6.S062: Mobile and Sensor Computing

Lecture 4: Device-Free Localization

So Far: Device-based Localization

This Lecture: Using radio signals to track humans without any sensors on their bodies

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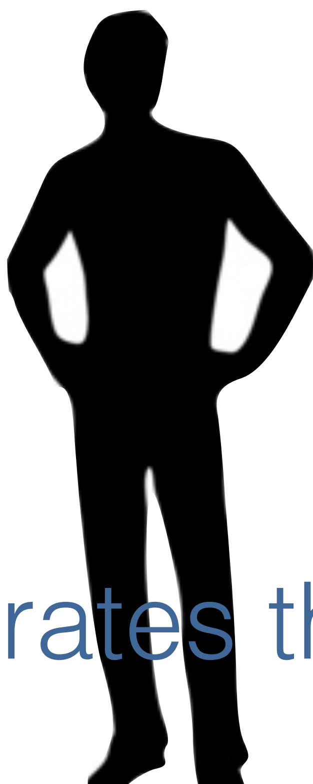
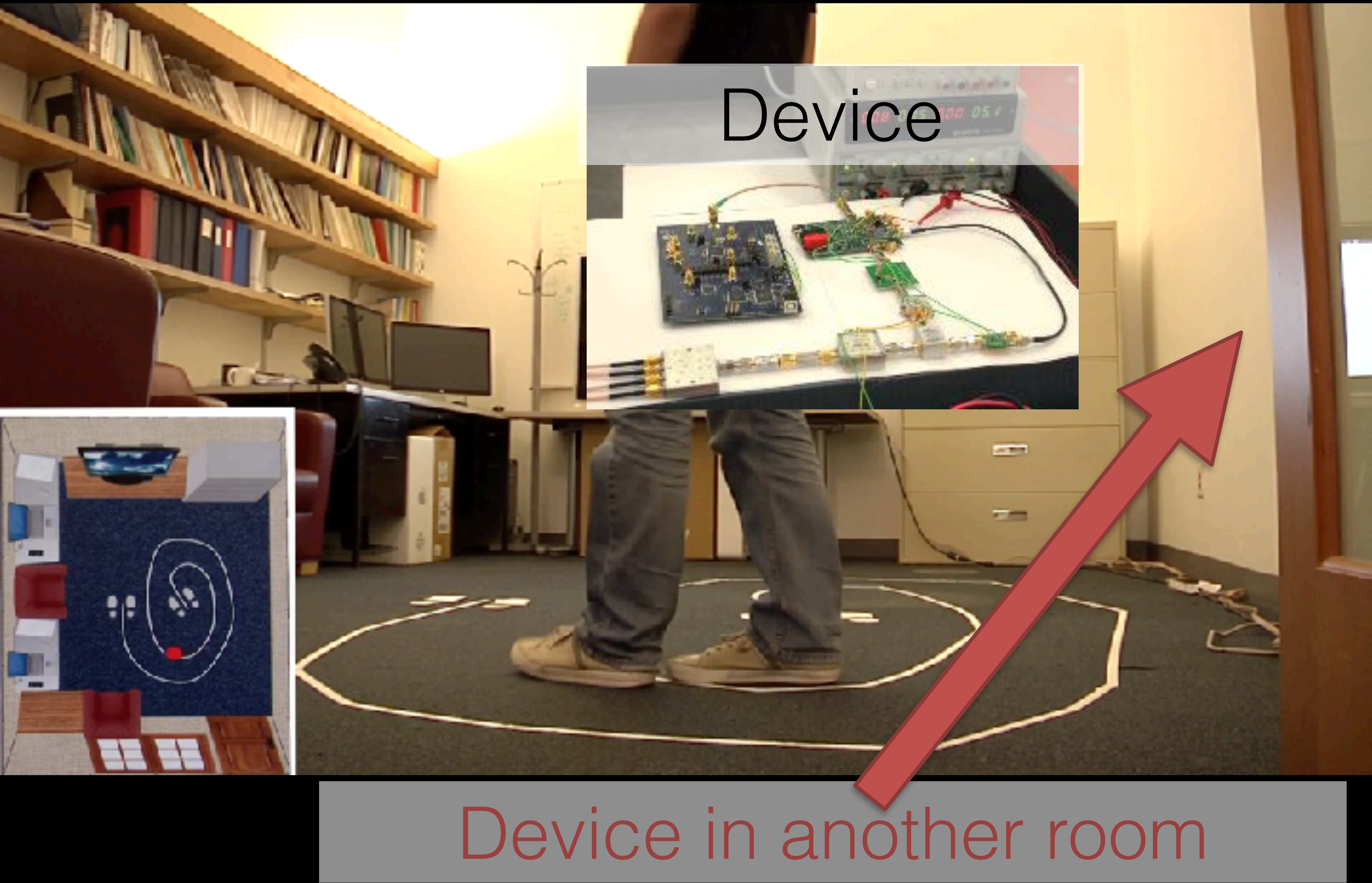
- Location
- Vital Signs
- Gestures

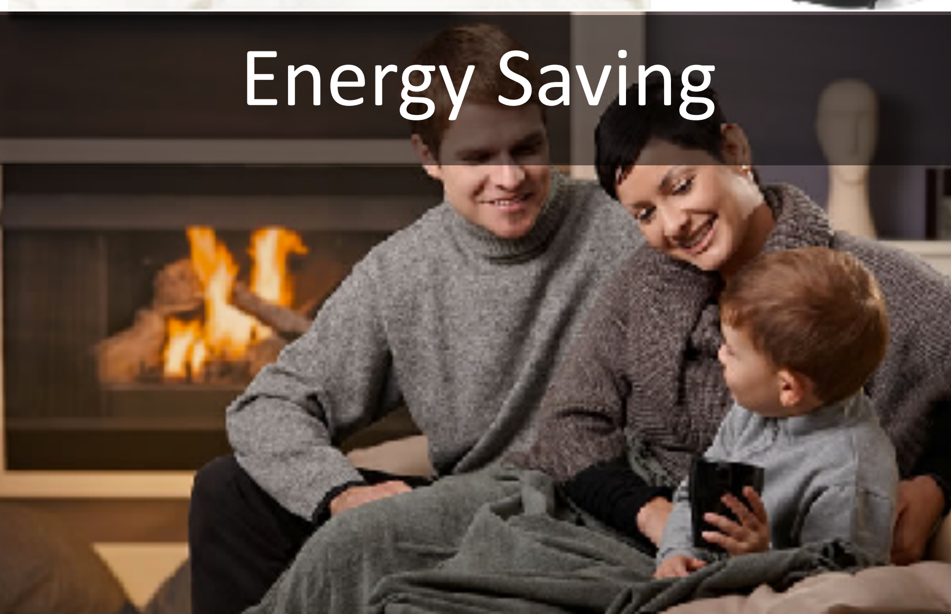


Operates through occlusions

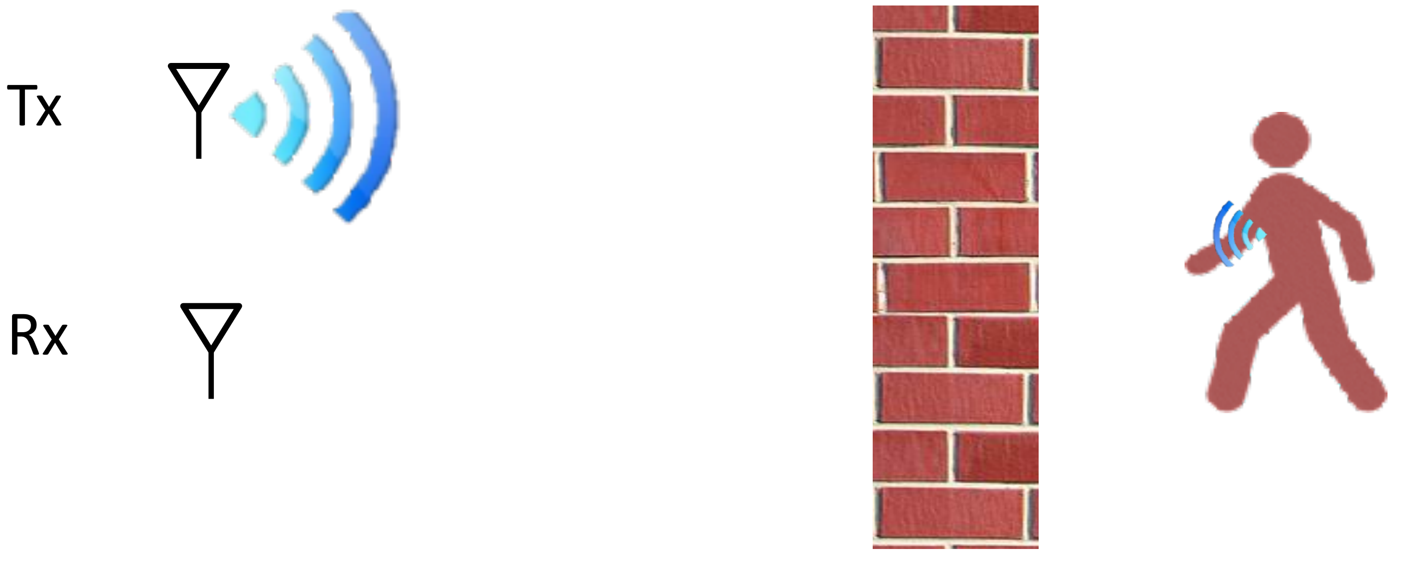
Example: WiTrack


Device
Device in another room

Applications



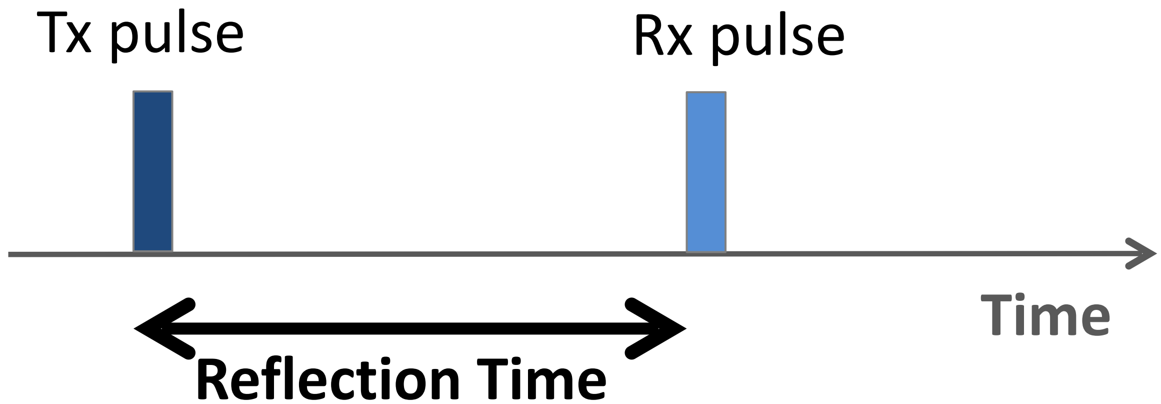
Measuring Distances



Distance = Reflection time x speed of light

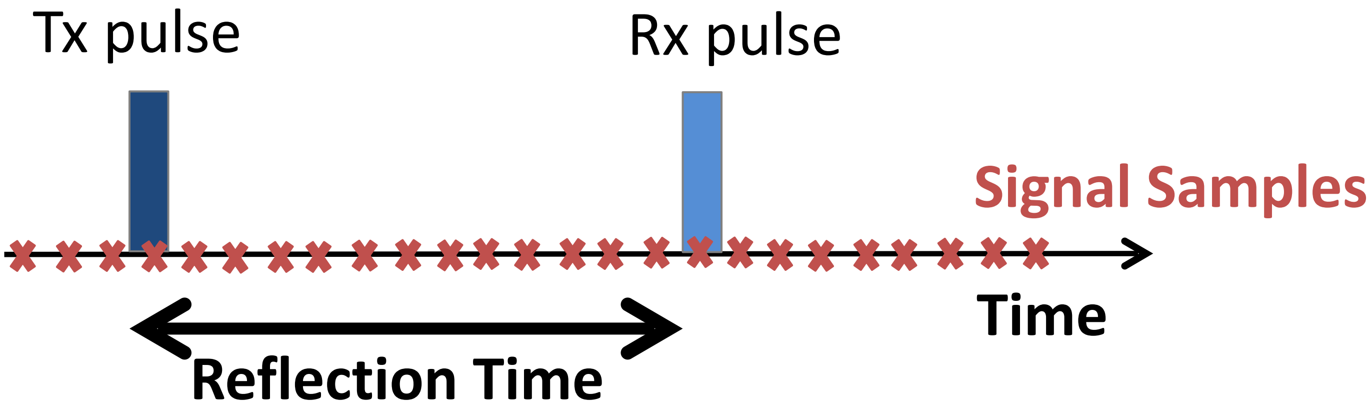
Measuring Reflection Time

Option1: Transmit short pulse and listen for echo



Measuring Reflection Time

Option1: Transmit short pulse and listen for echo



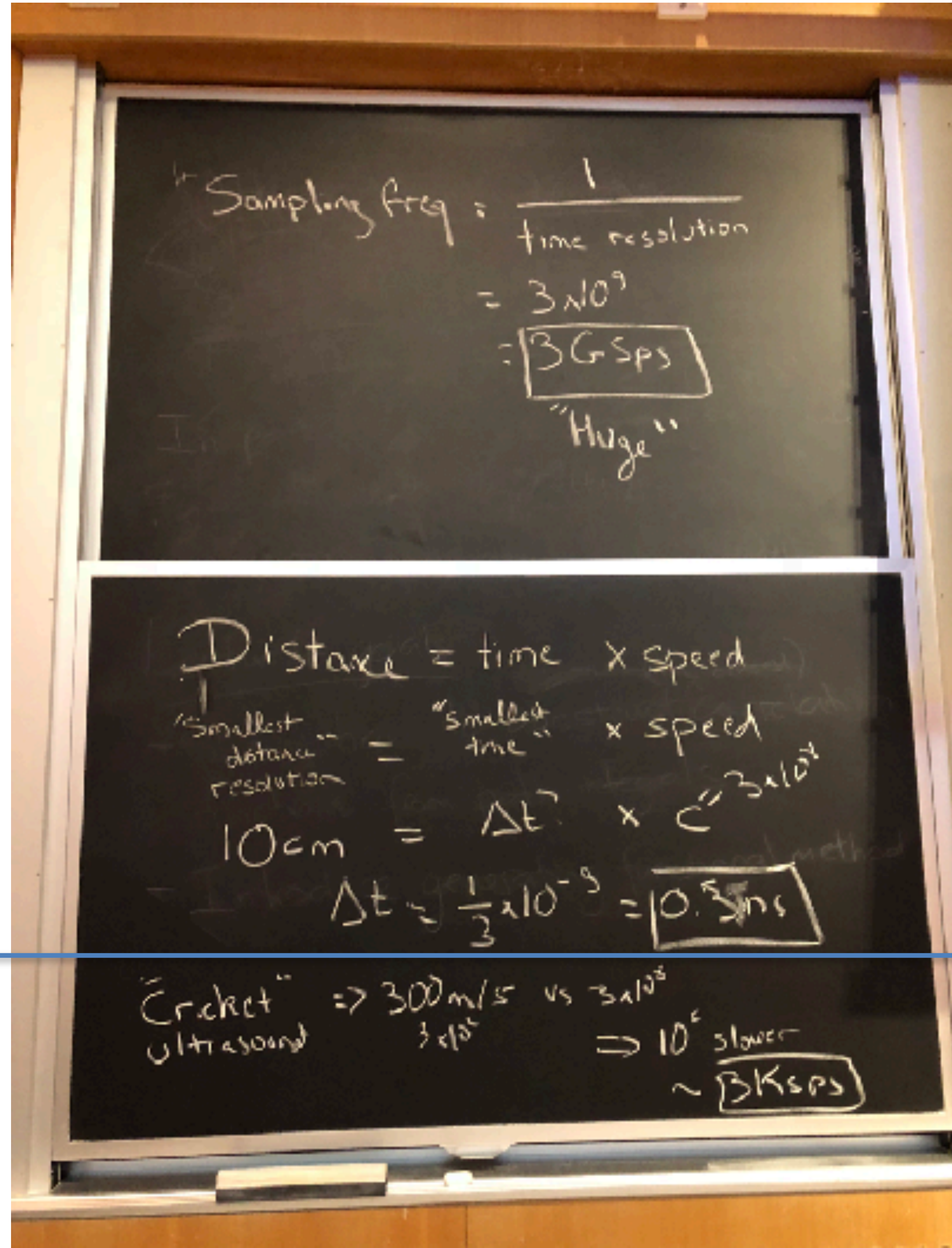
Capturing the pulse needs sub-nanosecond sampling

Why?

