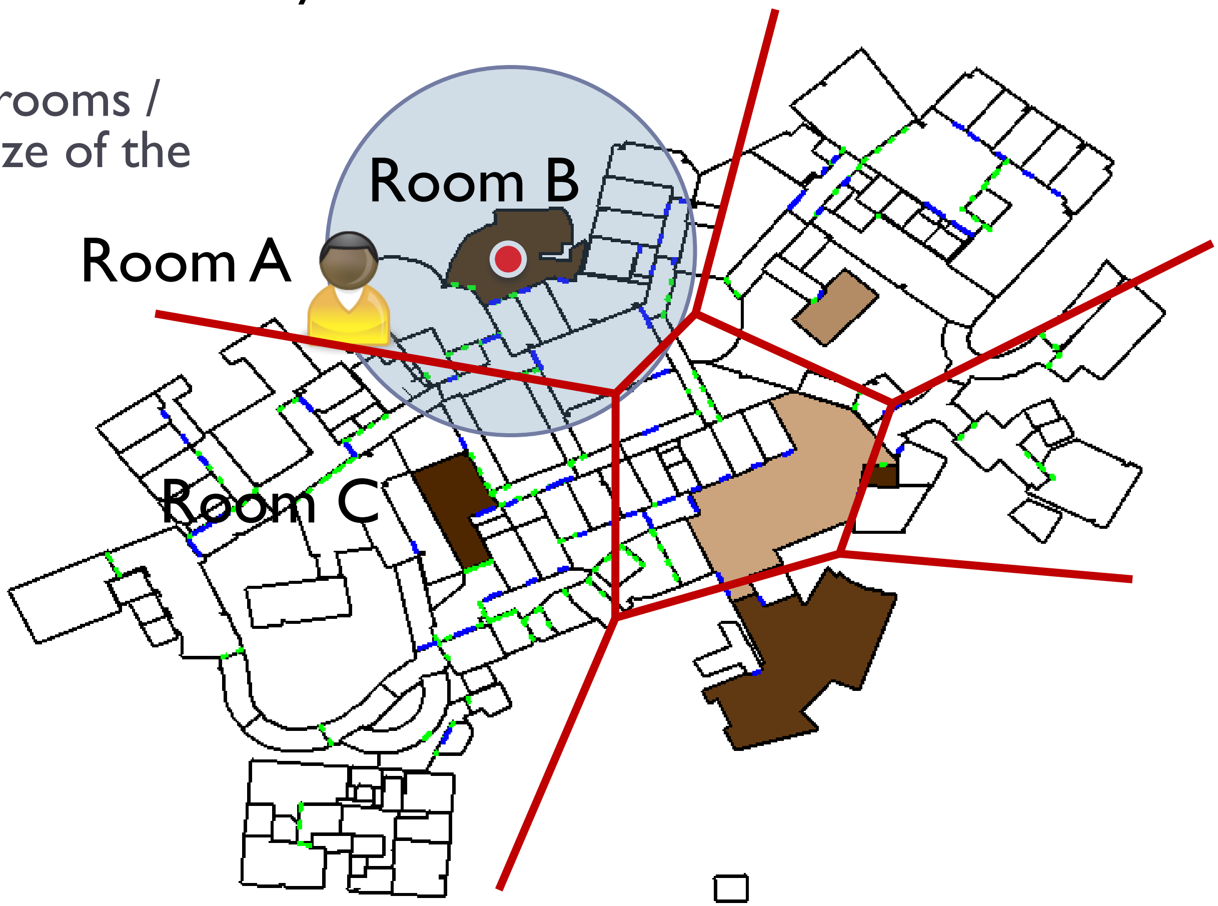
Voronoi Diagrams for Conveying Spatial Uncertainty to Users

- Can derive *spatial uncertainty* metrics:
  - Number of rooms / geometric size of the region



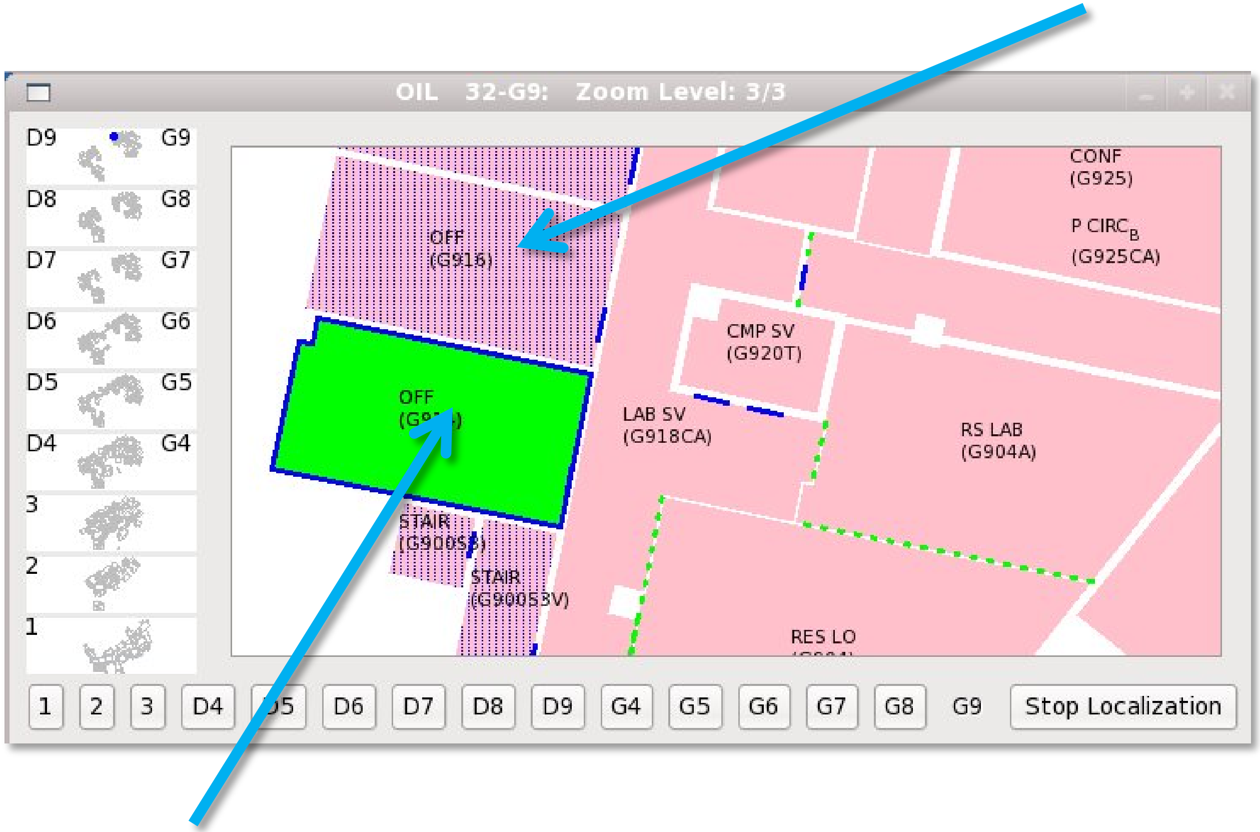
Voronoi Diagrams for Conveying Spatial Uncertainty to Users

