# 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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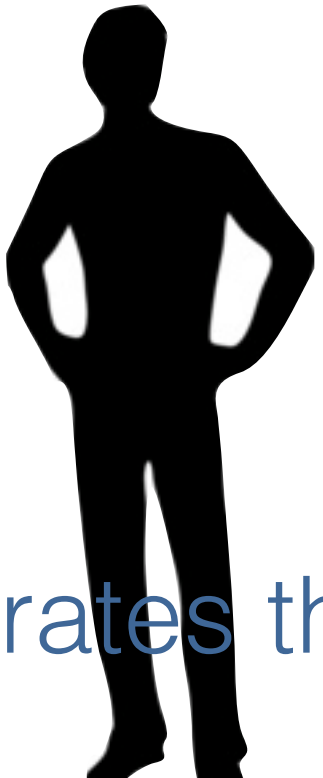
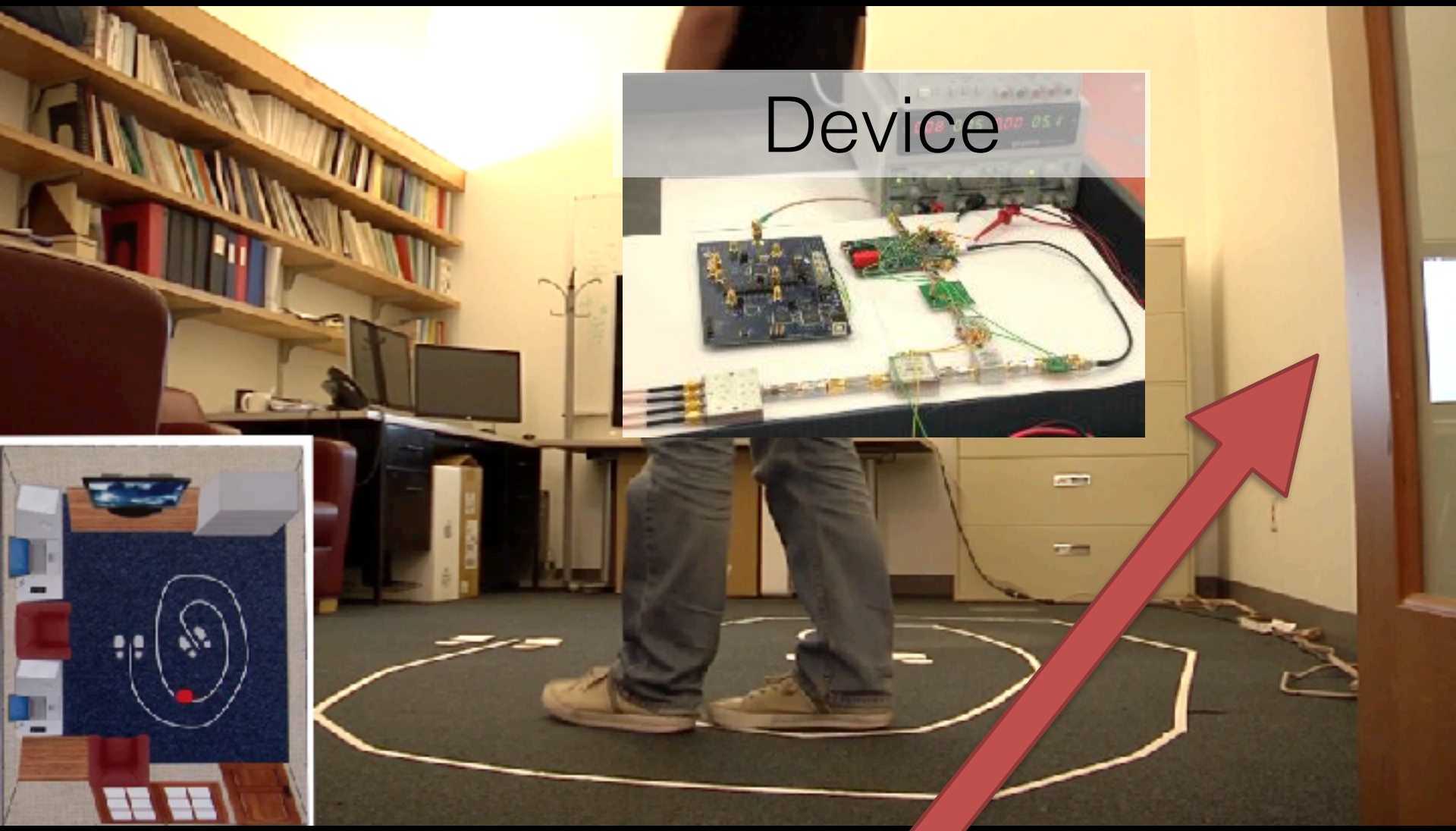


- Location
- Vital Signs
- Gestures

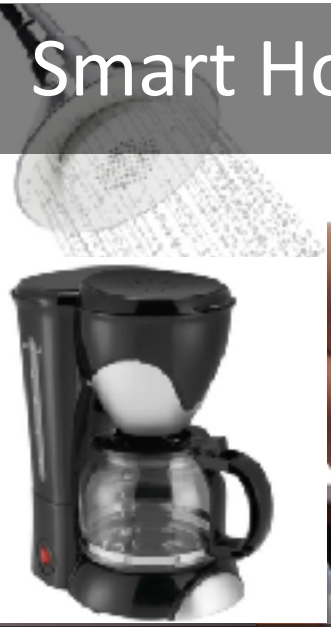
Operates through occlusions

# Example: WiTrack


Device
Device in another room

# Applications

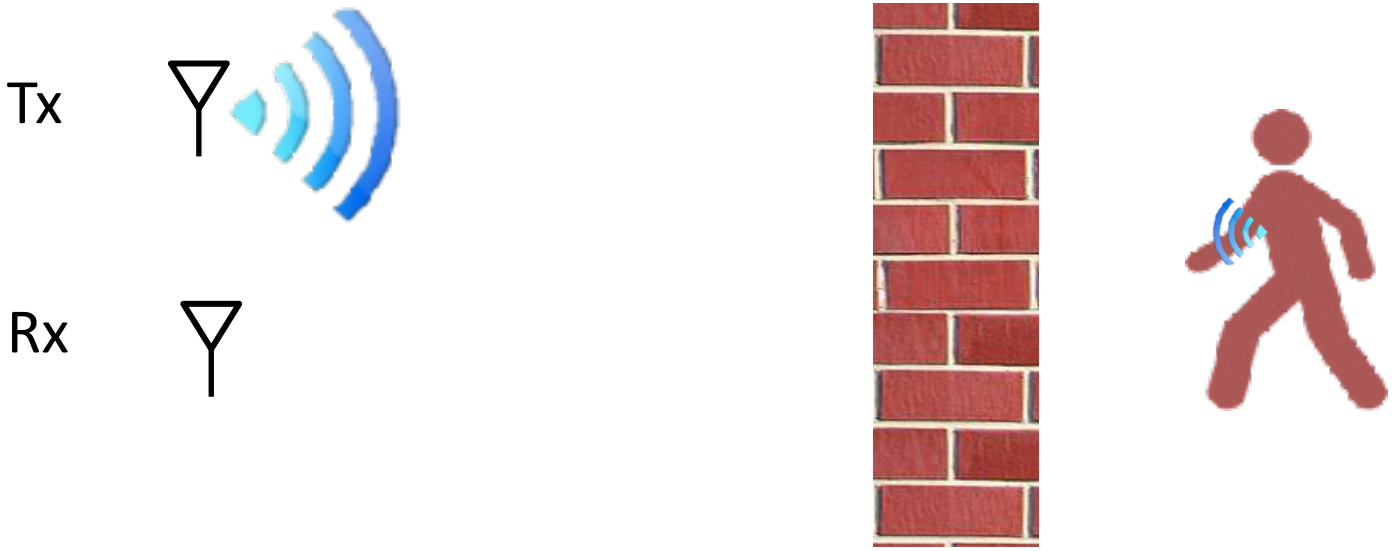
## Smart Homes



## Energy Saving

## Gaming & Virtual Reality

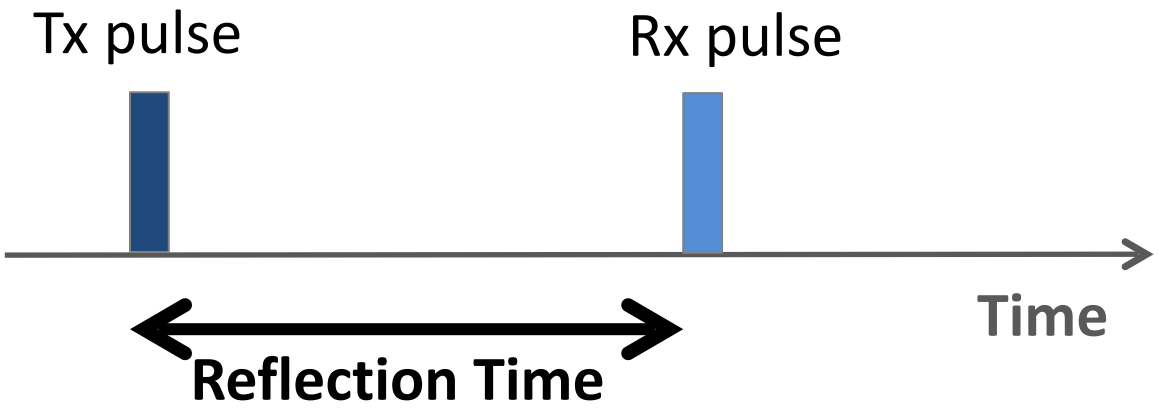
# Measuring Distances




Distance = Reflection time x speed of light

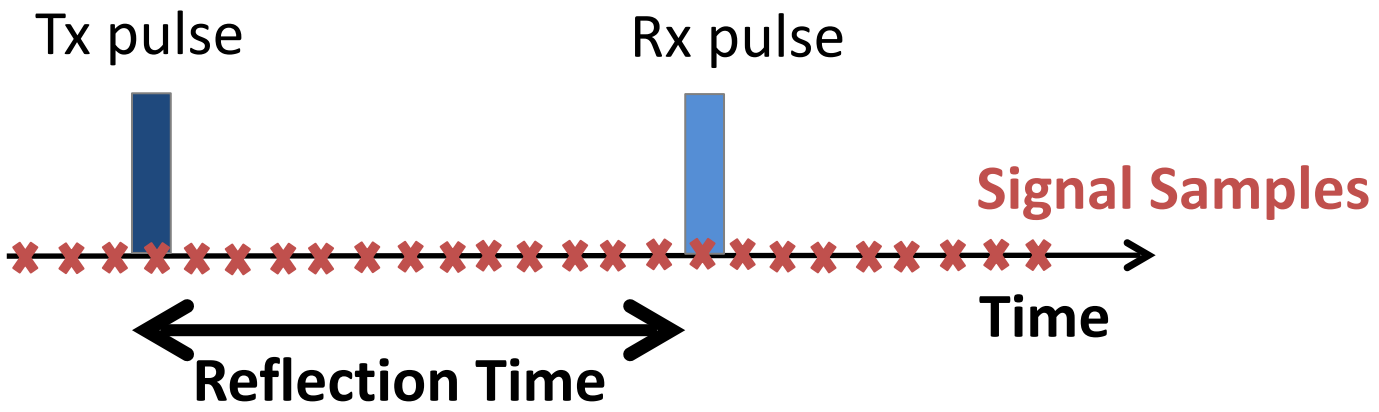
# Measuring Reflection Time

<u>Option1:</u> Transmit short pulse and listen for echo



# Measuring Reflection Time

Option1: Transmit short pulse and listen for echo

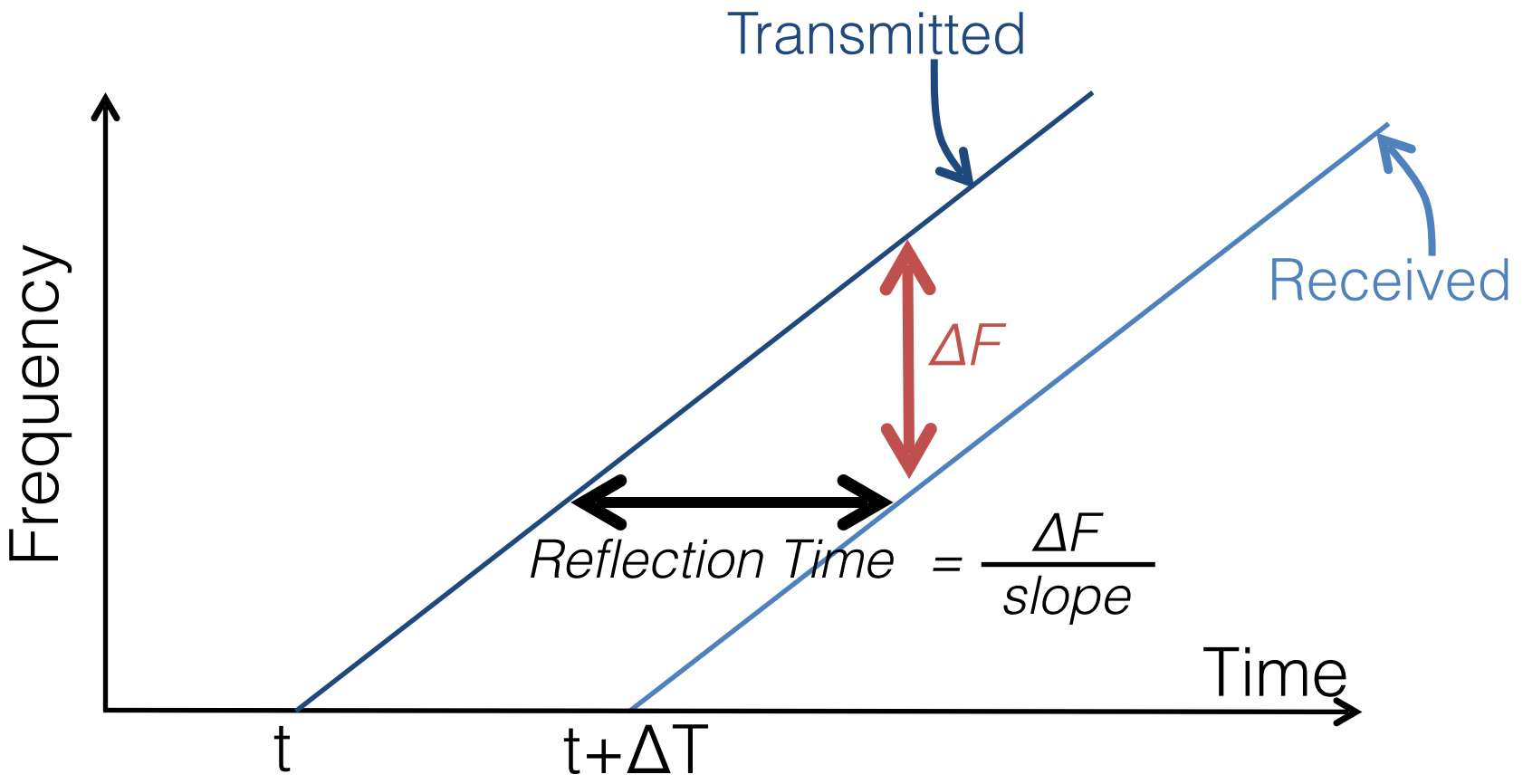



**Capturing the pulse needs sub-nanosecond sampling**

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

# Why was this not a problem for Cricket?

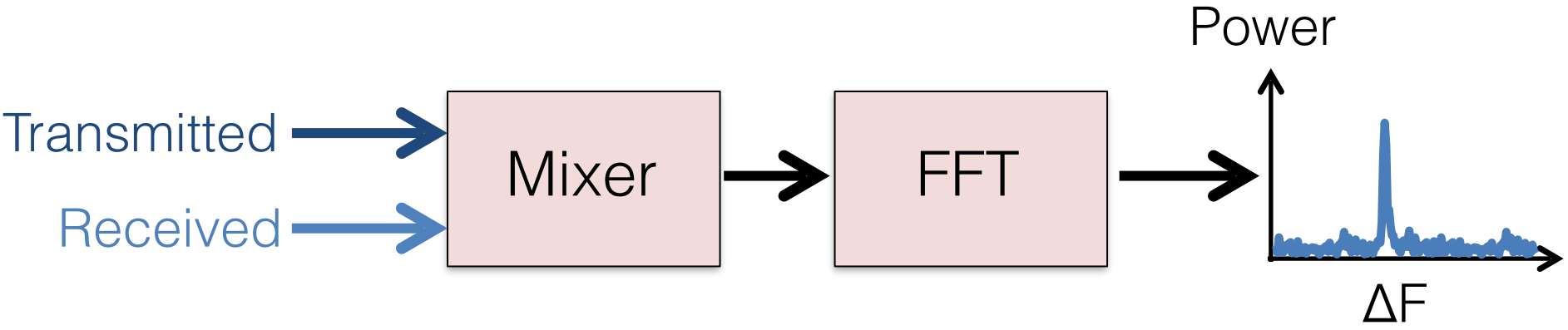
# FMCW: Measure time by measuring frequency




How do we measure ΔF?

