6.808: Mobile and Sensor Computing

aka IoT Systems

http://6808.github.io

Lecture 4:
Seeing Through Walls & Device-Free Localization

Course Staff

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Announcements

1- Lab 0 checkoff this week (in OH)

2- Lab 1 out; due Feb 14

3- PSet 1 out; due Feb 28

Today in IoT

Technology Review

Featured Topics Newsletters Events Podcast

"Metaverse is the successor to the mobile internet"
- Zuckerberg

Humans and technology Feb 8

The metaverse is a new word for an old idea

To understand what we are—and should be—building, we need to look beyond Snow Crash.

01.
This group of tech firms just signed up to a safer metaverse
Jan 20

02.
The metaverse is th venue for body dysmorphia online
Nov 16

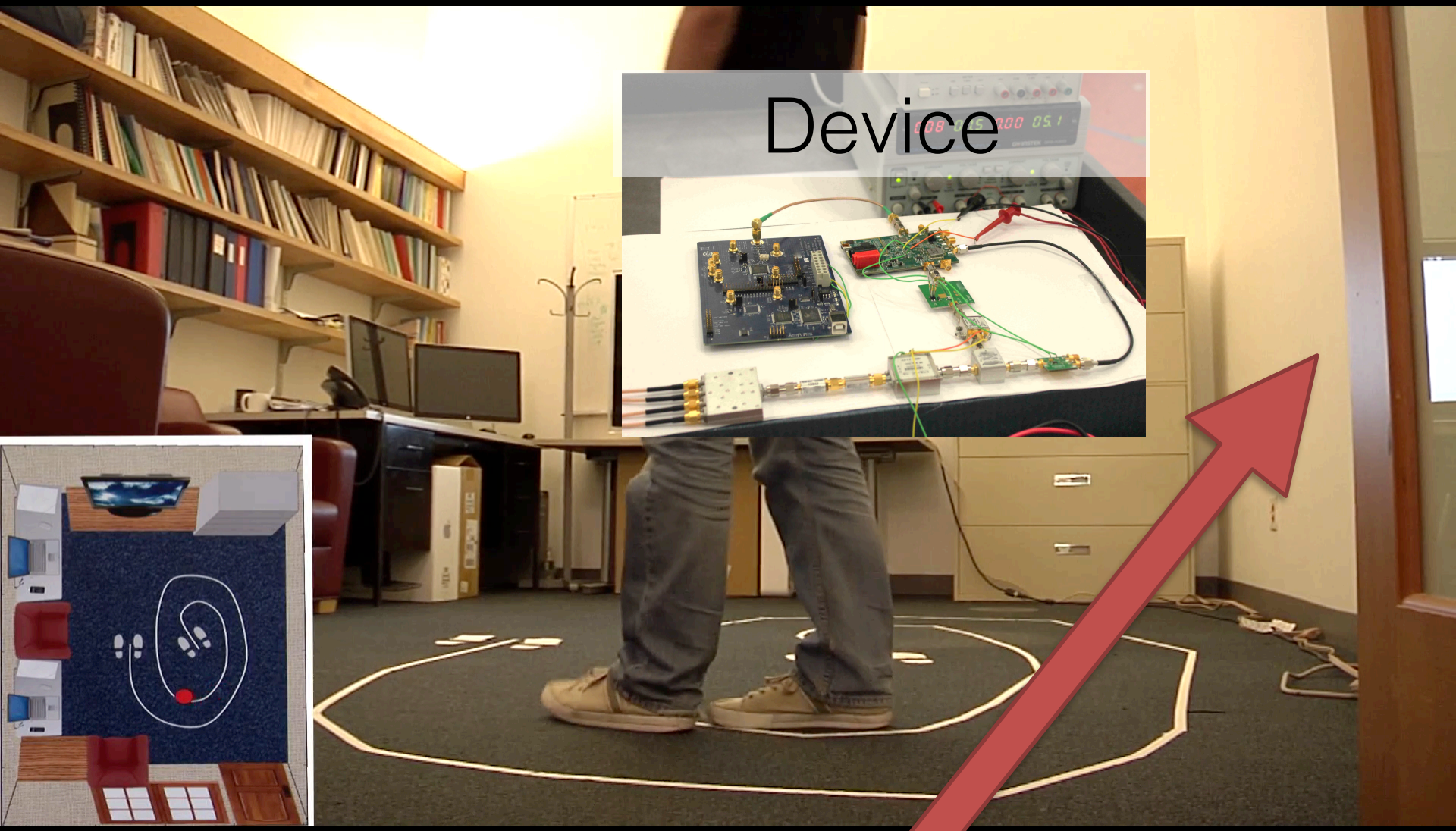
THE WALL STREET JOURNAL.

THE FUTURE OF EVERYTHING | WORK

Why the Metaverse Will Change the Way You Work

Virtual meetings that feel real, new ways to build and teach, plus jobs you haven't heard of—soon it won't be science fiction

Feb 7, 2022


Device
Device in another room

Applications

Smart Homes

Energy Saving

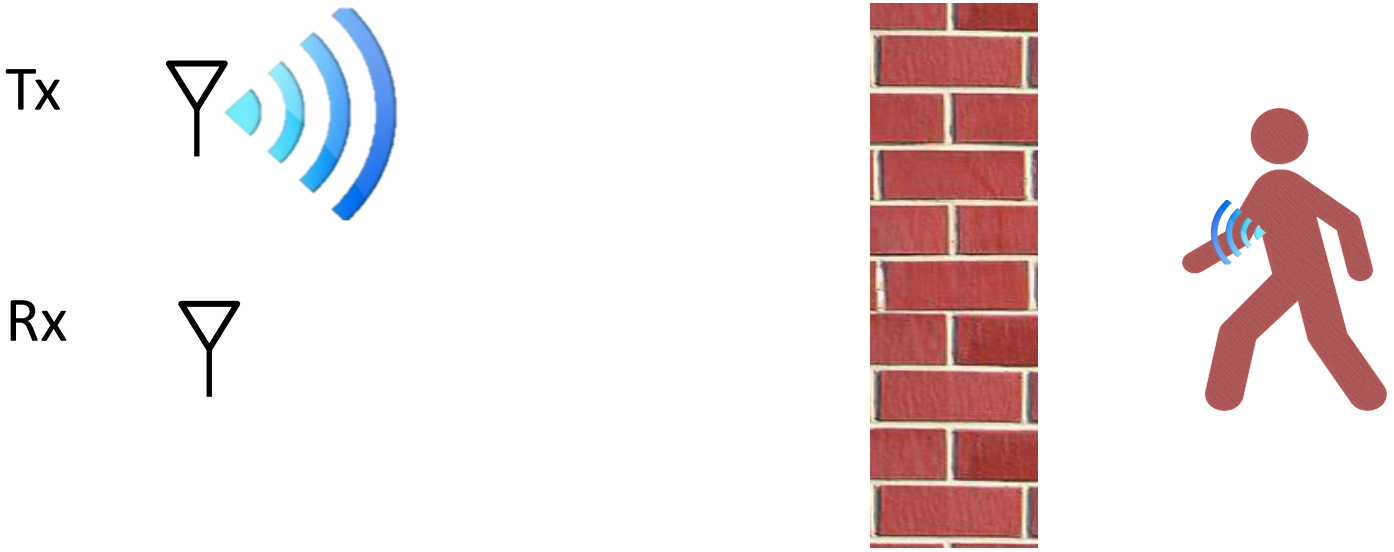
Gaming & Virtual Reality

Objectives of this Lecture

Learn the fundamentals, applications, and implications of **wireless sensing**

1. What are the basic principles of wireless sensing?
2. How can we obtain centimeter-scale localization from wireless reflections?
3. What are the possibilities of sensing beyond localization?
4. What are the industry opportunities and societal implications of wireless sensing (today and in the near+far future)?

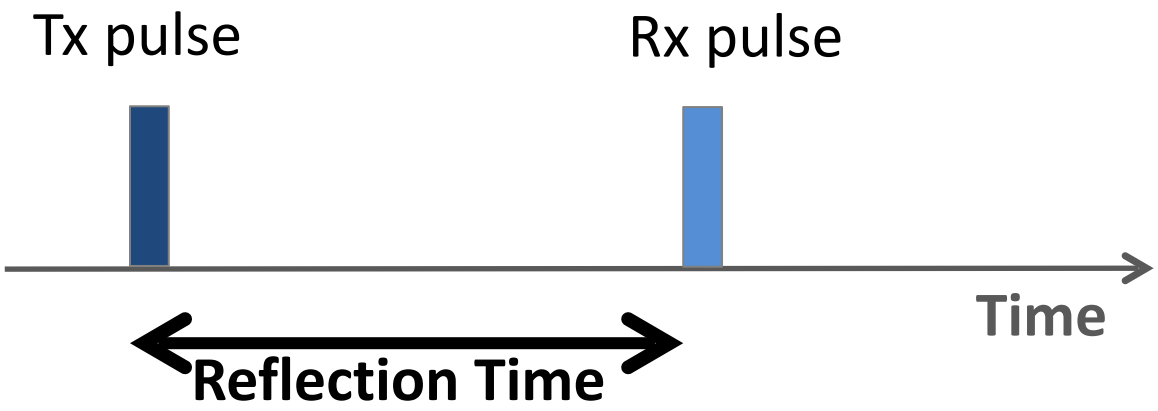
Measuring Distances



Distance = Reflection time x speed of light

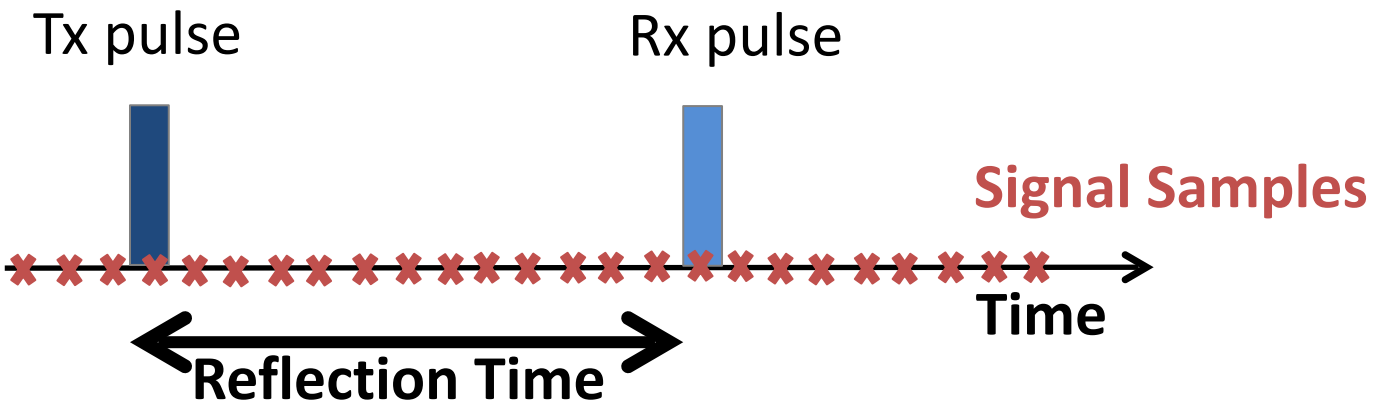
Measuring Reflection Time

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?

and why was this not a problem for Cricket?