- Can derive *spatial uncertainty* metrics:
  - Number of rooms / geometric size of the region
- Users get graphical feedback on system's uncertainty arising from organic growth of location database



GUI Implementation

Voronoi region



Location estimate

Spatial-Uncertainty-Based User Prompting

- Prompt user for location input if spatial uncertainty is too high (large Voronoi region)
  - Many nearby rooms have no fingerprint data

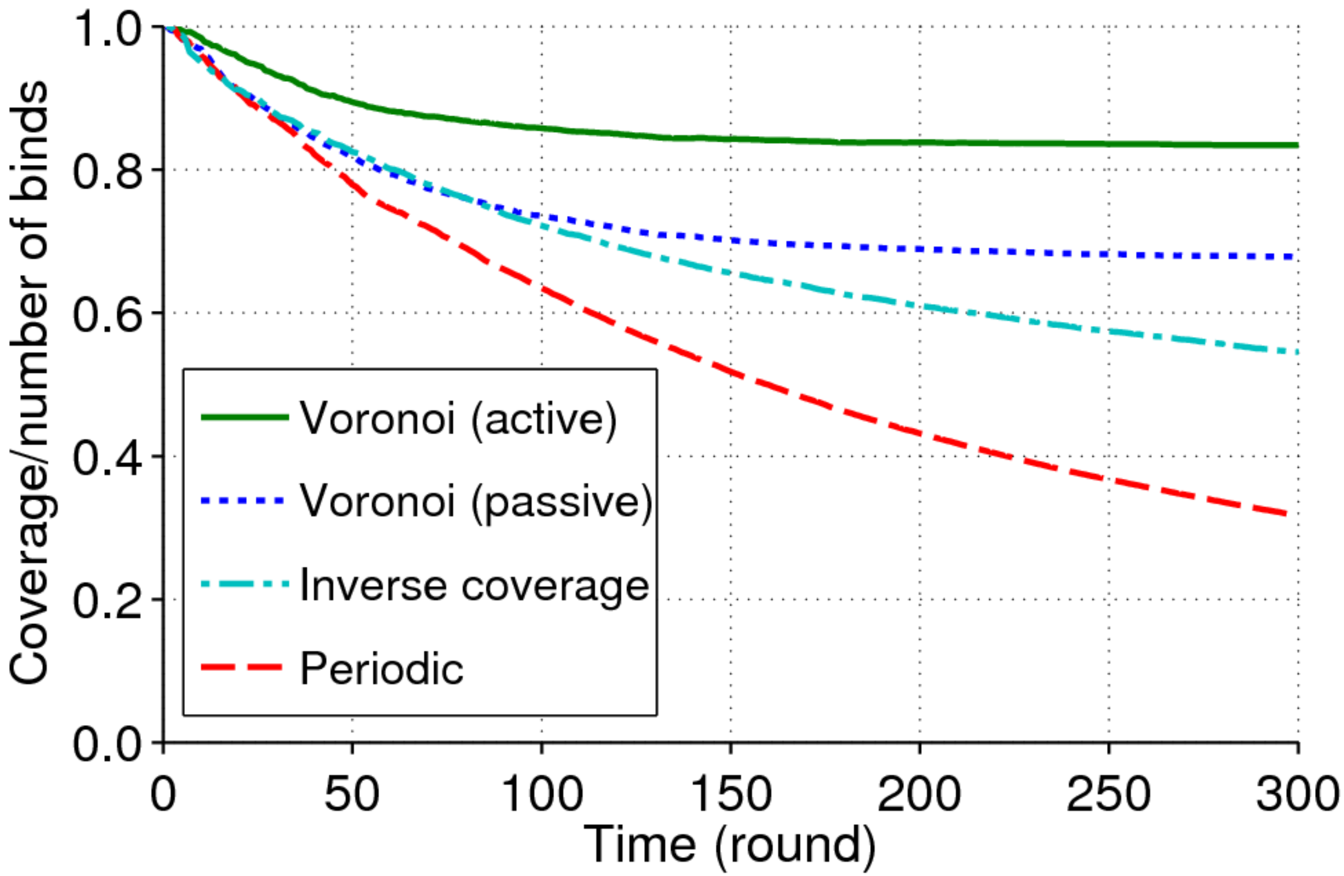
- Other methods for acquiring user input
  - Prompting when localization estimate is unstable
  - Voluntary user contribution

- Users can postpone or turn off prompting

Voronoi Evaluation: Setup

- Compared Voronoi-based user prompting to other basic methods
  - Quantitative analysis by simulation
- Real-world user testing
  - Qualitative analysis by interviewing users

Voronoi Evaluation (1)



Voronoi Evaluation (2)

- Responses from top contributors:
  - "Prompts were the main reason that I made so many binds."
  - "Voronoi regions were useful for quickly locating the room that I was in as well as assessing how well the tablet knew my current location."
  - "Prompting mechanism had no effect on my behavior."