# Measuring ΔF

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

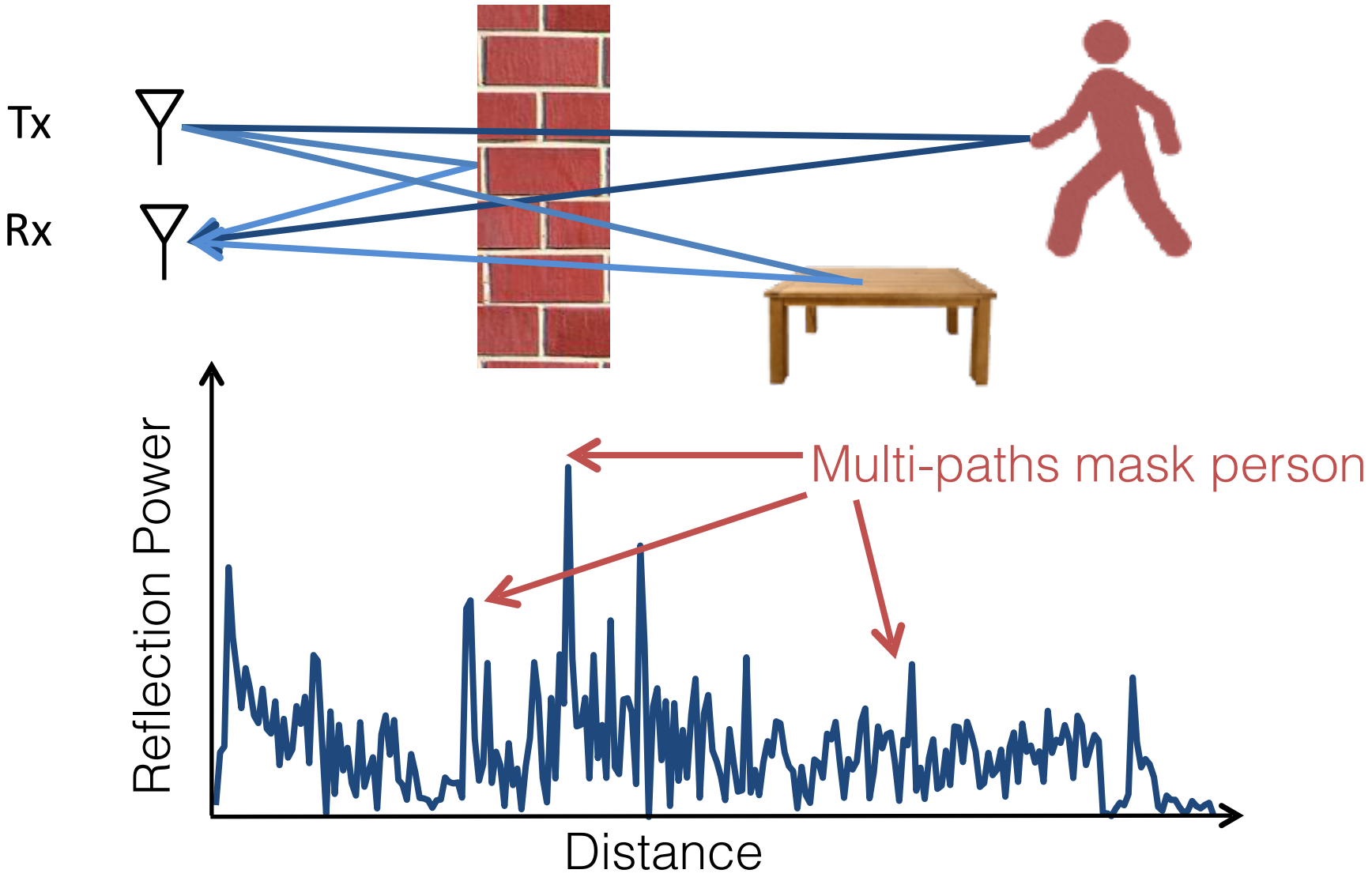



Signal whose frequency is ΔF

ΔF →Reflection Time → Distance

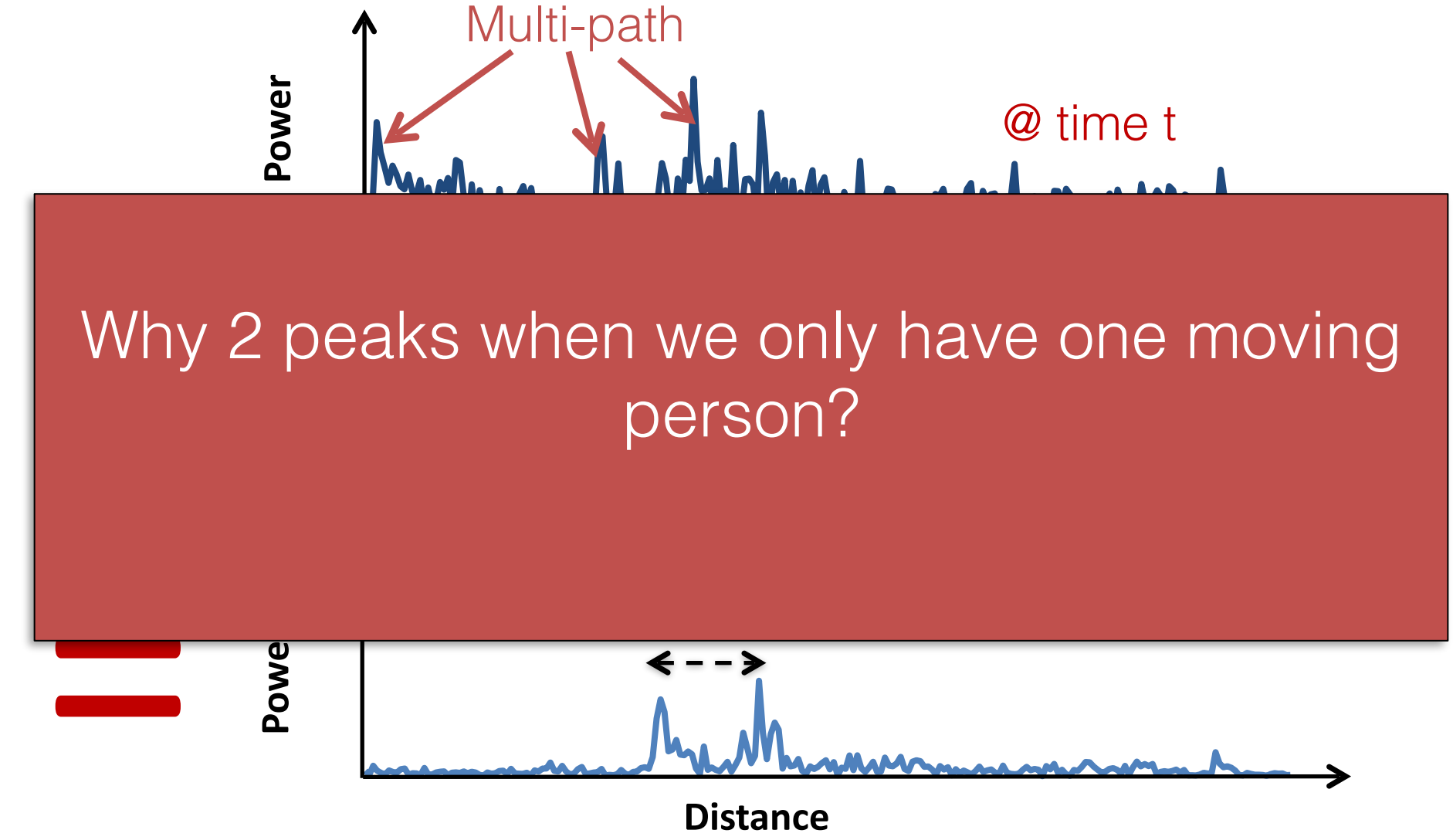
# What is the resolution of FMCW?