Capturing the pulse needs sub-nanosecond sampling

Why?

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

Distance = time x speed

"smallest distance resolution"

"smallest time"

$$10cm = \Delta t \times (3 \times 10^8)$$

$$\Delta t = 0.3ns$$

0.3ns period => how many samples per second?

$$SamplingRate = \frac{1}{\Delta t}$$

3GSps! >> MSps for WiFi, LTE…

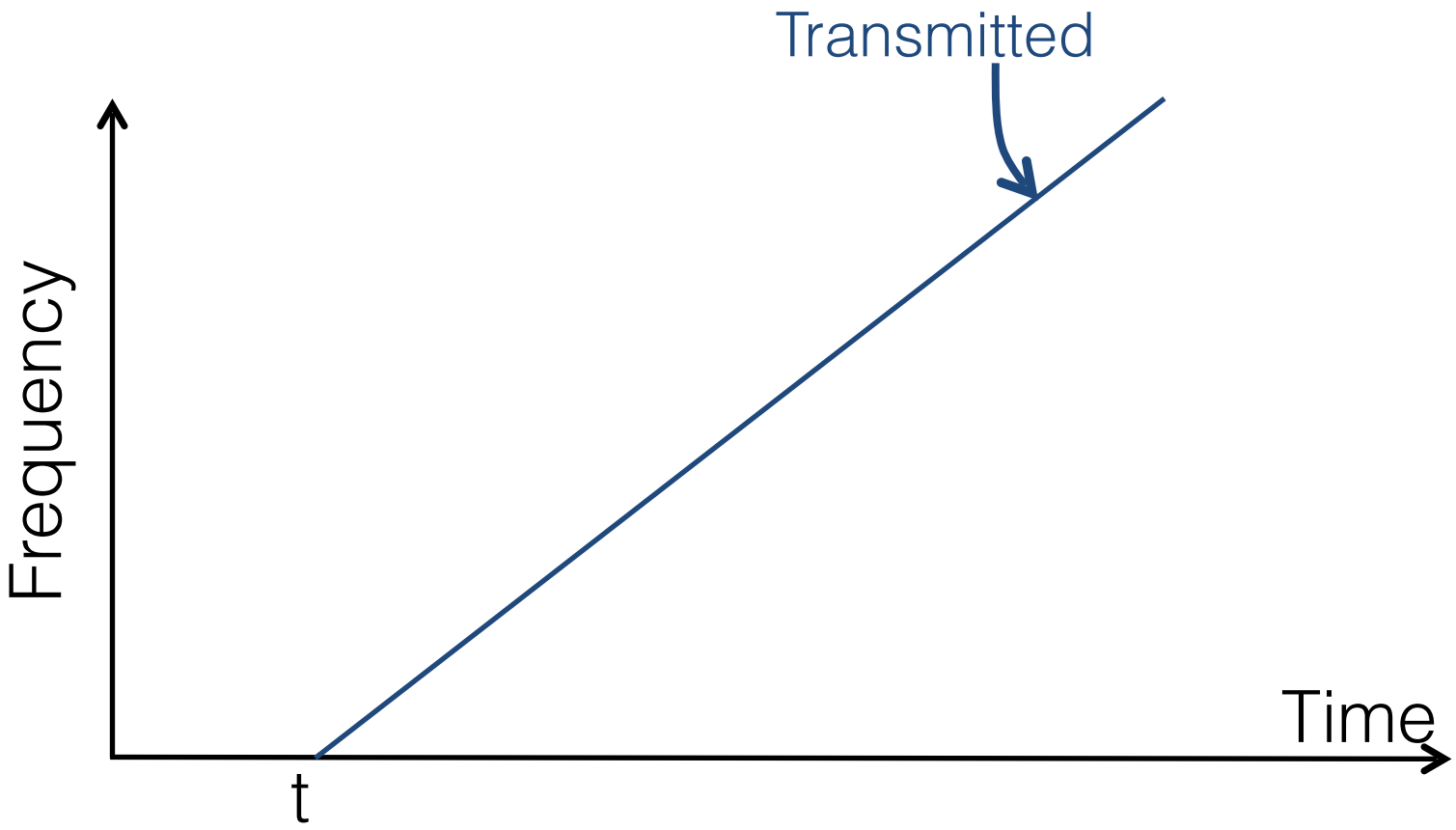
Why was this not a problem for Cricket?

because speed of ultrasound

$$10cm = \Delta t \times 345$$

$$SamplingRate = \frac{1}{\Delta t} \approx 3kbps$$

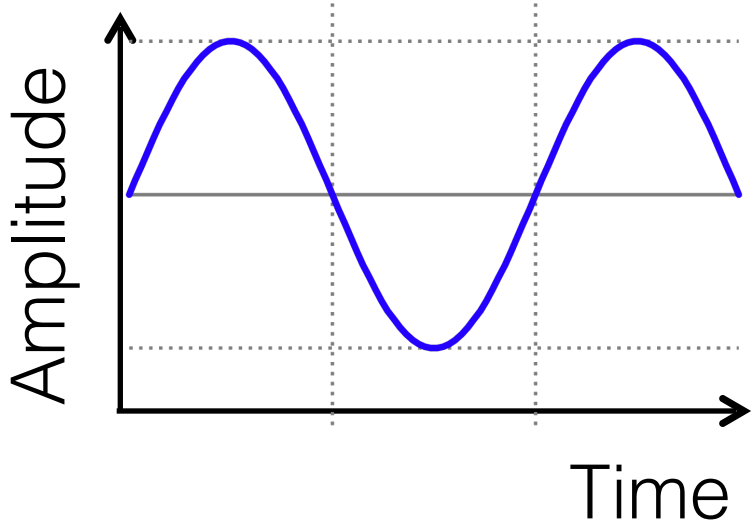
FMCW: Measure time by measuring frequency

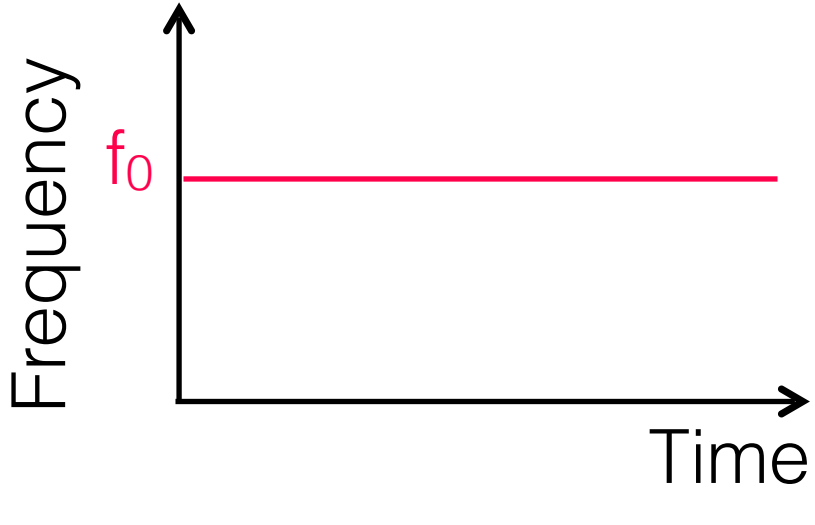


How does it look in time domain?
(and in comparison to single frequency)