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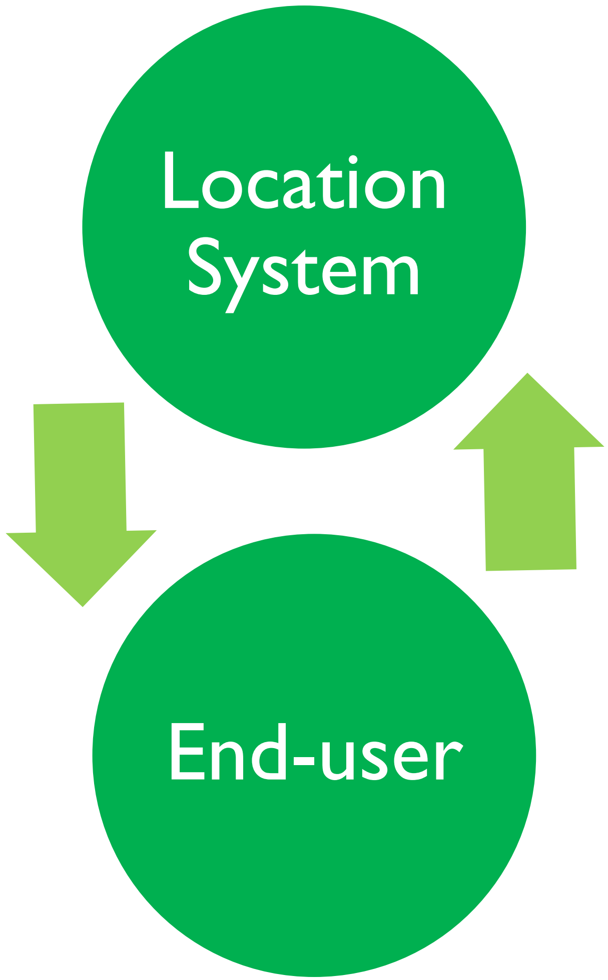
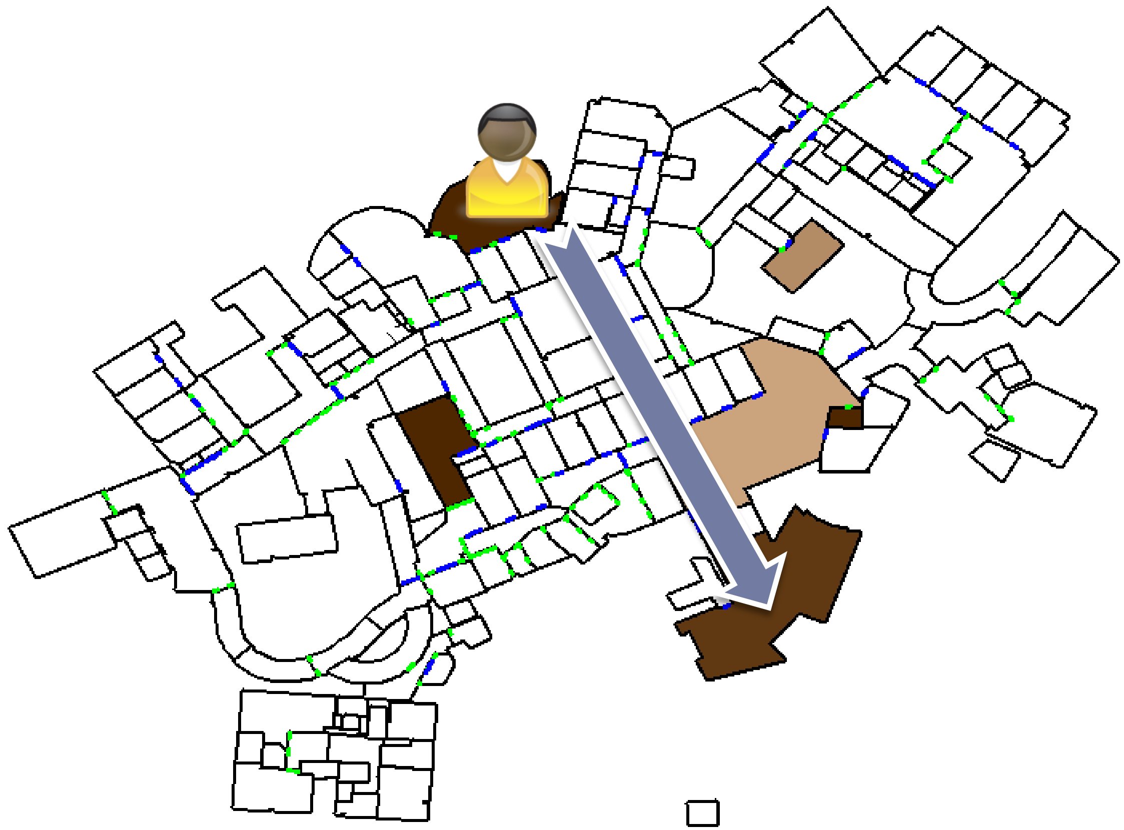


Weeding out
erroneous user-inputs

Erroneous User Input Filtering: Problem Statement

- Erroneous user inputs result in localization error



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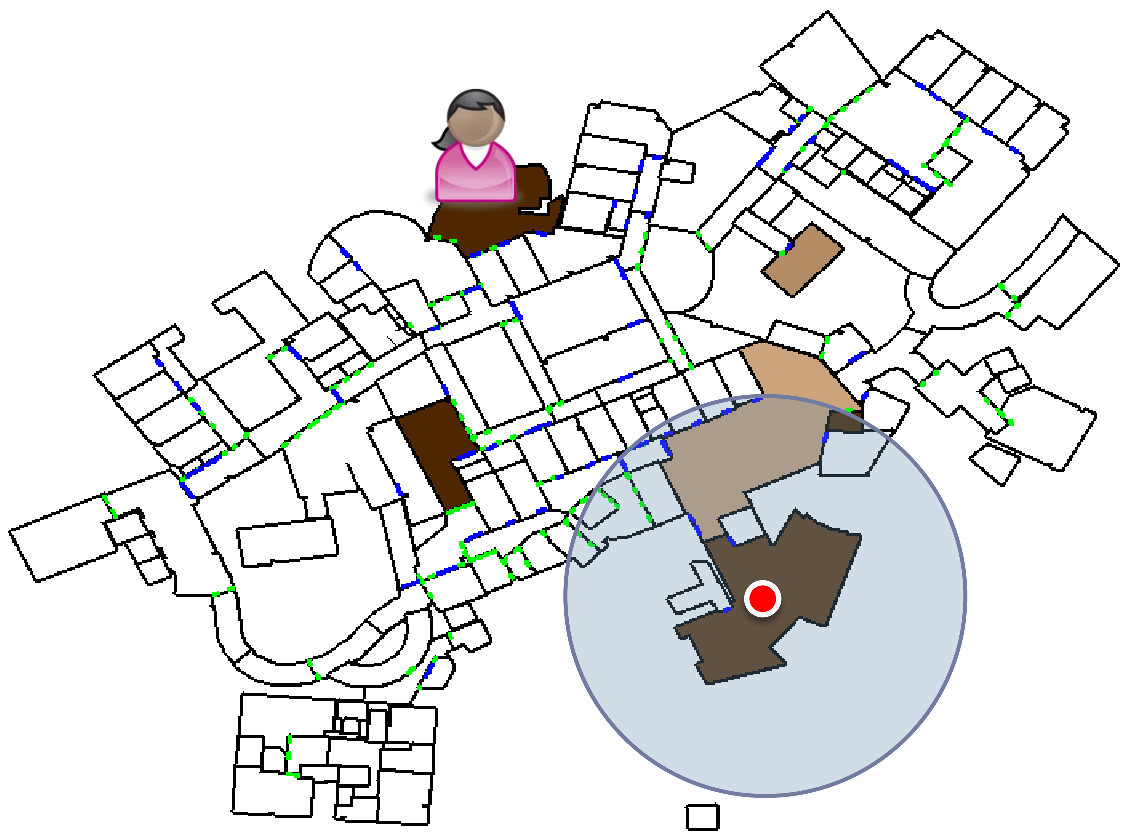

