CIS 3990

Mobile and IoT Computing

https://penn-waves-lab.github.io/cis3990-24spring

Lecture 6: Mobile Health & Vitals Sensing

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Course Organization

Module 1: Localization and Motion Tracking

Module 2: Sensing

Module 3: Connectivity

Module 4: Low-power IoT & Efficient Computing

Module 5: Emerging Topics

Course Organization

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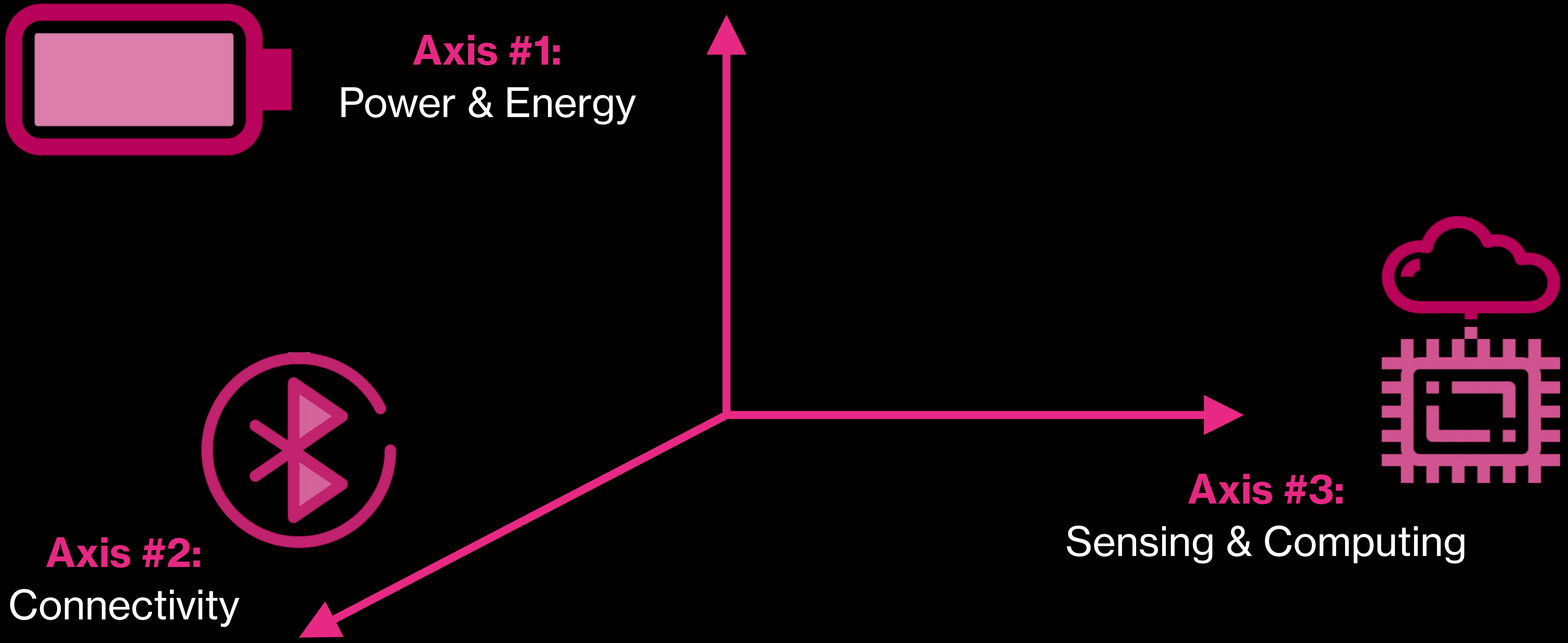
Main Component of IoT Systems



Axis #3: Sensing & Computing

WHAT?

Sensing Objectives

Locations

Health

Motion & Activity

Environment

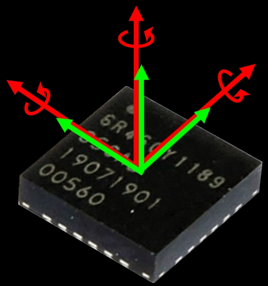
HOW?

Sensing Modalities

Radio

Acoustic

Inertial



Visual

Objectives of This Module

Learn how foundational sensing technologies can be used to extract diverse and meaningful insights

1. What are important application areas of Mobile and IoT sensing?
2. What are the foundational sensing mechanisms and how are they related to localization?
3. What processing algorithms can be used to transform raw sensor data?
4. Example sensing systems/solutions with real-world case studies.

Mobile Health

Monitoring health and well-being using mobile devices, wearable sensors, and smart environments

Applications: What do we want to measure? And why?

Calories

Sleep

Steps

Mental & emotional well-being

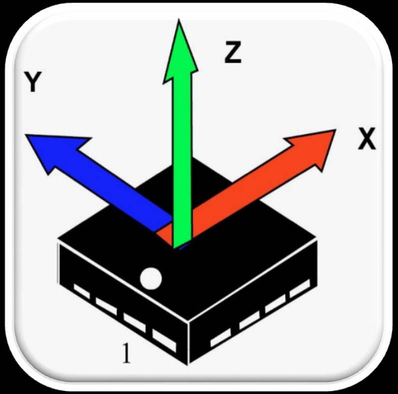
Gait & activity

Heart rate & breathing

How do we measure?