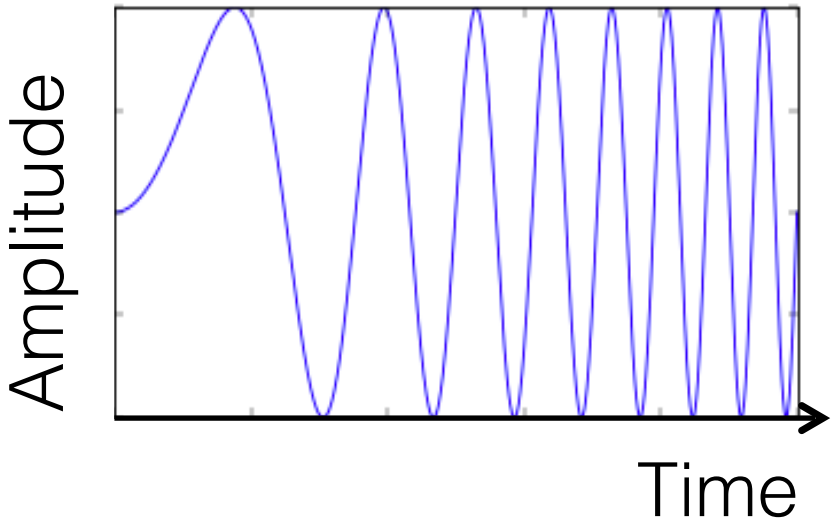
More intuitive understanding of FMCW

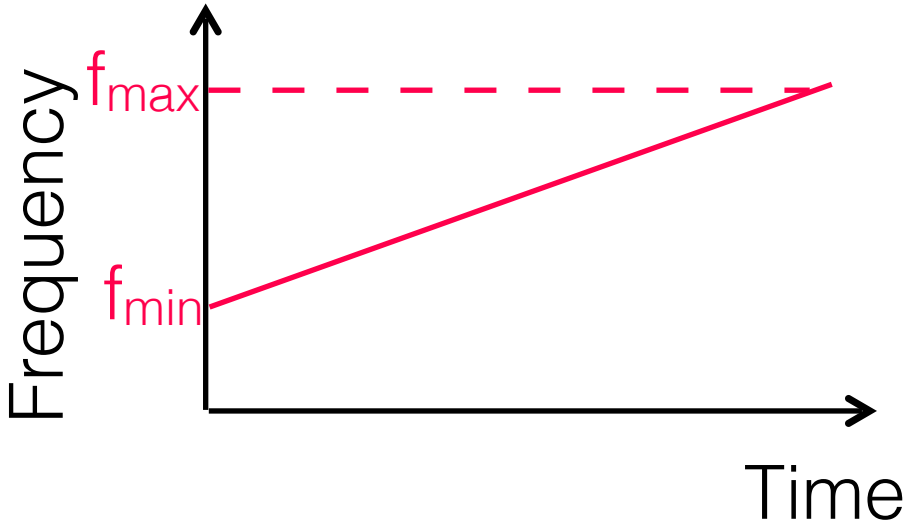
Wireless Signal at frequency f_0



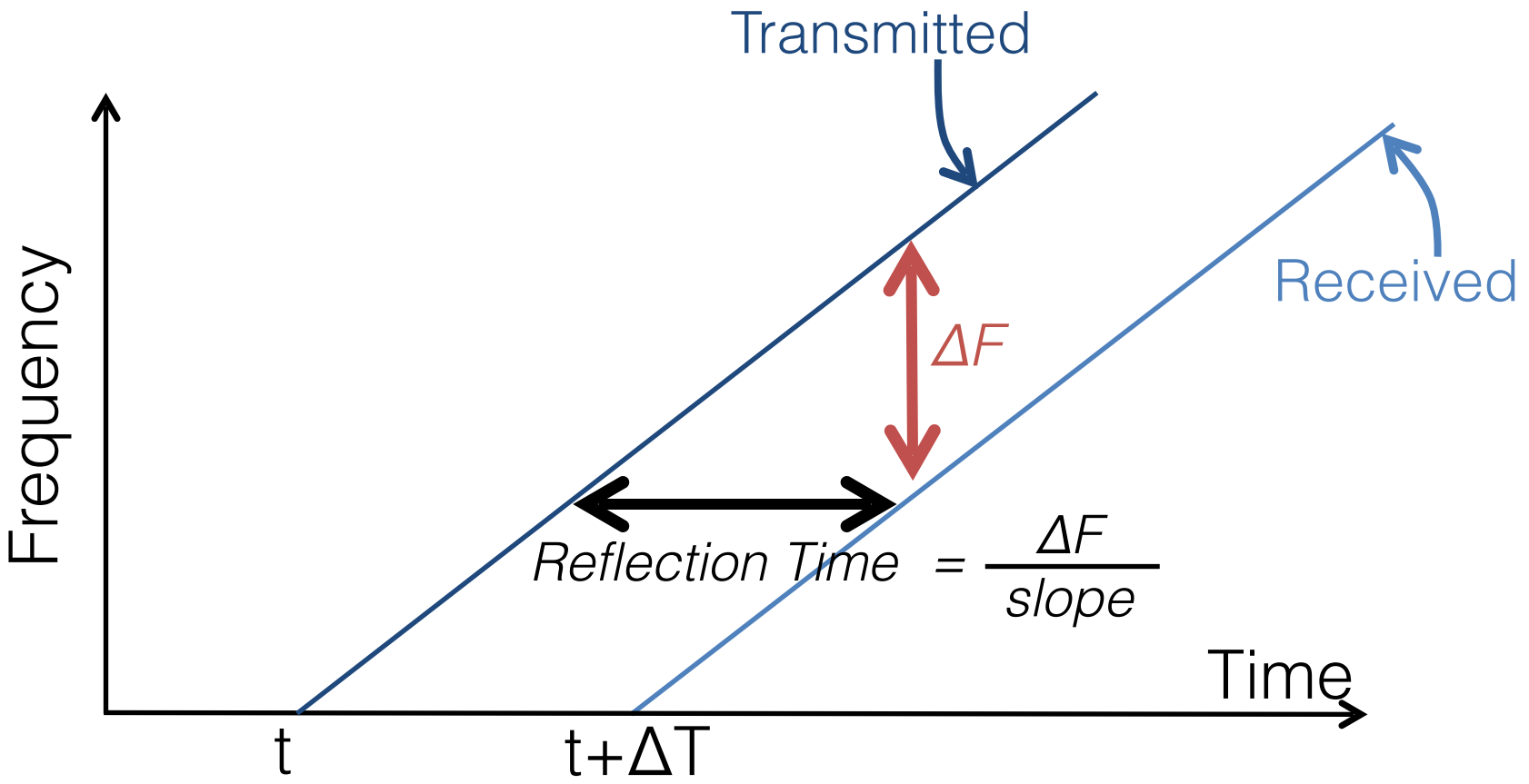


FMCW signal





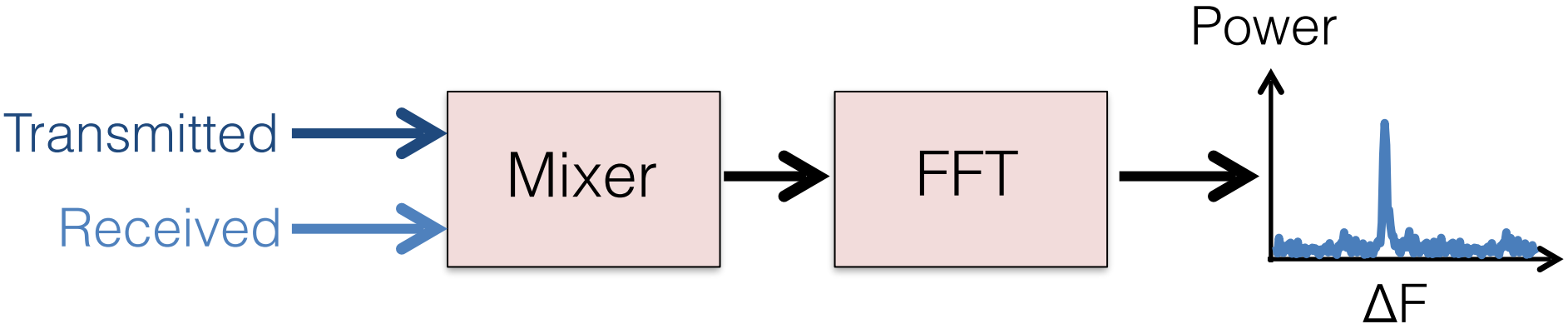
FMCW: Measure time by measuring frequency



How do we measure ΔF?