Capturing the pulse needs sub-nanosecond sampling

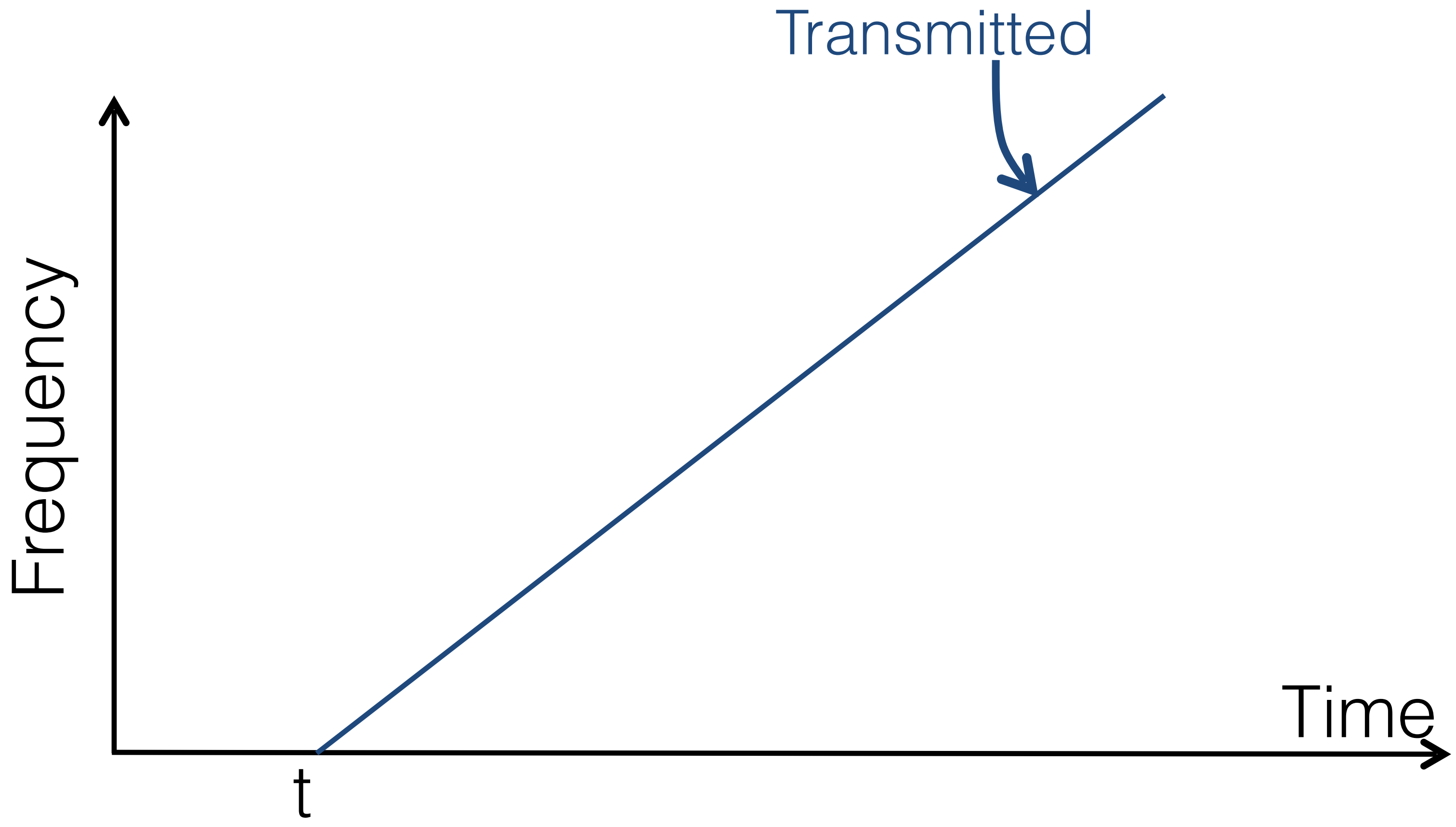
Why?

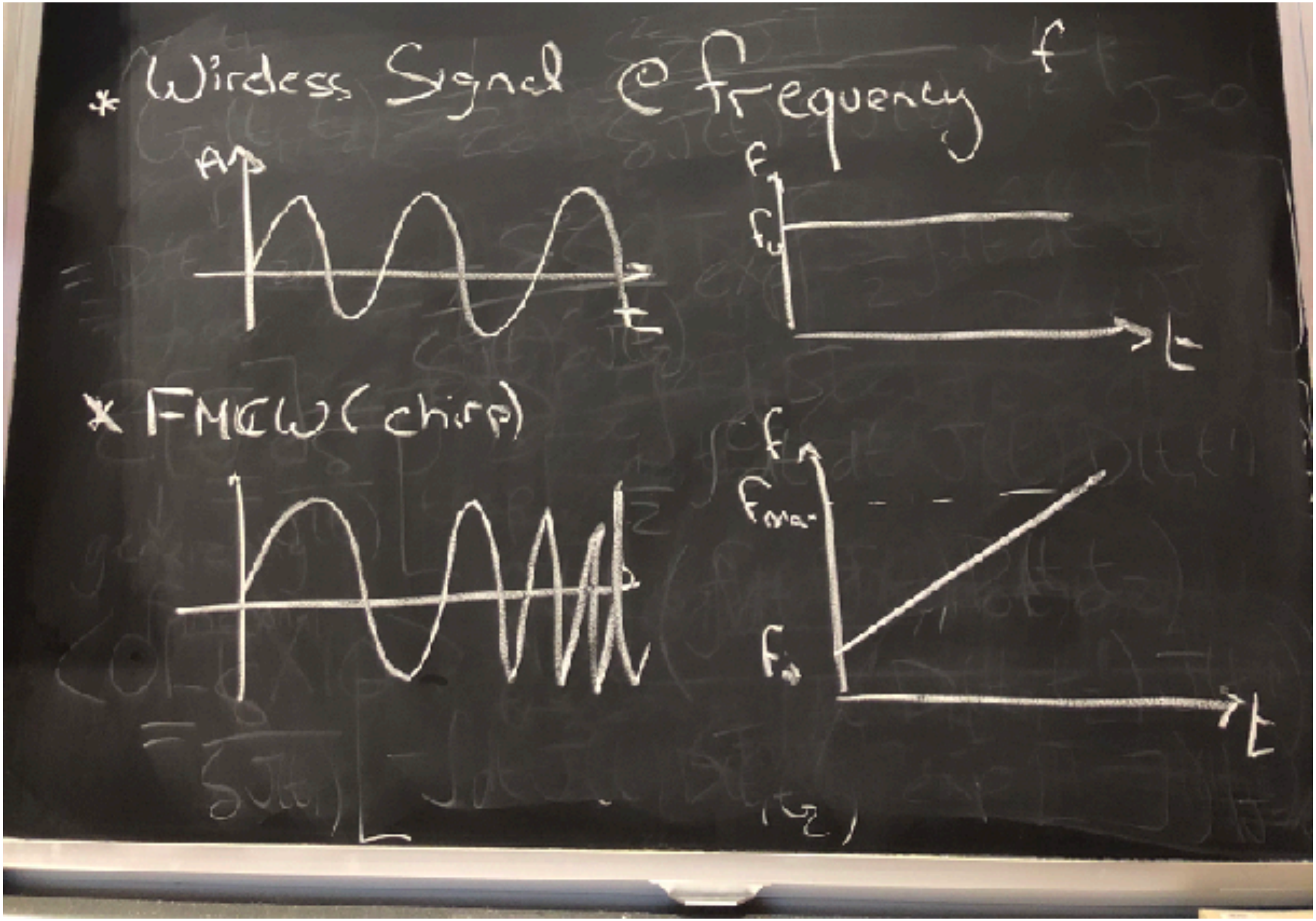
Multi-GHz samplers are expensive, have high noise, and create large I/O problem



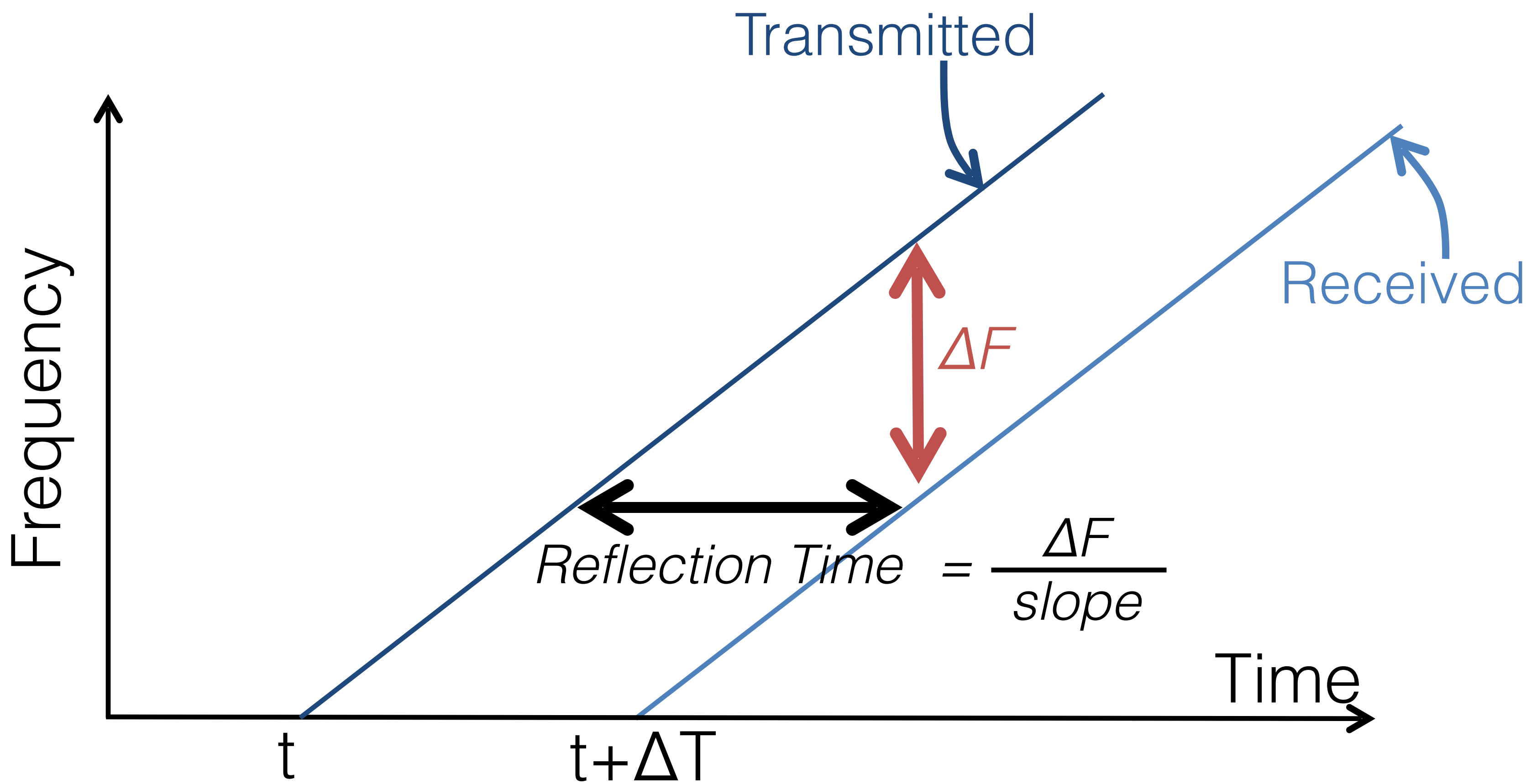
Why was this not a problem for Cricket?

FMCW: Measure time by measuring frequency




* Wireless Signal @ frequency
Amp
t
f
f
t
* FMCW (chirp)
f
f_max
f_0
t

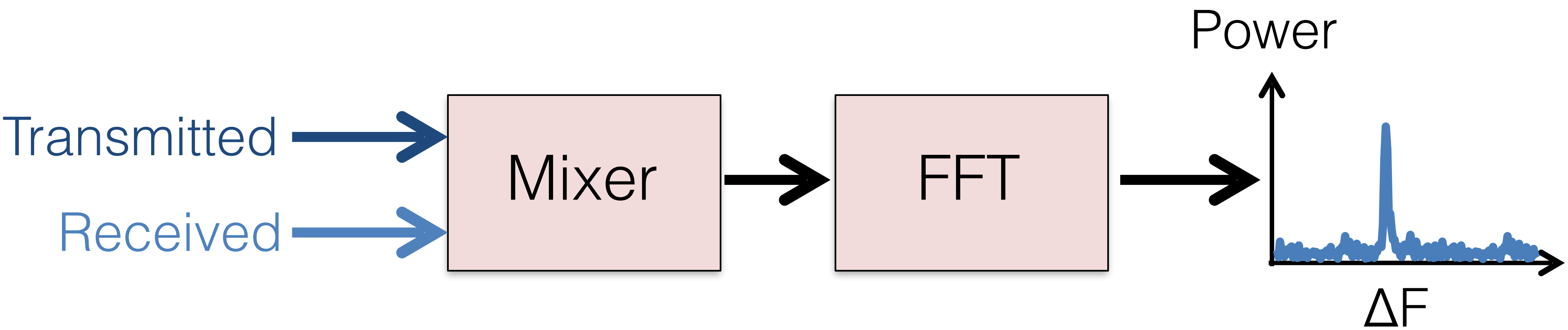
FMCW: Measure time by measuring frequency



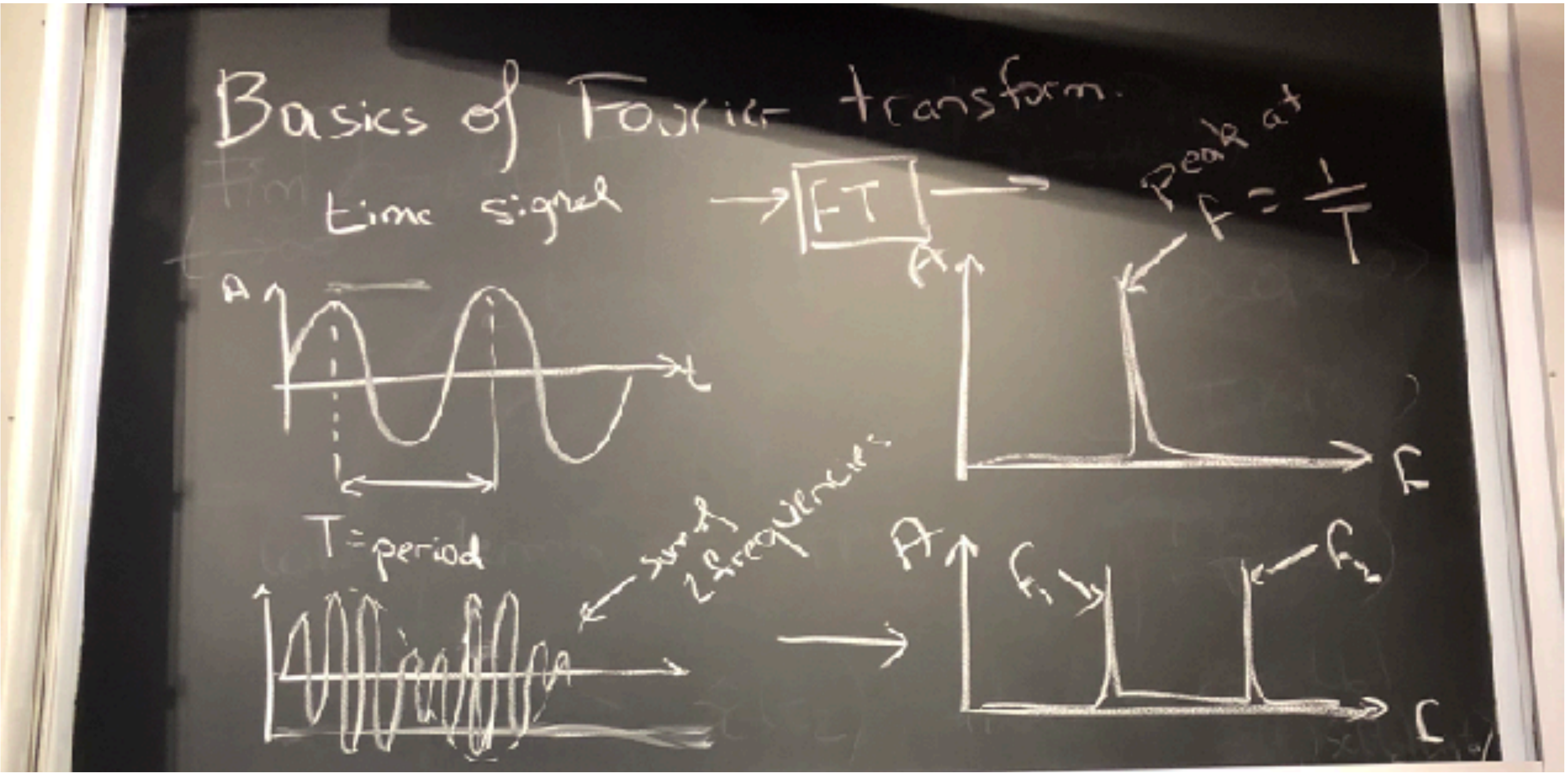
How do we measure ΔF?

Measuring ΔF

- Subtracting frequencies is easy (e.g., removing carrier in WiFi)
- Done using a mixer (low-power; cheap)

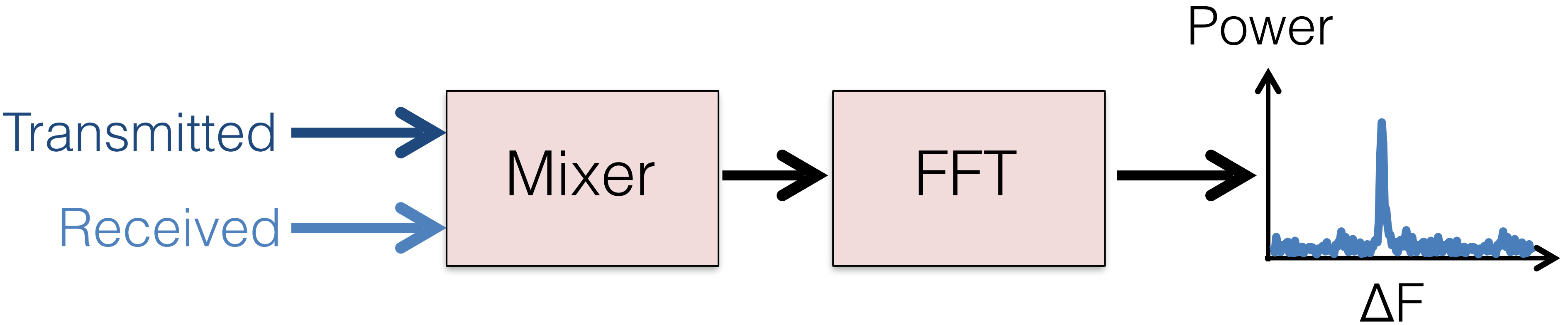


Signal whose frequency is ΔF


Basics of Fourier transform.
time signal
FT
peak at
f = 1/T
A
t
f
T = period
sum of
2 frequencies
f1
f2