Voice

Accelerometer



Cameras

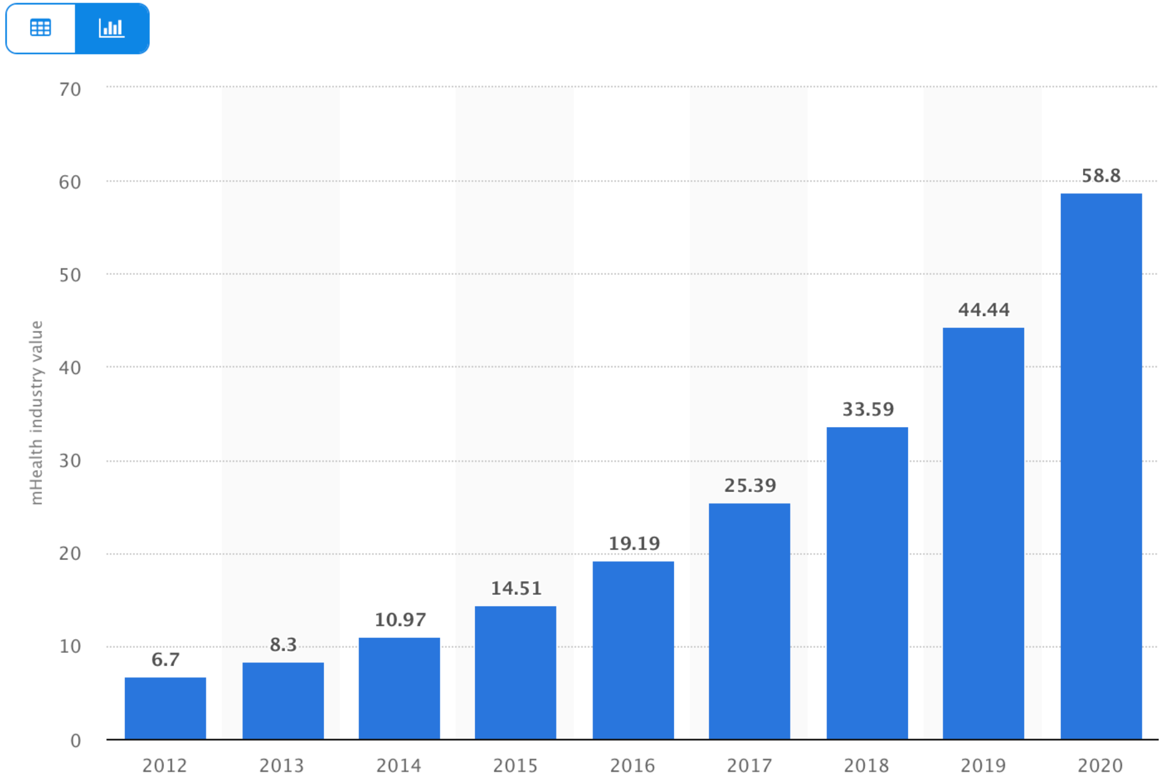
Logging

Wireless reflections

Digital pill

Background

mHealth (mobile health) industry market size projection from 2012 to 2020 (in billion U.S. dollars)*



Details: Worldwide; Allied Market Research; 2013

Can smart homes monitor and adapt to our breathing and heart rate

But: today's technologies for monitoring vital signs are cumbersome

Breath Monitoring

Heart Rate Monitoring

Not suitable for elderly & babies

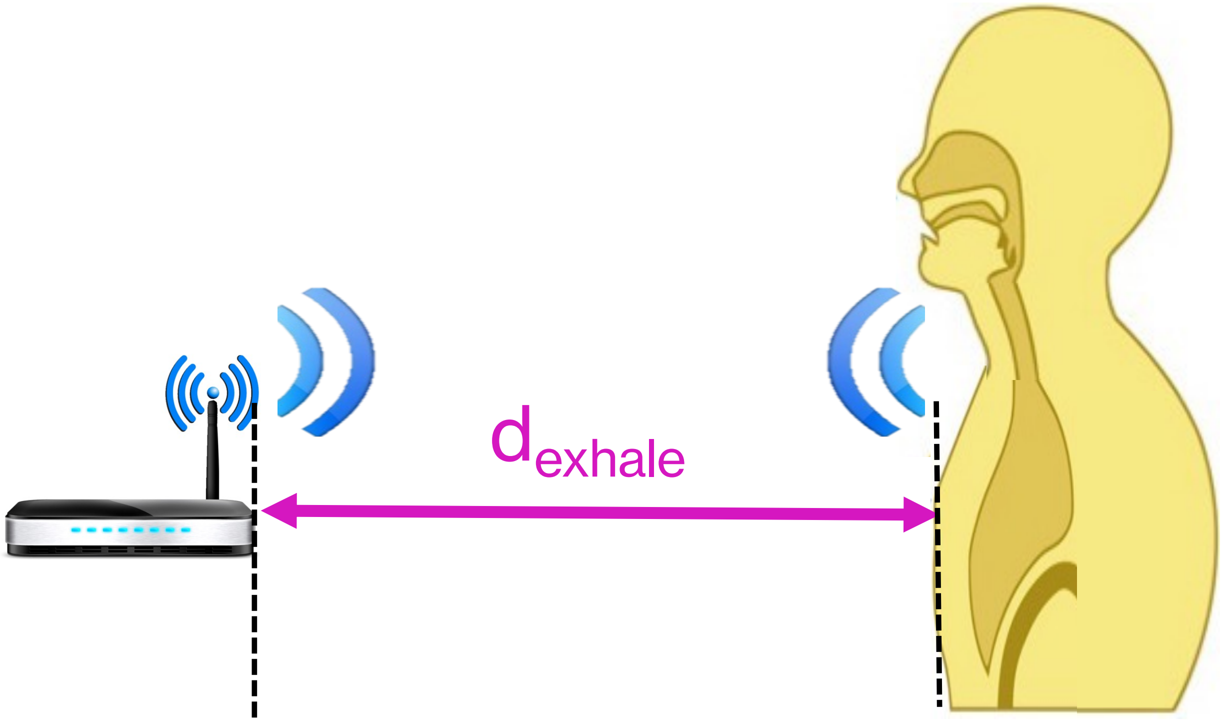
Imagine enabling these applications without sensors on the human body