Measuring ΔF

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

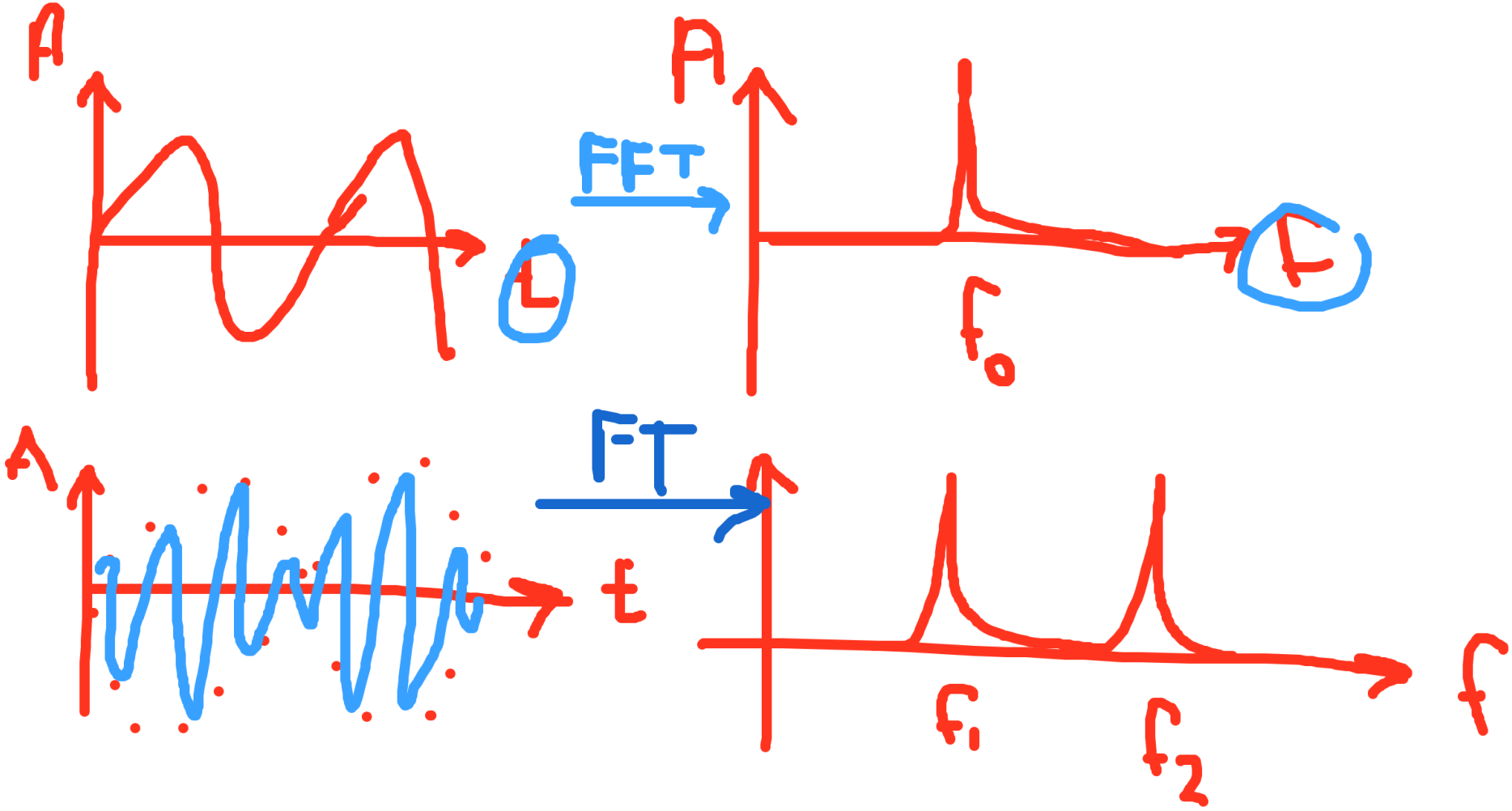


Signal whose frequency is ΔF

let's talk about FFTs a bit

Basics of Fourier Transform

Basics of Fourier Transform



Measuring ΔF

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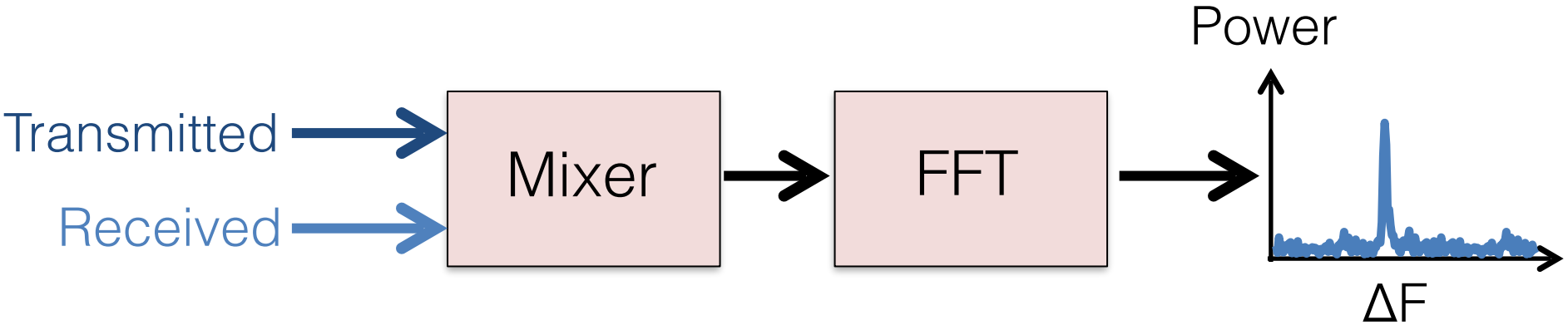
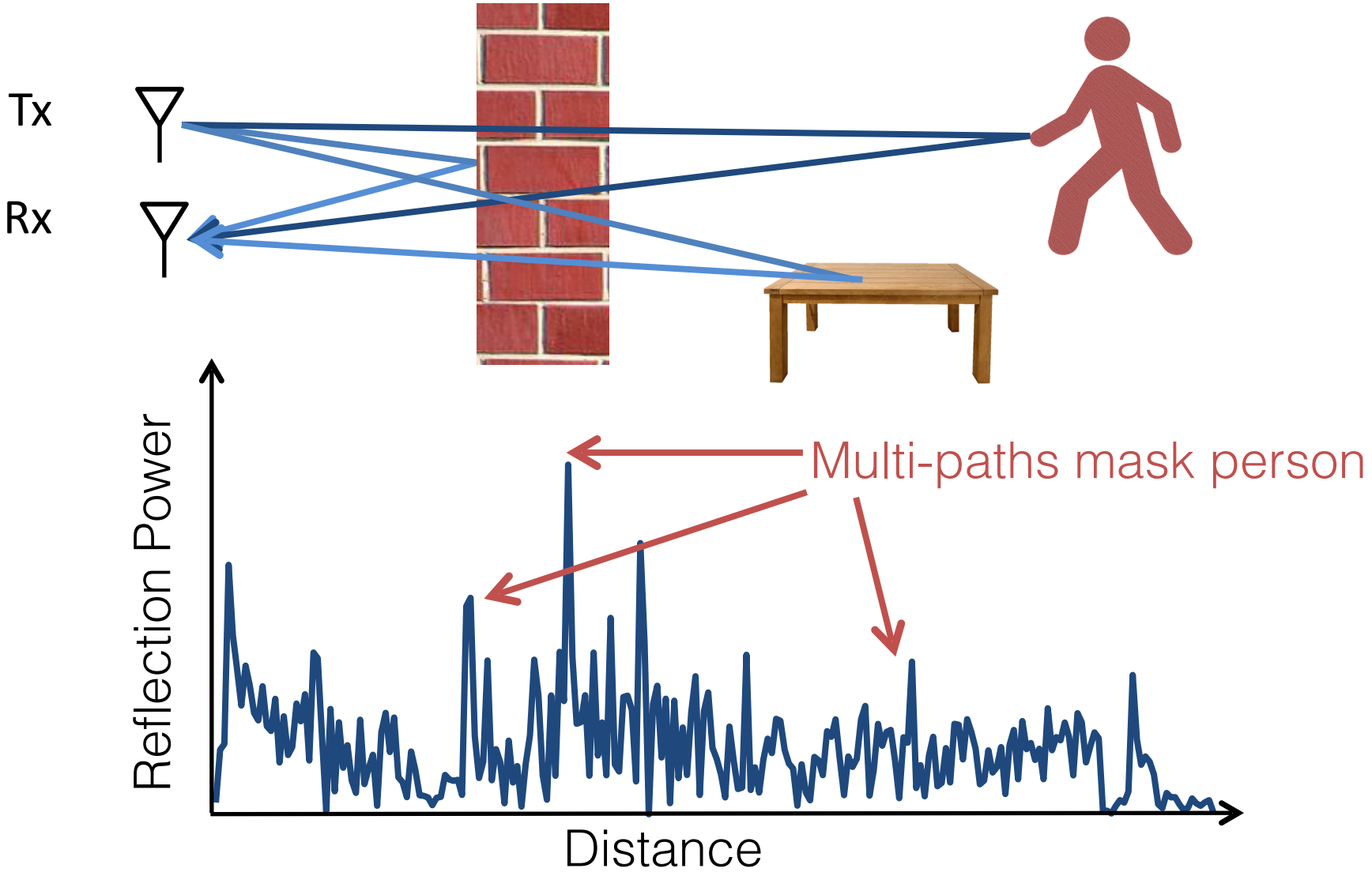