Measuring ΔF

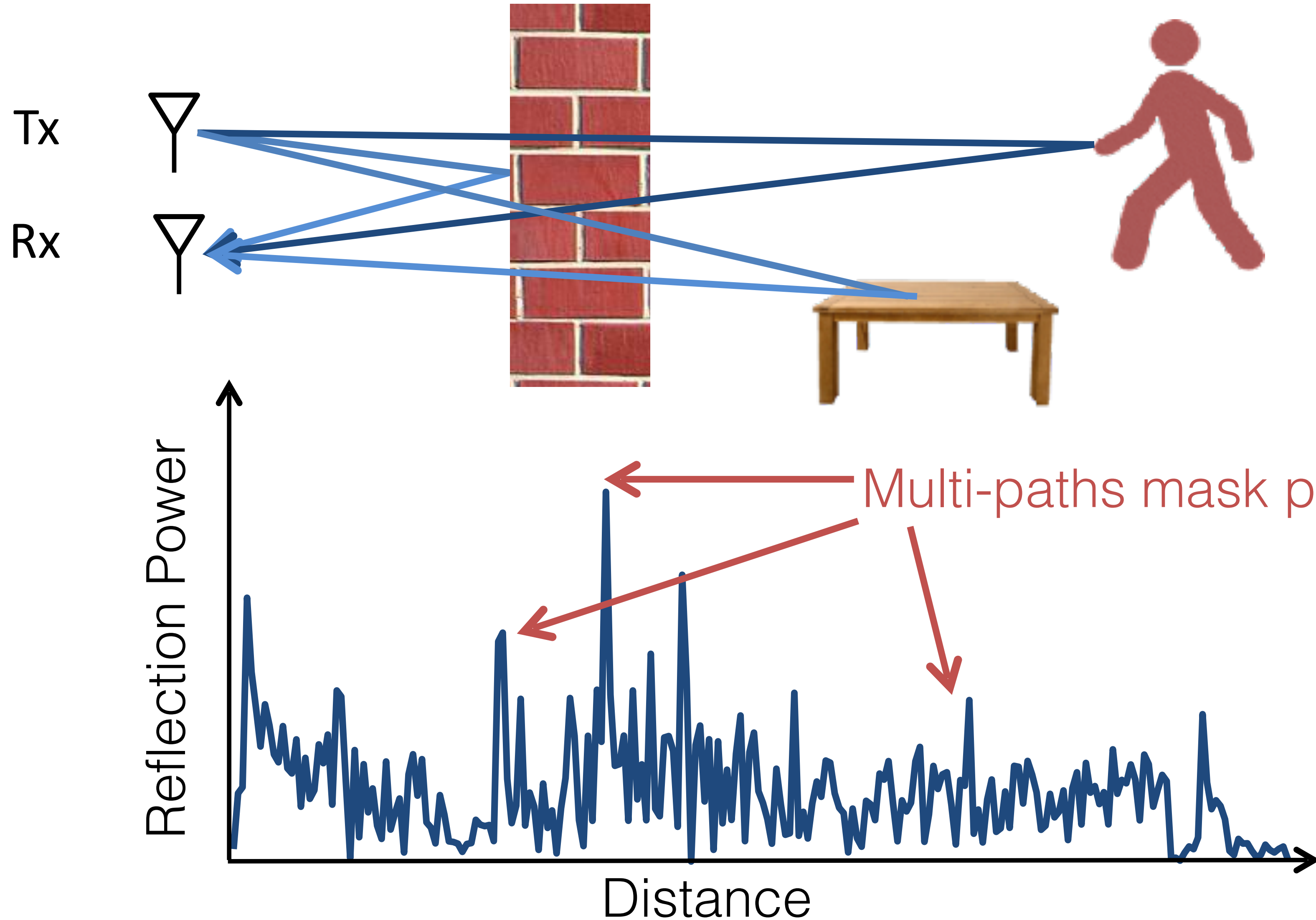
- Subtracting frequencies is easy (e.g., removing carrier in WiFi)
- Done using a mixer (low-power; cheap)



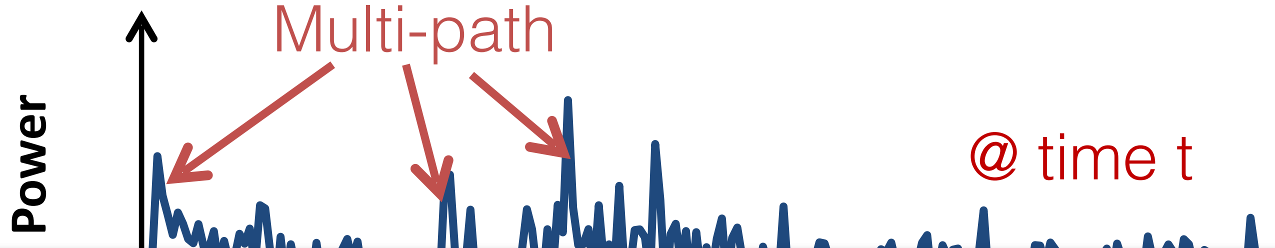
Signal whose frequency is ΔF

ΔF → Reflection Time → Distance

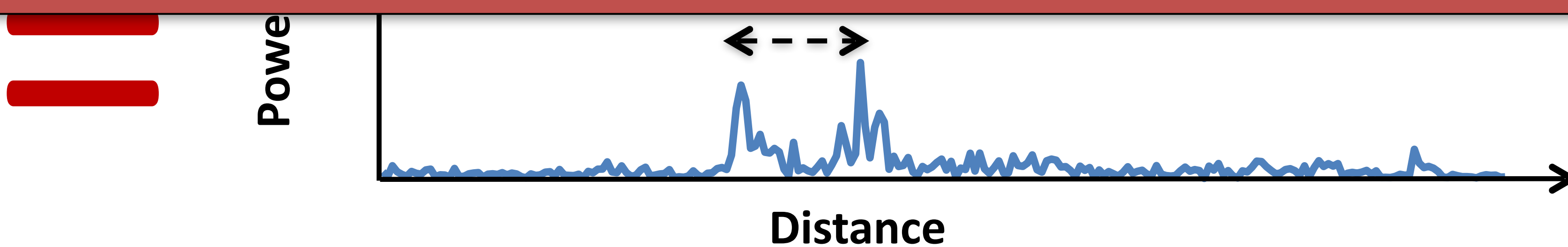
Challenge: Multipath→ Many Reflections



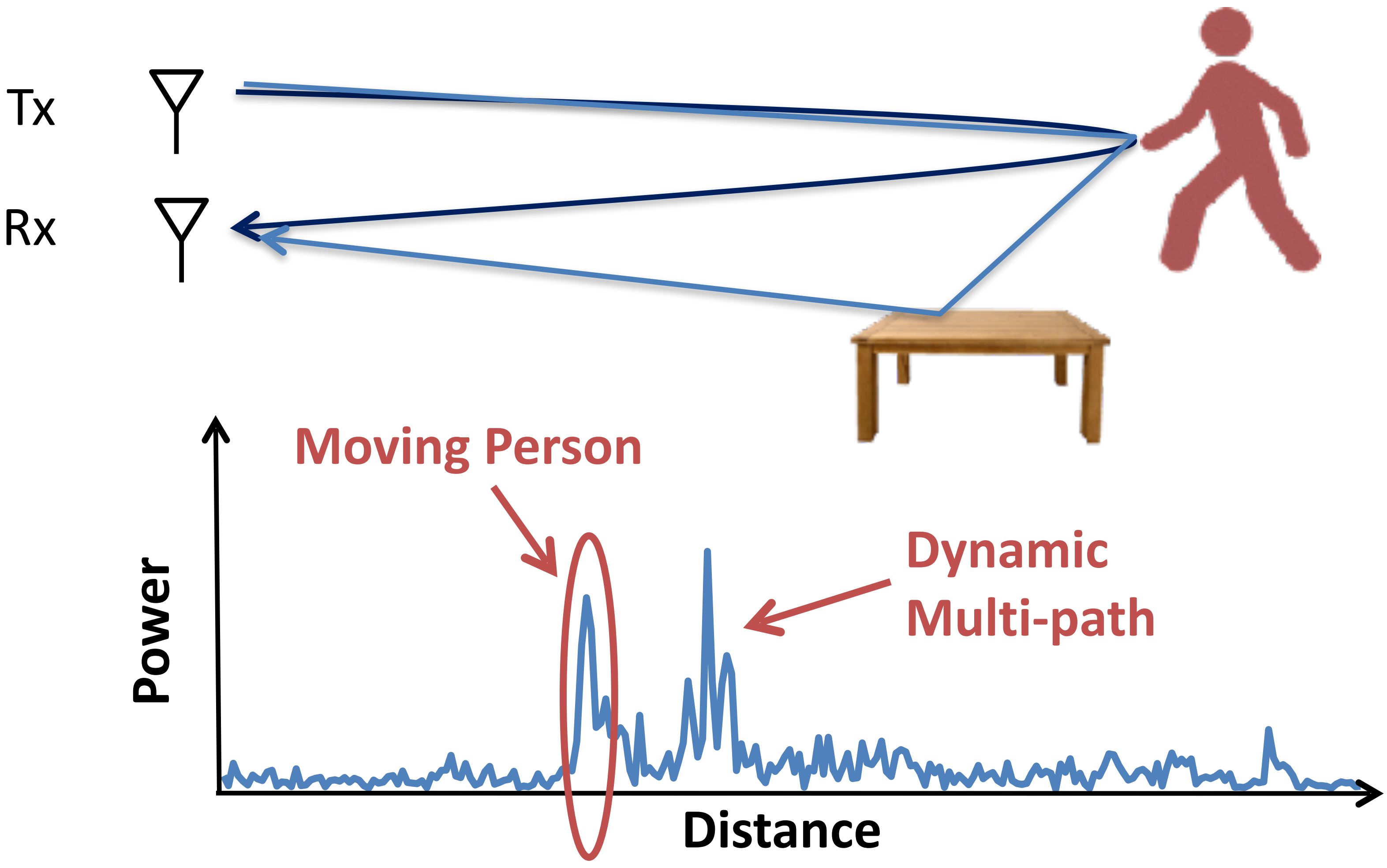
Static objects don't move
➔ Eliminate by subtracting consecutive measurements



Why 2 peaks when we only have one moving person?

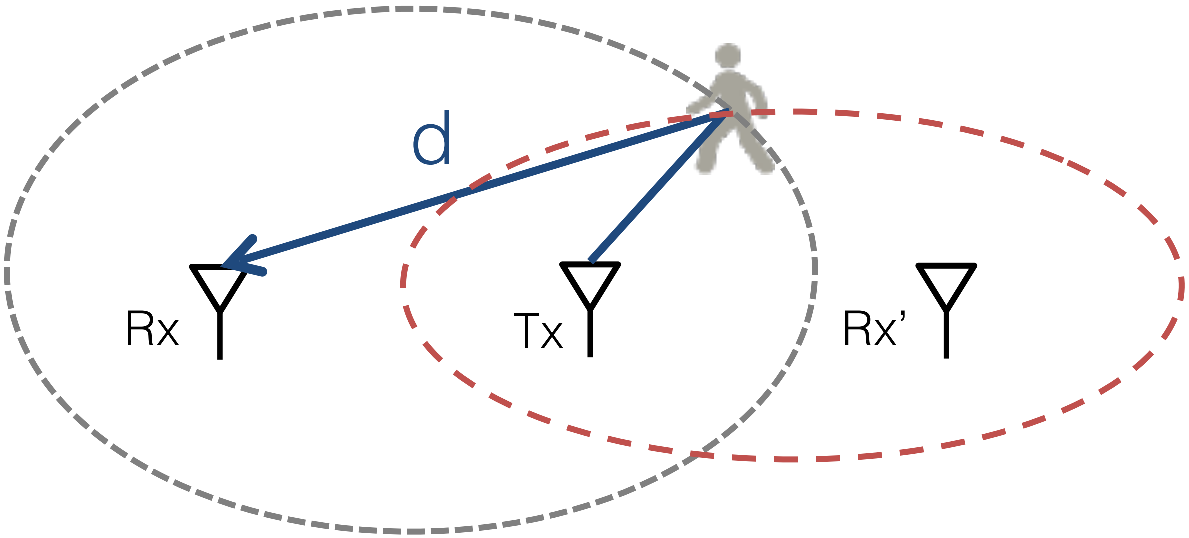


The direct reflection arrives before dynamic multipath!



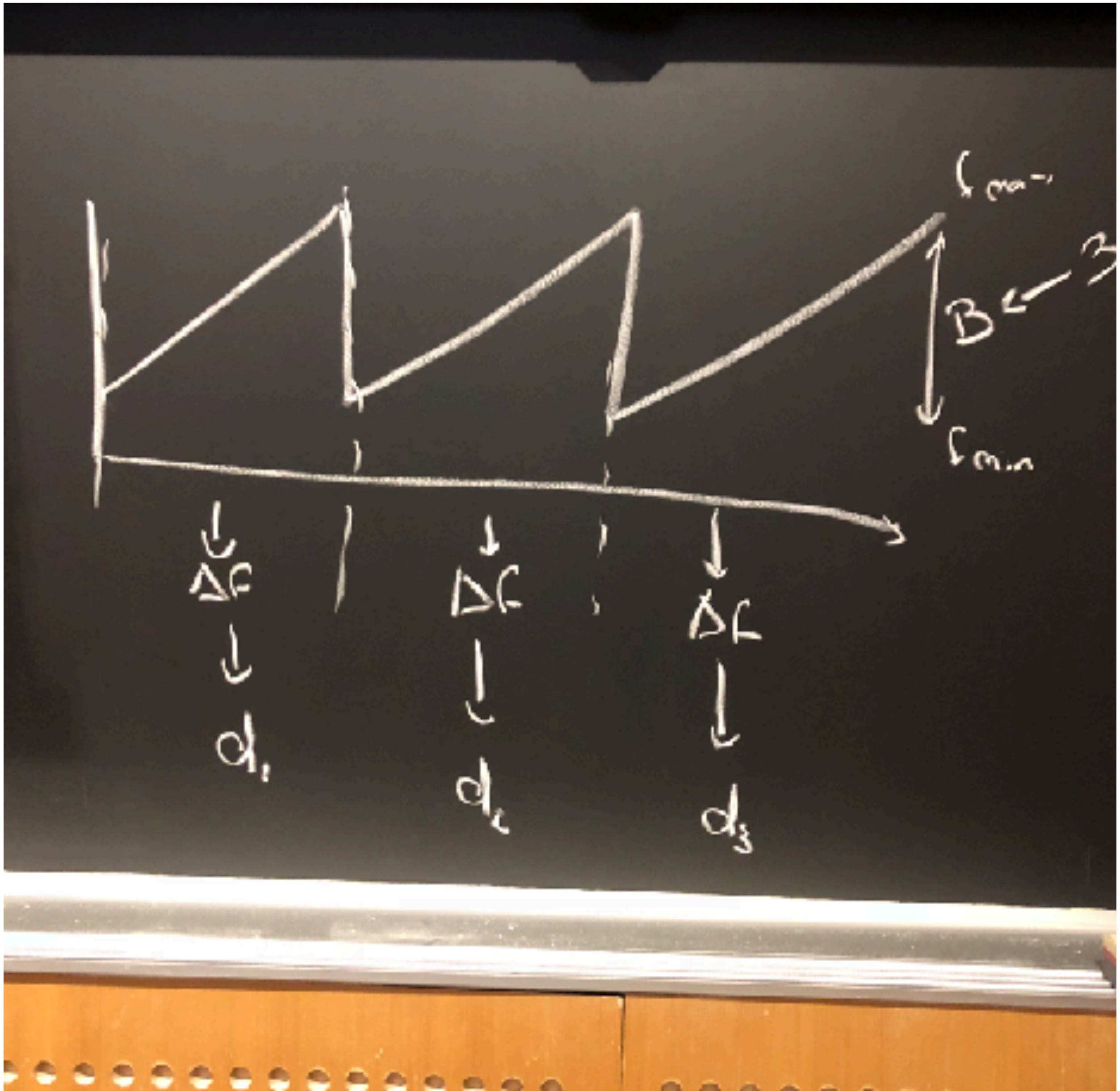
Mapping Distance to Location

Person can be anywhere on an ellipse whose foci are (Tx,Rx)

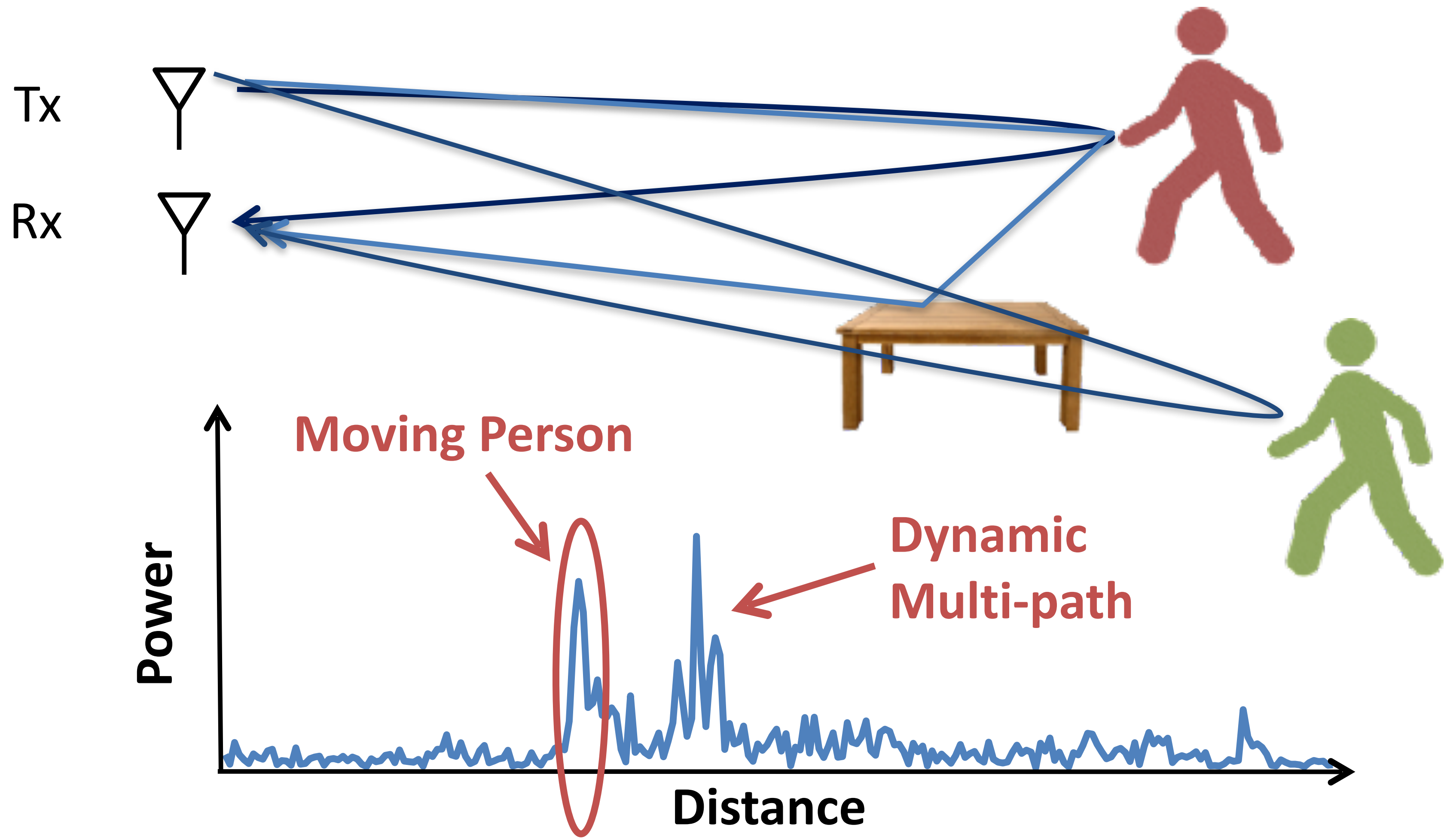


By adding another antenna and intersecting the ellipses, we can localize the person

From Location to tracking



Fails for multiple people in the environment, and we need a more comprehensive solution



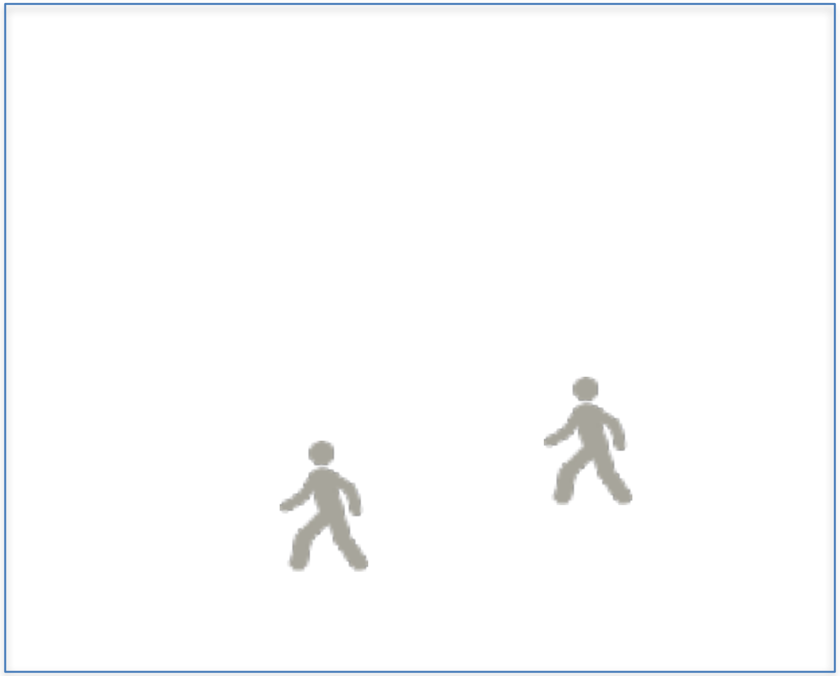
How can we deal with multi-path reflections when there are multiple persons in the environment?