Breath Monitoring

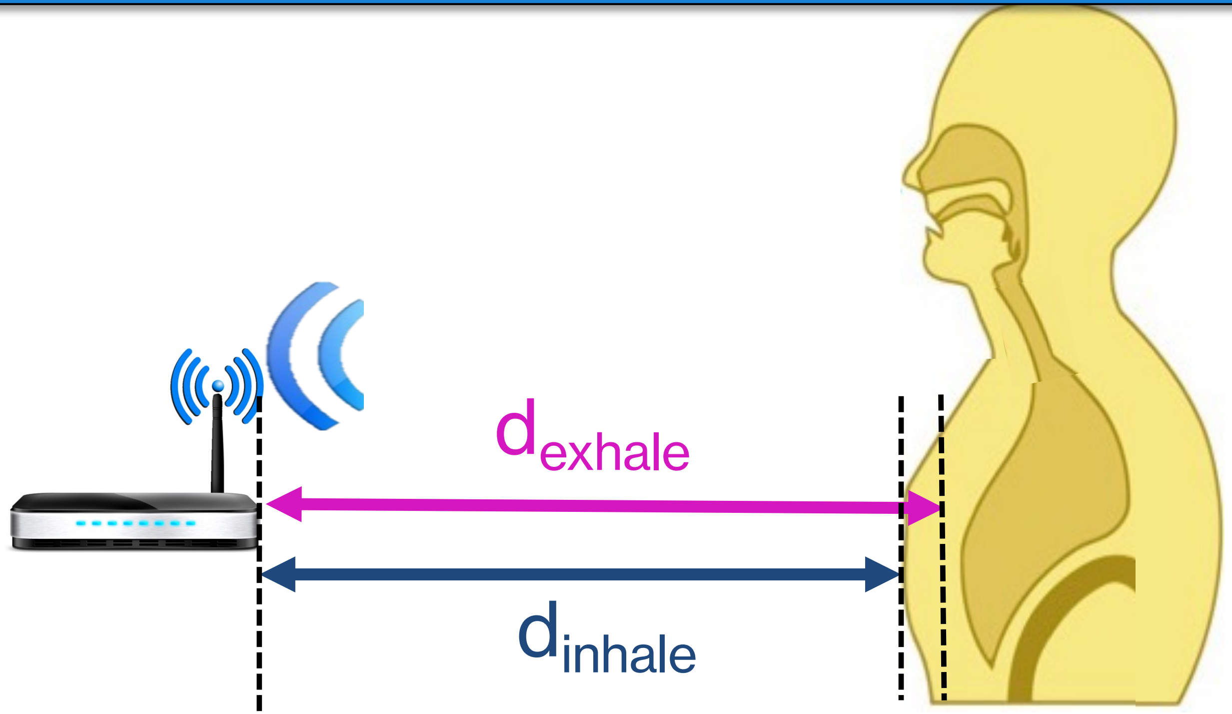
Heart Rate Monitoring

Not suitable for elderly & babies

Vital Radio: Use wireless reflections off the human body to monitor breathing and heart rate


d_{exhale}

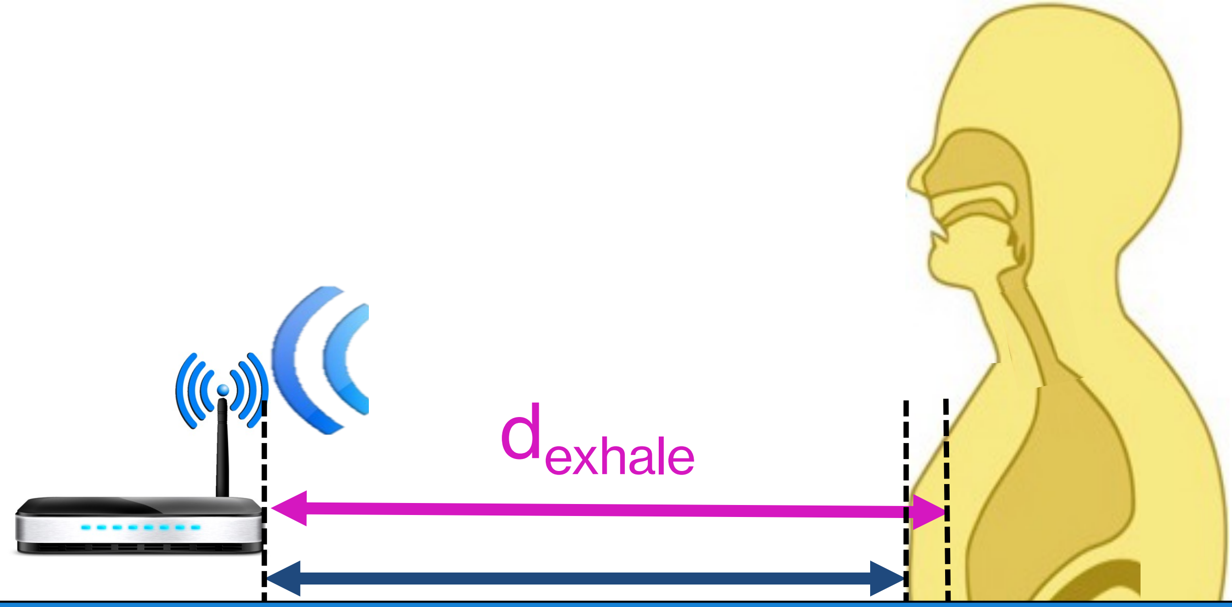
Problem: Localization accuracy is only 12cm and cannot capture vital signs