Signal whose frequency is ΔF

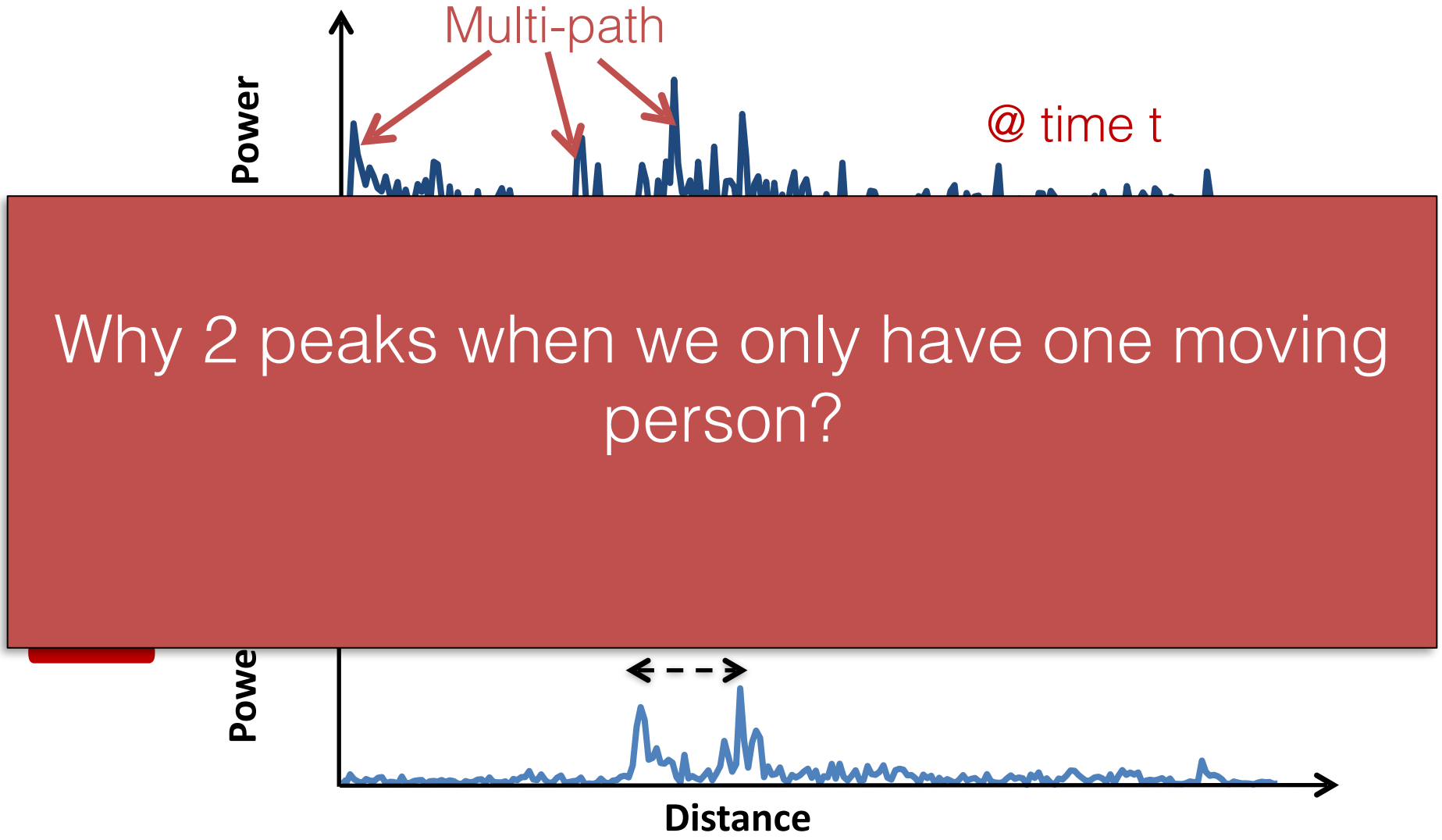
ΔF →Reflection Time → Distance

Challenge: Multipath➔ Many Reflections



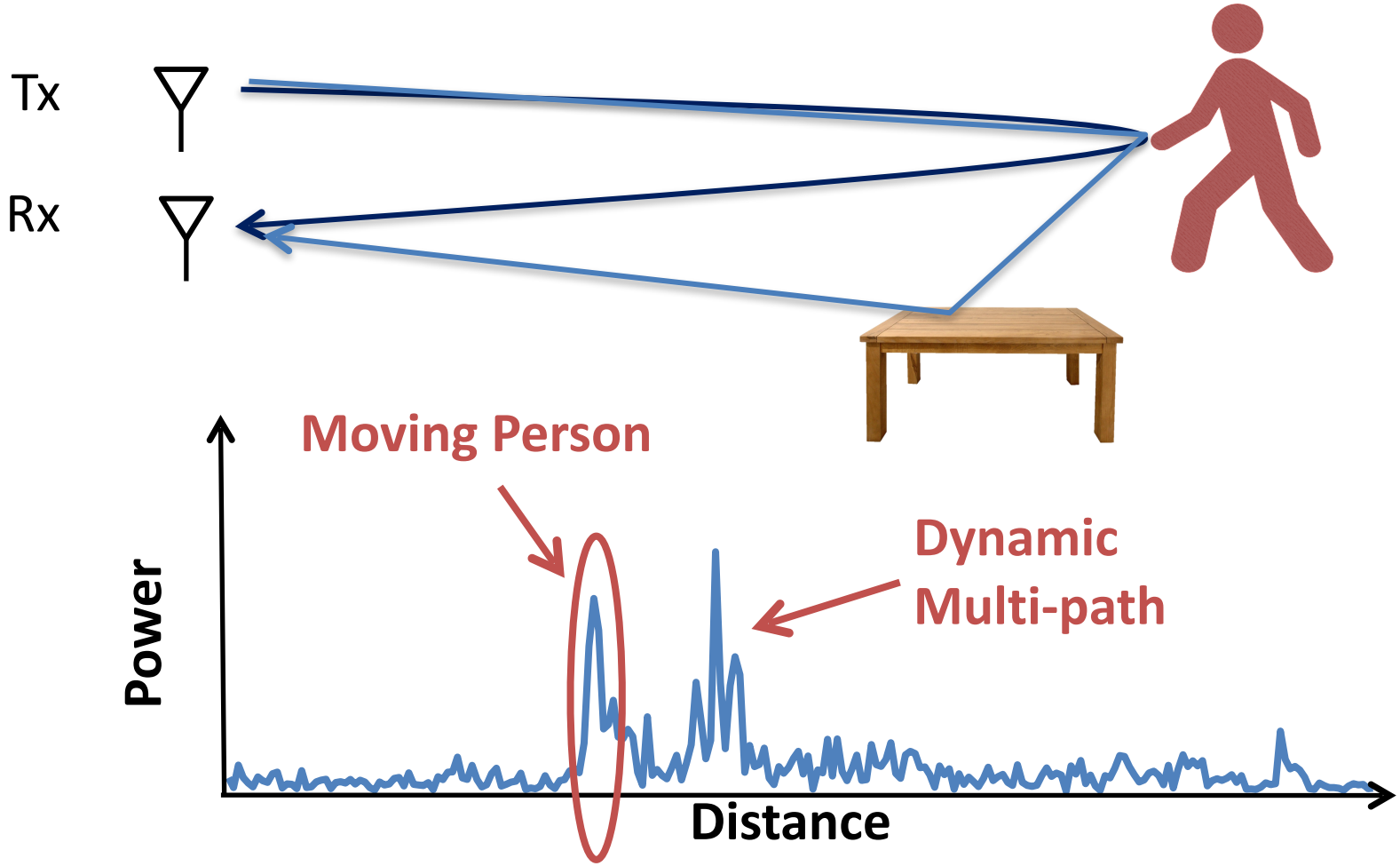
Static objects don't move

➔ Eliminate by subtracting consecutive measurements



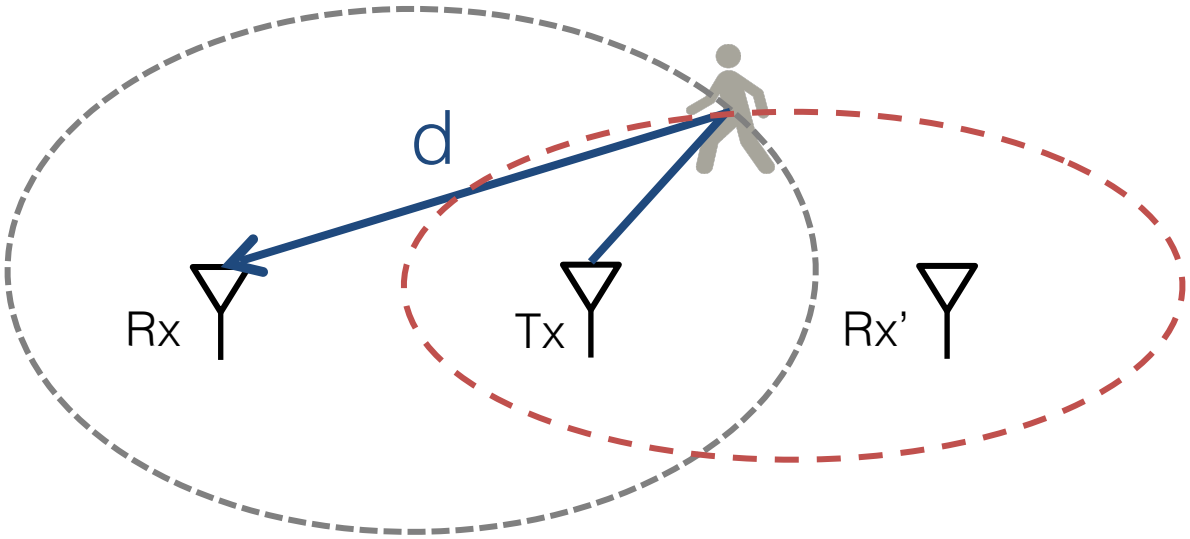
Why 2 peaks when we only have one moving person?

The direct reflection arrives before dynamic multipath!



Mapping Distance to Location

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



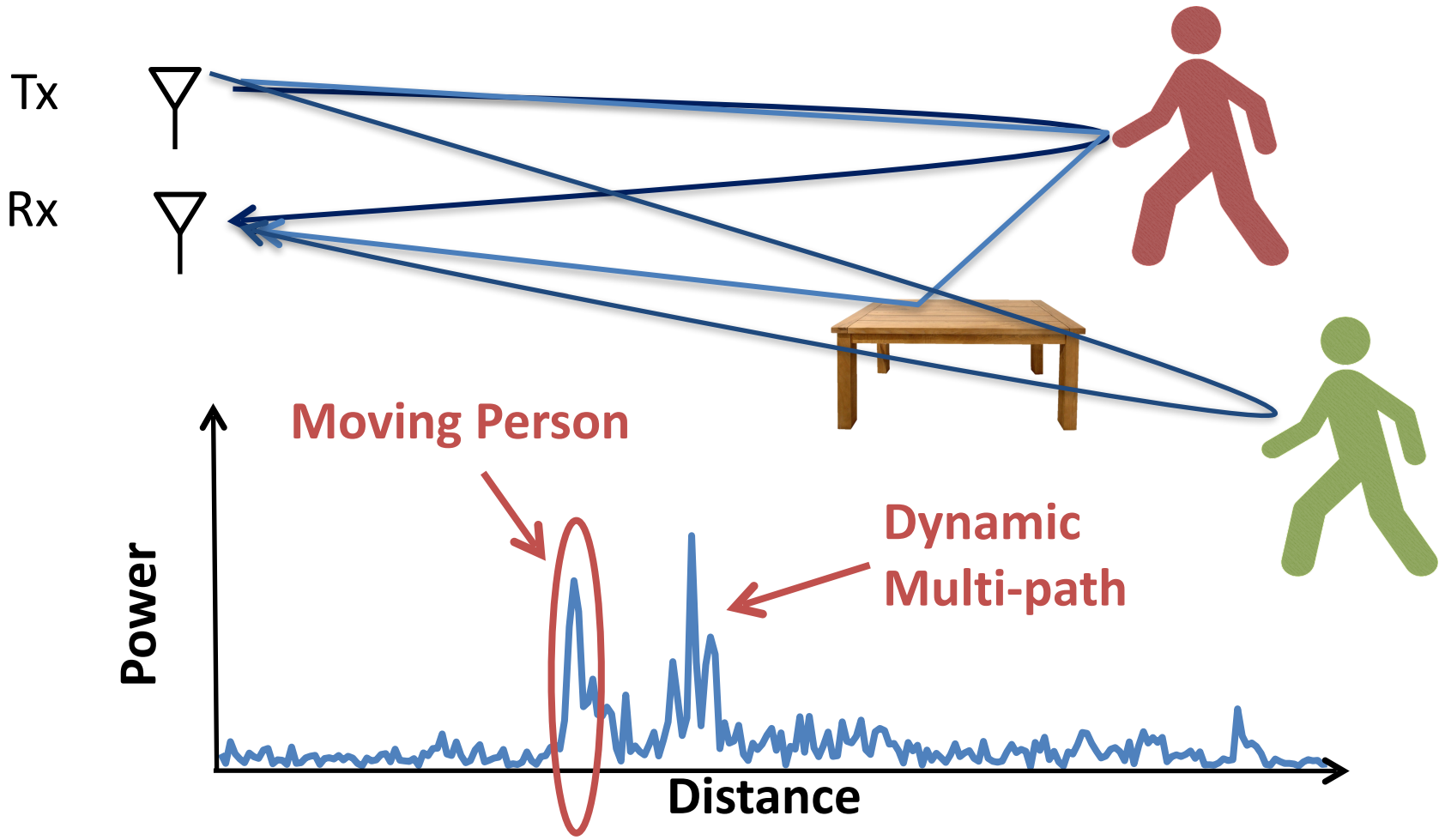
By adding another antenna and intersecting the ellipses, we can localize the person

From Location to tracking (over time)

What are some challenges for WiTrack?

How would you overcome these challenges?

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?

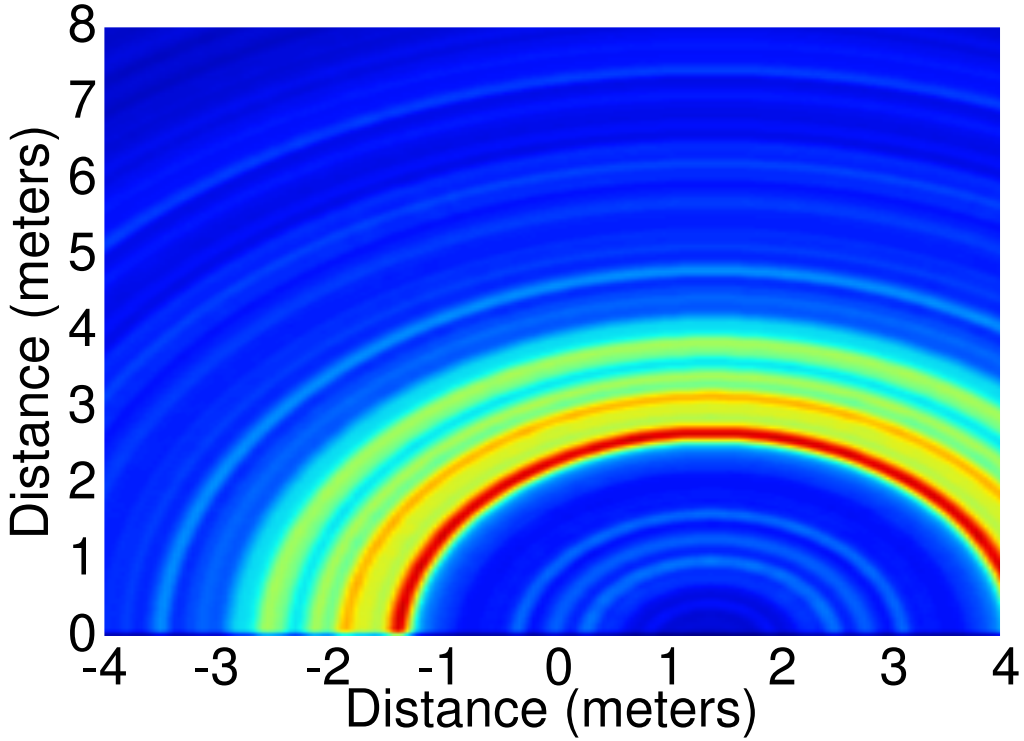
Idea: Person is consistent across different vantage points while multi-path is different from different vantage points