Idea: Person is consistent across different vantage points while multi-path is different from different vantage points

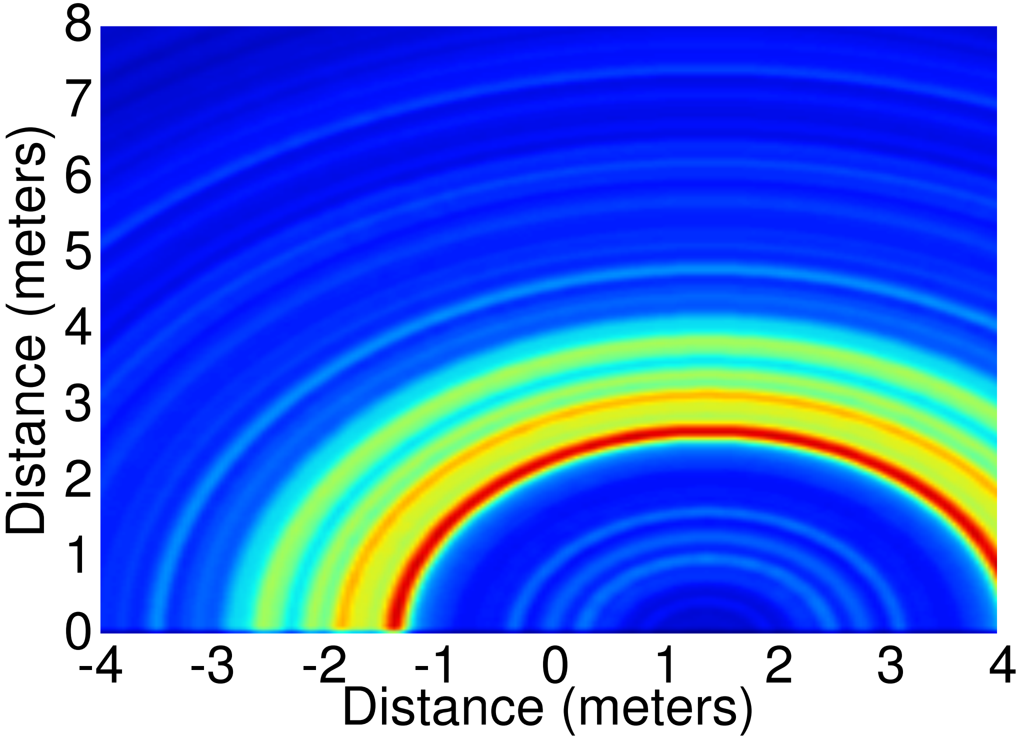
Combining across Multiple Vantage Points

Experiment: Two users walking

Setup



Single Vantage Point



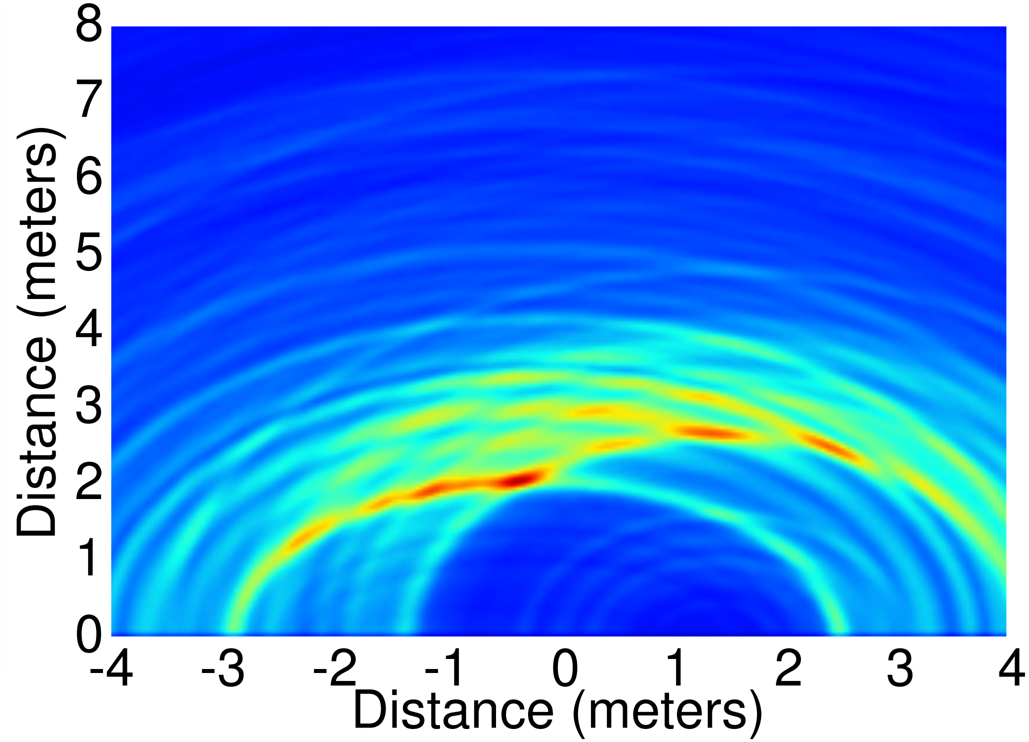
Mathematically: each round-trip distance can be mapped to an ellipse whose foci are the transmitter and the receiver

Combining across Multiple Vantage Points

Experiment: Two users walking

Setup

Two Vantage Points

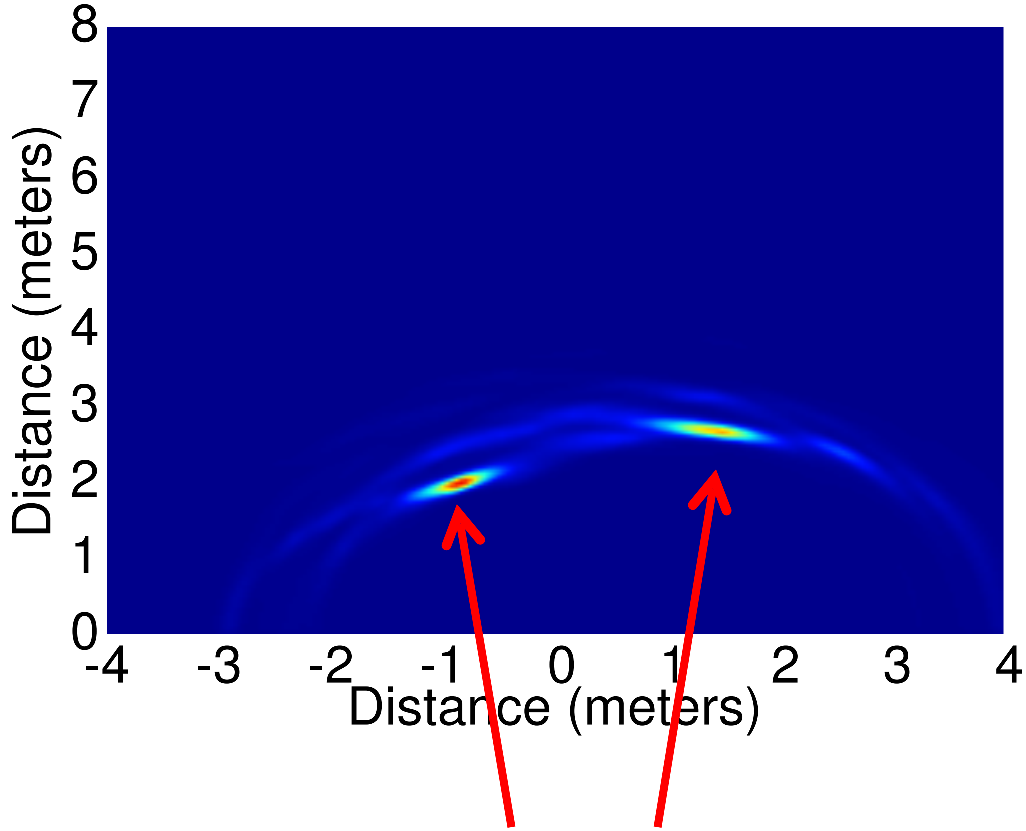


Combining across Multiple Vantage Points

<u>Experiment:</u> Two users walking

Setup

16 Vantage Points

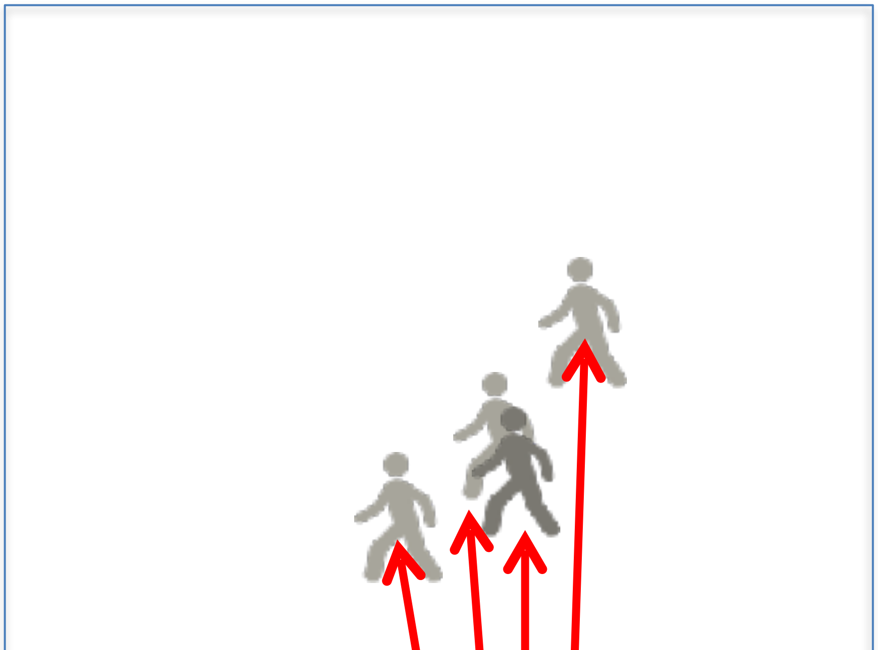


Localize the two users

Multi-User Localization

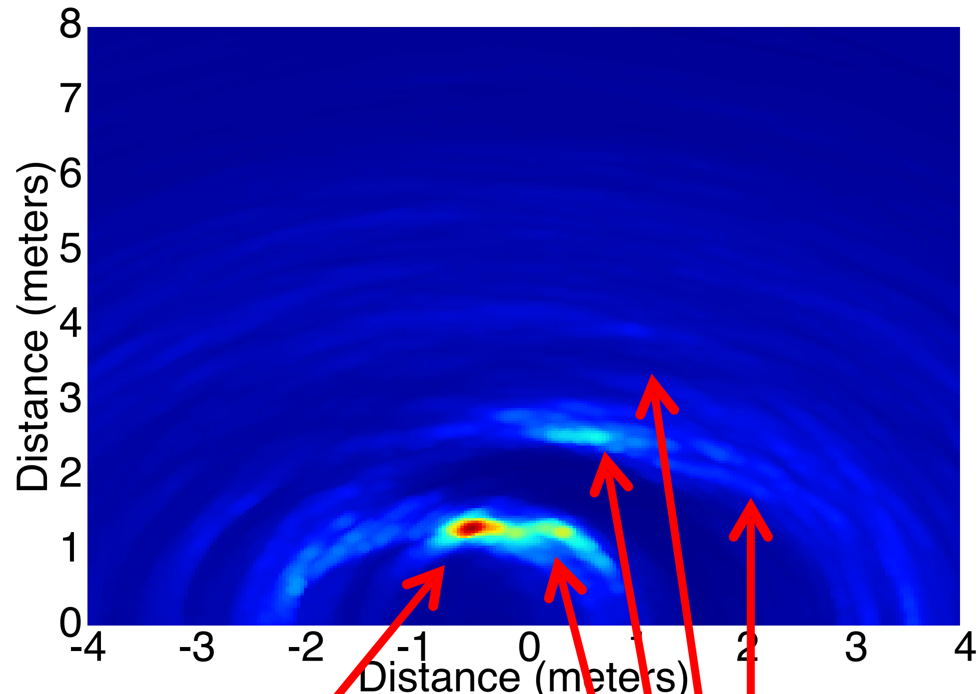
<u>Experiment:</u> Four persons walking

Setup



four persons

All Vantage Points

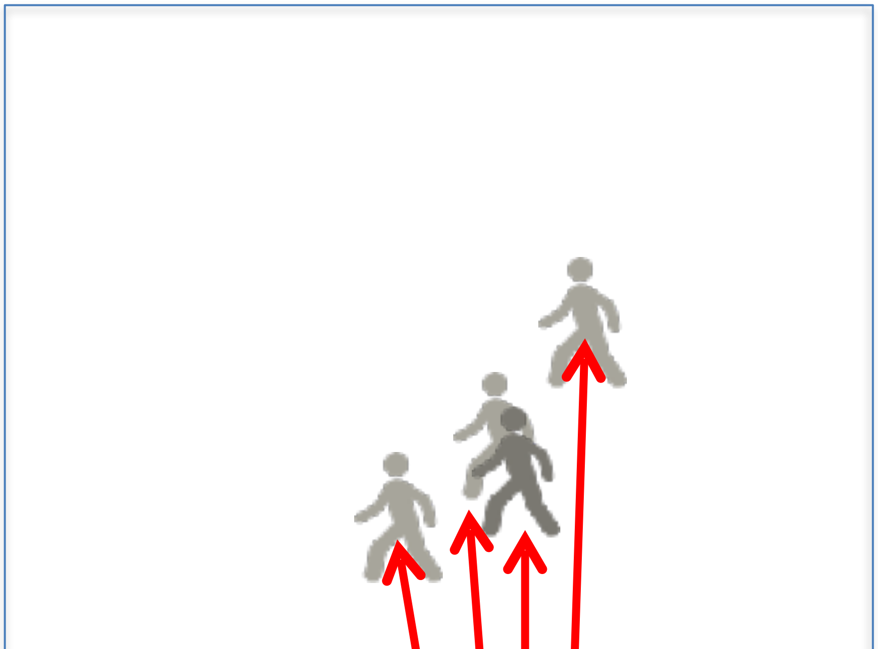


first person

other people or noise?

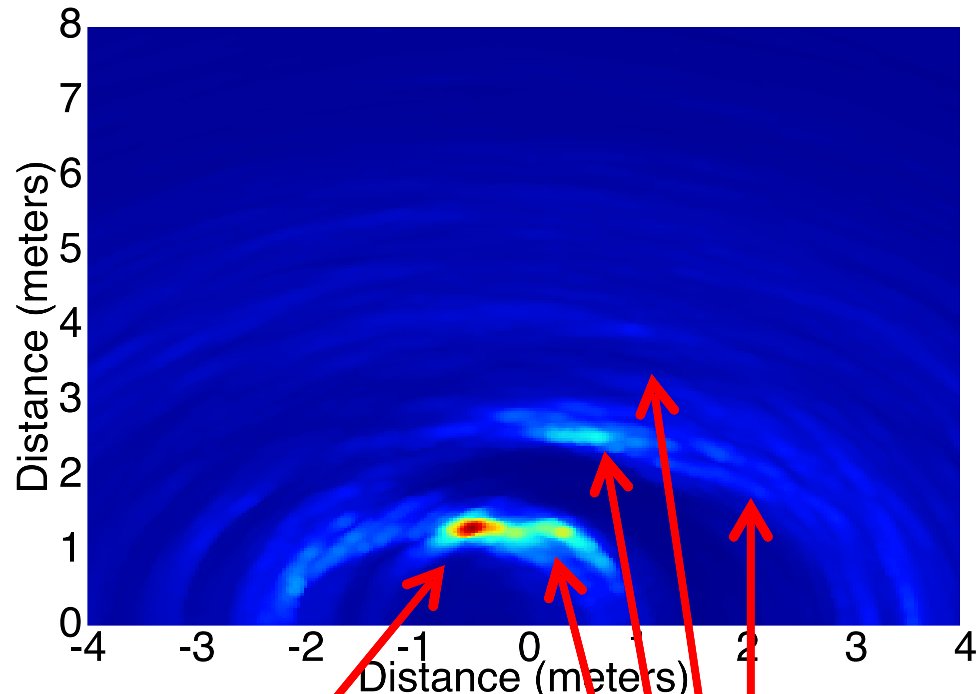
Near-Far Problem: Nearby persons have more power than distance reflectors and can mask them

Setup



four persons

All Vantage Points



first person

other people or noise?