$$h = \frac{1}{d} e^{j 2\pi \frac{d}{\lambda}}$$

$$\phi = 2\pi \frac{d}{\lambda}$$

Device analyzes the wireless reflections to compute distance to the body

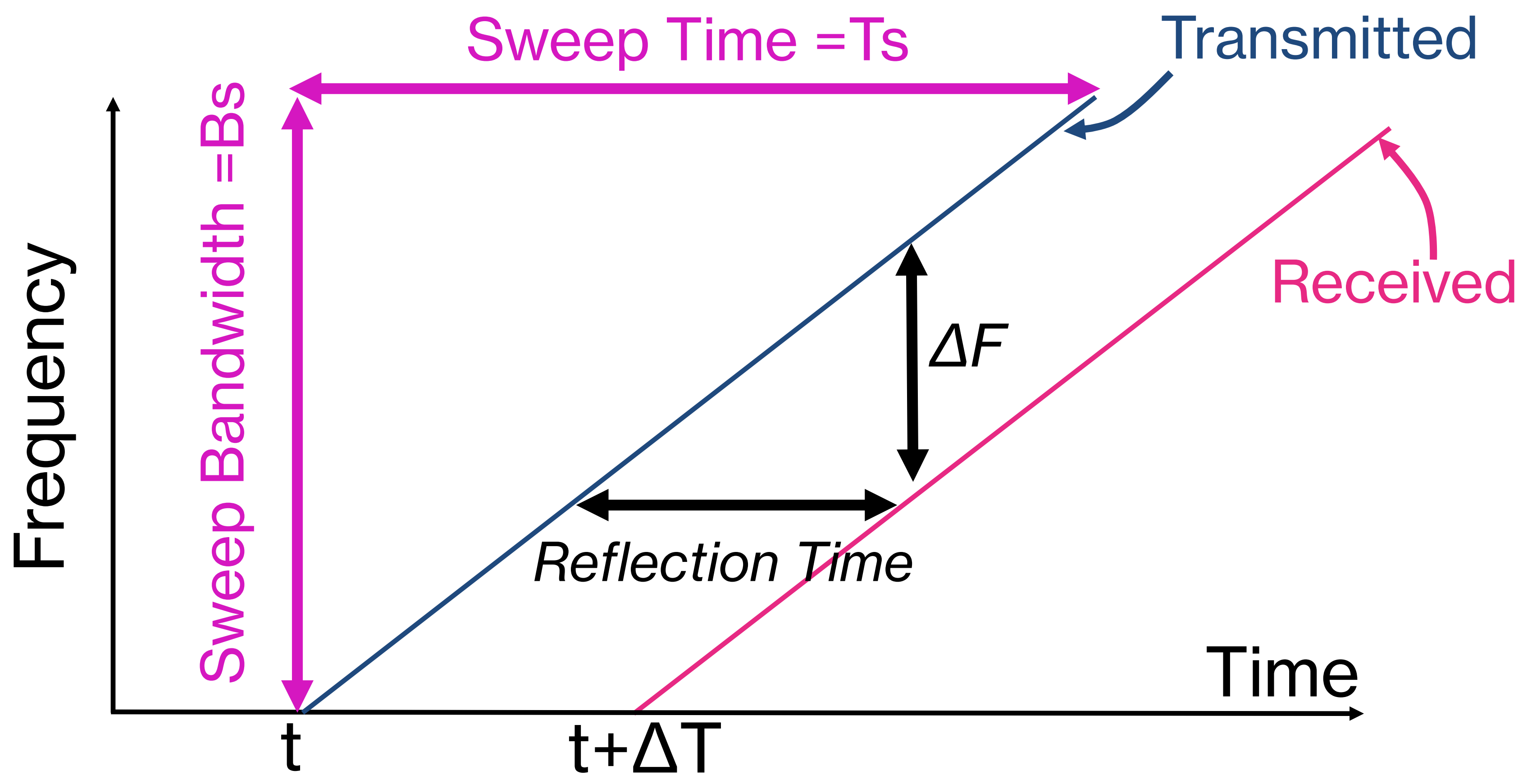


Why did we need FMCW if phase is so accurate?

$$h = \frac{1}{d} e^{j 2\pi \frac{d}{\lambda}}$$

$$\phi = 2\pi \frac{d}{\lambda}$$

FMCW: Measure time by measuring frequency



Slope = k = Bs/Ts

Reflection Time =ΔF/k

FMCW

- FMCW Transmitted Signal:

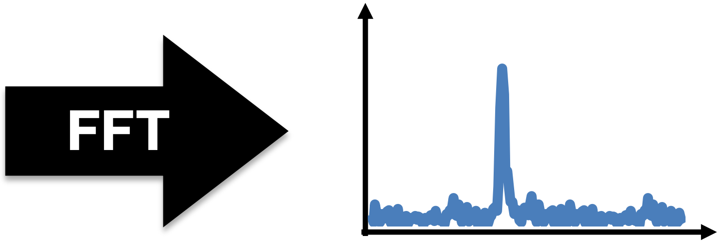
$$x(t) = e^{j2\pi(\frac{k}{2}\ t^2 + f_0 t)}$$

- FMCW Received Signal:

$$y(t) = \sum_i A_i e^{j2\pi(\frac{k}{2}\ (t-\tau_i)^2 + f_0(t-\tau_i))}$$

- FMCW after down-conversion:

$$y_b(t) = \sum_i A_i e^{j2\pi(k\tau_i t + f_0 \tau_i)}$$



$\Delta F = k\ \tau_i$

FMCW

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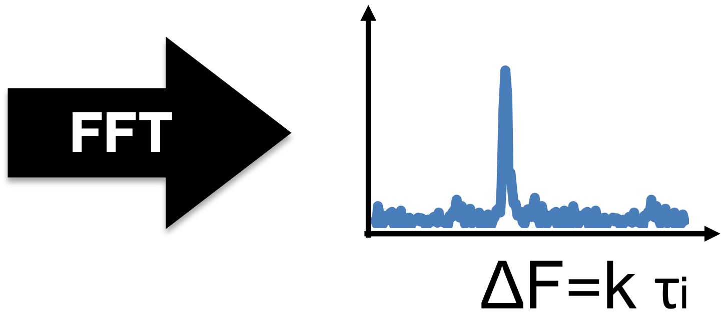

- Sampling Rate = B

$\Delta F < B \longrightarrow \tau_{max} = B/k = BxTs/Bs \longrightarrow d_{max} = cxBxTs/2Bs$

FMCW

- FMCW Transmitted Signal:

$$x(t) = e^{j2\pi(\frac{k}{2}\ t^2+f_0 t)}$$

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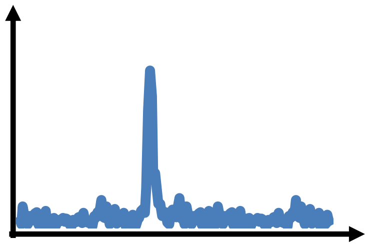
$$y_b(t) = \sum_i A_i e^{j2\pi(k\tau_i t+f_0\tau_i)}$$

FFT



$\Delta F = k\ \tau_i$

- Sampling Rate = B

$\Delta F < B \longrightarrow \tau_{max} = B/k = BxTs/Bs \longrightarrow d_{max} = cxBxTs/2Bs$

- Sampling Window = Ts

$\Delta F > 1/Ts \longrightarrow \tau_{min} = 1/(kxTs) = 1/Bs \longrightarrow d_{min} = c/2Bs$

FMCW

- FMCW Transmitted Signal:

$$x(t) = e^{j2\pi(\frac{k}{2}\ t^2 + f_0 t)}$$

- FMCW Received Signal:

$$y(t) = \sum_i A_i e^{j2\pi(\frac{k}{2}\ (t-\tau_i)^2 + f_0(t-\tau_i))}$$

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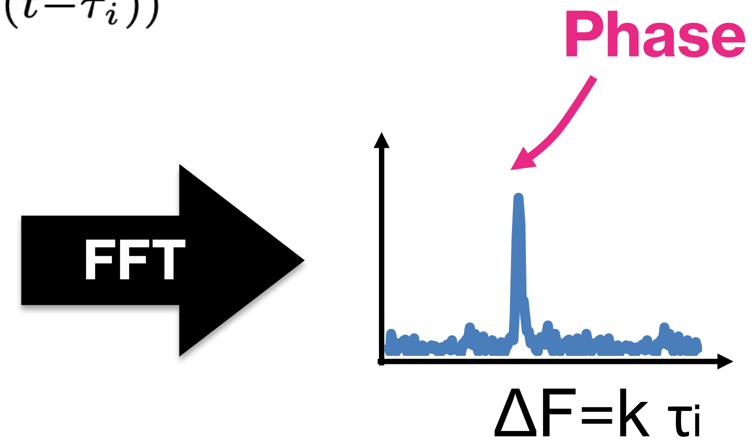


Phase of peak = $f_0\tau_i$

- Phase wraps around 2π
- Use peak position $\Delta F = k\ \tau_i$ for course estimate of τ_i
- Use peak phase $f_0\tau_i$ for fine estimate of τ_i