Combining across Multiple Vantage Points

Experiment: Two users walking

Setup

Single Vantage Point



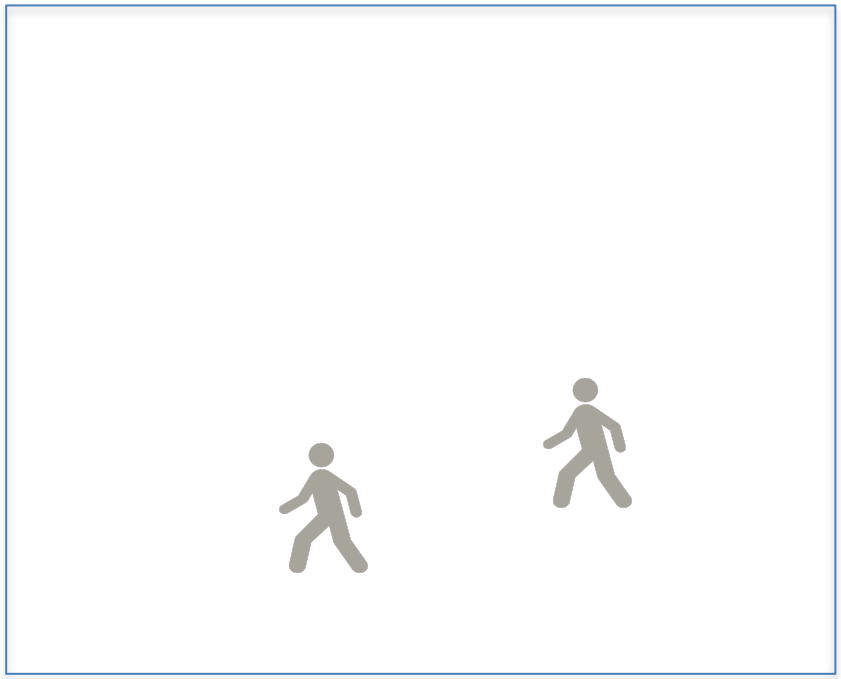
Mathematically: each round-trip distance can be mapped to an ellipse whose foci are the transmitter and the receiver

Mapping 1D to 2D heatmap

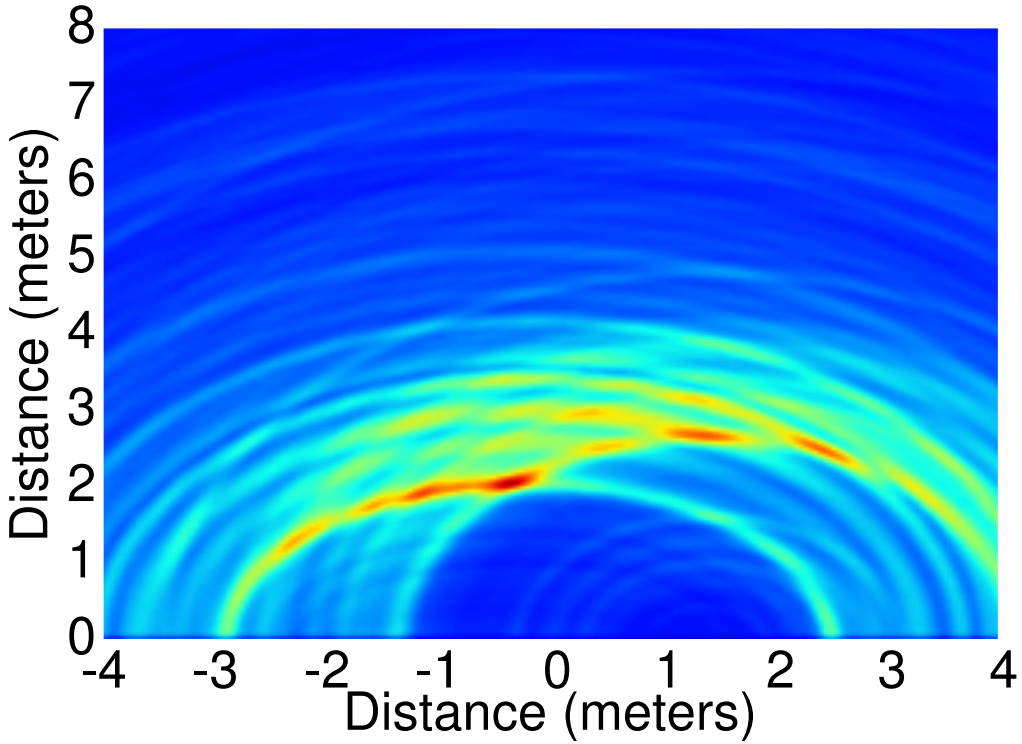
Combining across Multiple Vantage Points

Experiment: Two users walking

Setup



Two Vantage Points

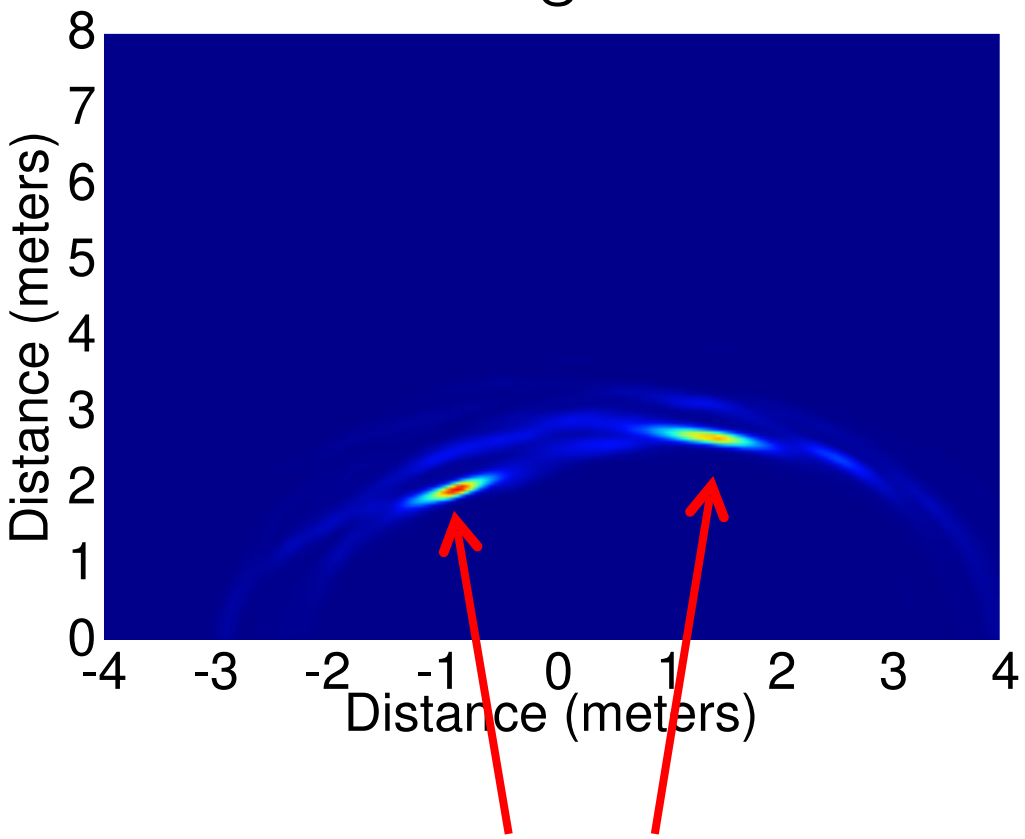


Combining across Multiple Vantage Points

Experiment: Two users walking

Setup

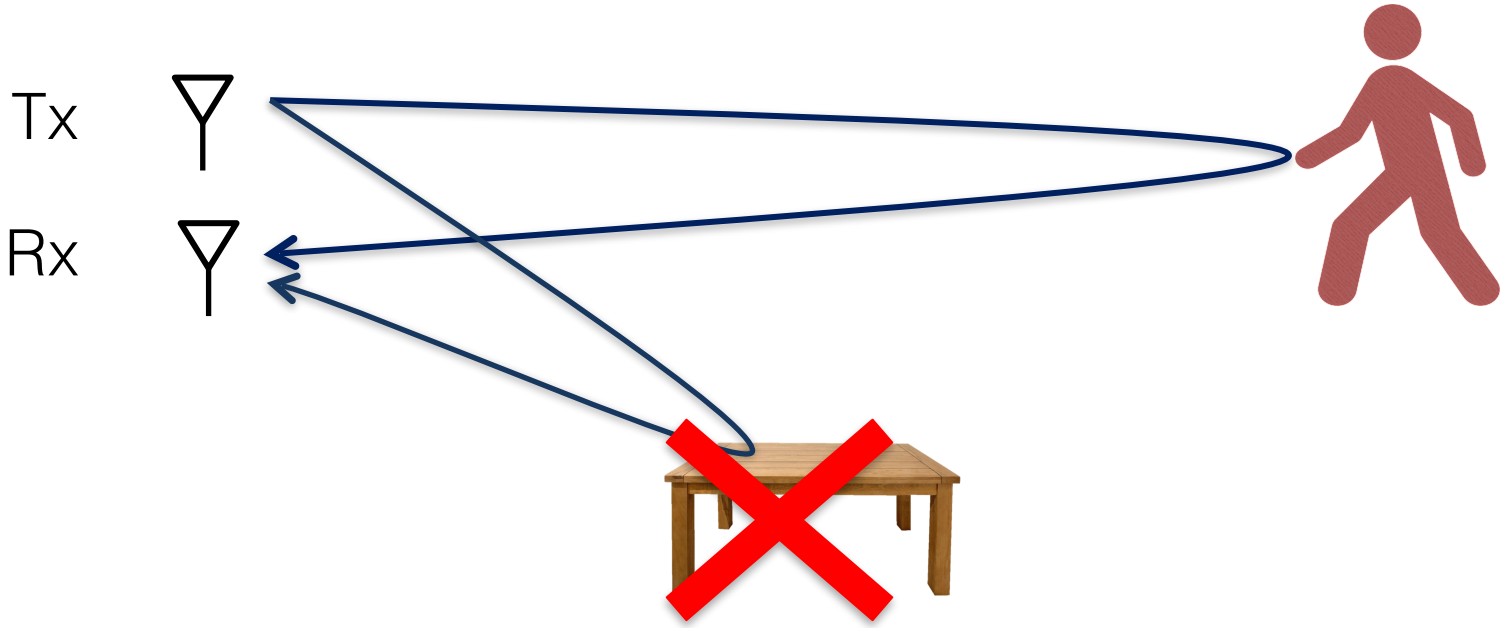
16 Vantage Points



Localize the two users

How can we localize static users?