Erroneous User Input Filtering

- Common approaches for outlier detection…
  - Density estimation
  - Clustering + majority vote
- … are not suitable for organic location systems. Why?
  - Organic systems have no data at start

Erroneous User Input Filtering

- Common approaches for outlier detection…
  - Density estimation
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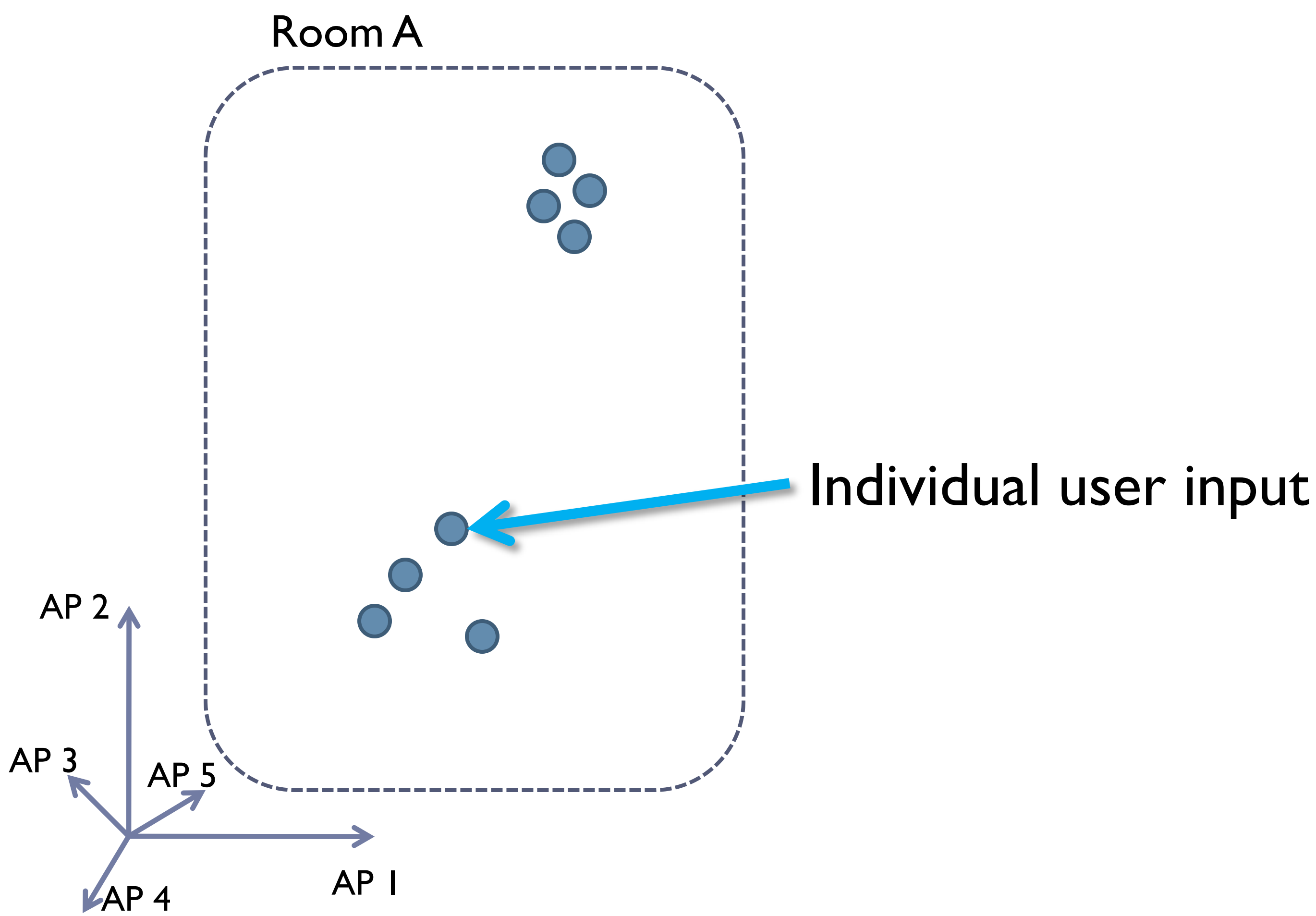
- … are not suitable for organic location systems. Why?
  - Organic systems have no data at start
- Our idea: instead of checking validity directly, check for *consistency*
  - WiFi scans from nearby locations tend to be similar
  - Given a set of scans from a single location, choose the most consistent subset w.r.t. physically adjacent locations