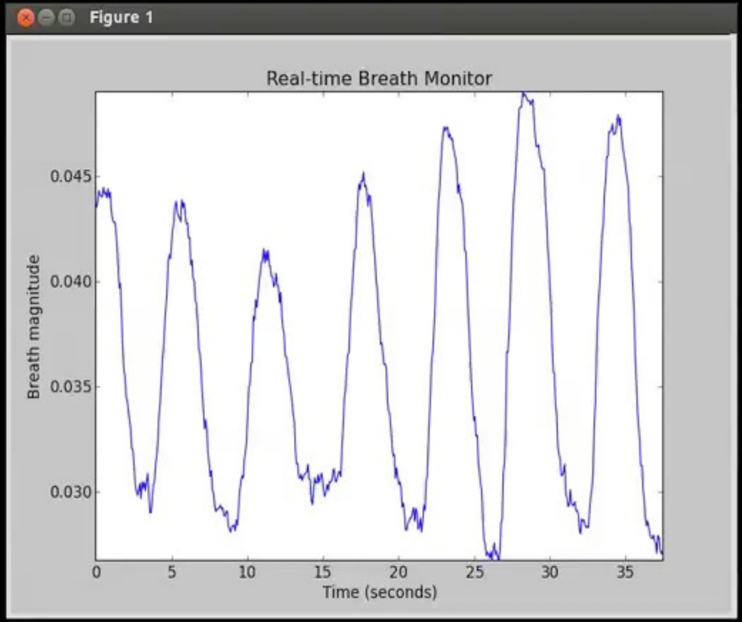
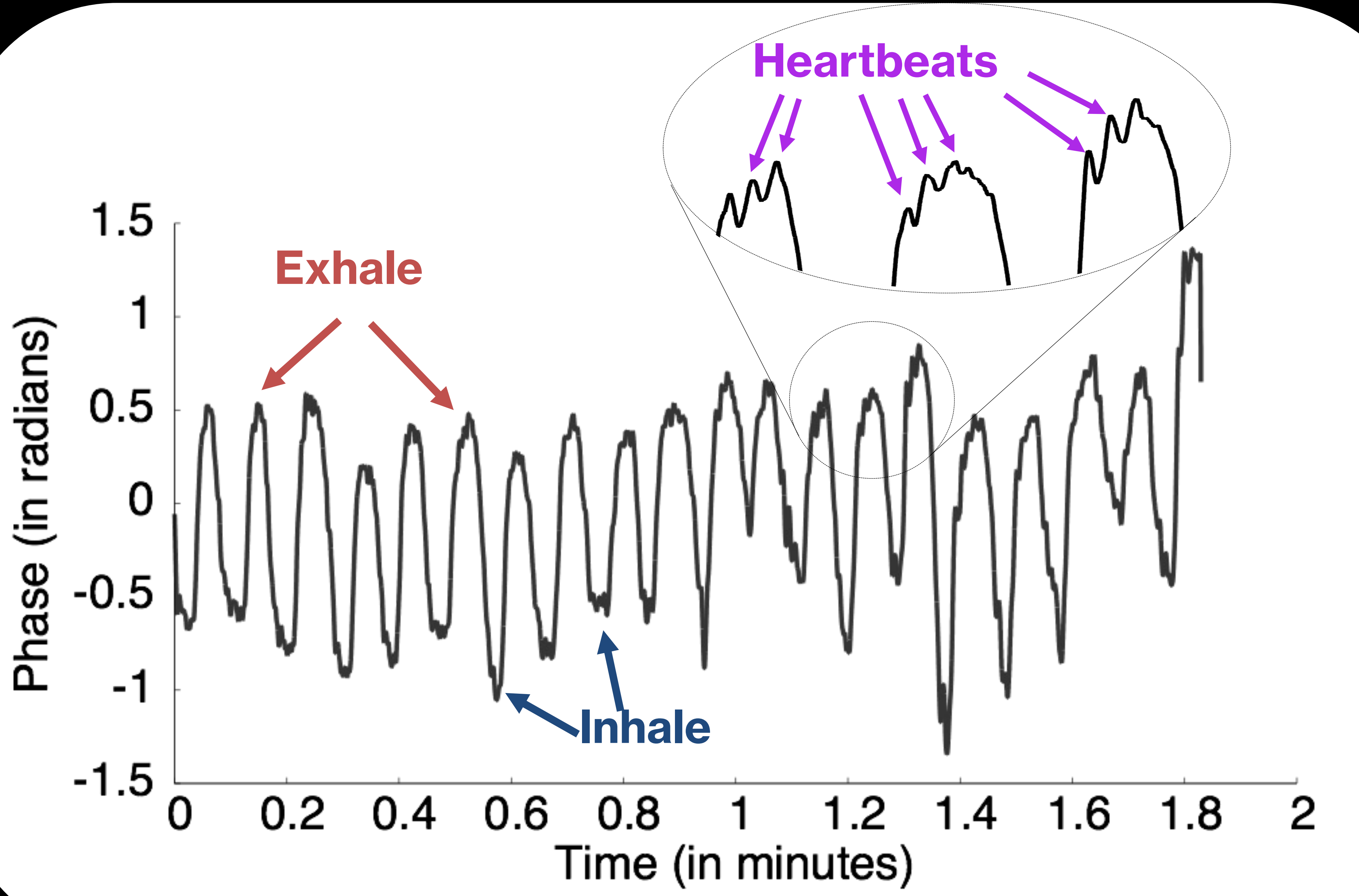
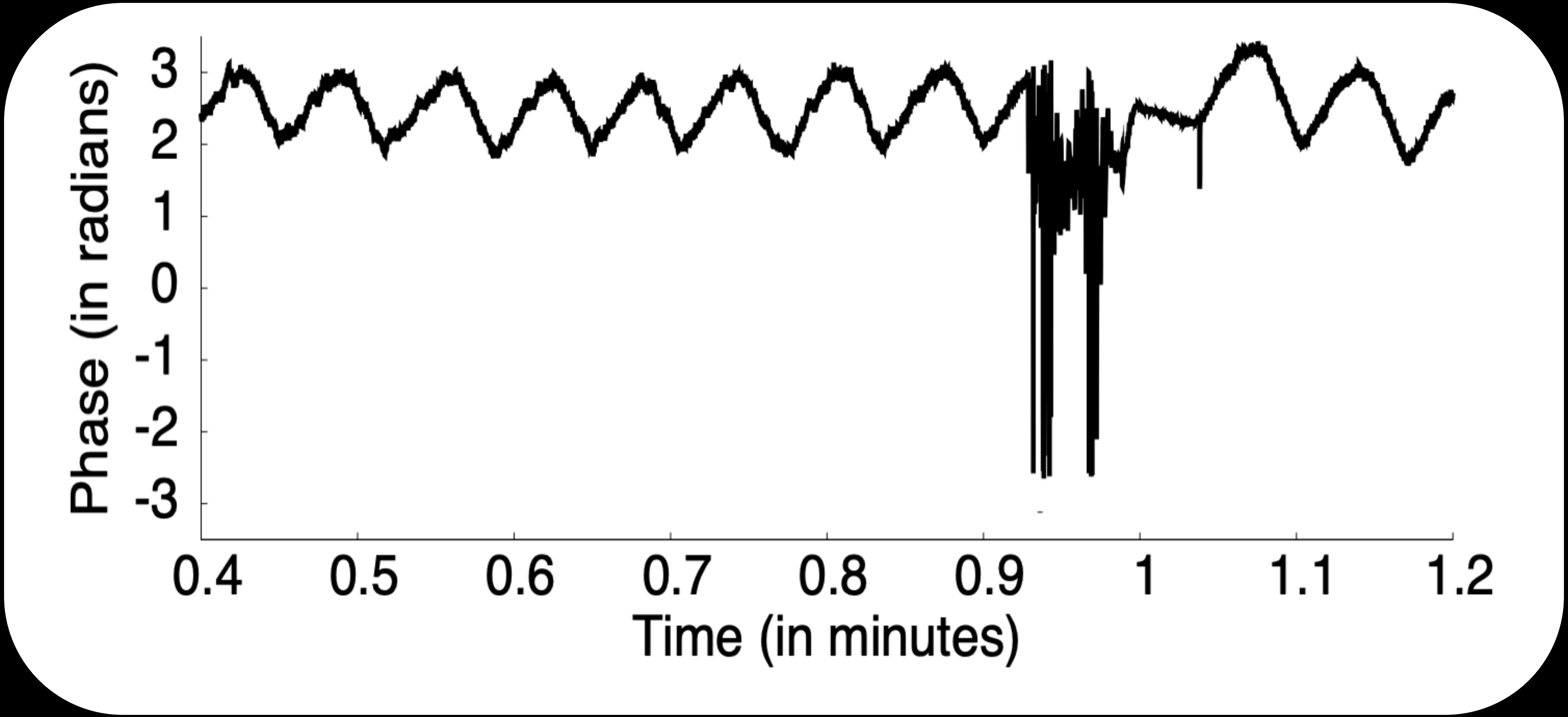