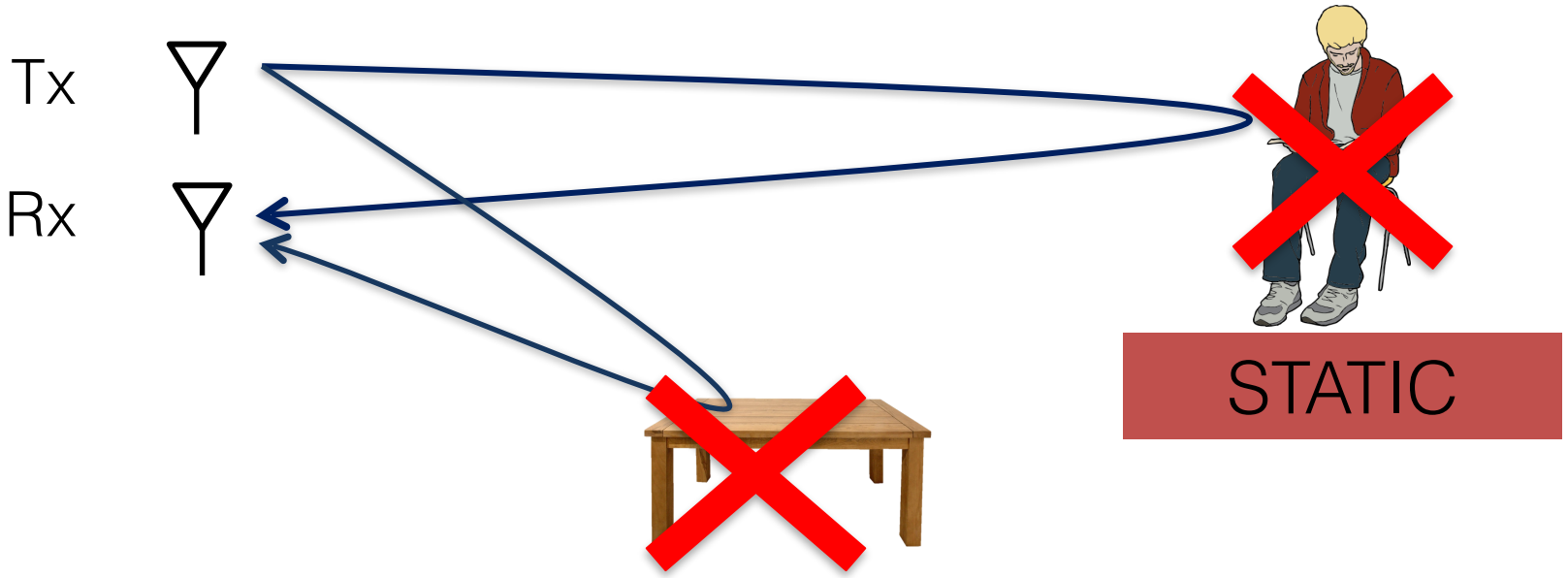
Dealing with multi-path when there is one moving user



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

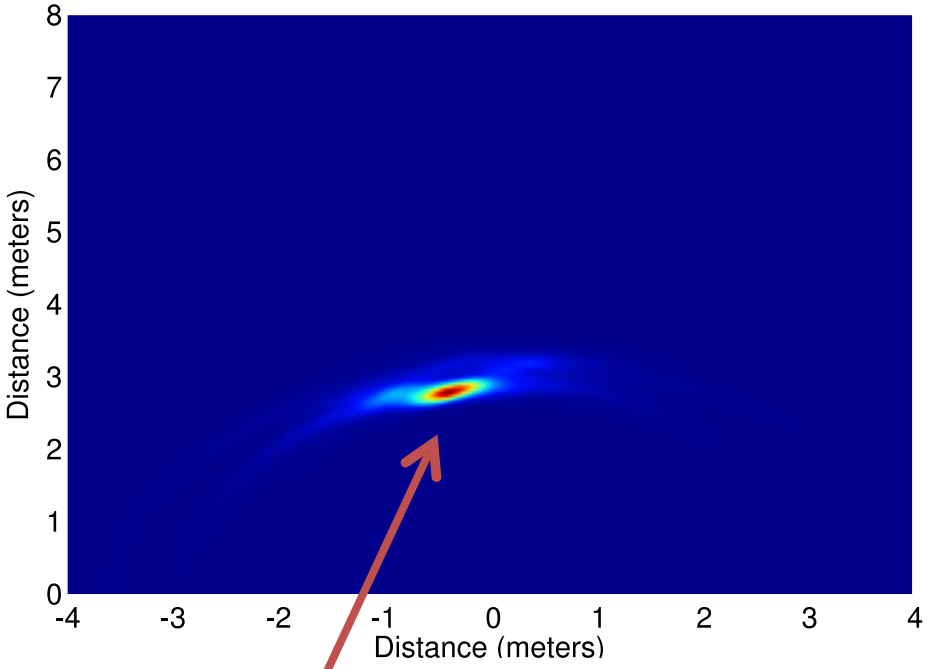
Needs User to Move

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

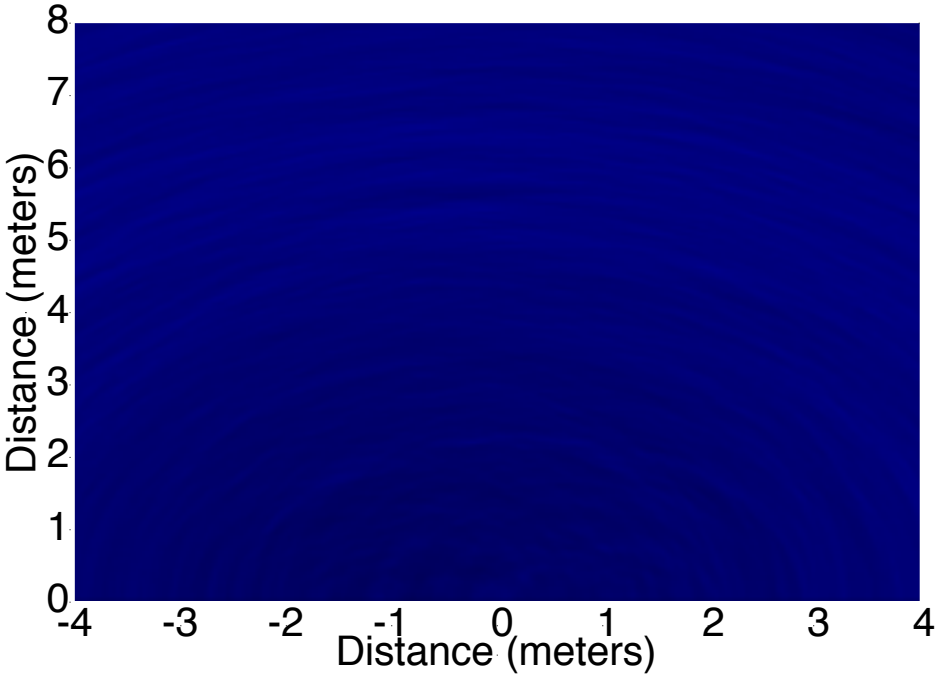
30ms subtraction window

User walking @ 1m/s



Localize the person

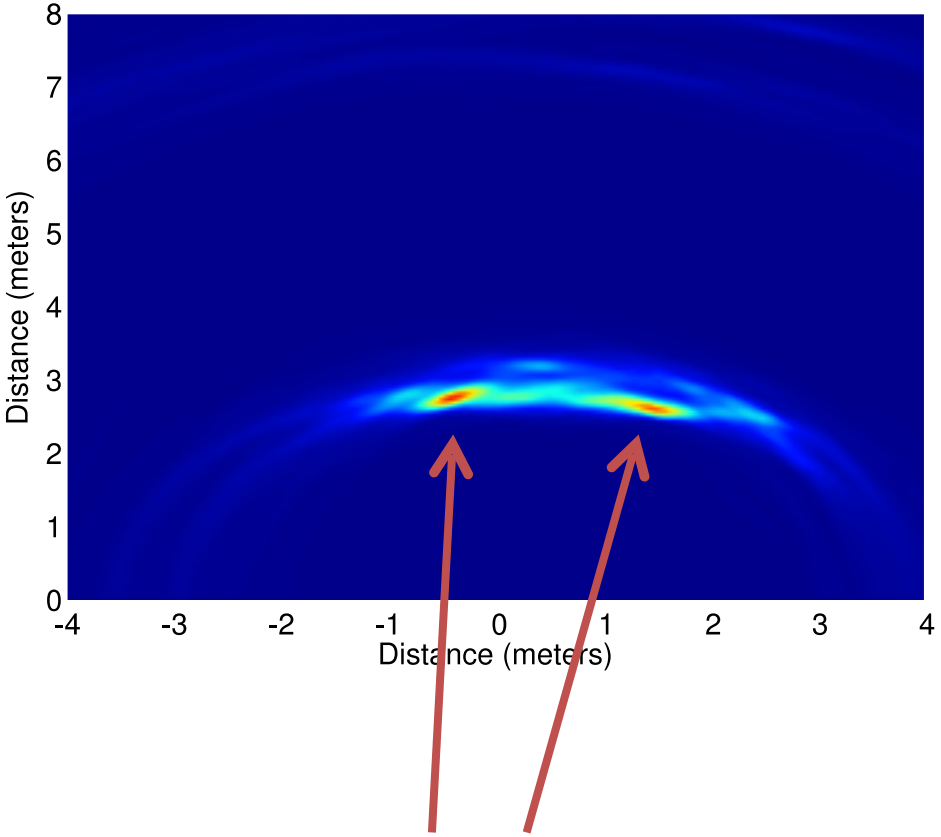
User Still (Breathing)