Erroneous User Input Filtering

- Step 1: Hierarchical clustering



Erroneous User Input Filtering

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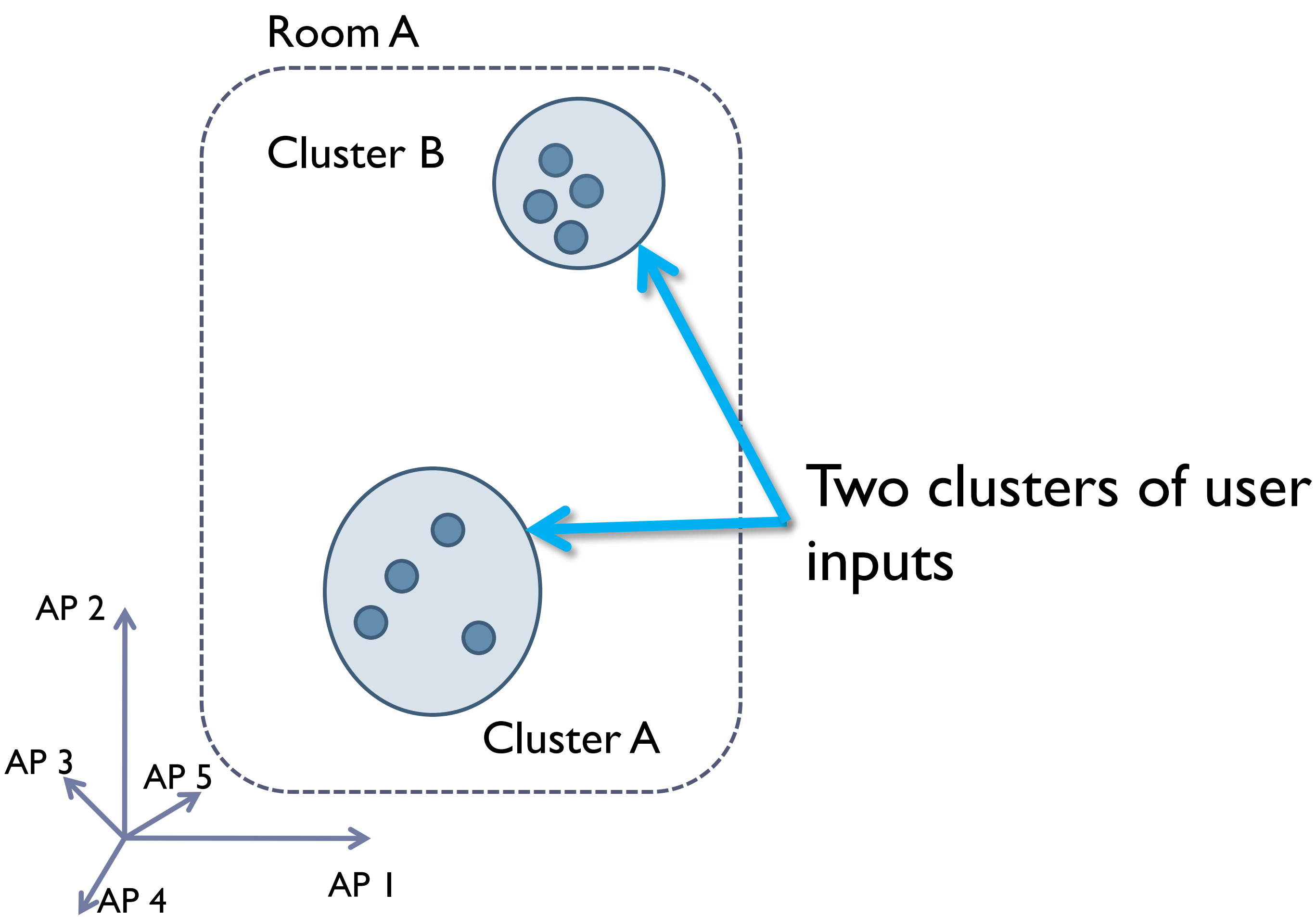
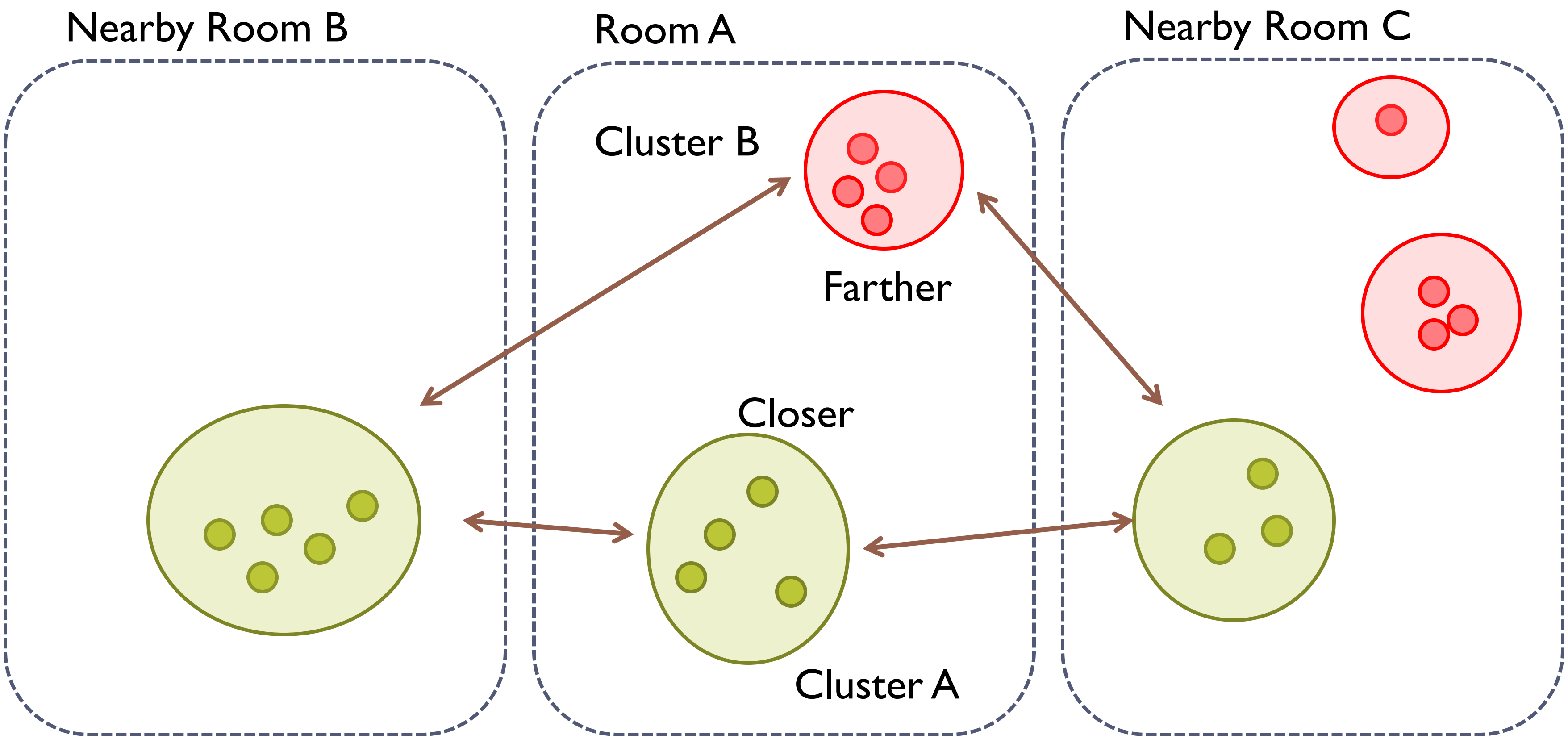