Figure 1
Real-time Breath Monitor
Breath magnitude
0.045
0.040
0.035
0.030
0 5 10 15 20 25 30 35
Time (seconds)

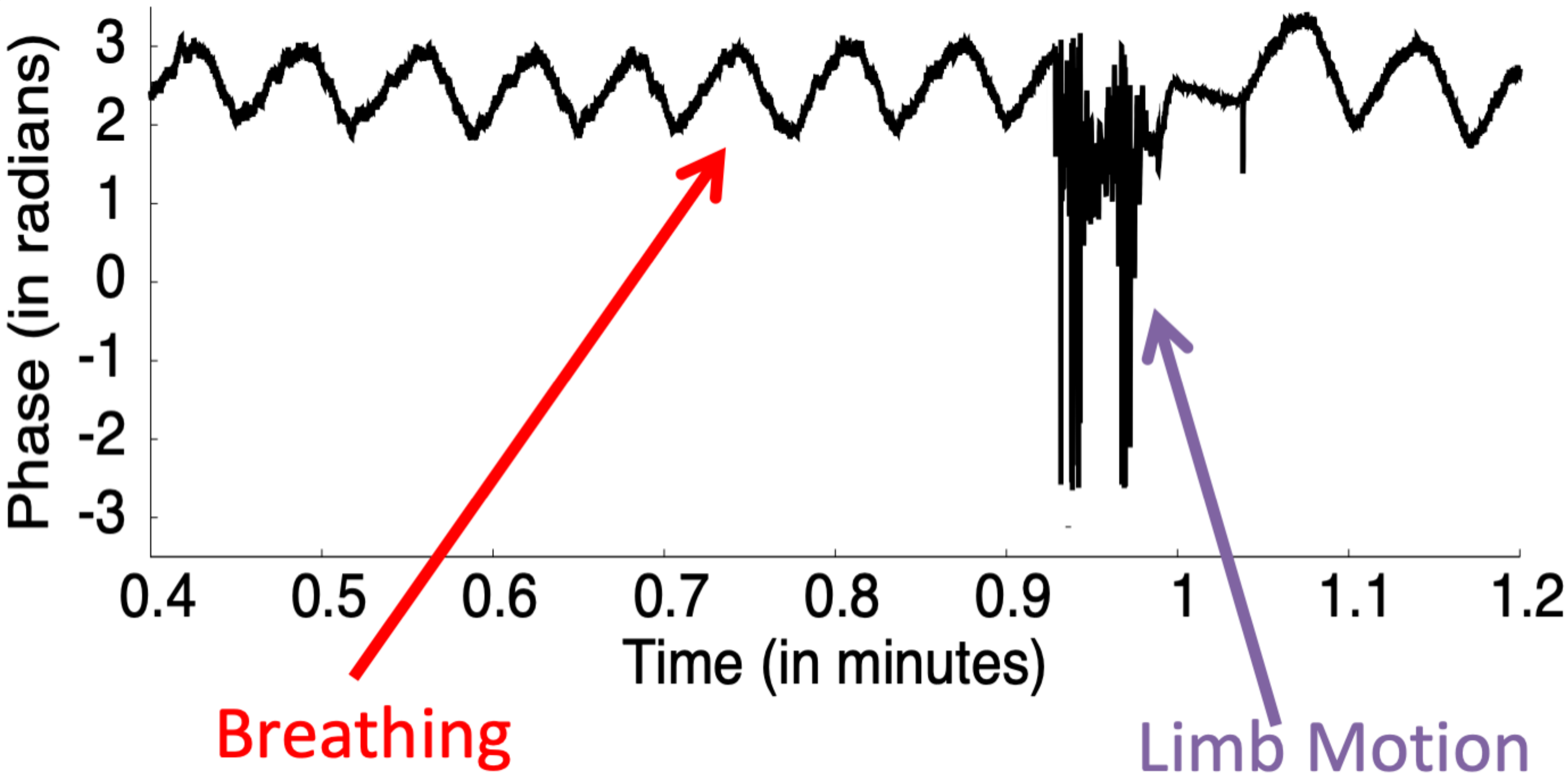
Let’s zoom in on these signals


Heartbeats
Exhale
Inhale
1.5
1
0.5
0
-0.5
-1
-1.5
Phase (in radians)
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
Time (in minutes)

What happens when a person moves his limb?