# Challenge: Multipath➔ Many Reflections

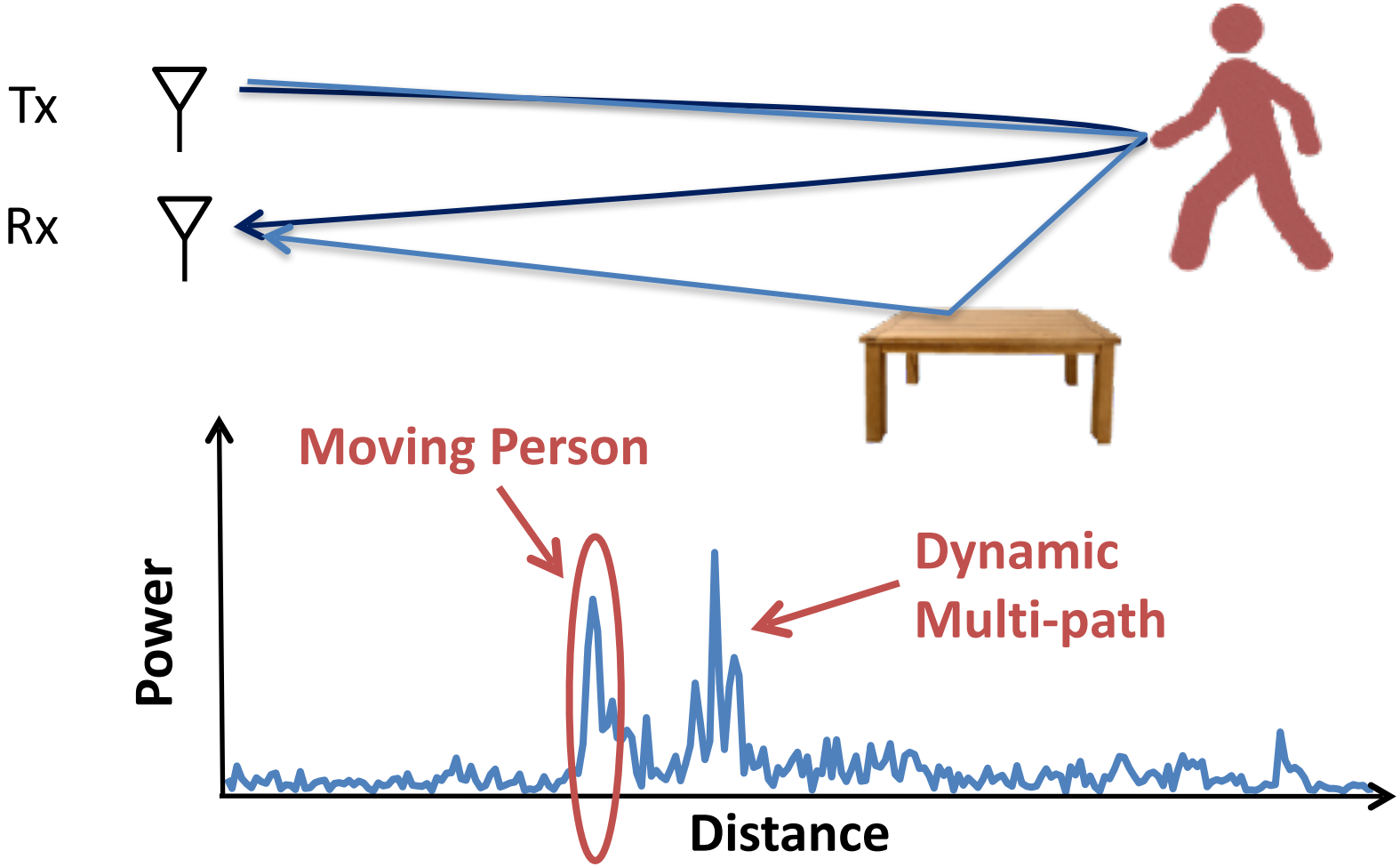


Static objects don't move

➔ Eliminate by subtracting consecutive measurements

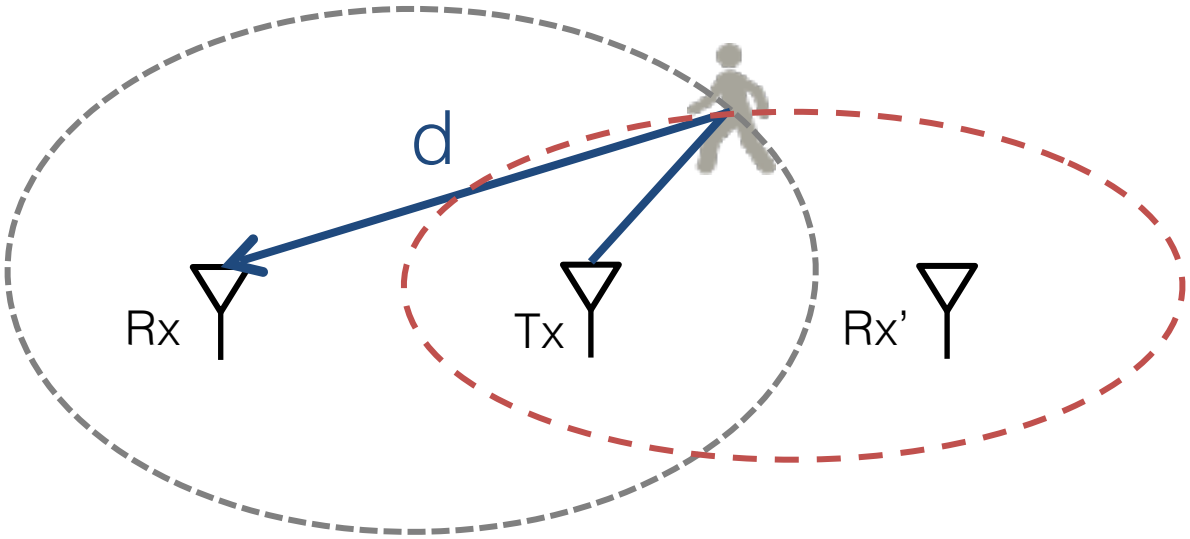


# The direct reflection arrives before dynamic multipath!



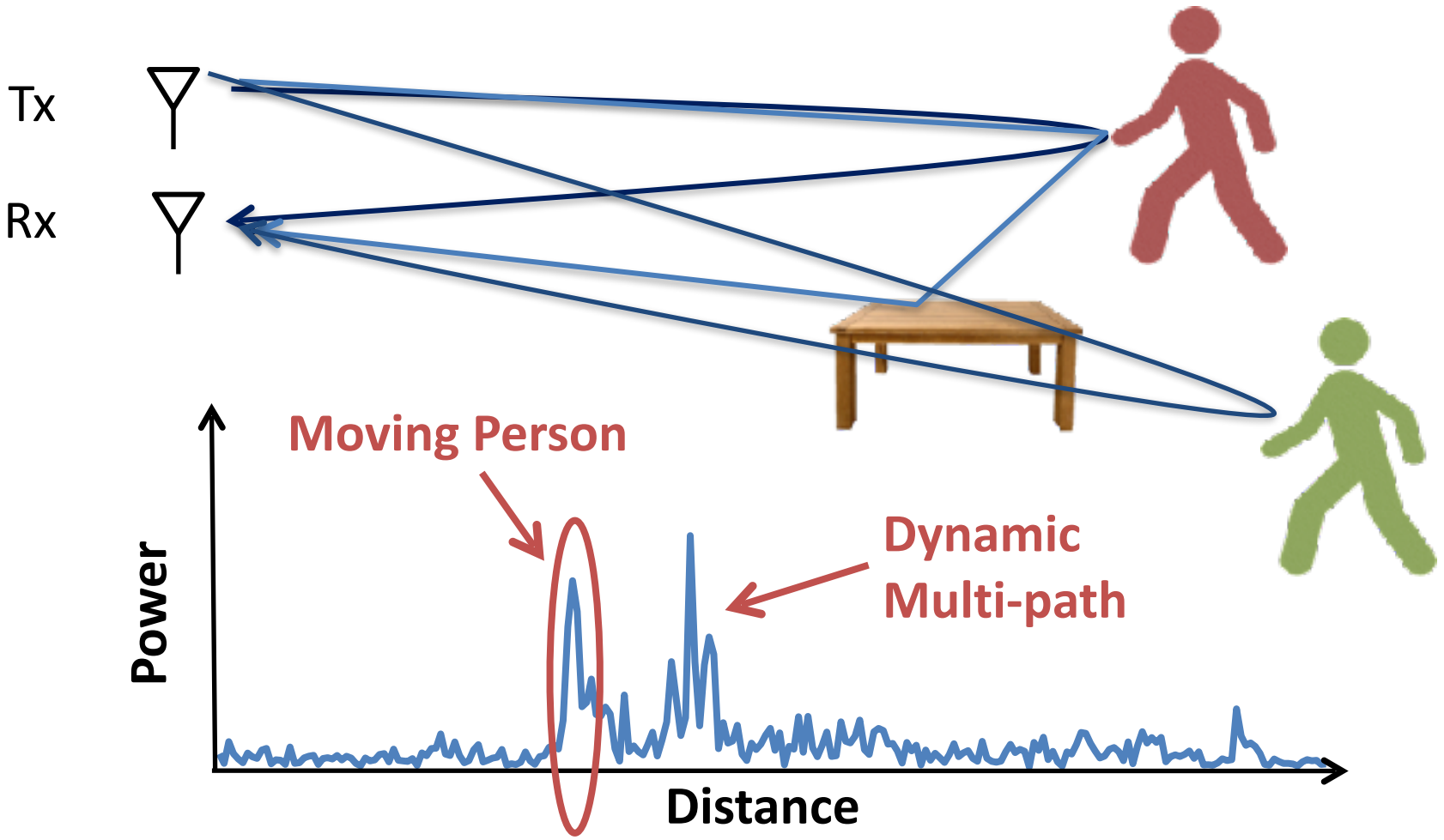
# Mapping Distance to Location

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

# 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?

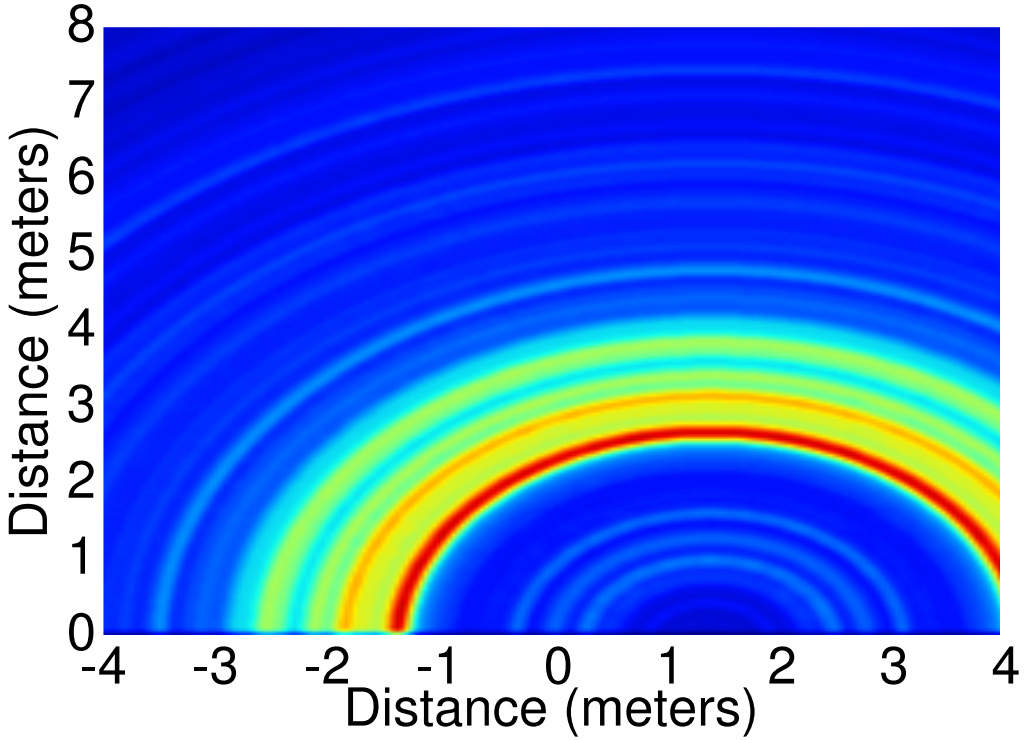
Idea: Person is consistent across different vantage points while multi-path is different from different vantage points

# Combining across Multiple Vantage Points

Experiment: Two users walking

Setup

Single Vantage Point



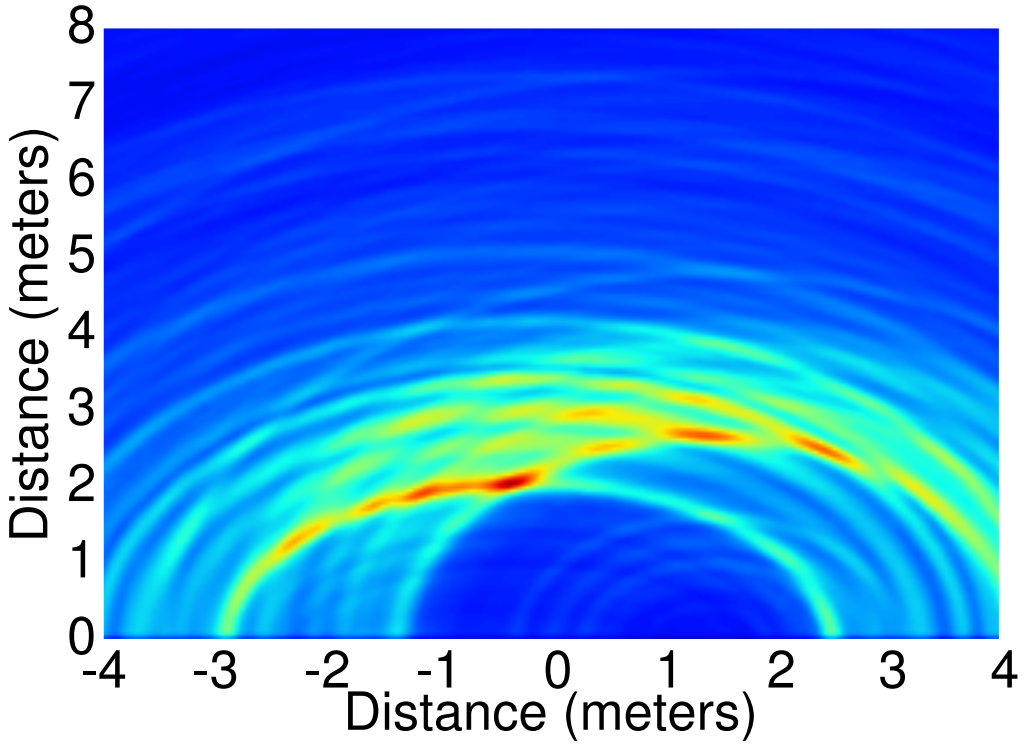

Mathematically: each round-trip distance can be mapped to an ellipse whose foci are the transmitter and the receiver