Erroneous User Input Filtering

- Step 2: Pick the most consistent cluster



Erroneous User Input Filtering: Result

- Filtering performance improves with additional data
- If 20~30% of user inputs are erroneous, filtering improves the number of spot-on localization estimates by up to 9%
- Refer to our paper for details

Conclusion & Future Work

Conclusion

- Organic localization eliminates survey effort while achieving comparable accuracy
- Organic localization can be improved by adequate methods to facilitate organic process
- Voronoi-diagram-based method for conveying uncertainty and user-prompting
- Clustering-based method for discarding erroneous user inputs

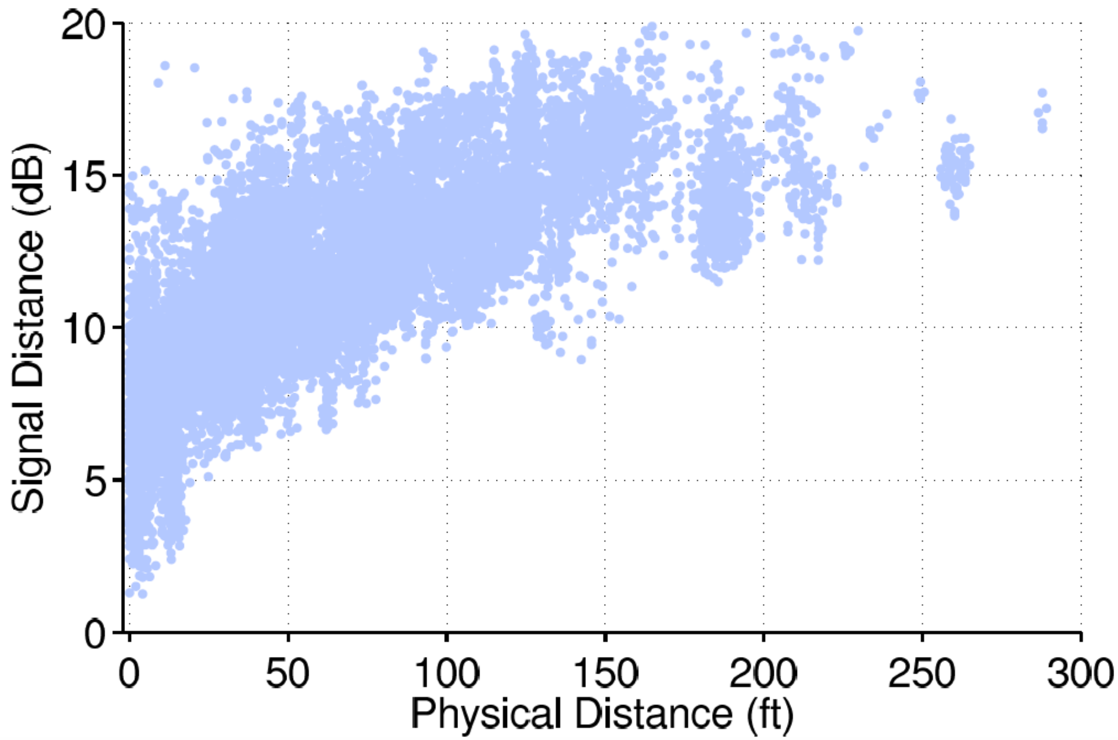
Future work

- Adapts to environmental changes (e.g. AP upgrades)
- Handle device diversity
- Combine with "organic" mobile applications

Thank you.
Questions?

Physical Distance vs. Signal Distance

Normalized signal-space Euclidean distance $$d_s(b^s, b^t) = \left[\frac{1}{M}\sum_{i=1}^{k}(b_i^s - b_i^t)^2\right]^{1/2}$$



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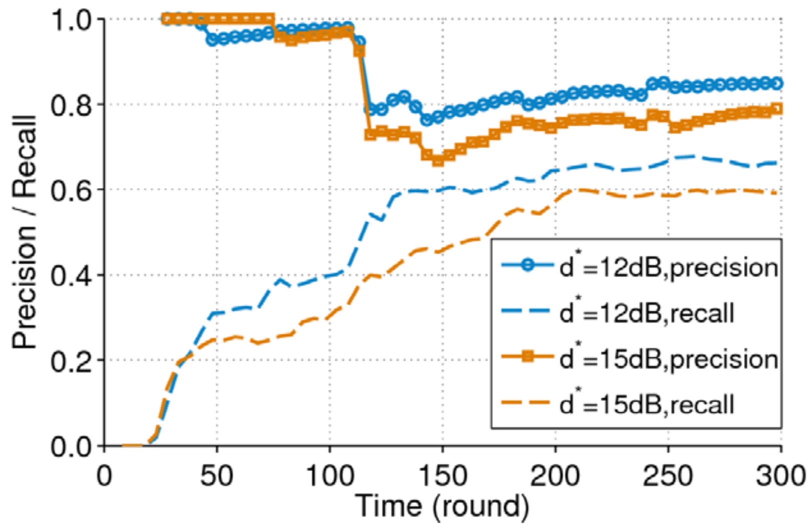