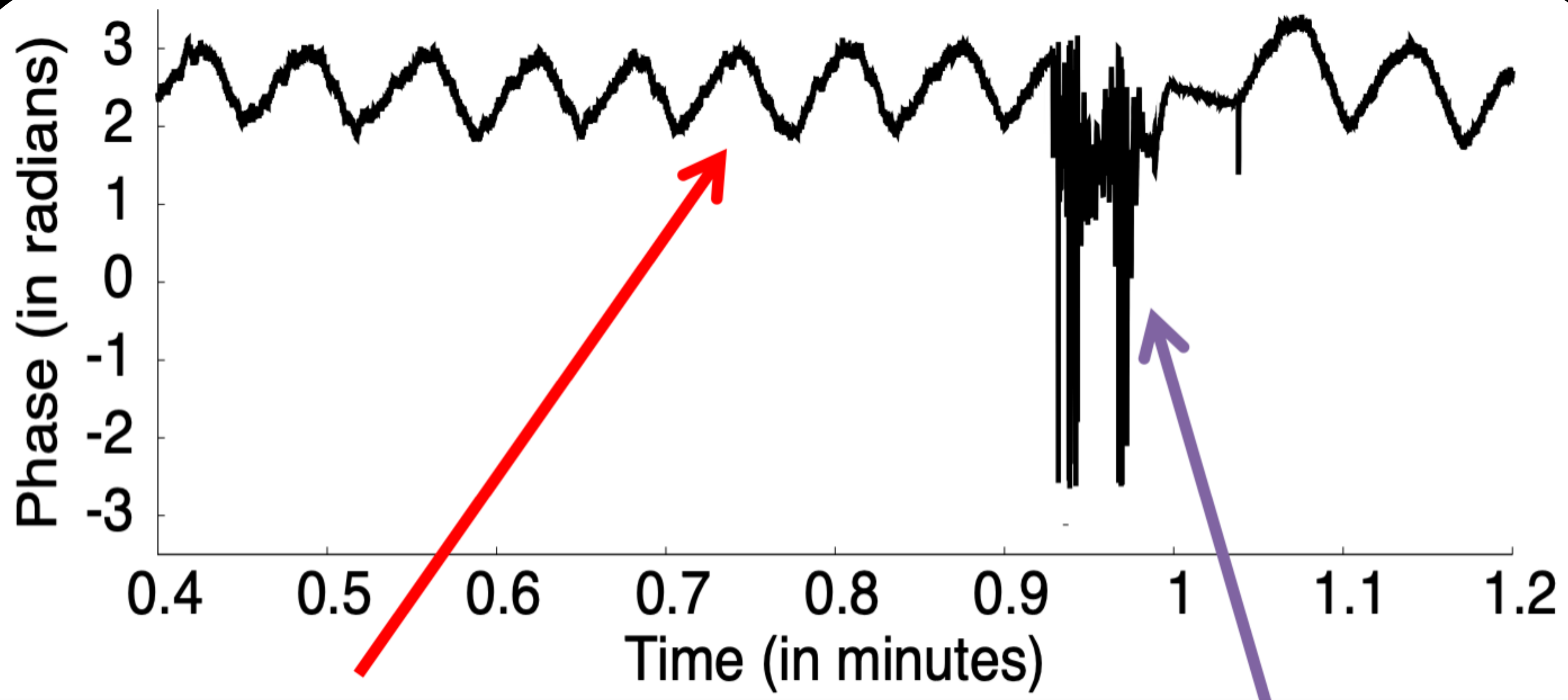
What happens when a person moves his limb?



Periodic

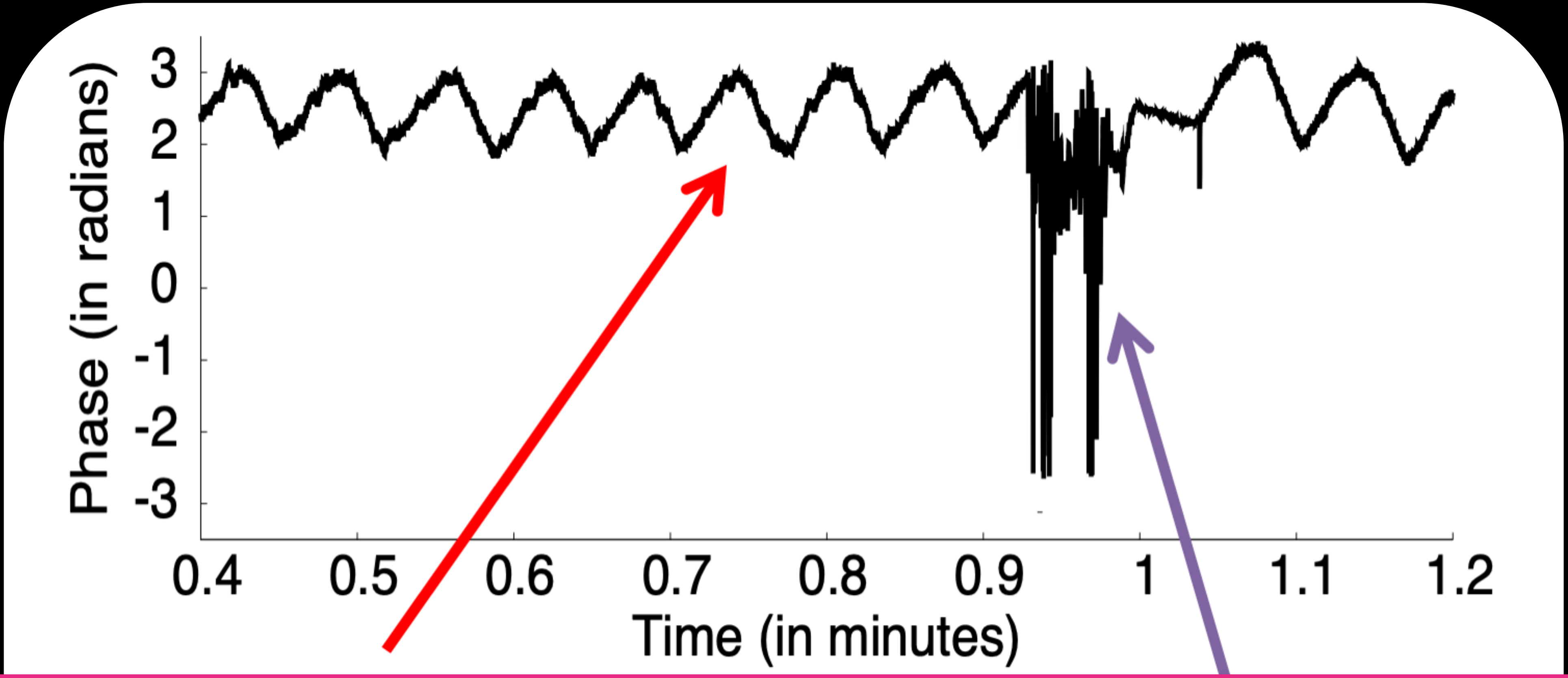
Not periodic

What happens when a person moves his limb?