# Combining across Multiple Vantage Points

Experiment: Two users walking

Setup

Two Vantage Points

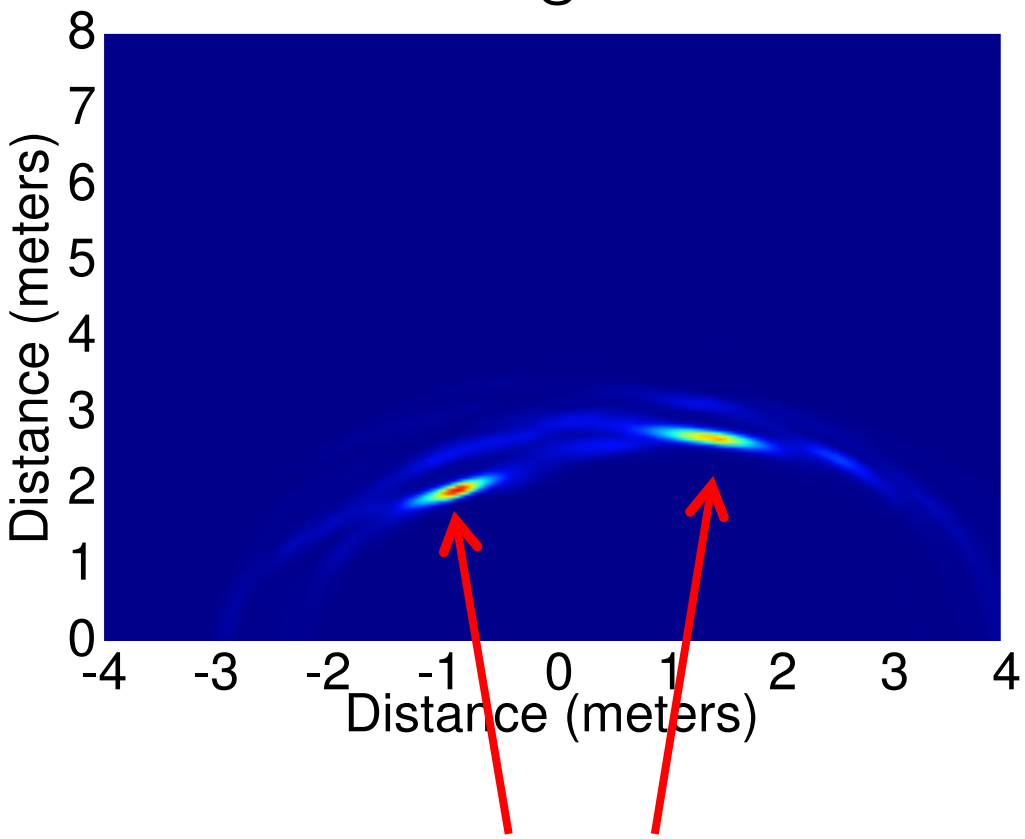


# Combining across Multiple Vantage Points

Experiment: Two users walking

Setup

16 Vantage Points

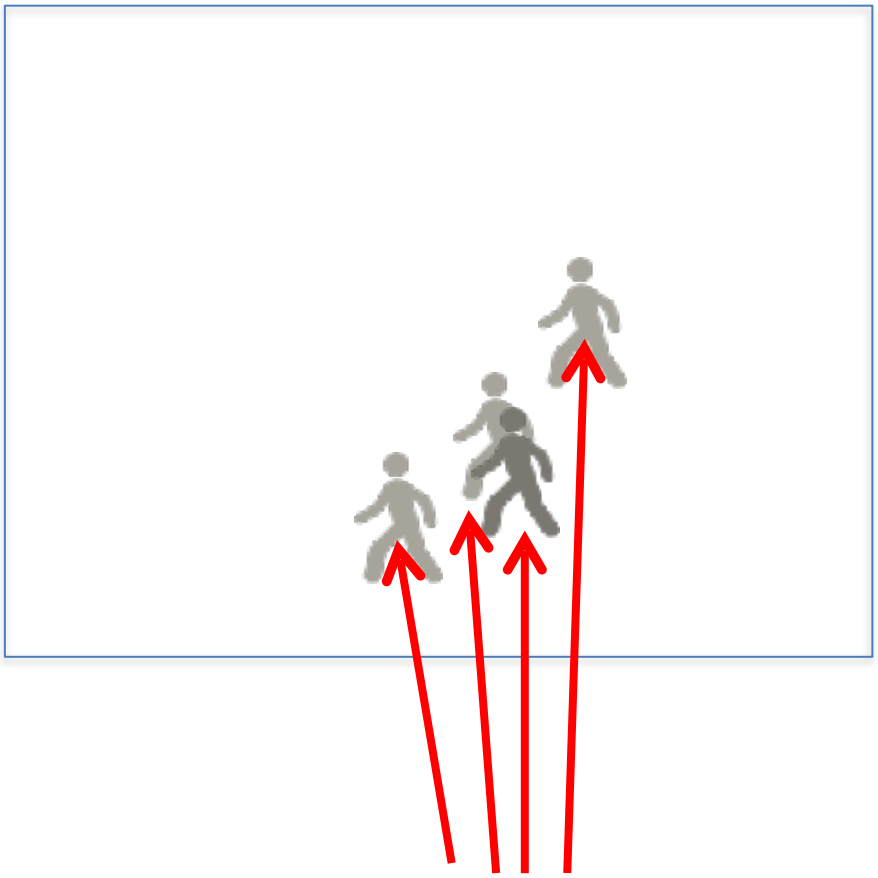



Localize the two users

# Multi-User Localization

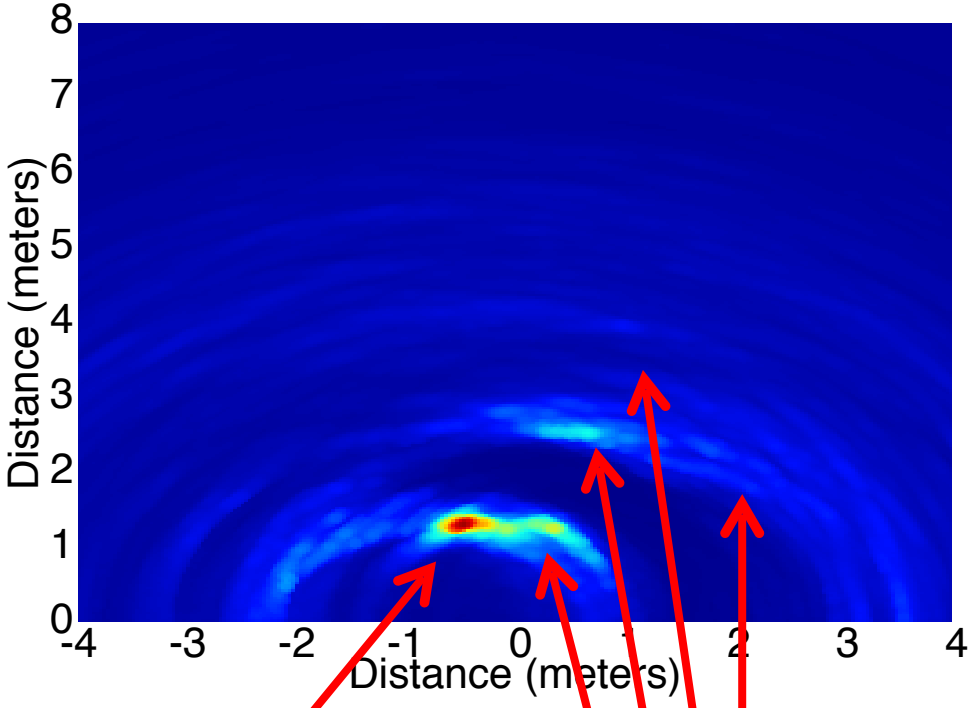
Experiment: Four persons walking

Setup



four persons

All Vantage Points

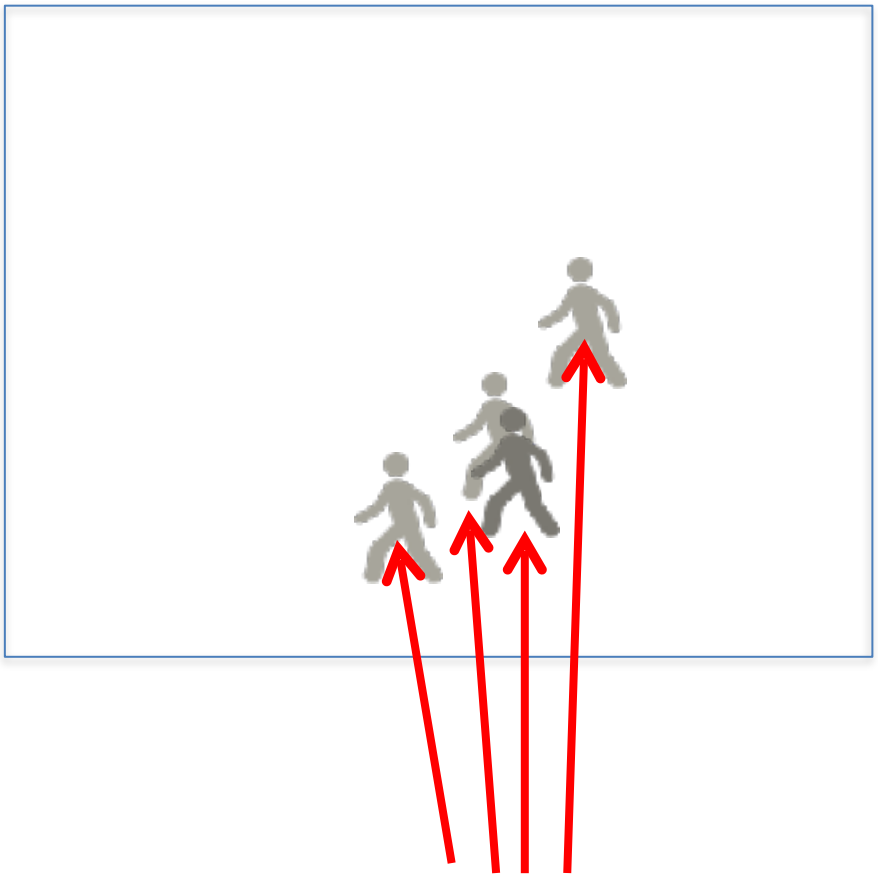



first person

other people or noise?

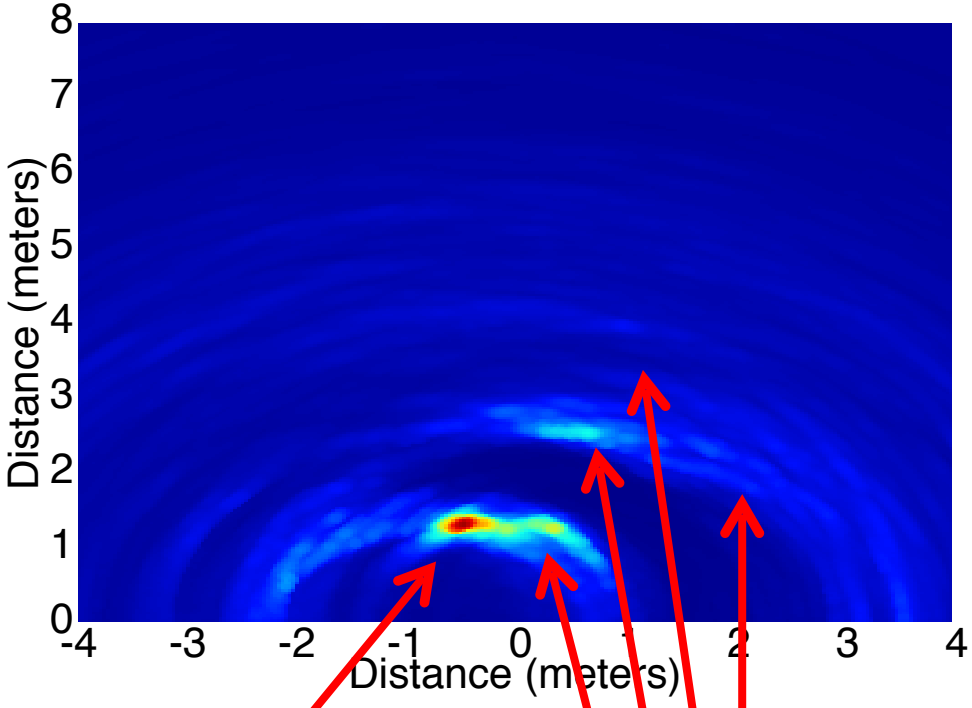
# Near-Far Problem: Nearby persons have more power than distance reflectors and can mask them

Setup



four persons

All Vantage Points




first person

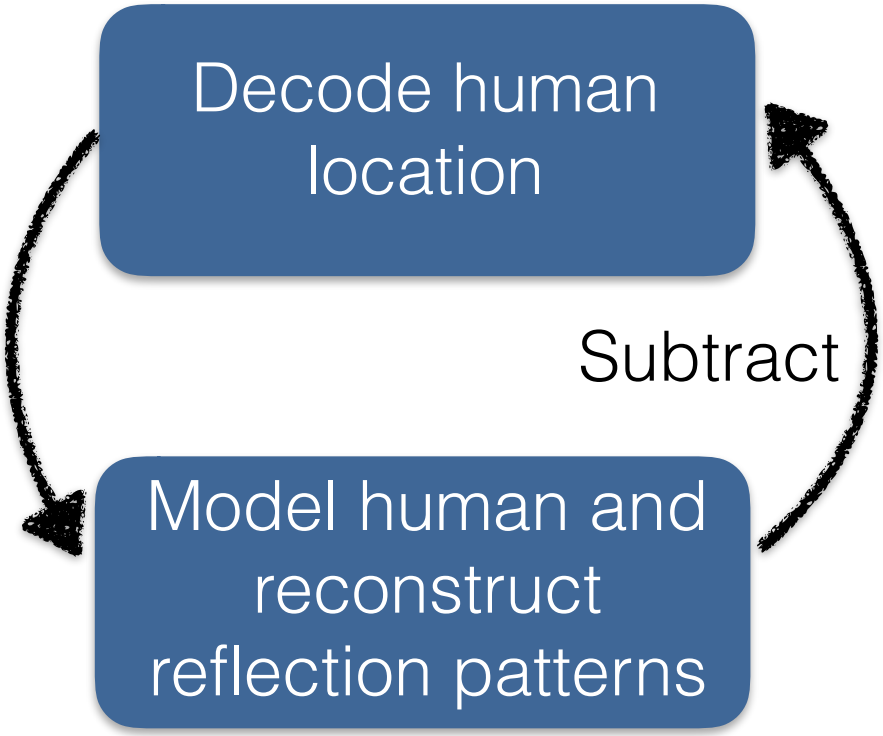
other people or noise?

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

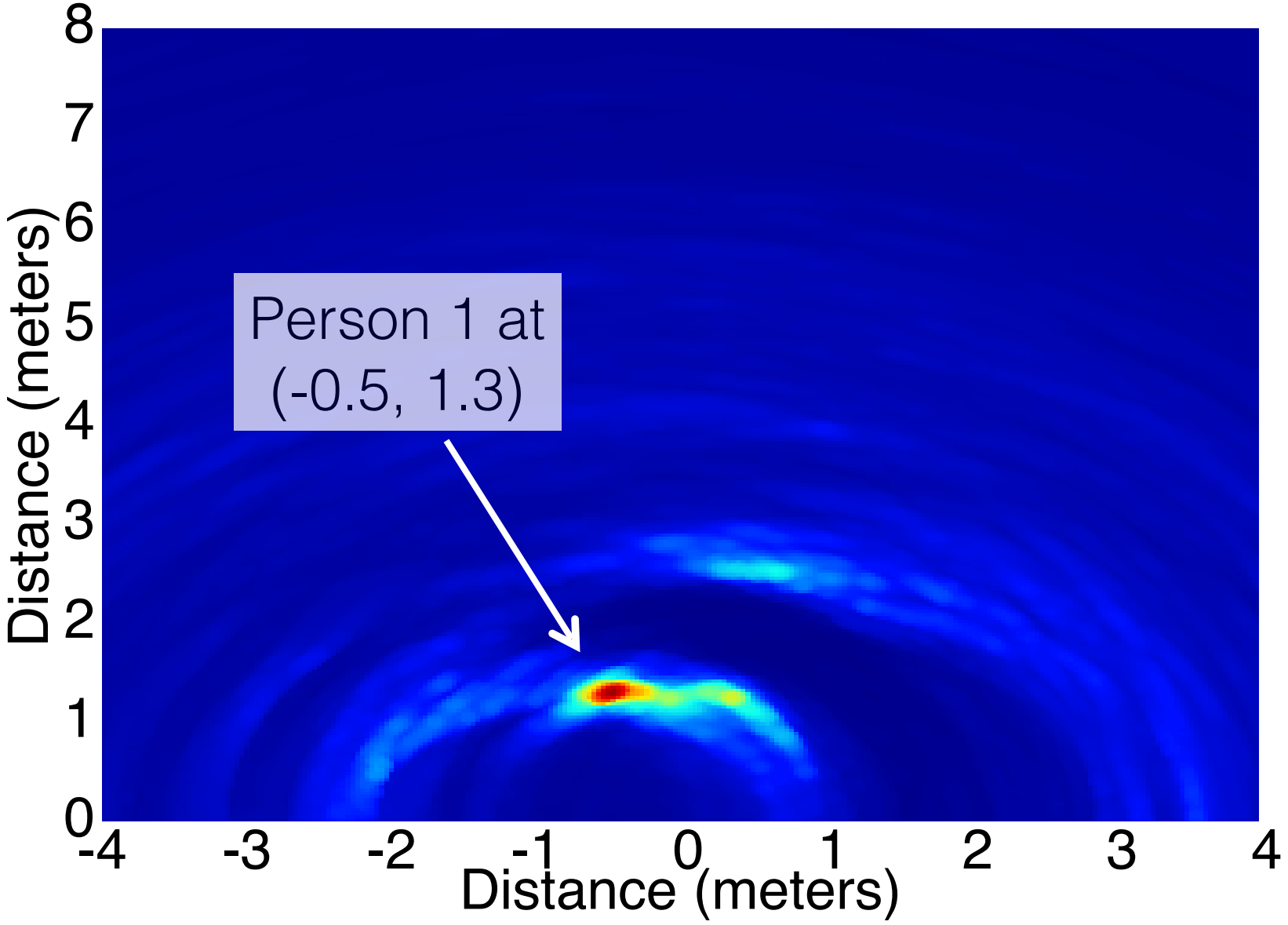
# Successive Silhouette Cancellation:

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

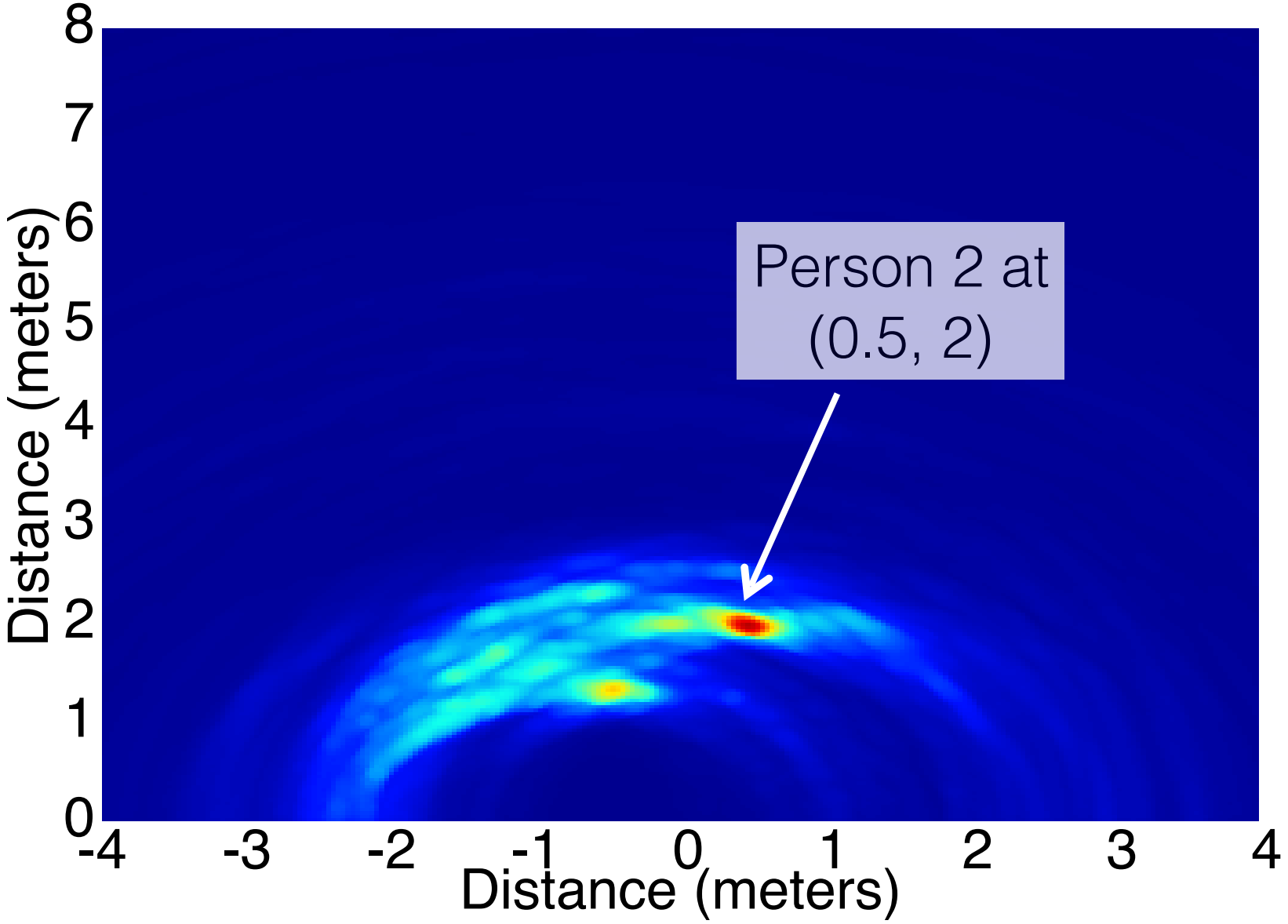
Goal: Recover human reflections



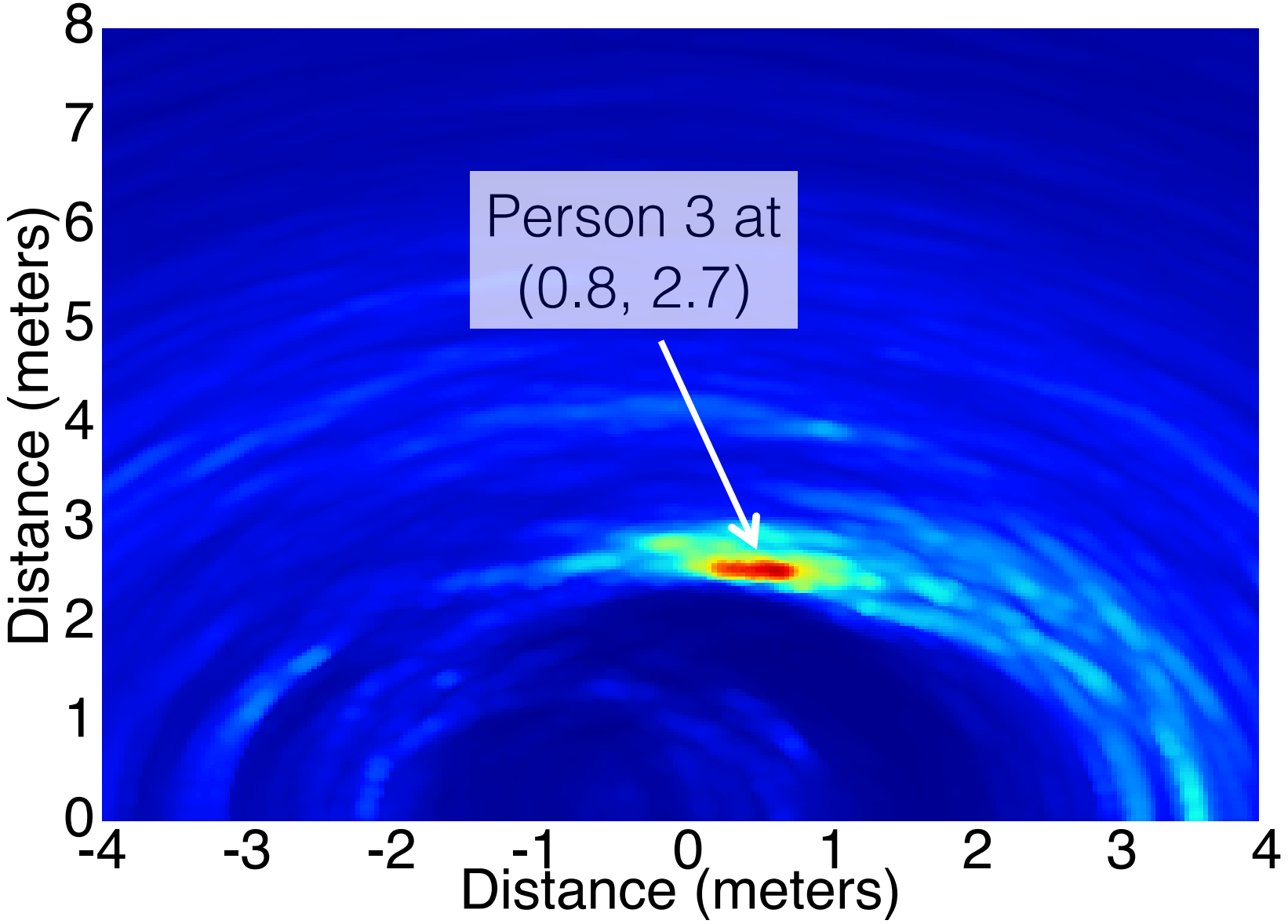
# First localize the user with the strongest reflection



# After reconstructing and cancelling the first user's reflections



# Iteratively localize the remaining users in the scene



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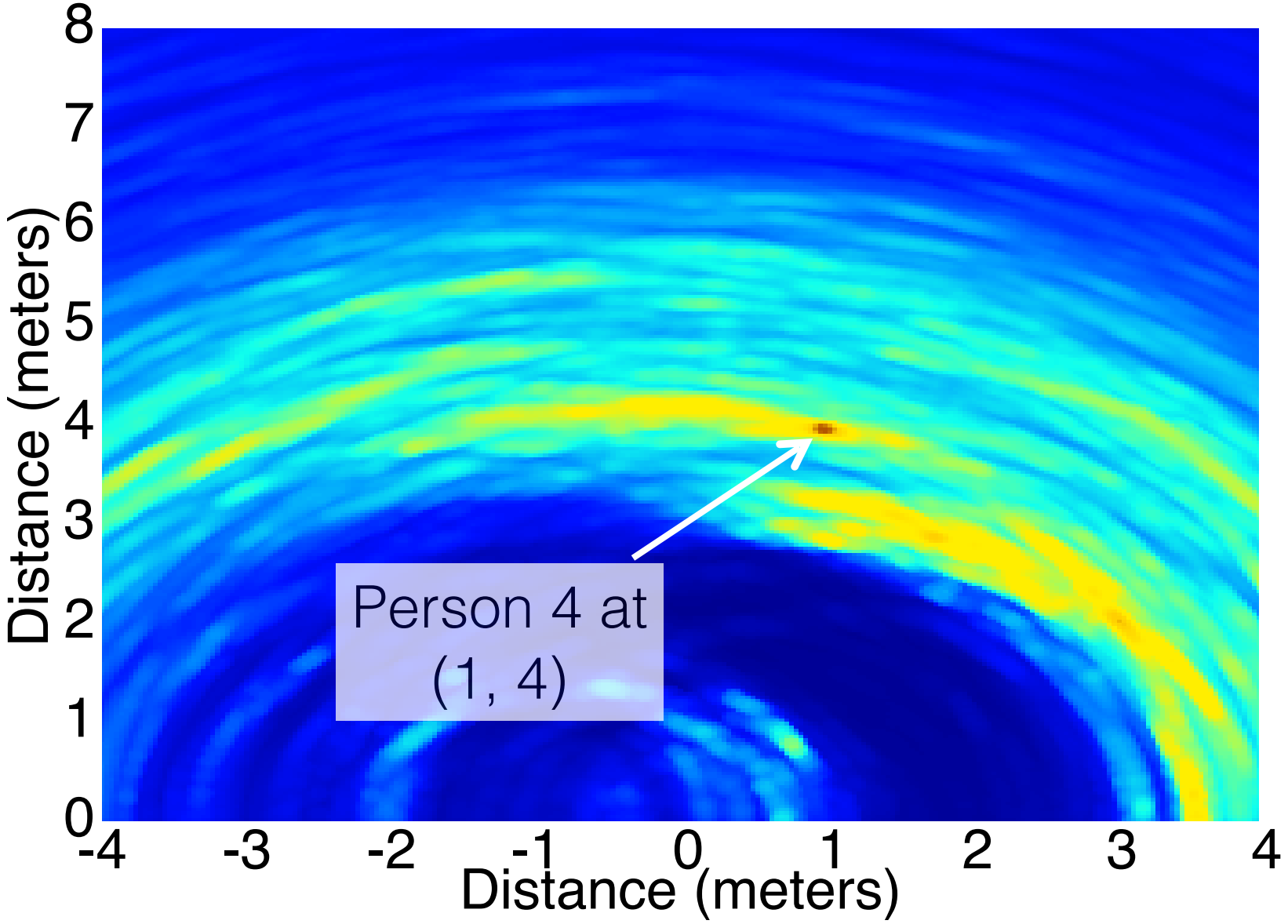
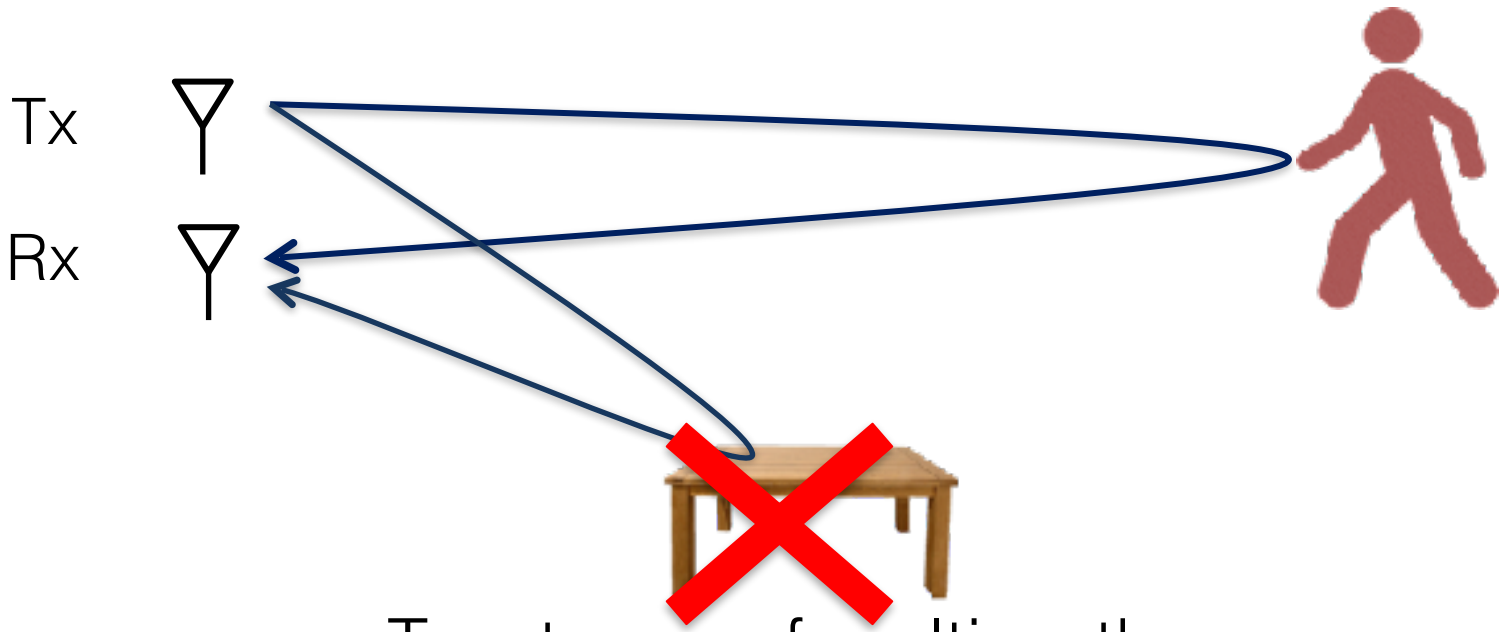


# How can we localize static users?

# Dealing with multi-path when there is one moving user

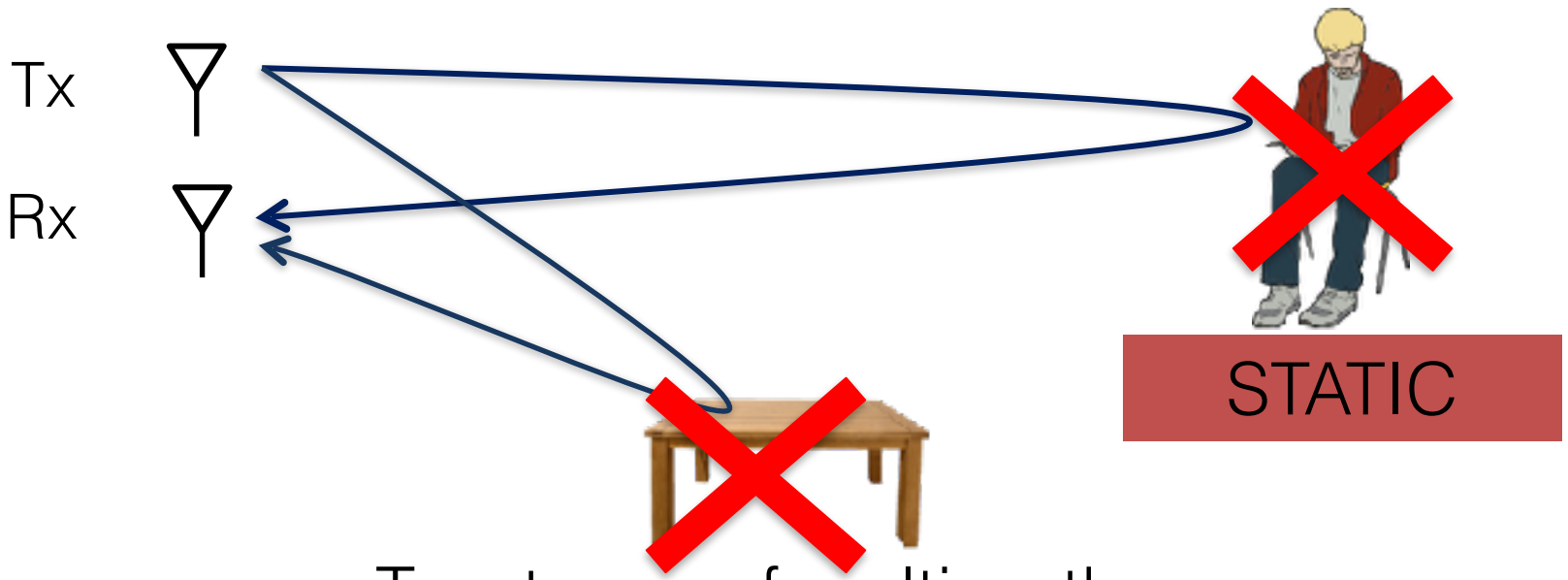



Two types of multi-path:

We eliminated direct table reflections by subtracting consecutive measurements

Needs User to Move

# Dealing with multi-path when there is one moving user




Two types of multi-path:

We eliminated direct table reflections by subtracting consecutive measurements

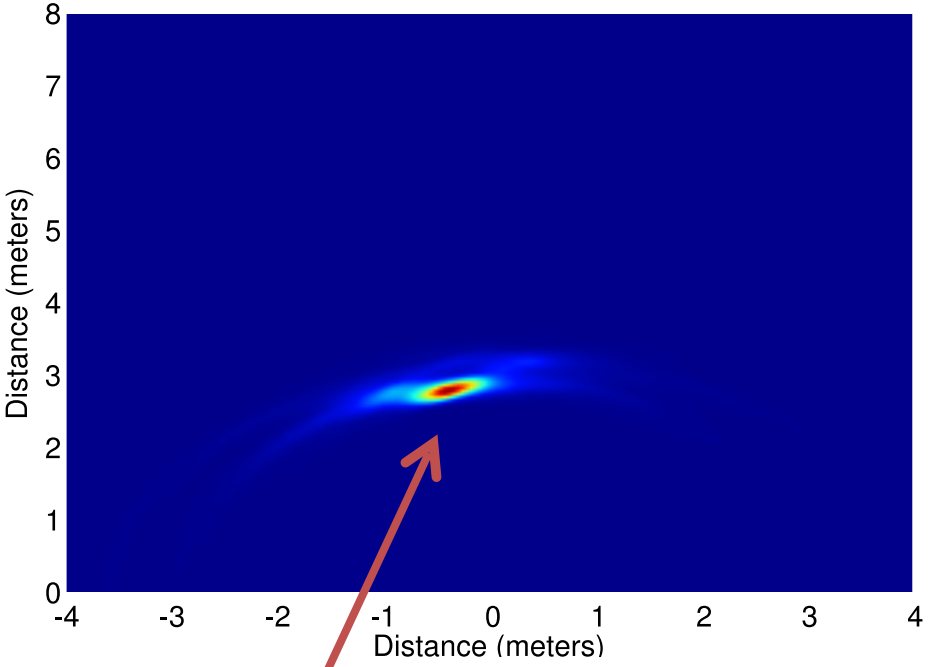
Needs User to Move

# 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

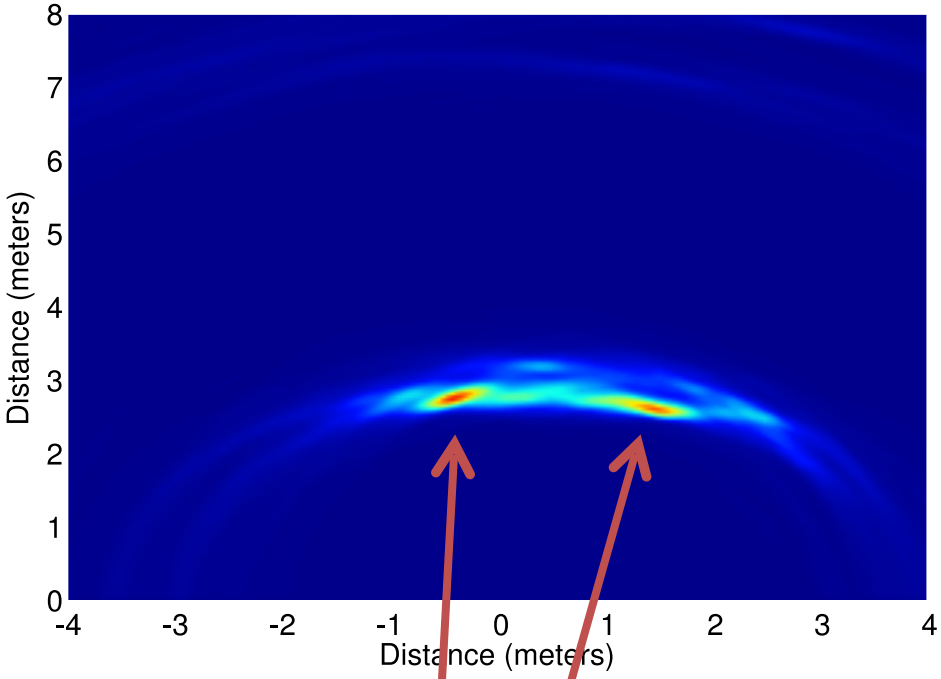
# User Walking at 1m/s

30ms subtraction window




Localize the person

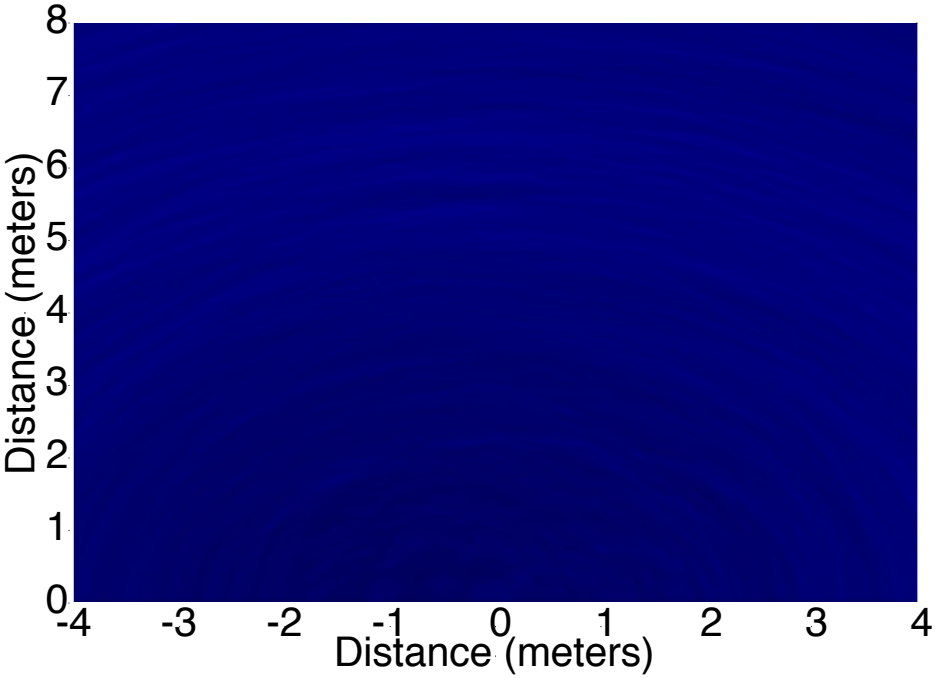
3s subtraction window




Person appears in two locations

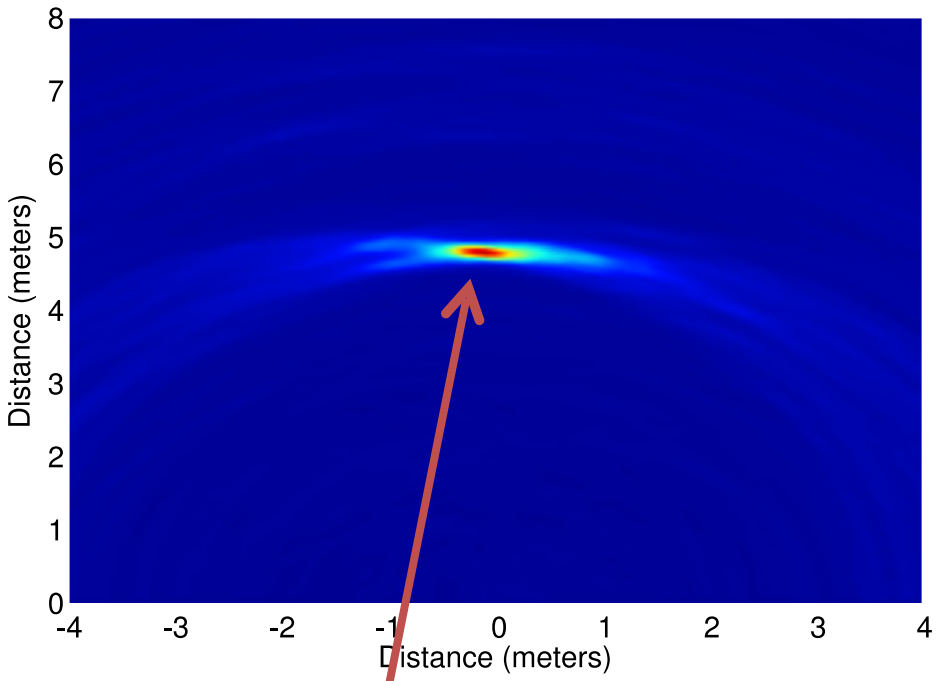
# User Sitting Still (Breathing)