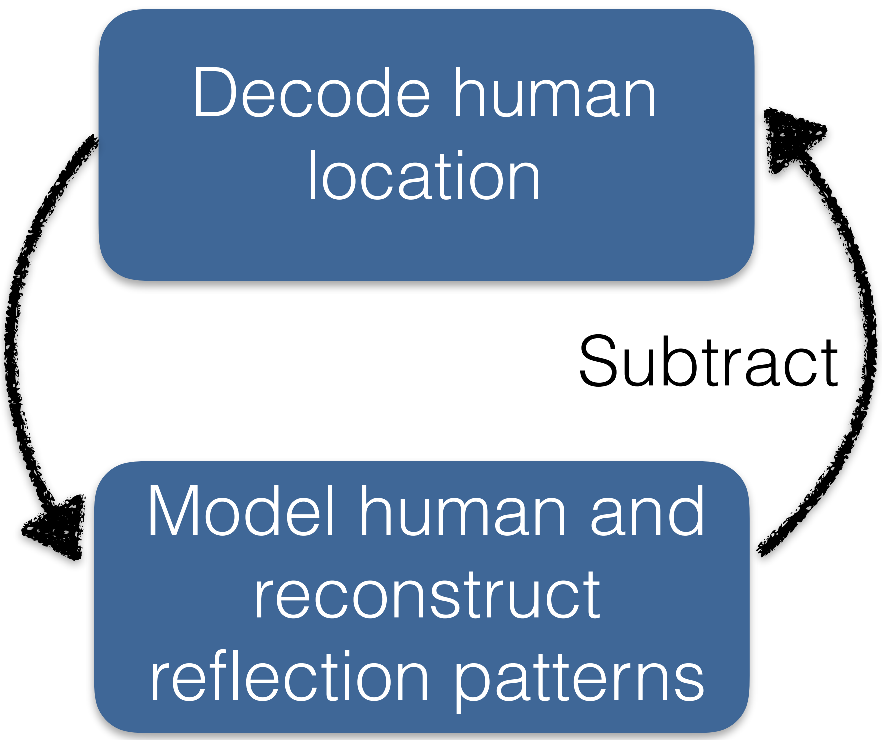
Successive Silhouette Cancellation:

a new algorithm that localizes multiple persons in the scene by addressing the near-far problem

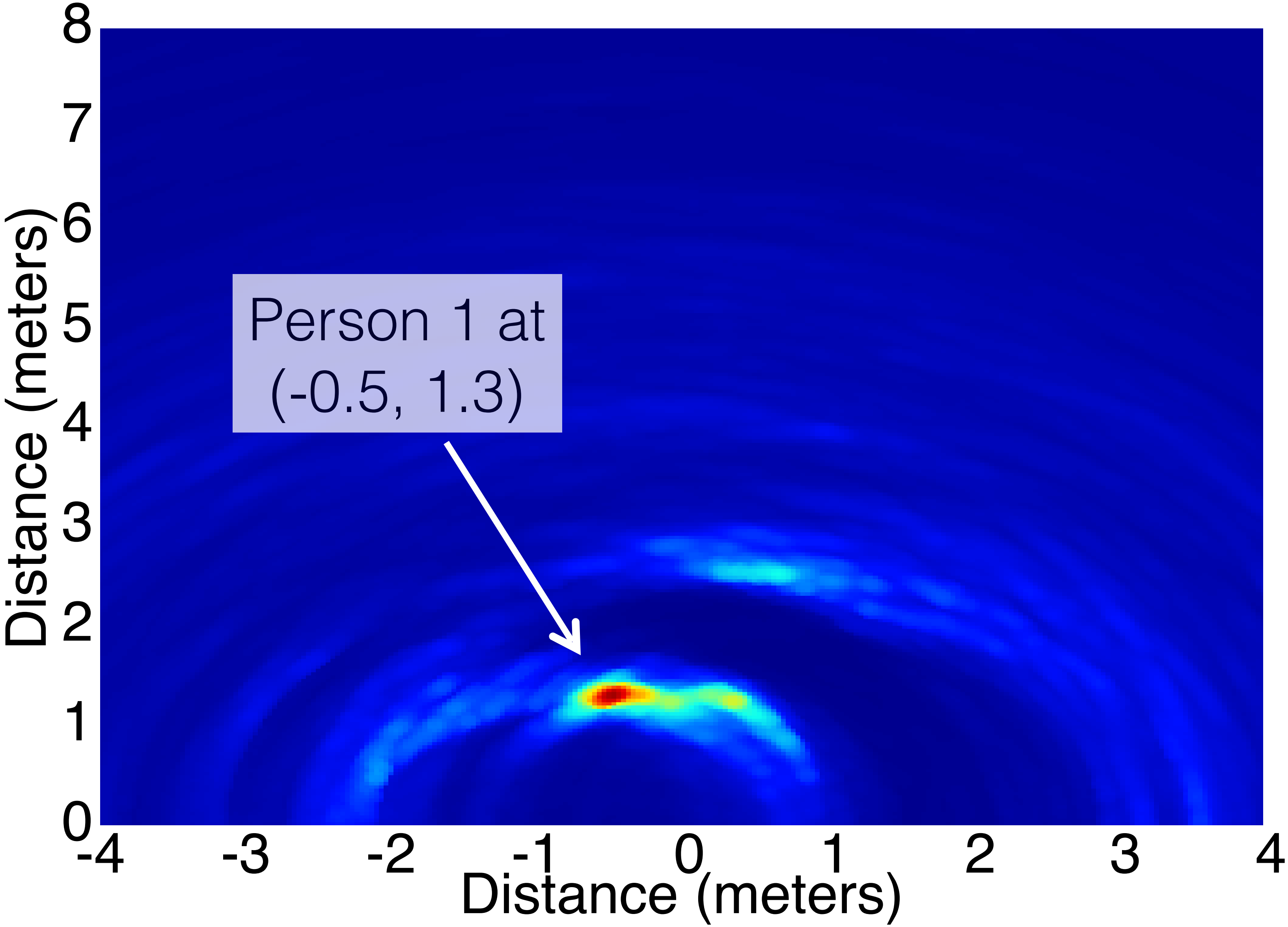
Successive Silhouette Cancellation:

a new algorithm that localizes multiple persons in the scene by addressing the near-far problem

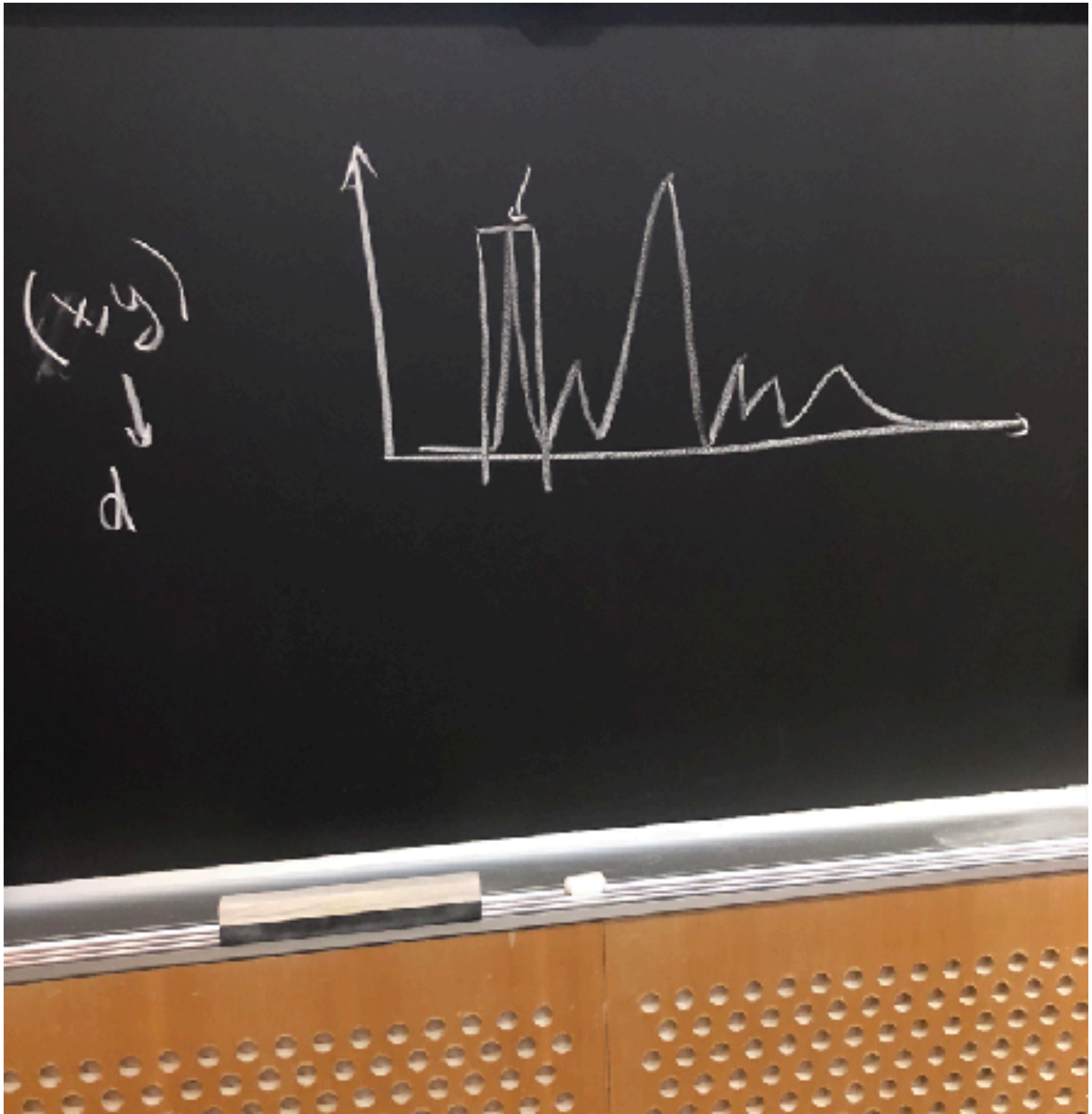
Goal: Recover human reflections



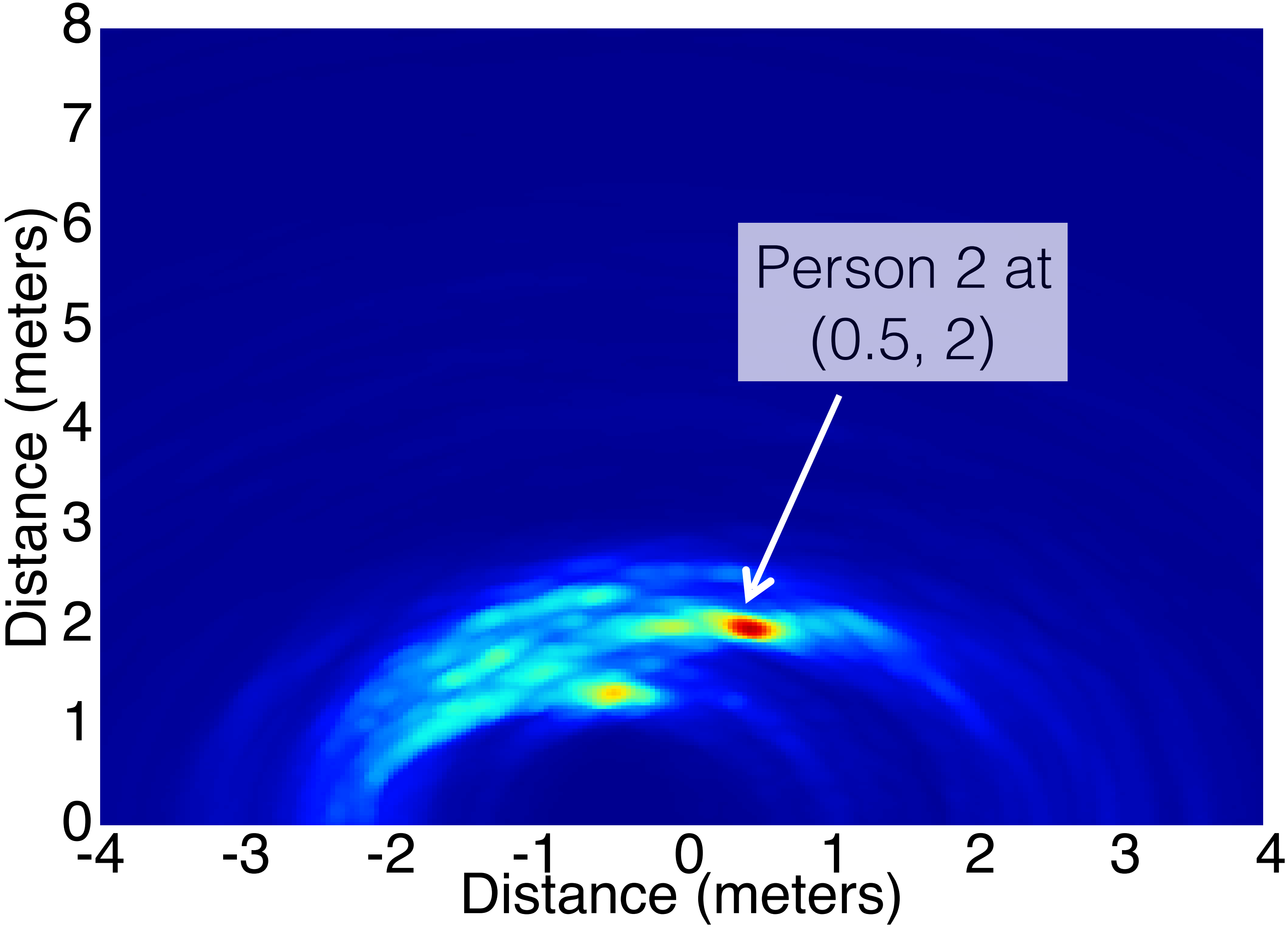
First localize the user with the strongest reflection



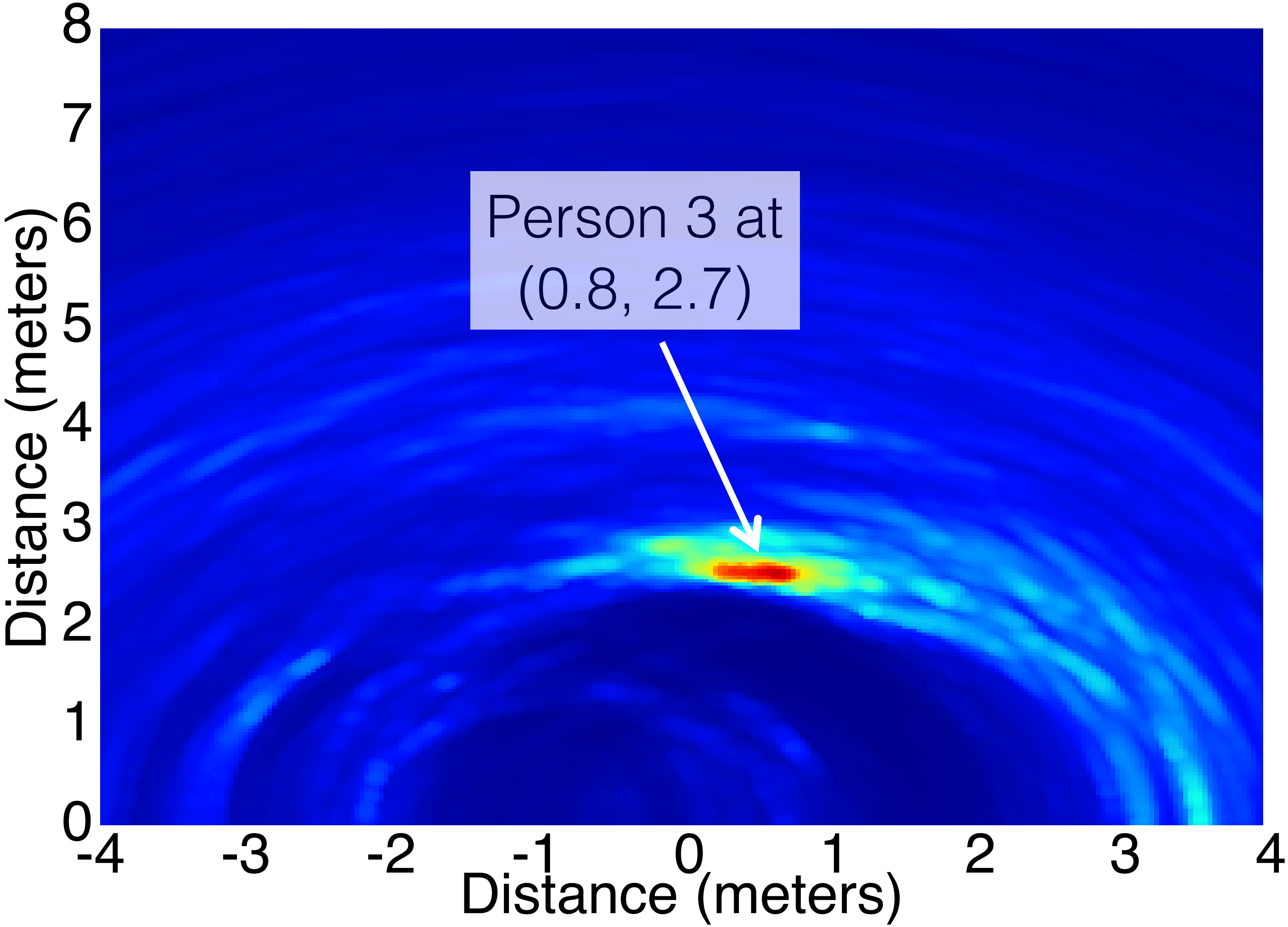
Cancel the impact of the person's whole body