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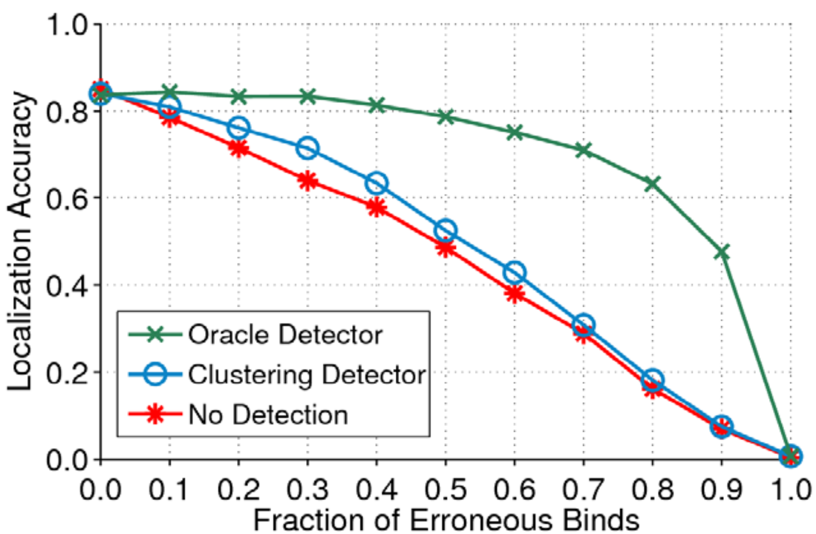
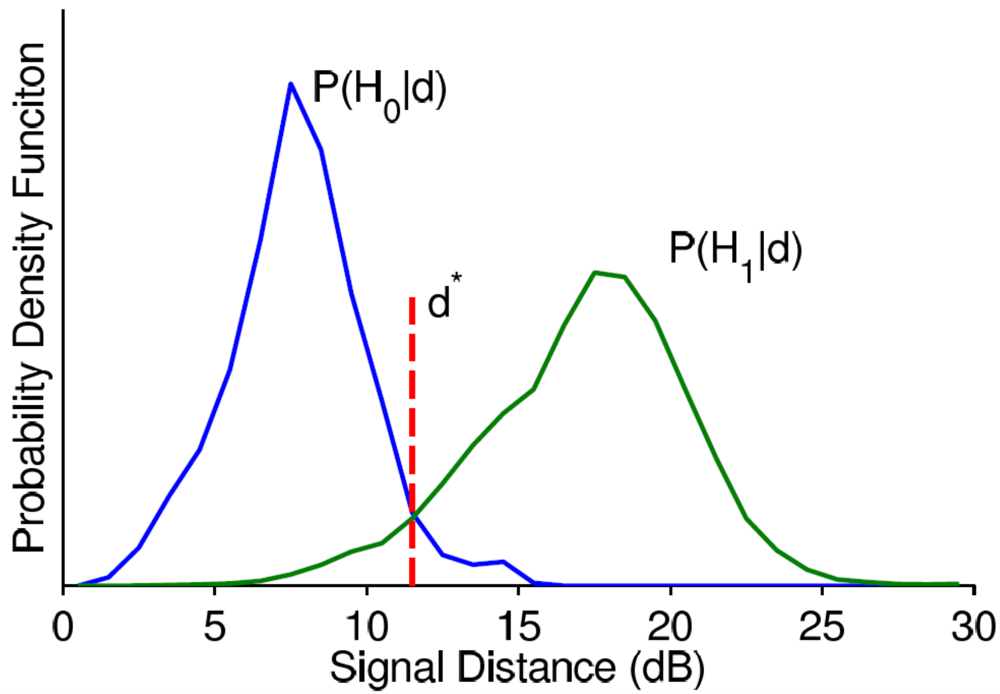


- Filtering improves accuracy of location estimates

Clustering Threshold Tuning

- H_0: User inputs are from the same location
- H_1: User inputs are from different locations
- Select H_0 if: $P(\mathcal{H}_0|d) > P(\mathcal{H}_1|d)$.



User Deployment Statistics

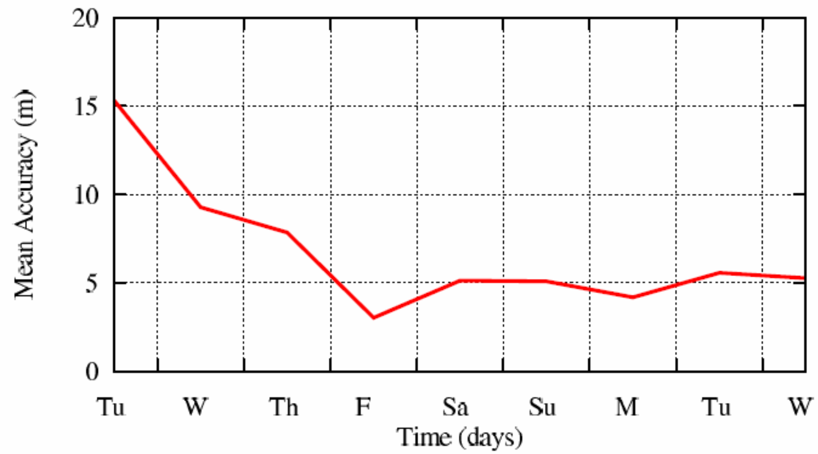
- 9-day user deployment

Map Spaces	1,373
Contributing Users	19
Bind Intervals (from users)	604
Scans (from devices)	1,142,812
Bound Scans	108,418 (9.4%)
Spaces with Bound Scans	116 (8.4%)