30ms subtraction window




Cannot localize

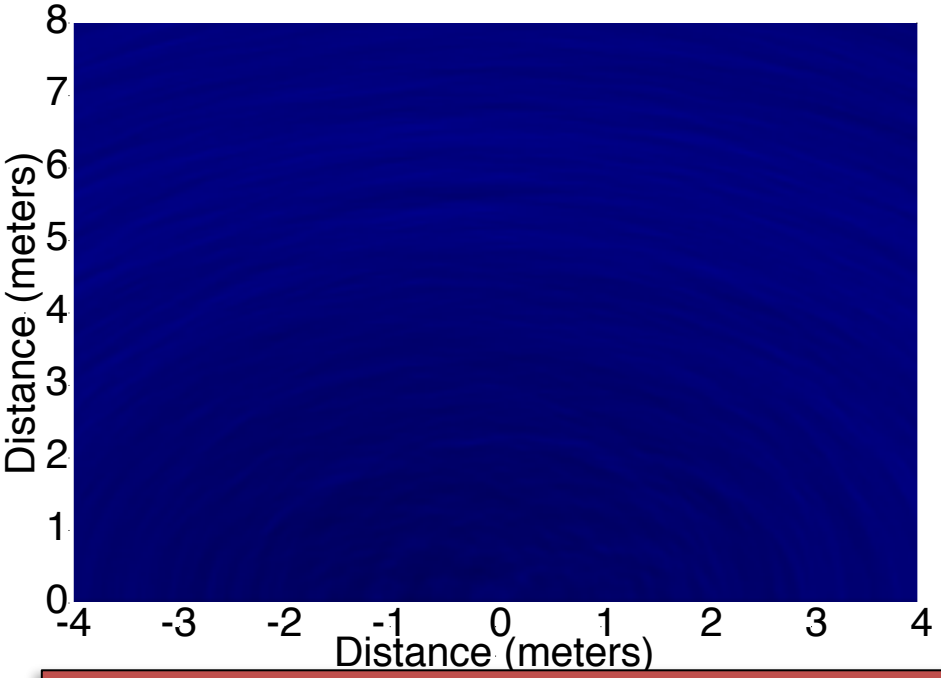
3s subtraction window



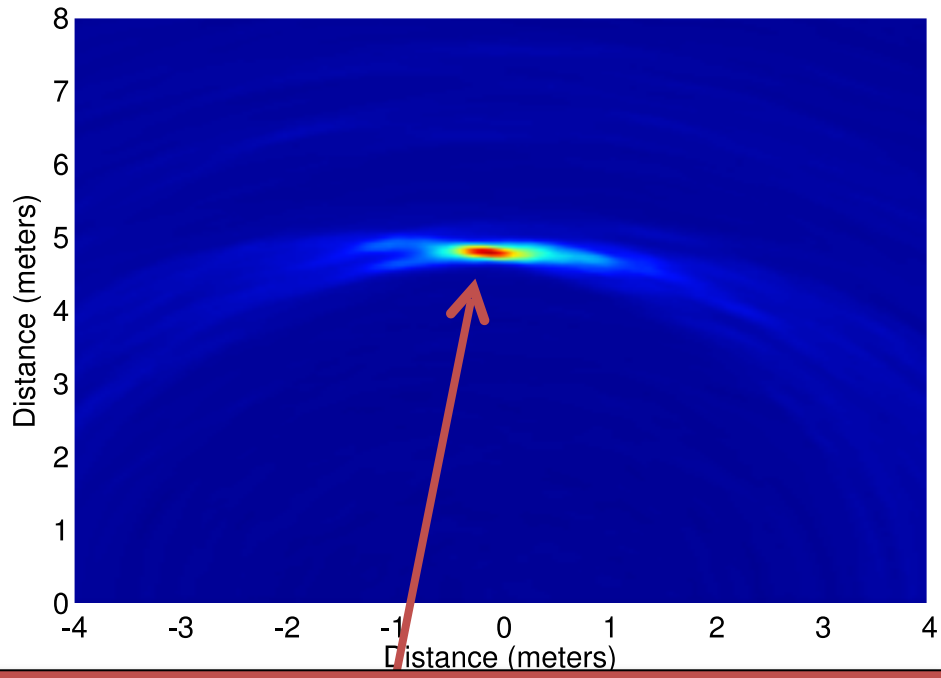

Localize the person

# User Sitting Still (Breathing)

30ms subtraction window

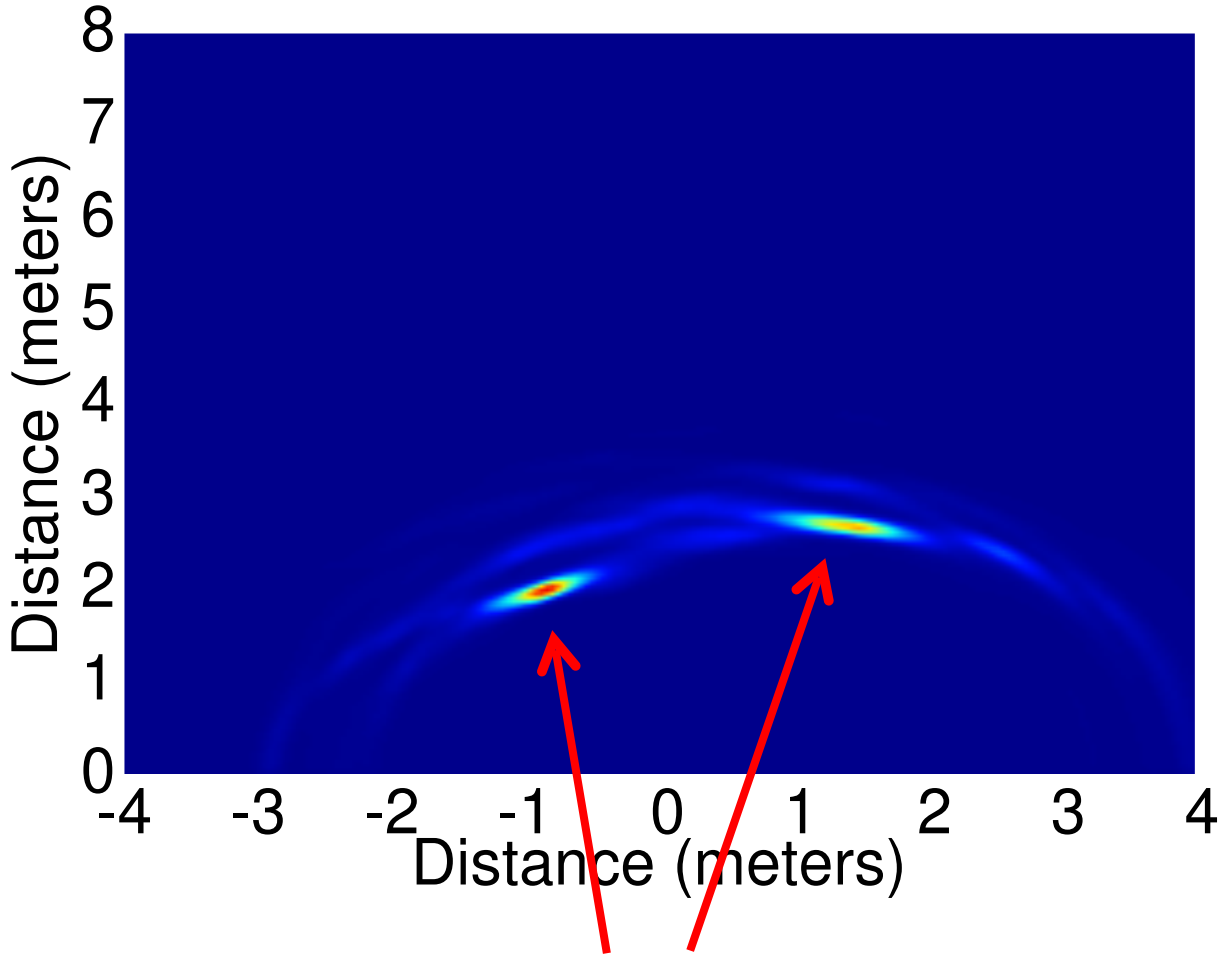



3s subtraction window




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

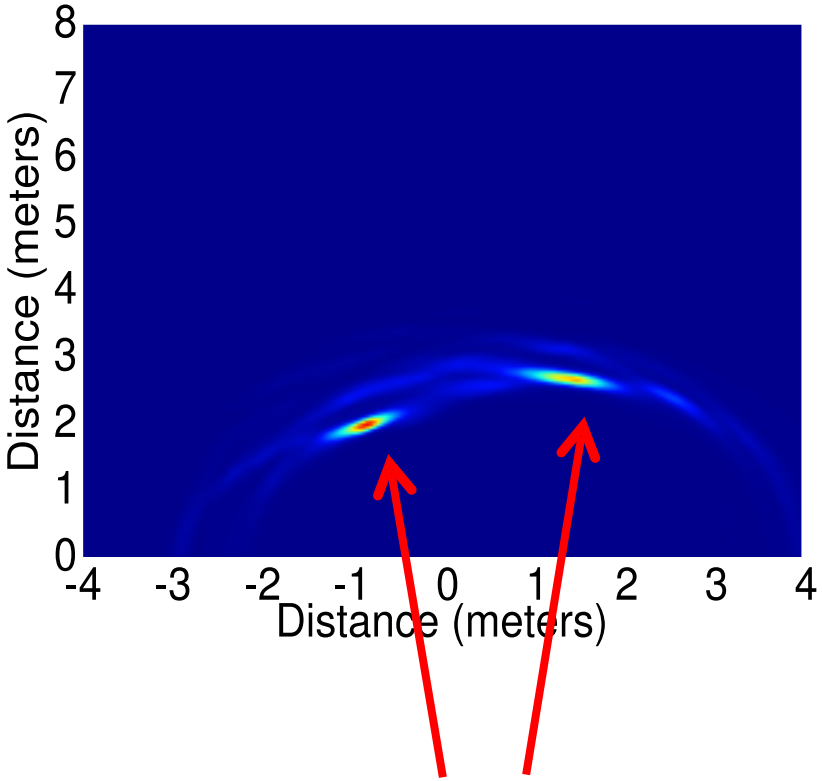
# Centimeter-scale localization without requiring the user to carry a wireless device

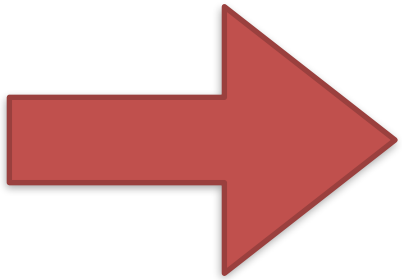


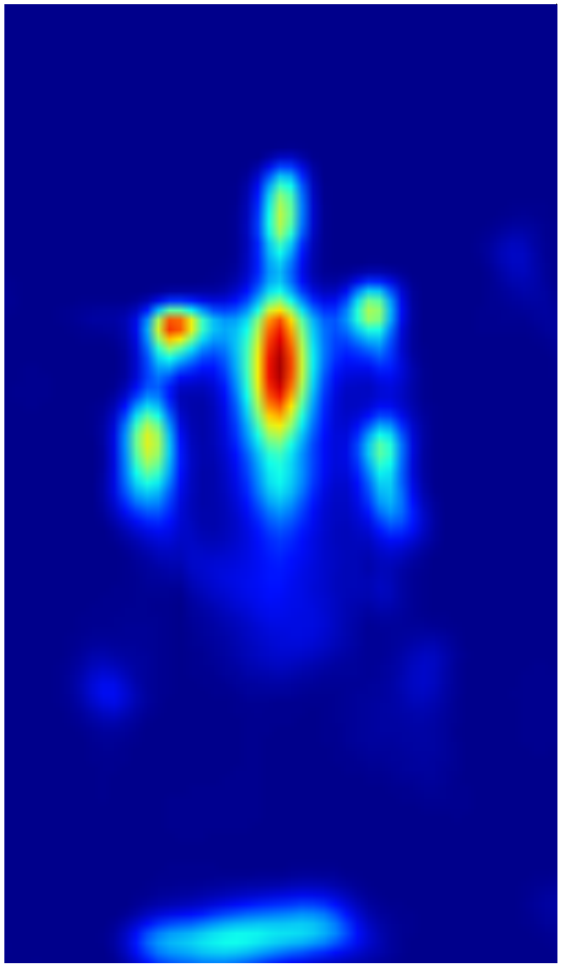

Localize the two users

Want a silhouette

People are points



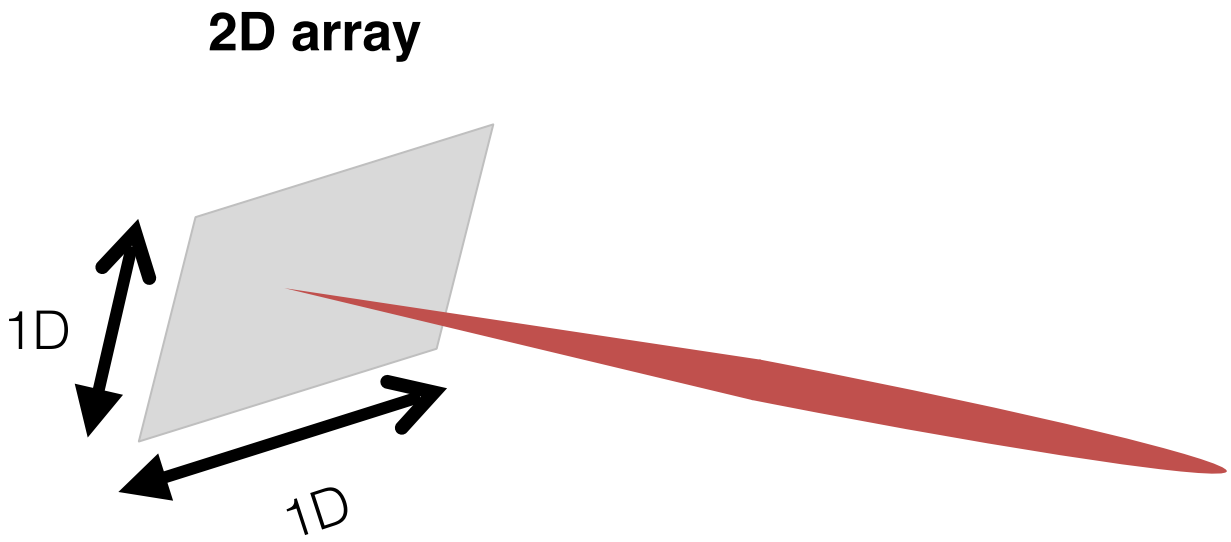





Localize the two users

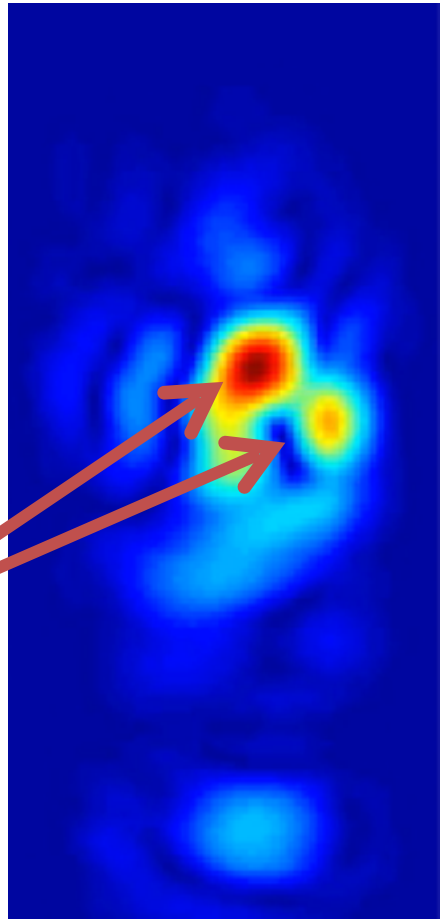
# Approach: Combine antenna arrays with FMCW to get 3D image

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



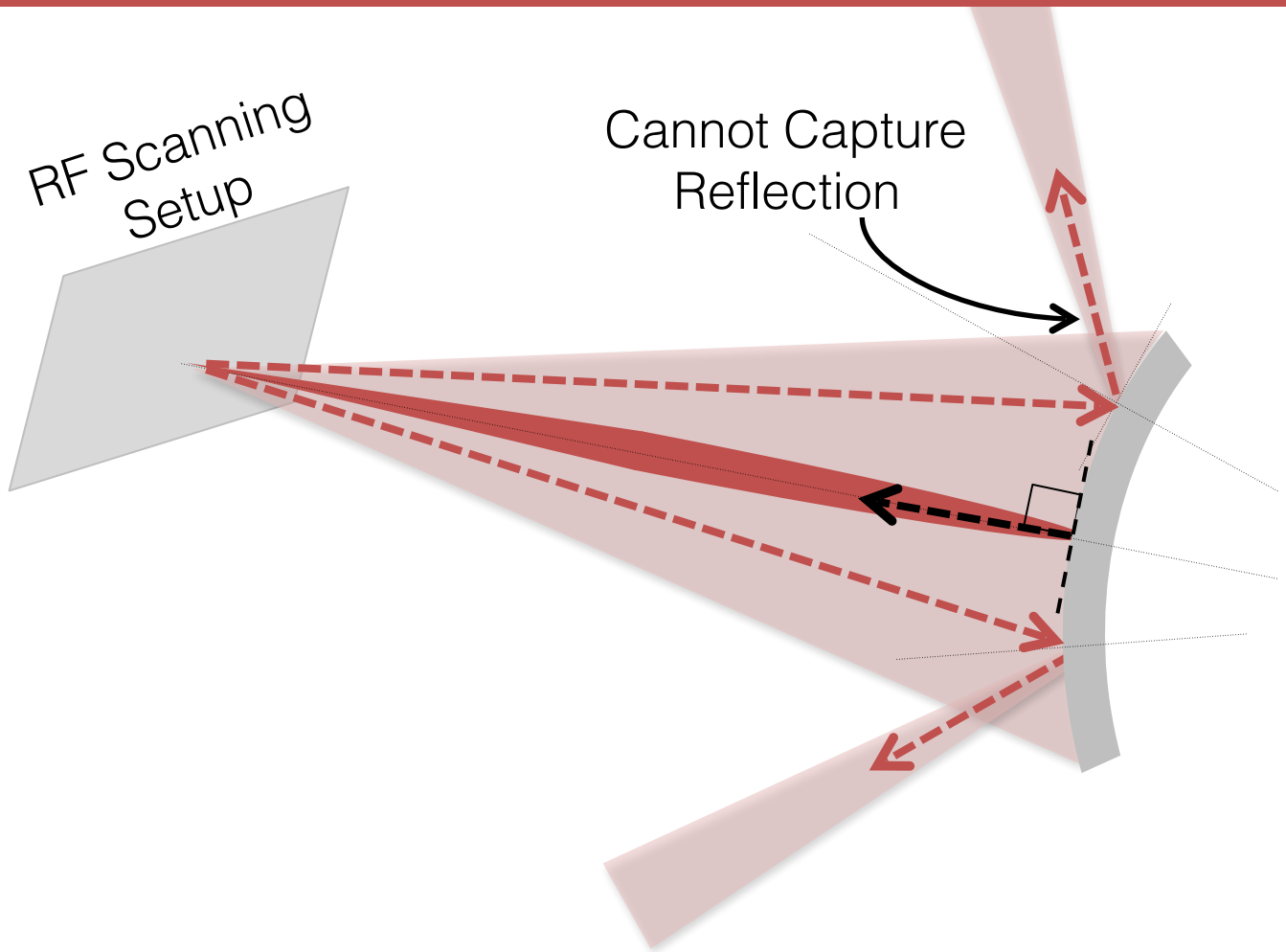
# Challenge: We only obtain blobs in space