After reconstructing and cancelling the first user's reflections



Iteratively localize the remaining users in the scene



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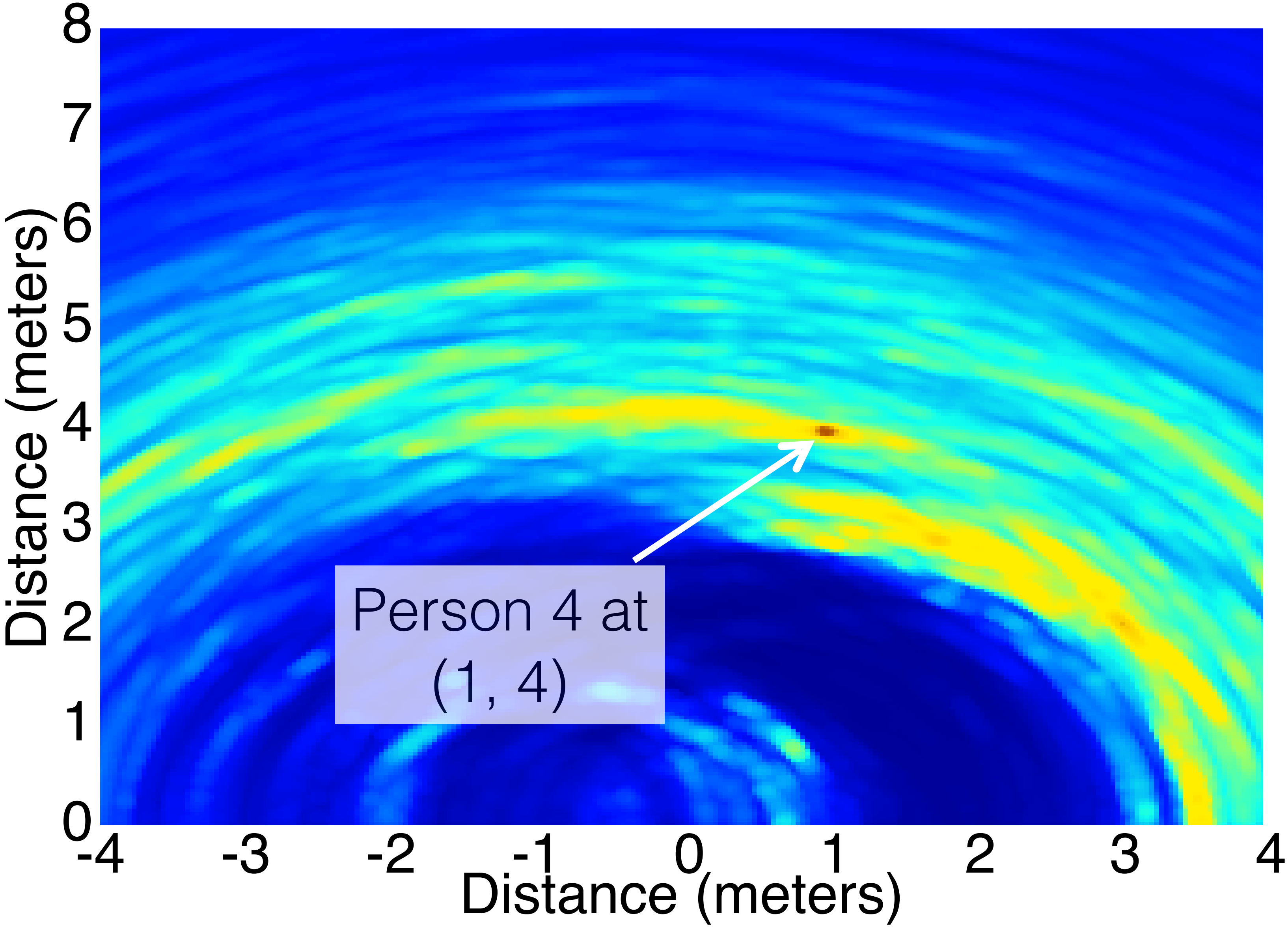
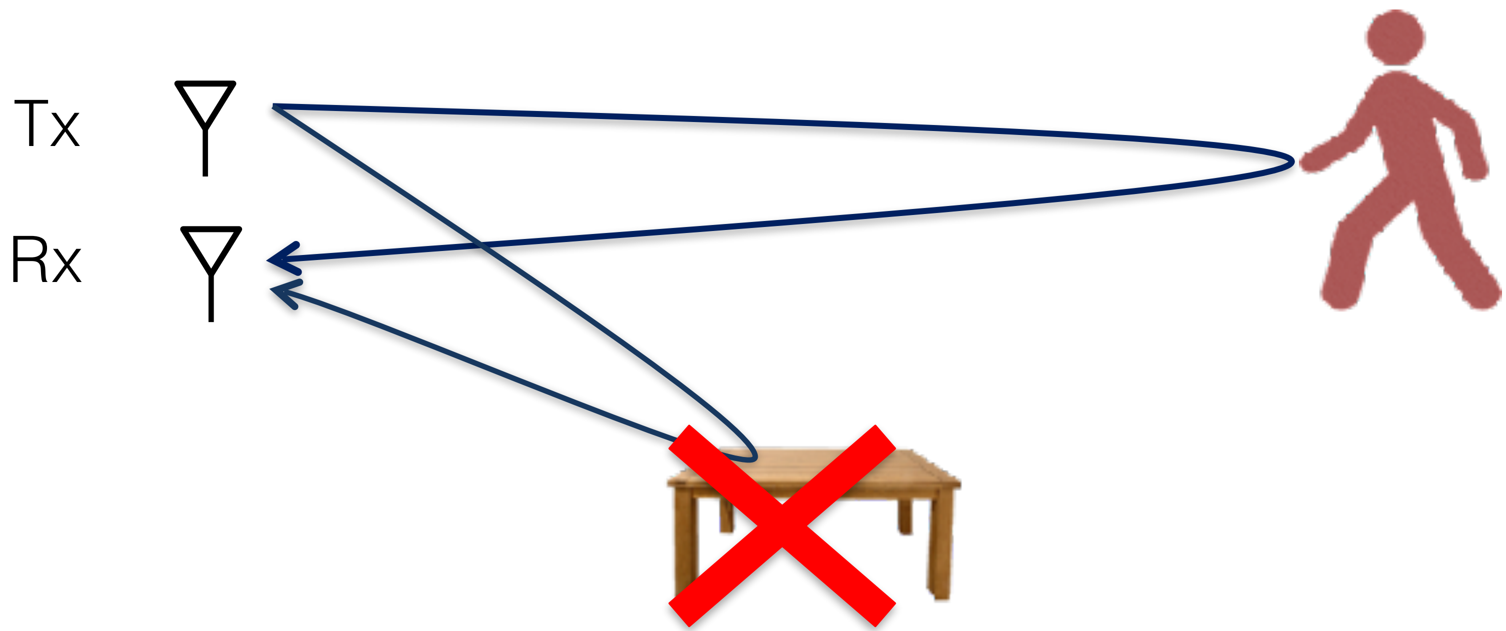


How can we localize static users?

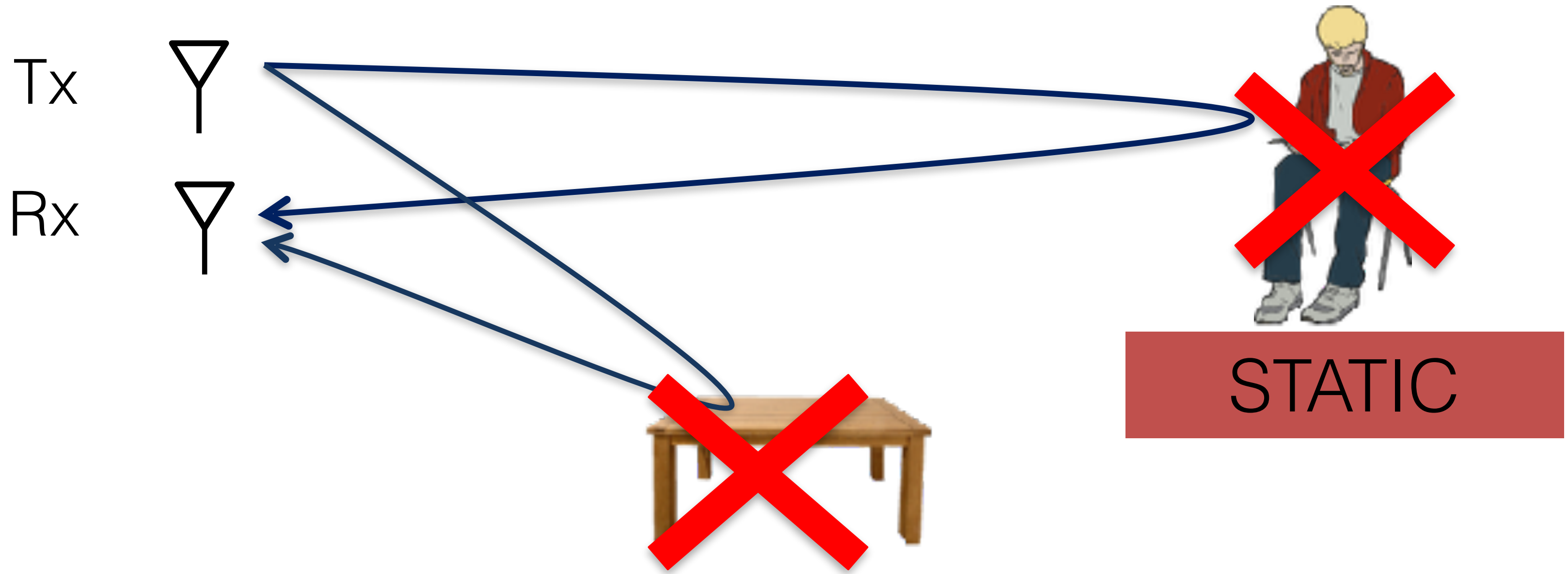
Dealing with multi-path when there is one moving user



We eliminated direct table reflections by subtracting consecutive measurements

Needs User to Move

Dealing with multi-path when there is one moving user



We eliminated direct table reflections by subtracting consecutive measurements

Needs User to Move

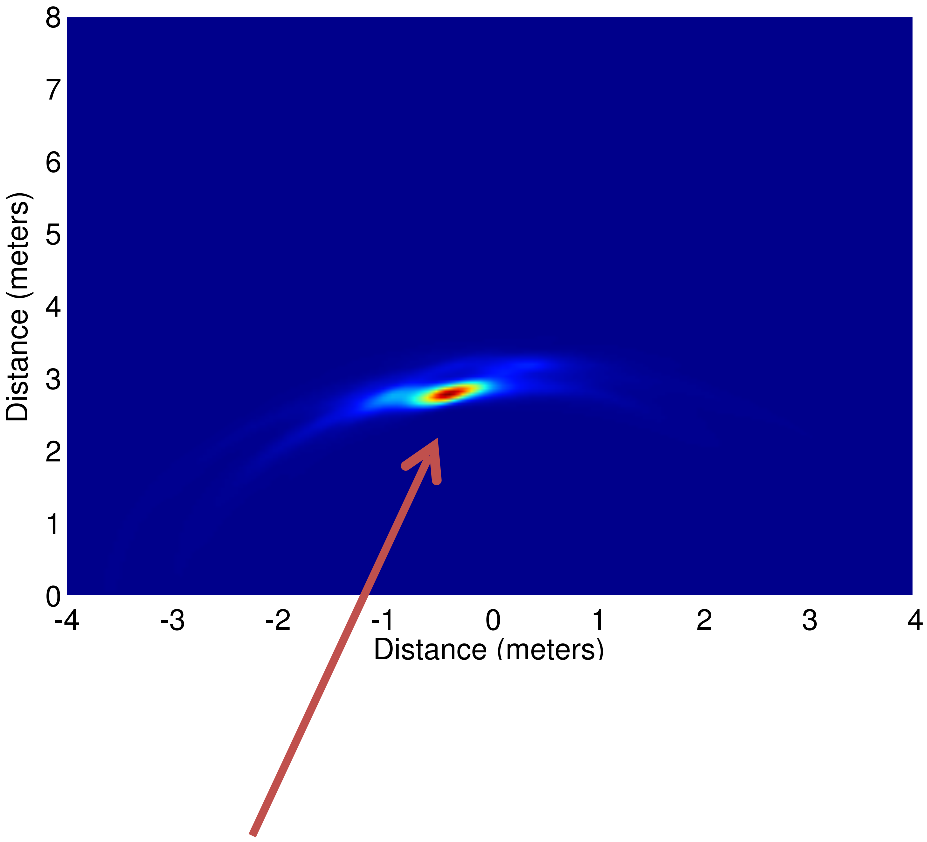
Exploit breathing motion for localize static users

- Breathing and walking happen at different time scales
  - A user that is pacing moves at 1m/s
  - When you breathe, chest moves by few mm/s

- Cannot use the same subtraction window to eliminate multi-path

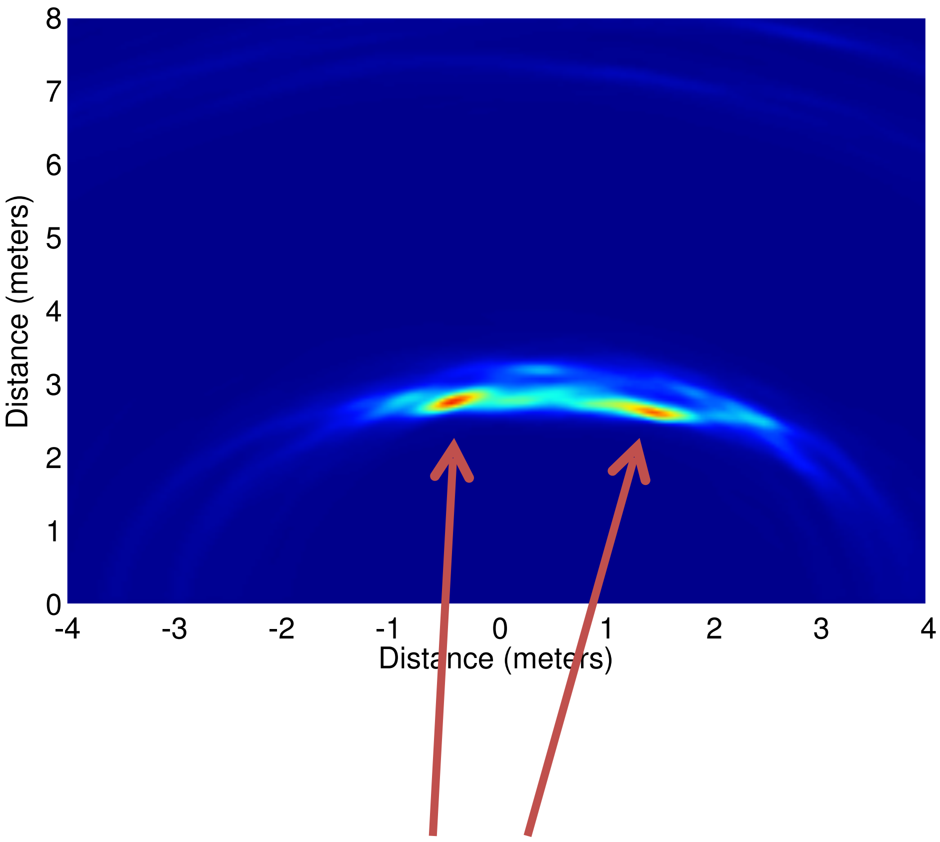
User Walking at 1m/s

30ms subtraction window



Localize the person

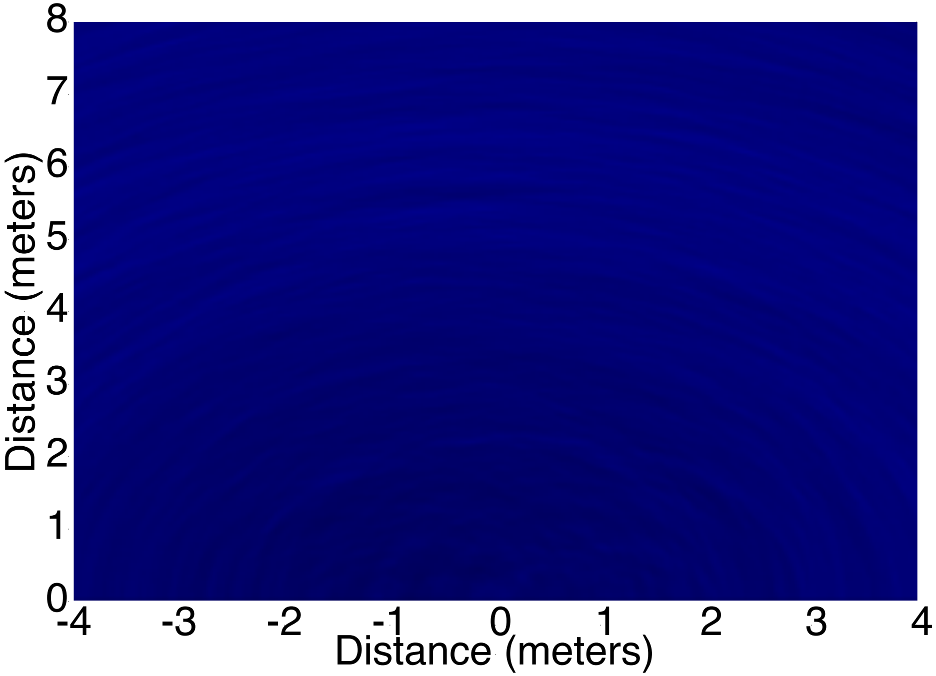
3s subtraction window



Person appears in two locations

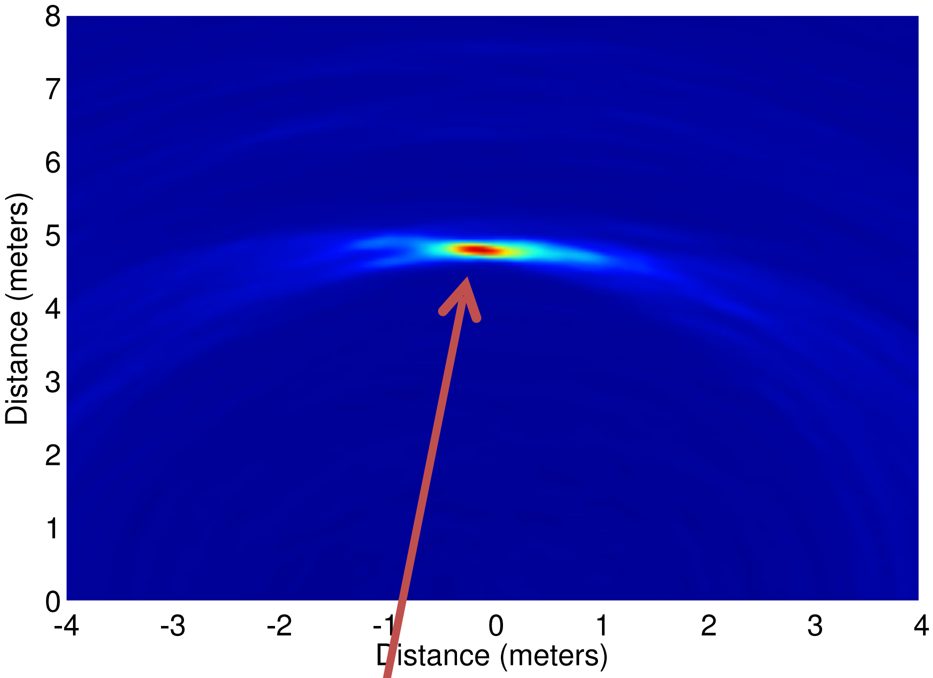
User Sitting Still (Breathing)