- Previous user deployment for 20-days showed similar characteristics

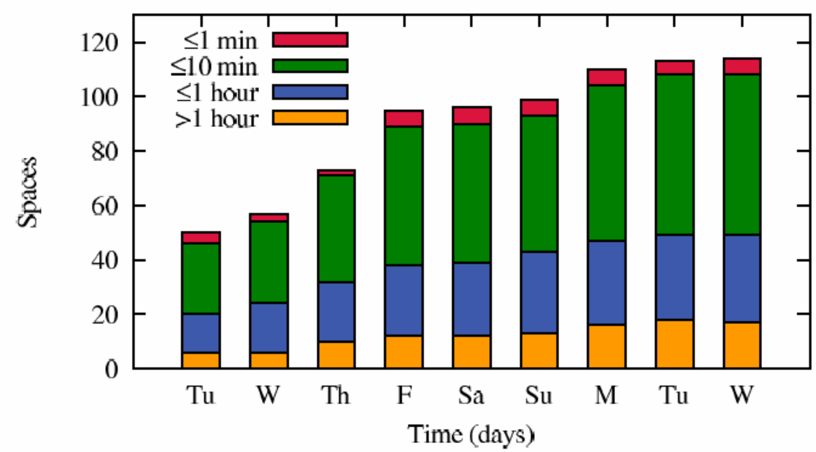
User Deployment Result

- Accuracy over time
  - Pre-installed tablets



(a) Spot check Accuracy

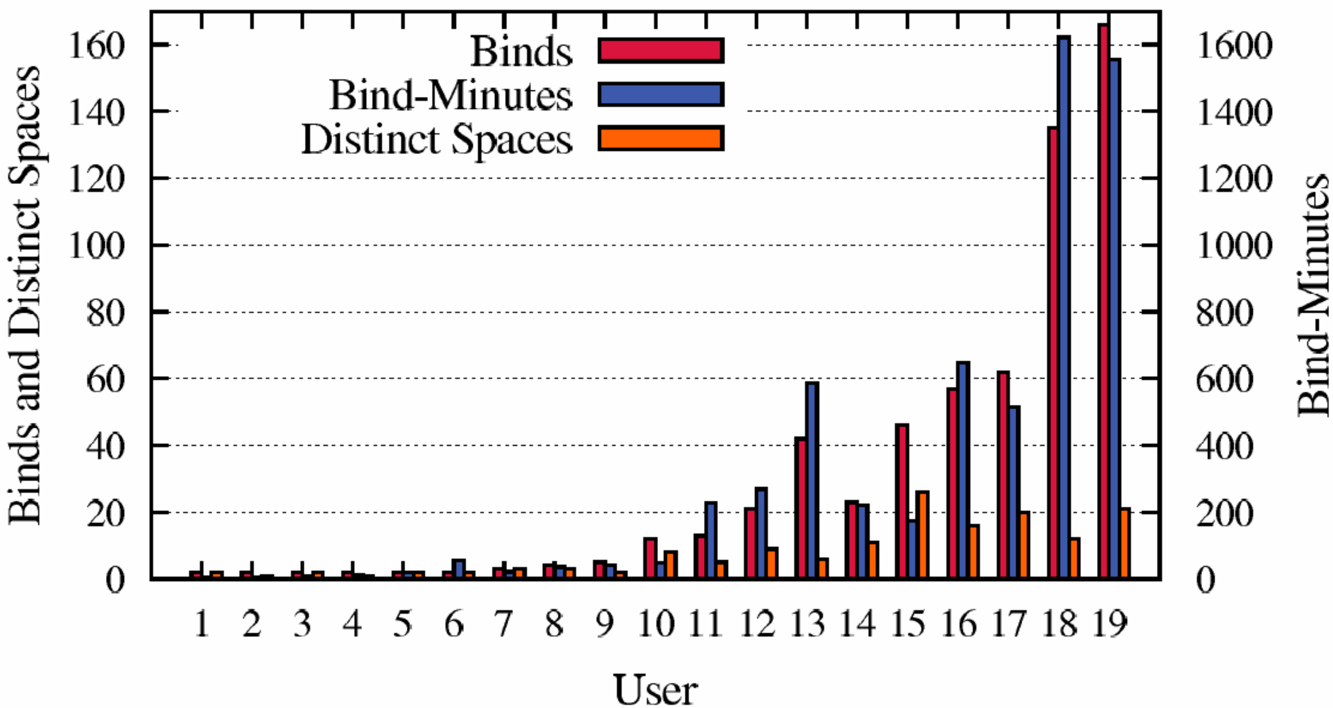
- Amount of user input over time



(b) Cumulative Per-Space Bind-Minutes

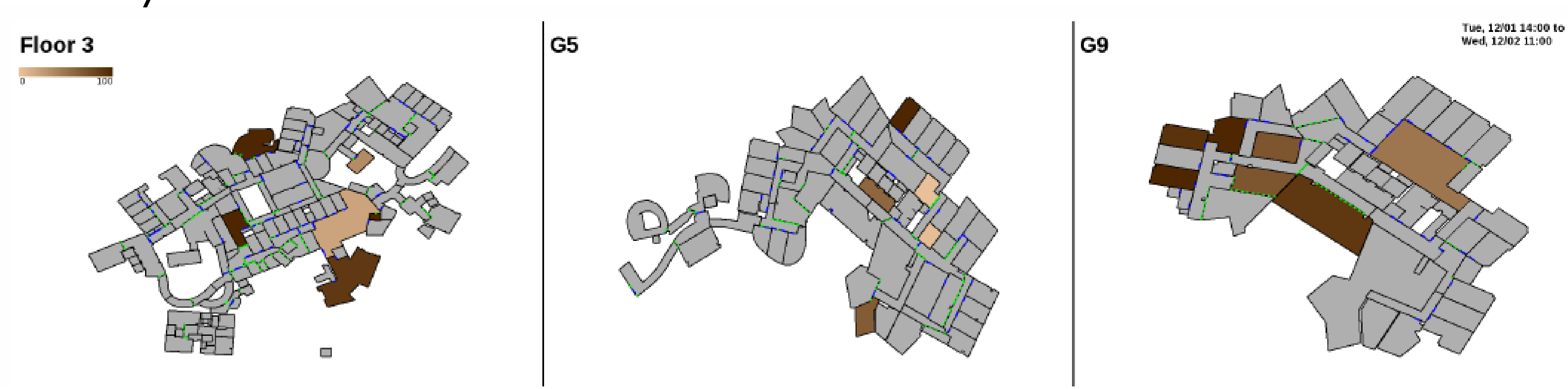
User Deployment Result

- Distribution of per-user contribution

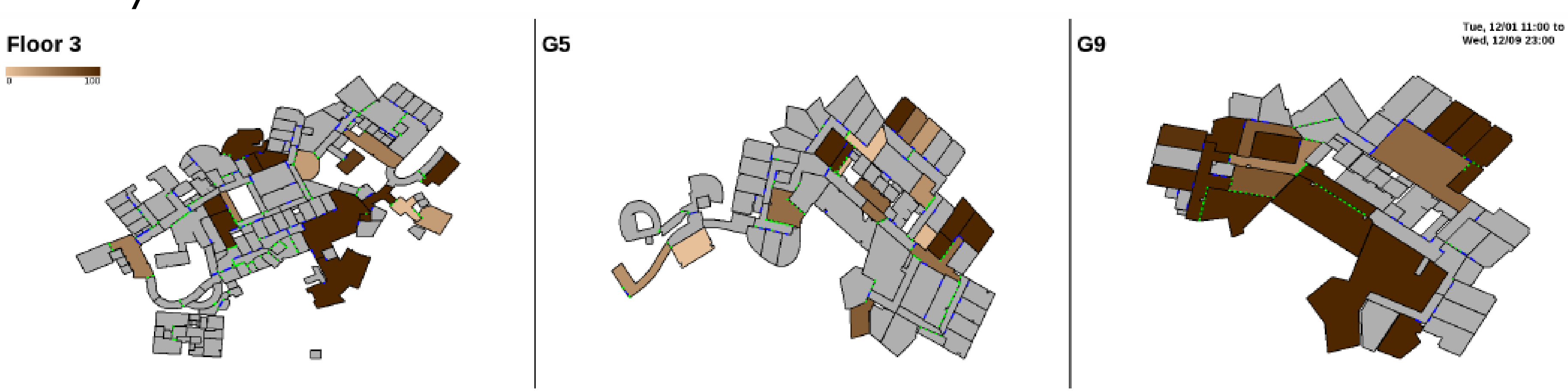


User Deployment Result: Coverage

- Day 1



- Day 9



System Architecture