Cannot localize

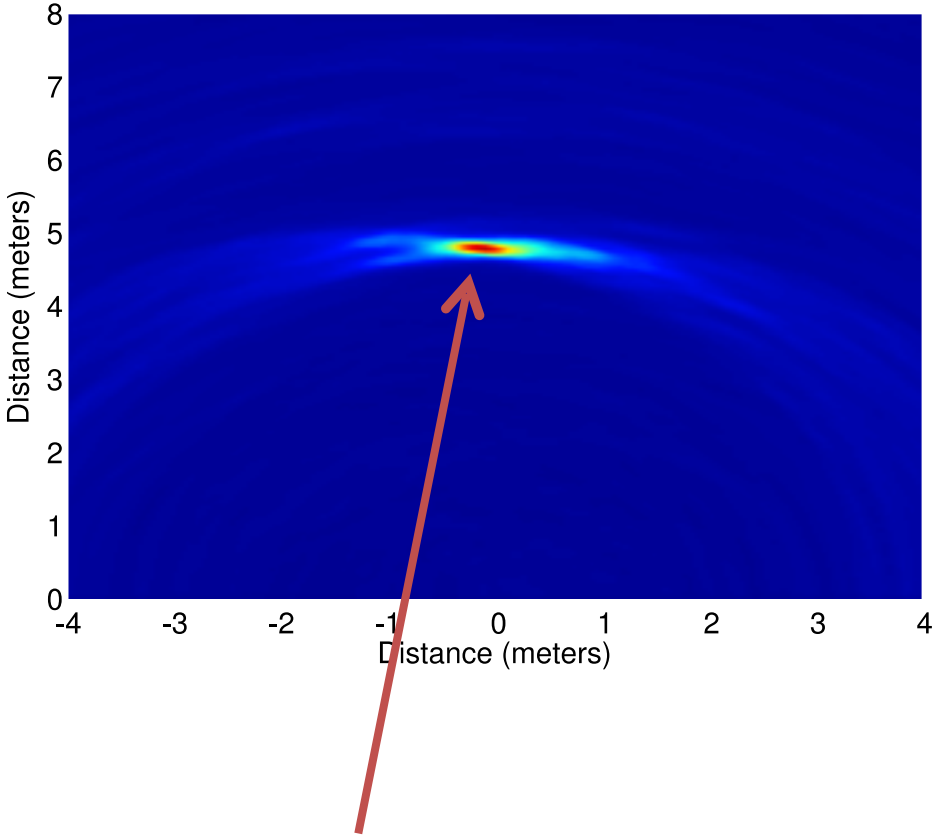
3s subtraction window

User walking

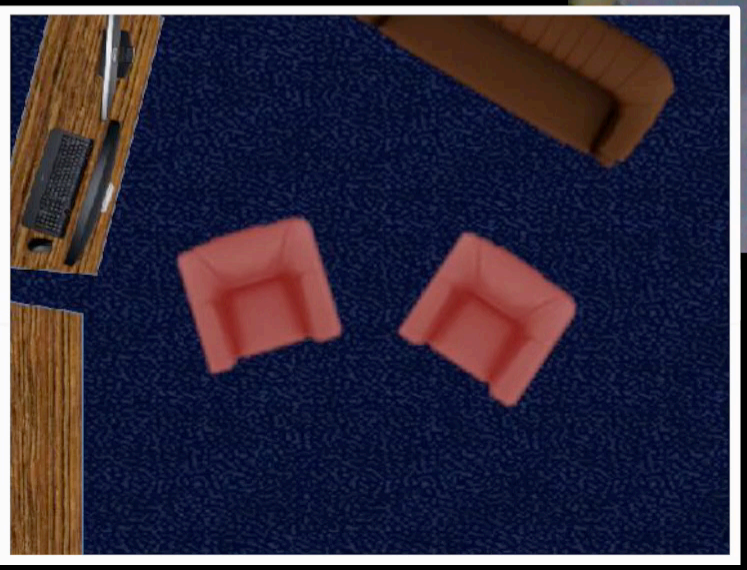


Person appears in two locations

User Still (Breathing)

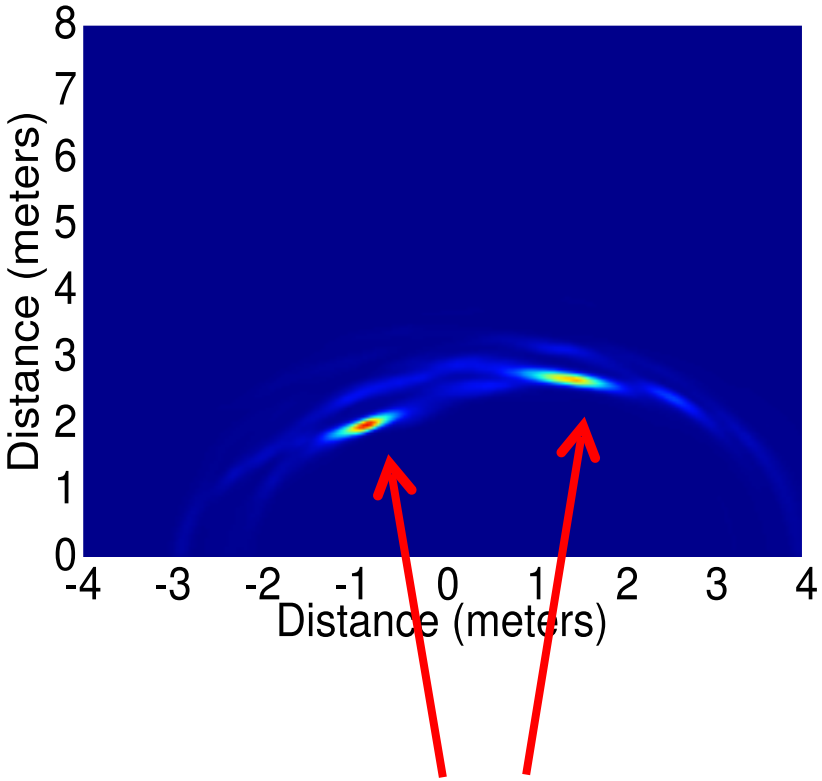


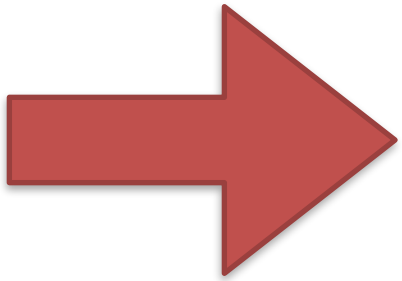
Localize the person

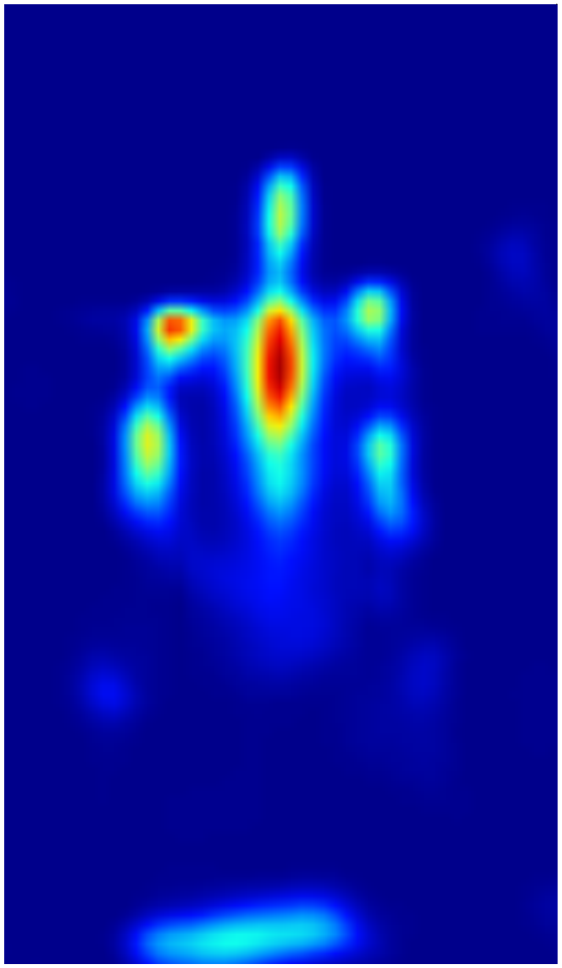


Want a silhouette

People are points







Localize the two users


COMMUNICATIONS
ACM

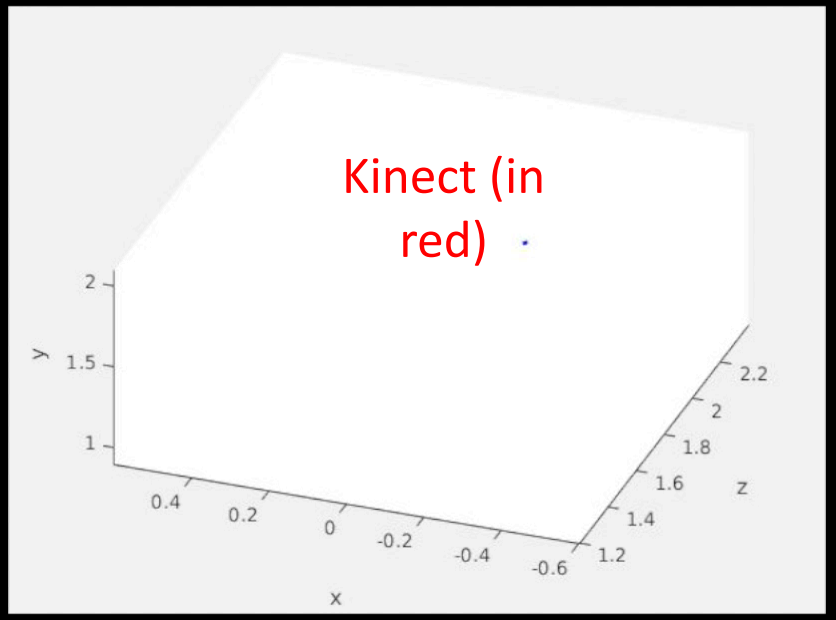
Who is behind the wall?

How is the person standing?

Writing in the air

Device

Our Tracking Result



Where is Wireless Sensing today?

1. **Research-wise:**
   - Sensitivity: close to ECG in measuring micro-cardiac events (2020)
   - Reconstruction: can recover 3D human skeleton + meshes (2020)
   - Can monitor new affective metrics: stress levels (2021)
   - Technologies: WiFi, millimeter wave, etc.

2. **Real-world Uses:**
   - Multiple startups in the space
   - Medical use in monitoring 1,000s of patients with Alzheimer's, Parkinson's, COVID-19, Multiple Sclerosis, etc.
   - Influenced the design of sensors like Google Soli and others

3. **Standards:**
   - Upcoming WiFi standard (802.11bf)
   - Planning for 6G

How can you use this technology in the metaverse?

Objectives of this Lecture

Learn the fundamentals, applications, and implications of **wireless sensing**

1. What are the basic principles of wireless sensing?
2. How can we obtain centimeter-scale localization from wireless reflections?
3. What are the possibilities of sensing beyond localization?
4. What are the industry opportunities and societal implications of wireless sensing (today and in the near+far future)?

TODO:

1- Lab 0 checkoff this week

2- Lab 1 due on Valentine's day

3- PSet 1 due Feb 28

Start thinking about your projects