30ms subtraction window



Cannot localize

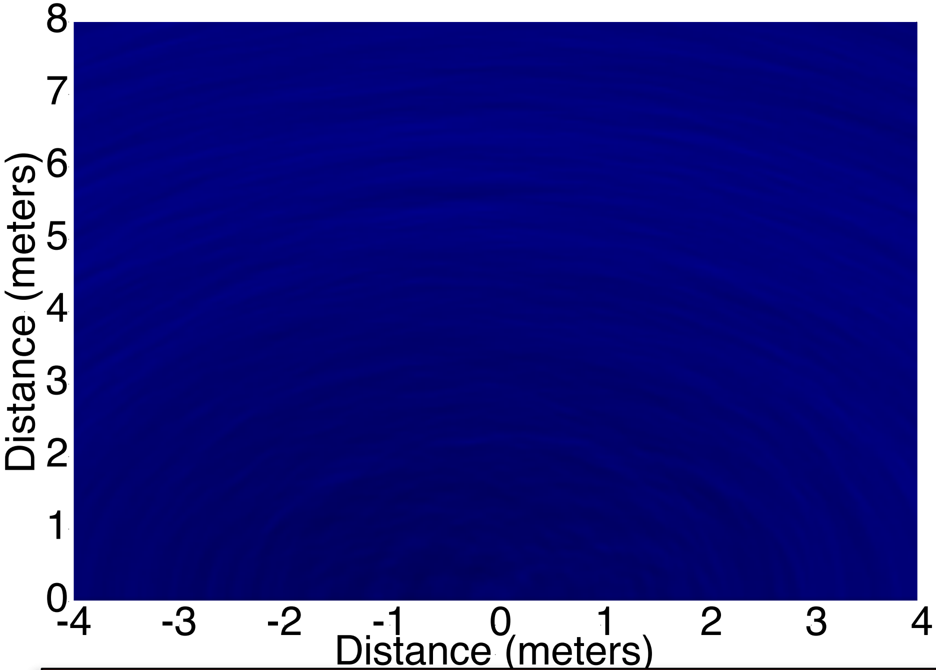
3s subtraction window



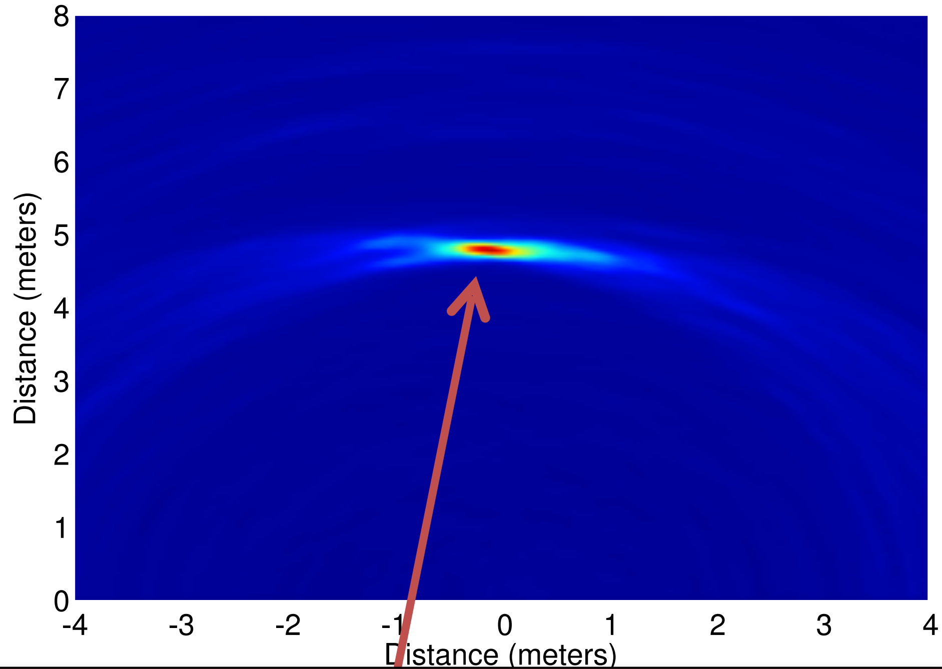
Localize the person

User Sitting Still (Breathing)

30ms subtraction window

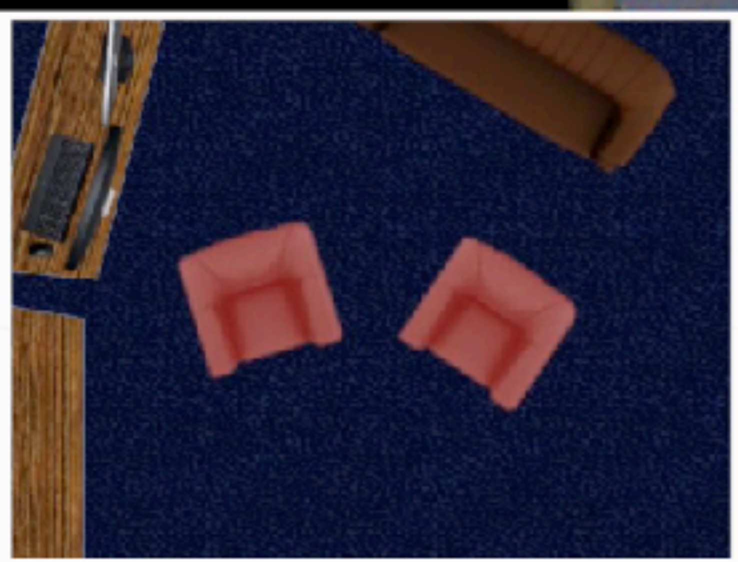


3s subtraction window

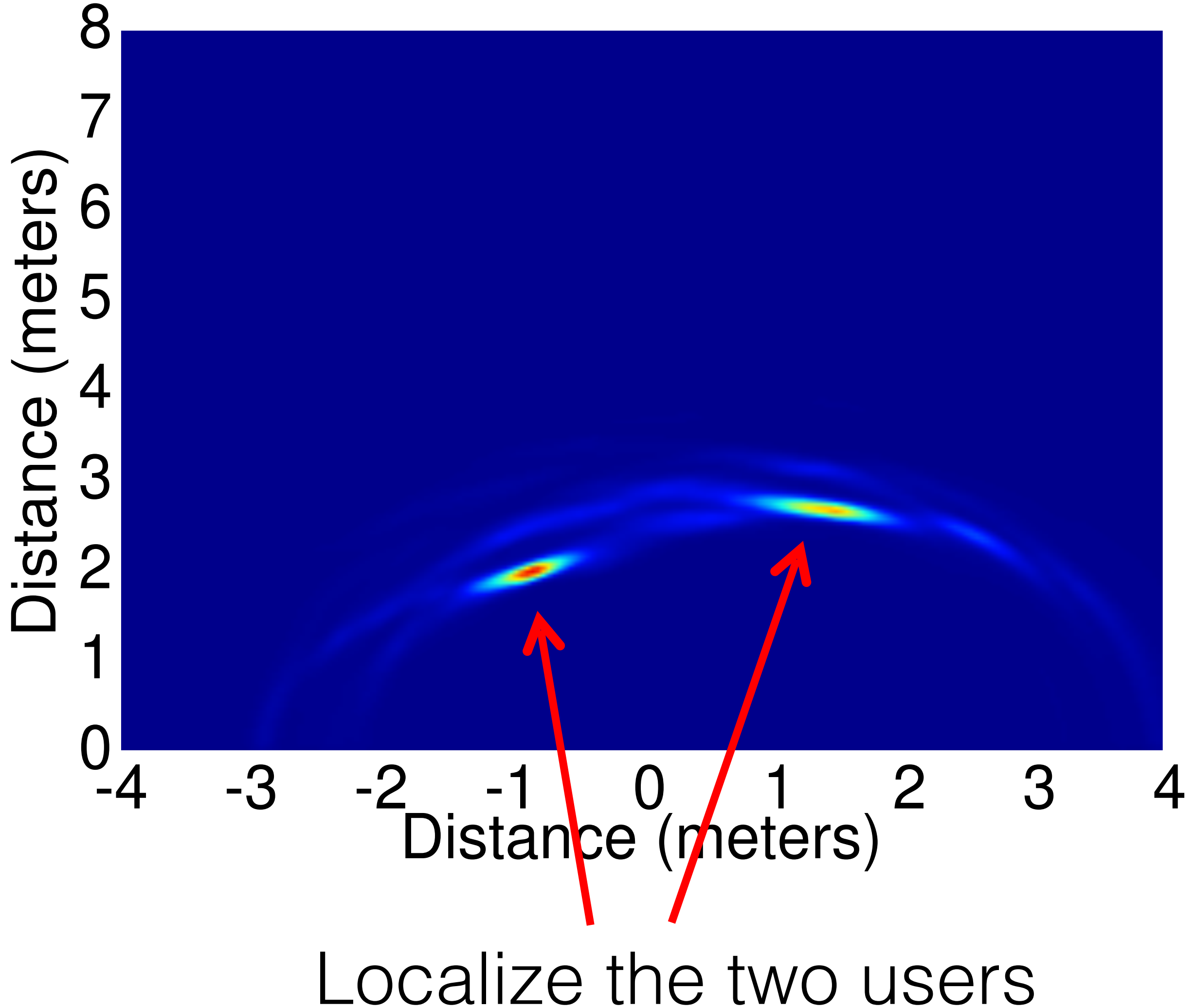


Use multi-resolution subtraction window to eliminate multi-path while being able to localize both static and moving users


MIT

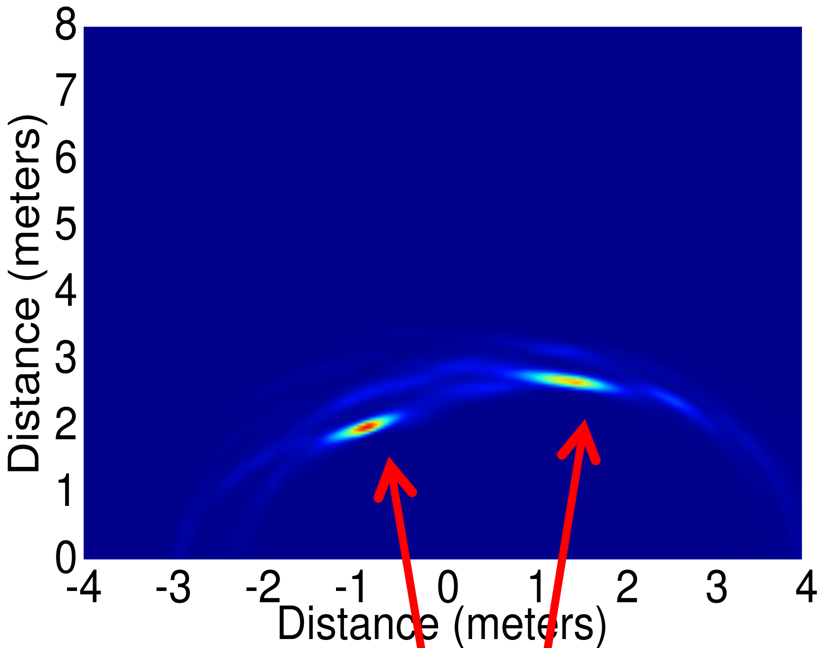


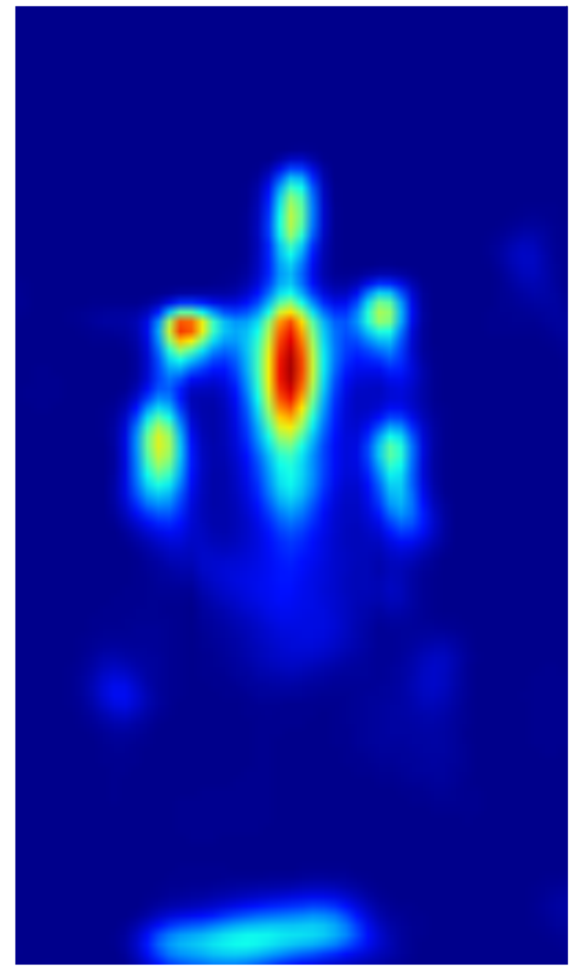
Centimeter-scale localization without requiring the user to carry a wireless device



Want a silhouette

People are points

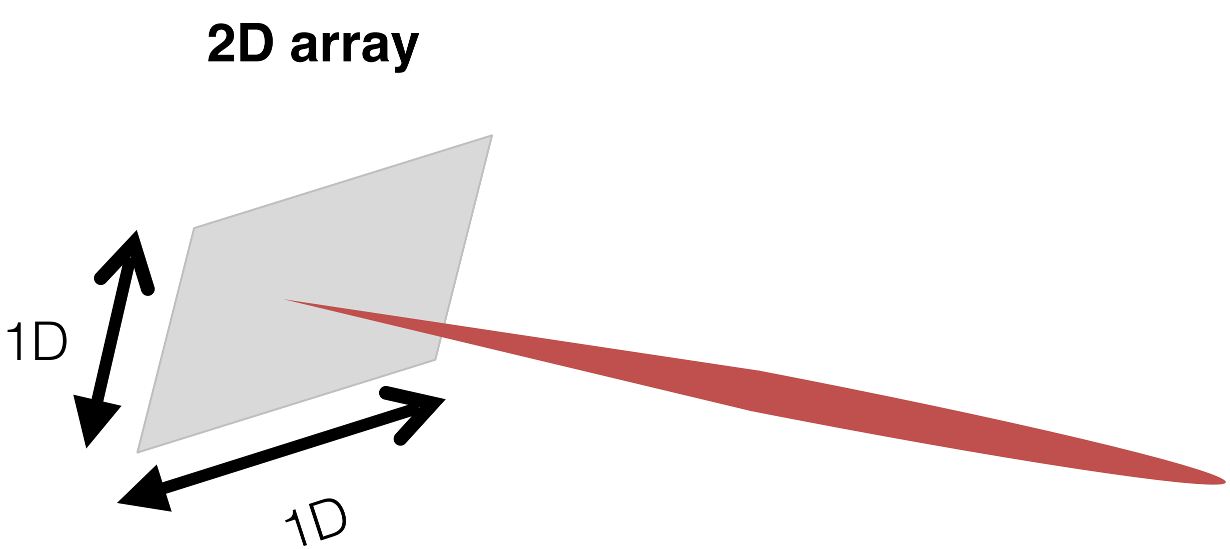




Localize the two users

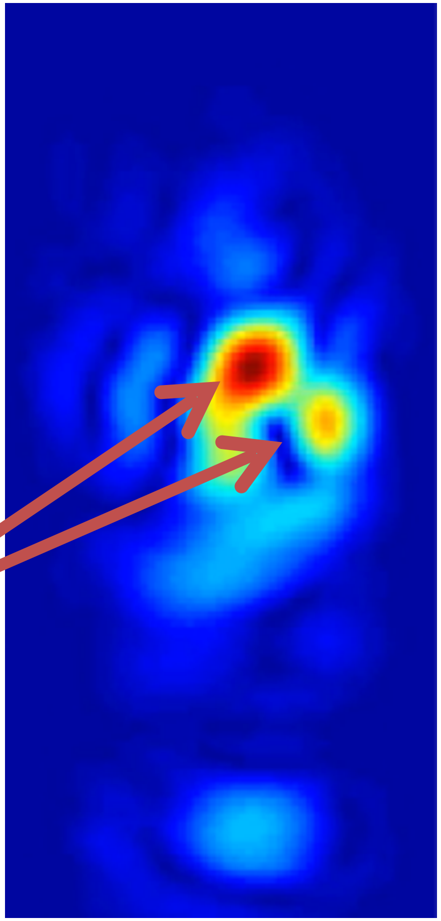
Approach: Combine antenna arrays with FMCW to get 3D image

- 2D Antenna array gives 2 angles
- FMCW gives depth (1D)