Output of 3D RF Scan

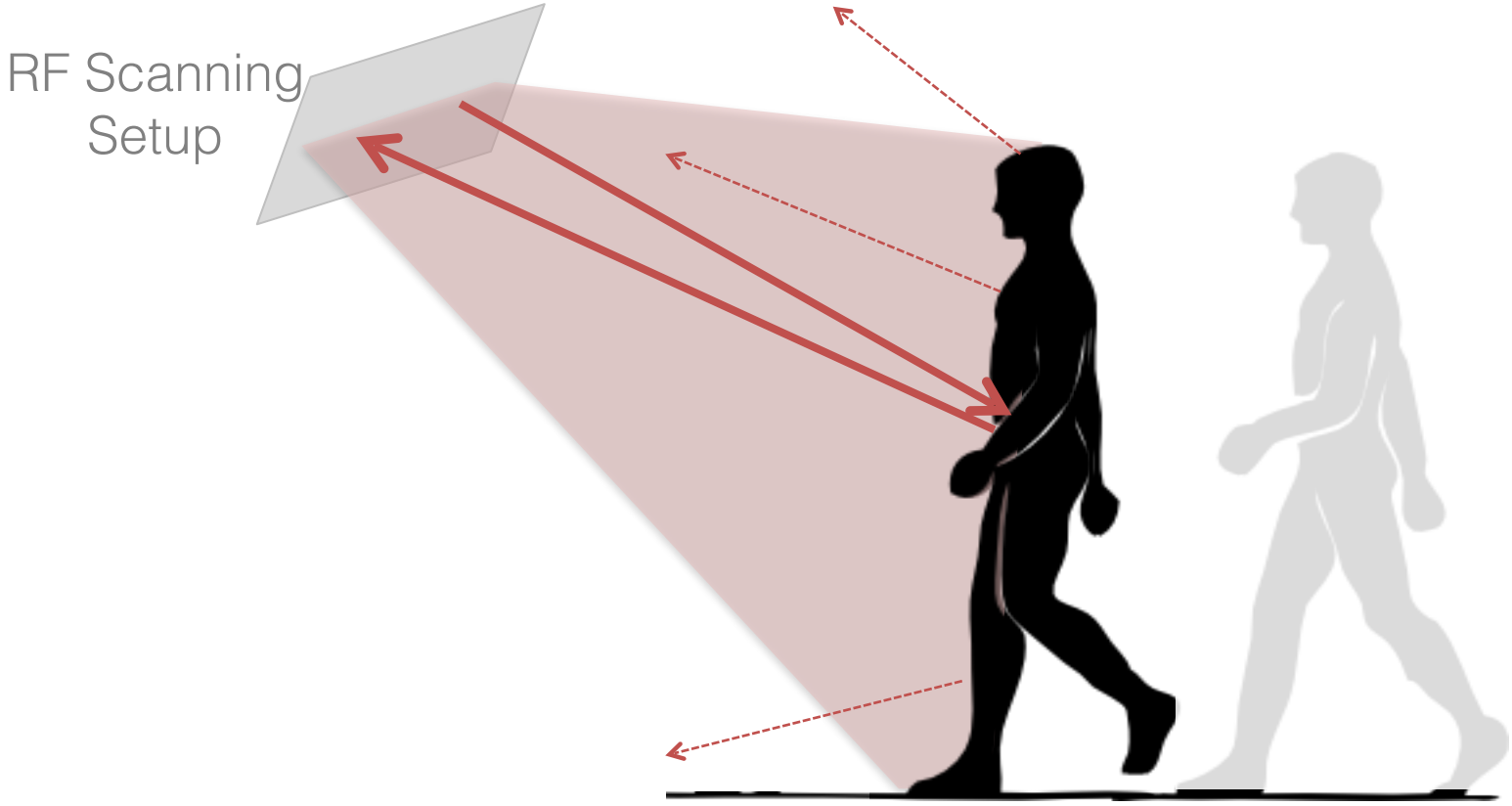


Blobs of reflection power

# 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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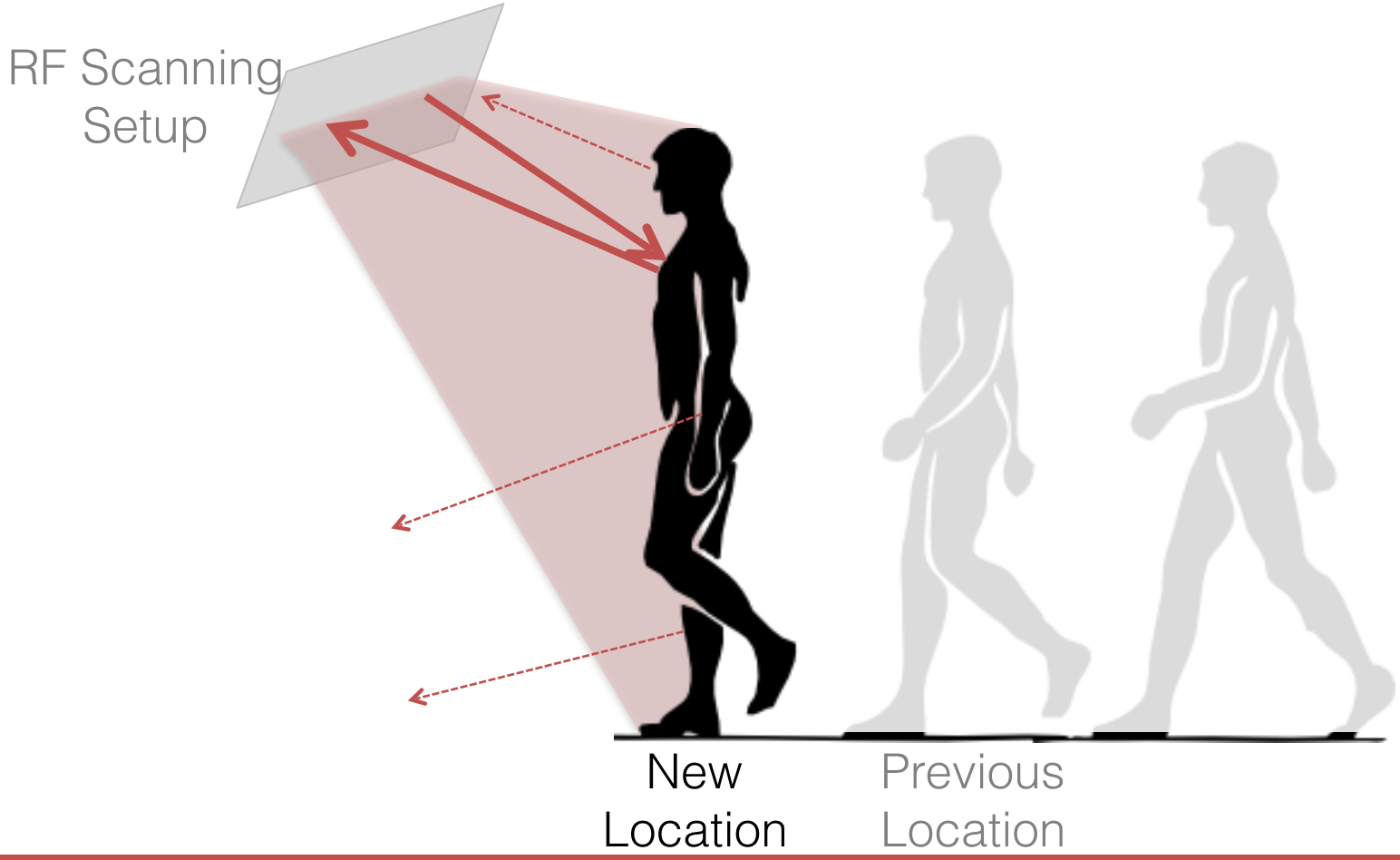
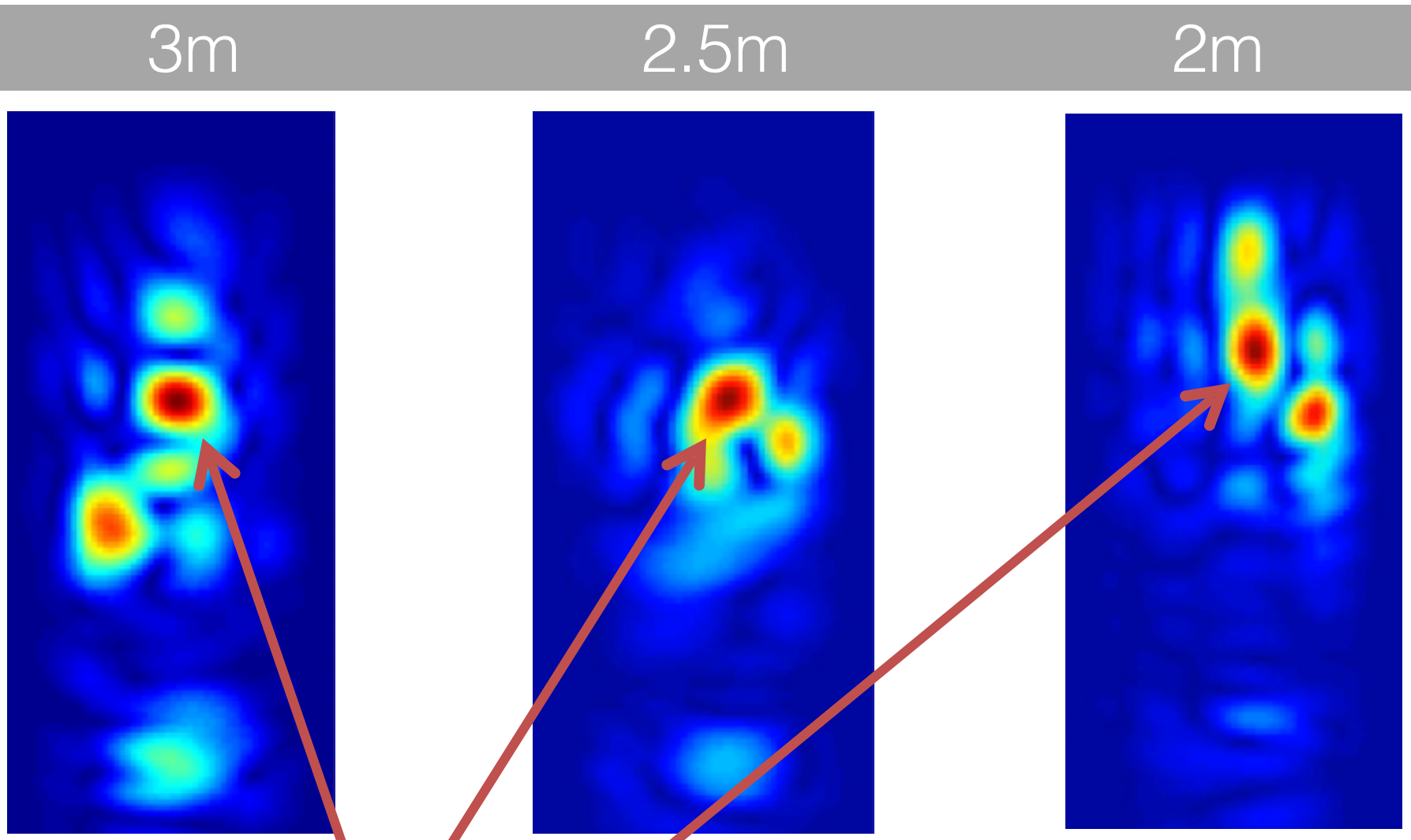


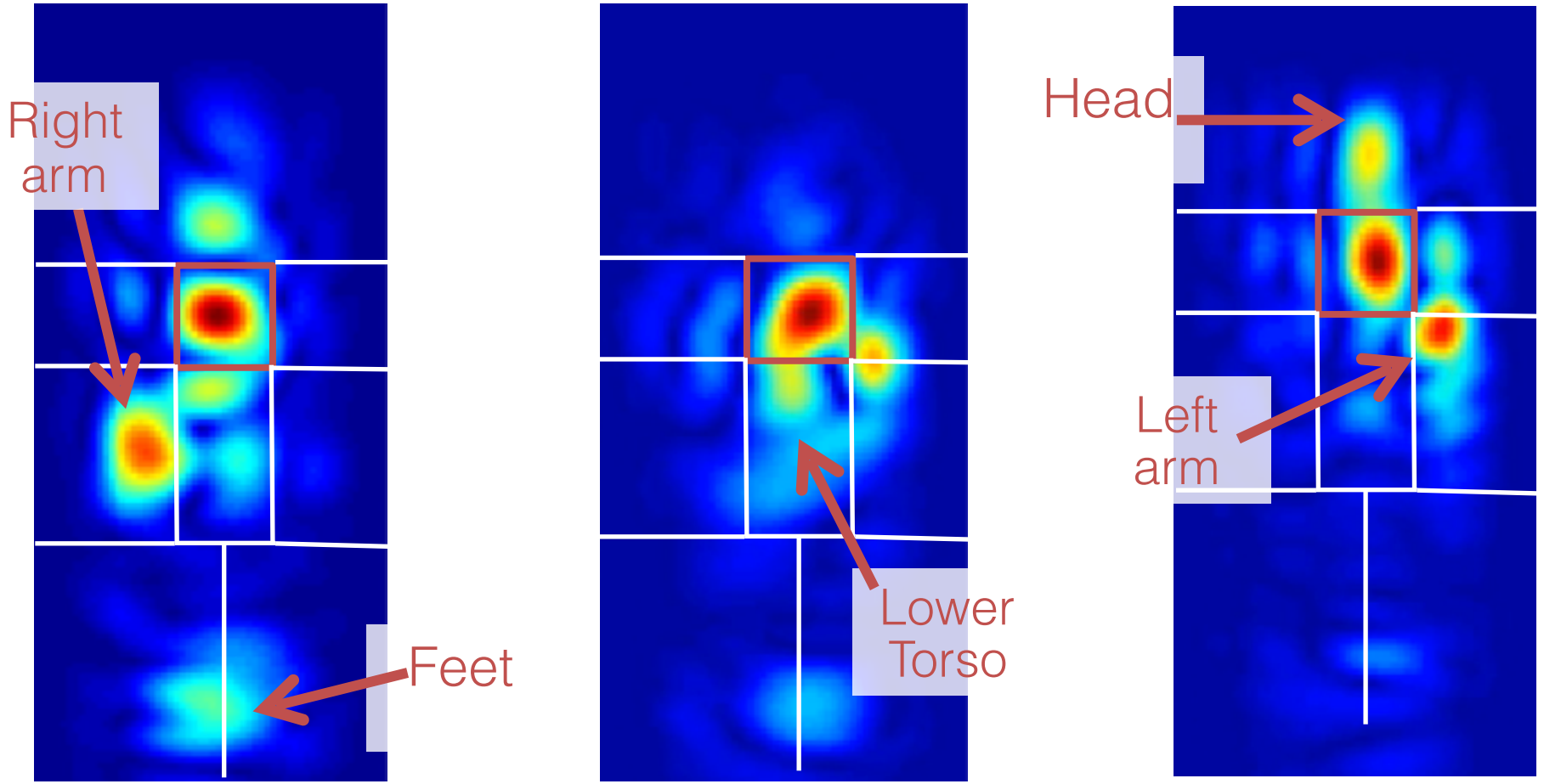

Combine the various snapshots

# Human Walks toward Sensor



# Human Walks toward Sensor

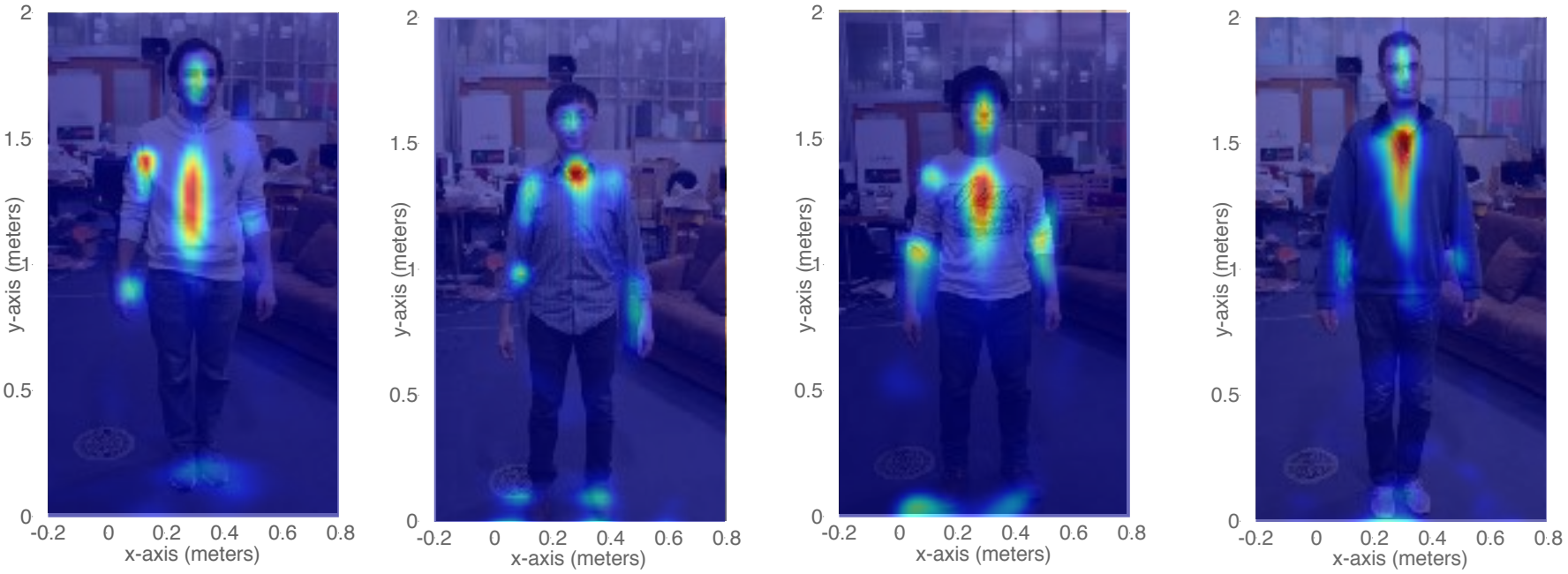
3m | 2.5m | 2m




Combine the various snapshots

# Human Walks toward Sensor

# Sample Captured Figures through Walls



# Through-wall classification accuracy of 90% among 13 users