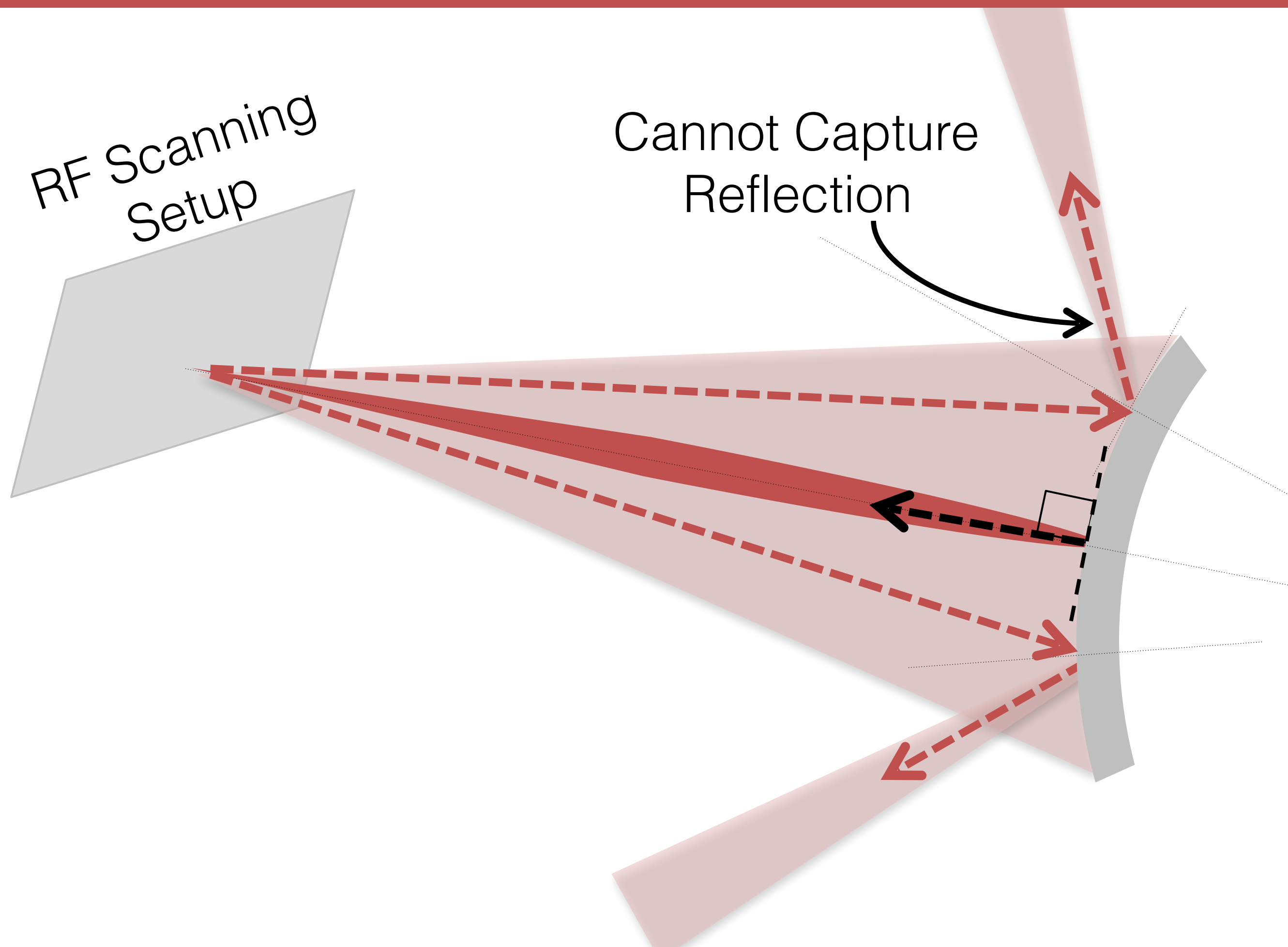
Challenge: We only obtain blobs in space

Output of 3D RF Scan

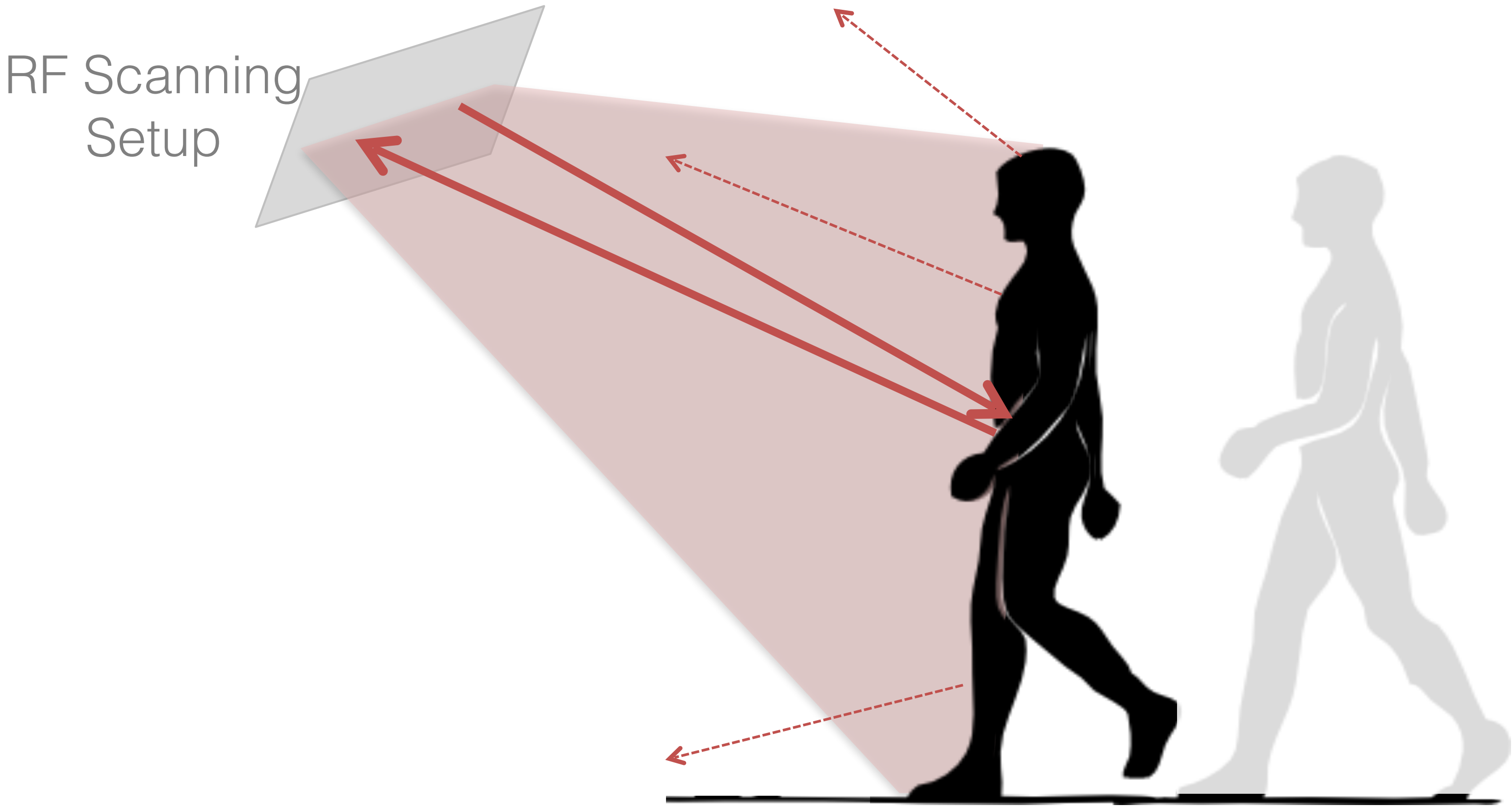


Blobs of
reflection power

At every point in time, we get reflections from only a subset of body parts.



Solution Idea: Exploit Human Motion and Aggregate over Time



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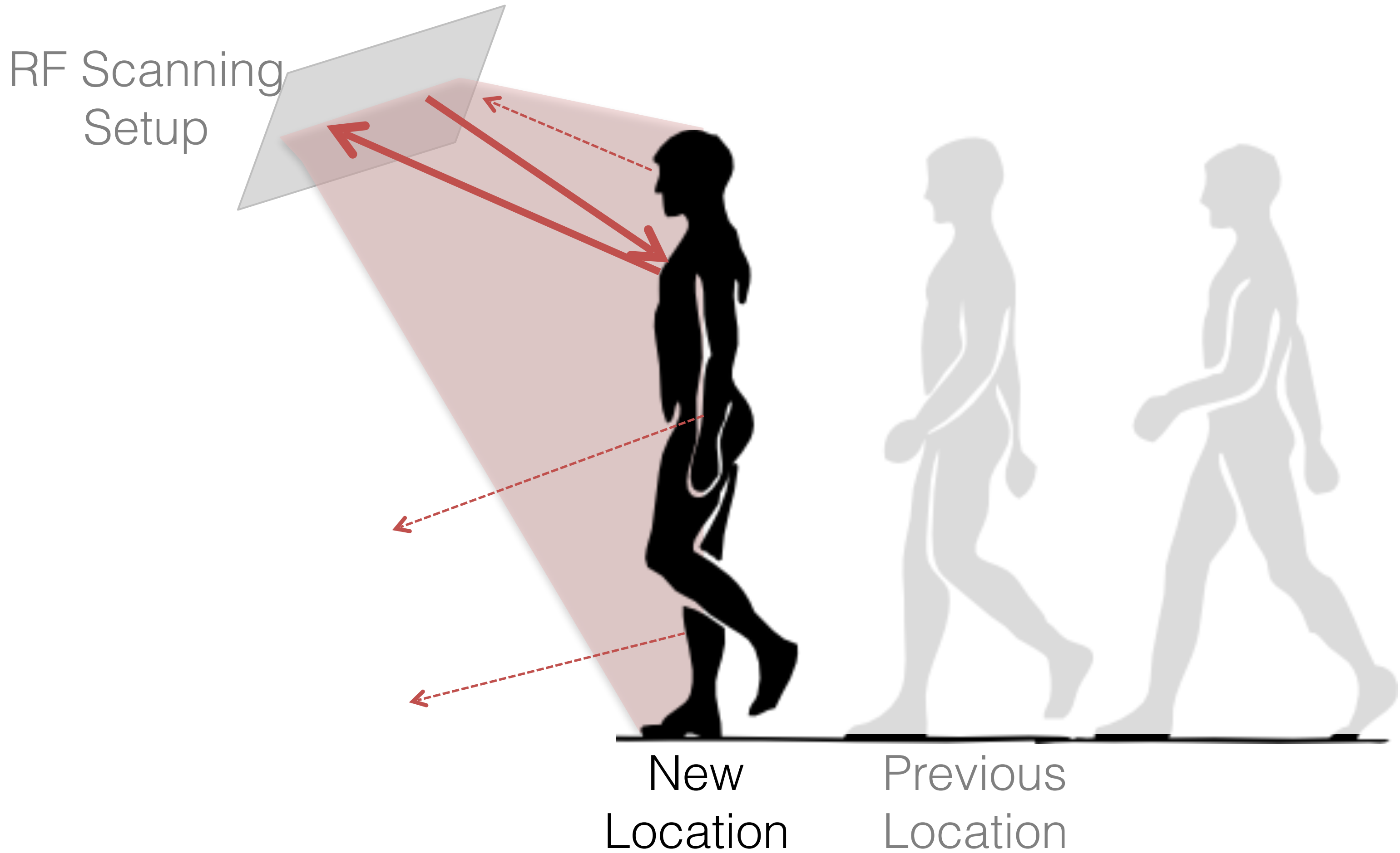
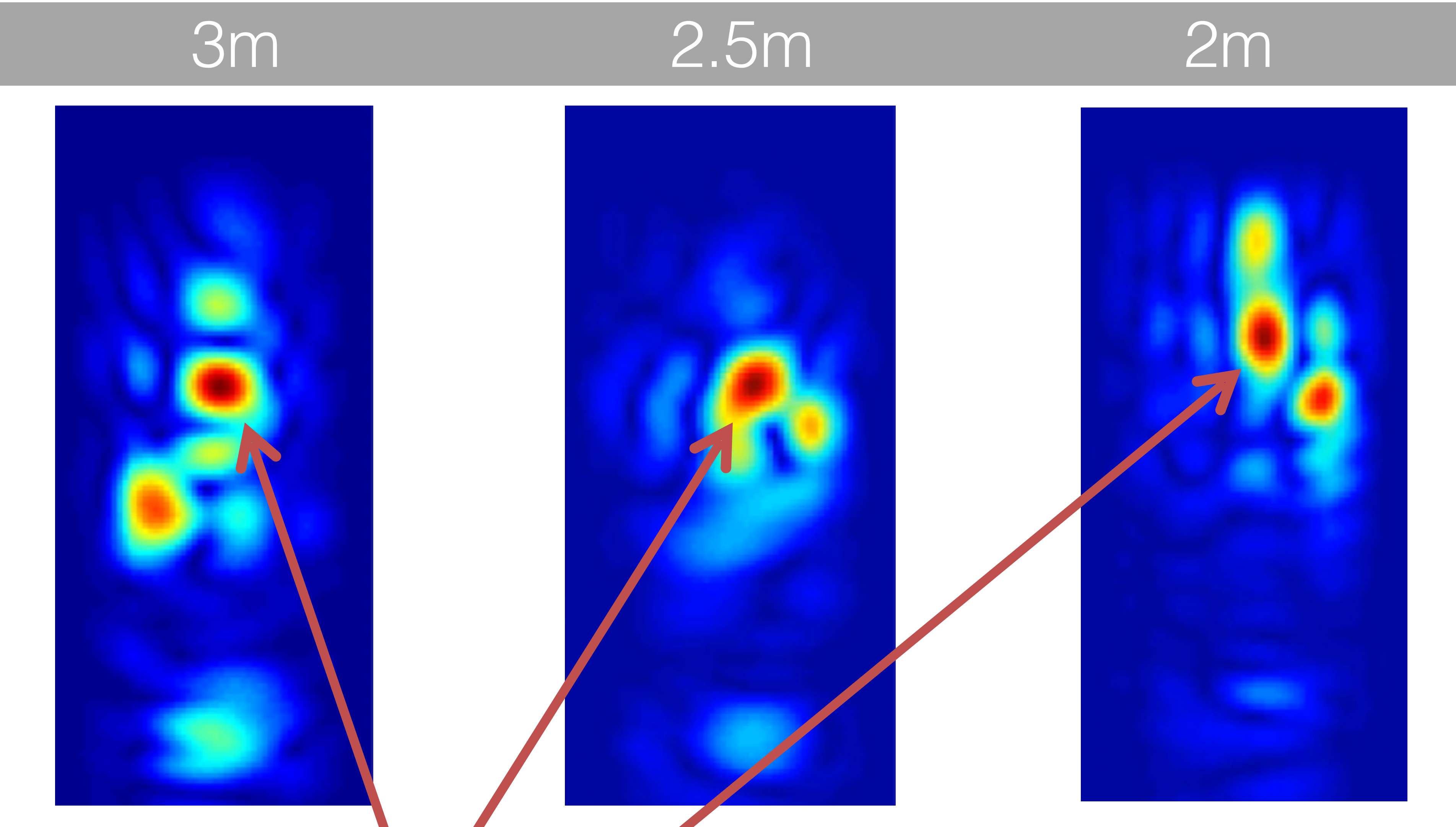


Combine the various snapshots

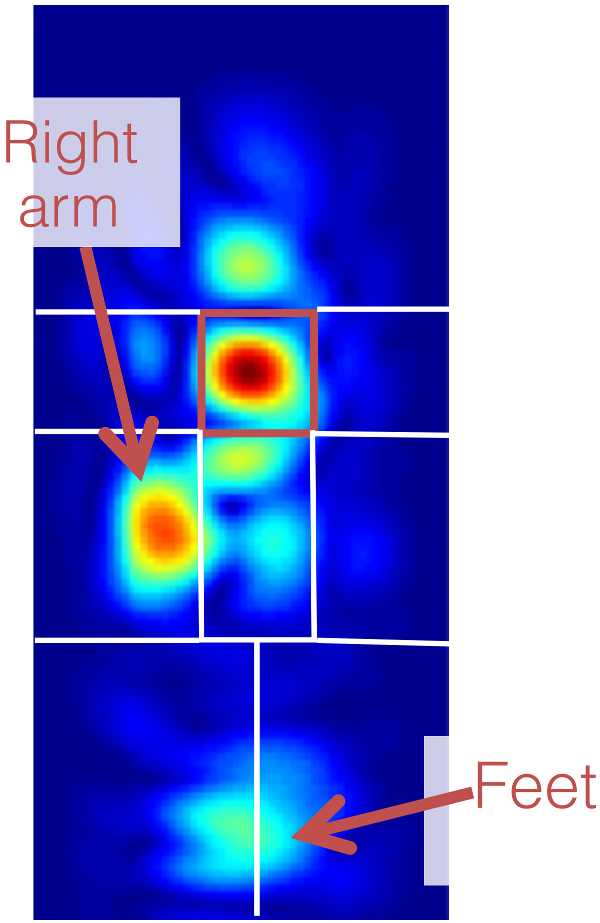
Human Walks toward Sensor



Chest (Largest Convex Reflector) → Use it as a pivot: for motion compensation and segmentation

Human Walks toward Sensor

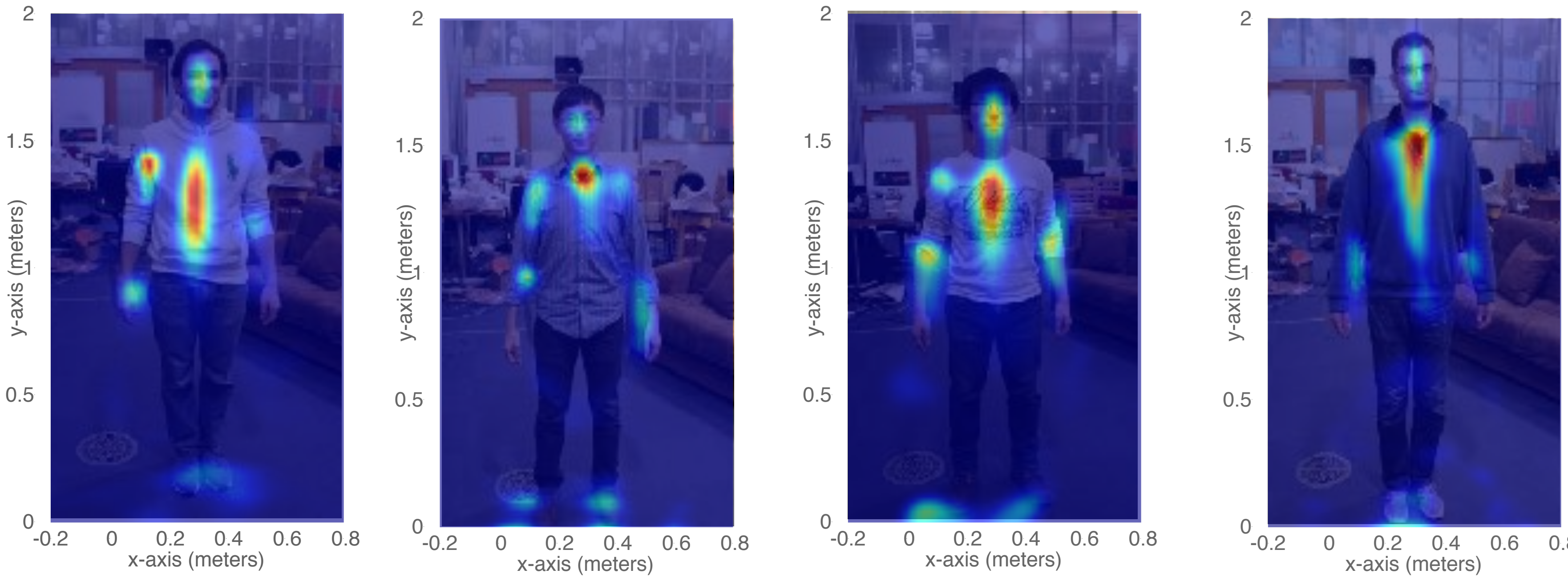
3m	2.5m	2m



Combine the various snapshots

Human Walks toward Sensor

Sample Captured Figures through Walls



Through-wall classification accuracy of 90% among 13 users