Use periodicity test to eliminate variations that are not due to beathing/heartbeats

What happens when a person moves his limb?



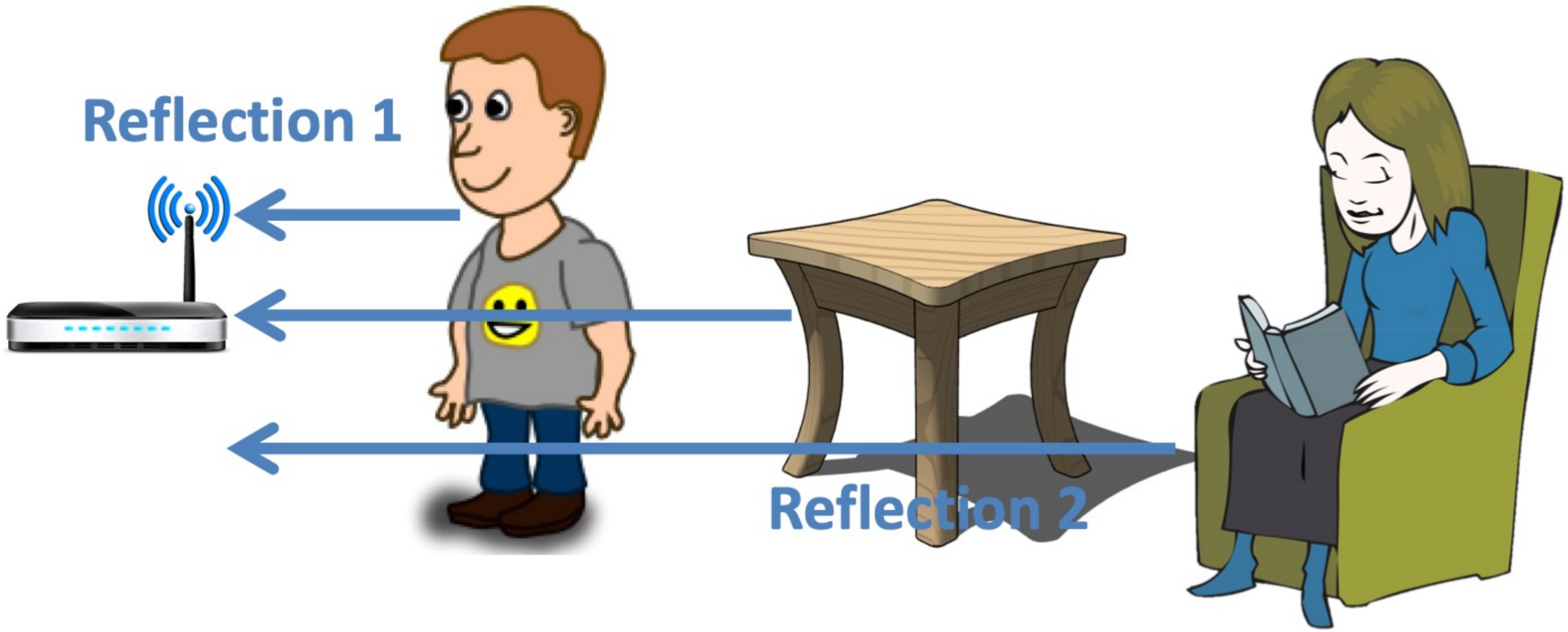
Band-pass filter the cleaned signal to extract breathing and heart rate

Baby Monitoring

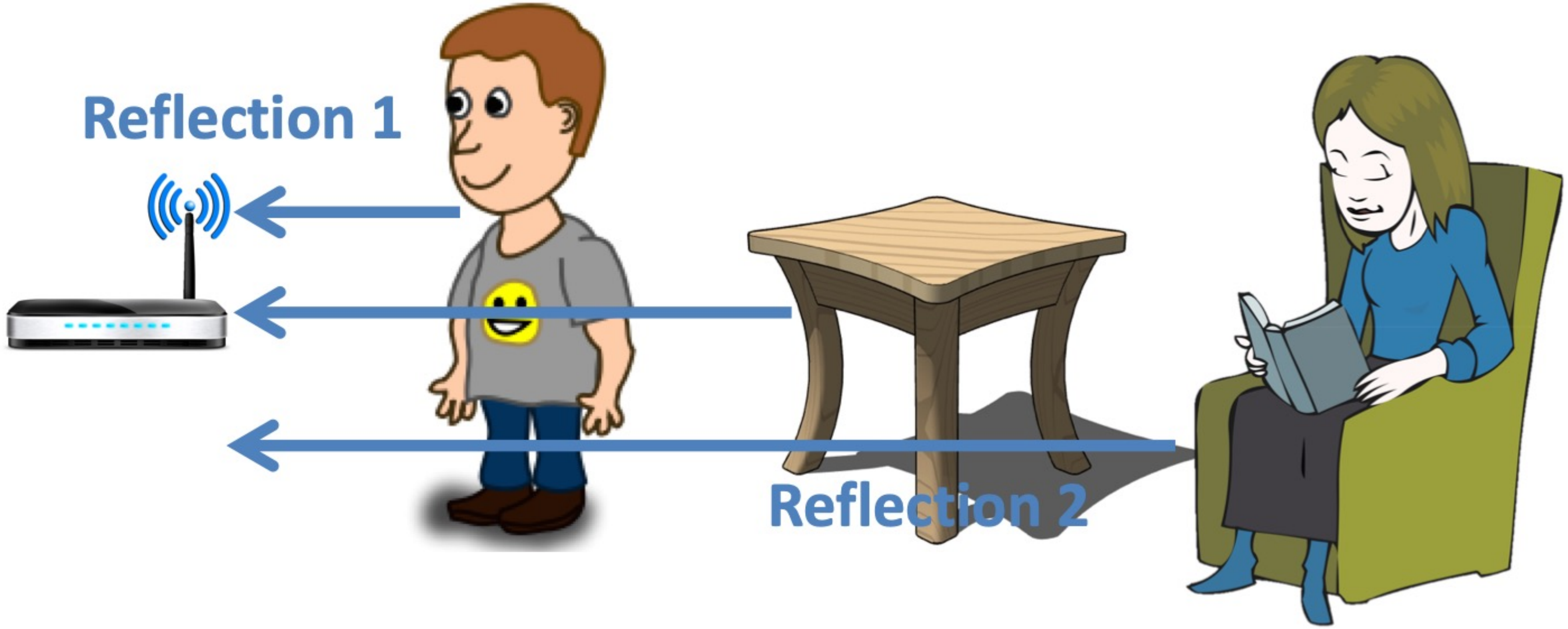
What happens with multiple users in the environment?

Reflections from different objects collide

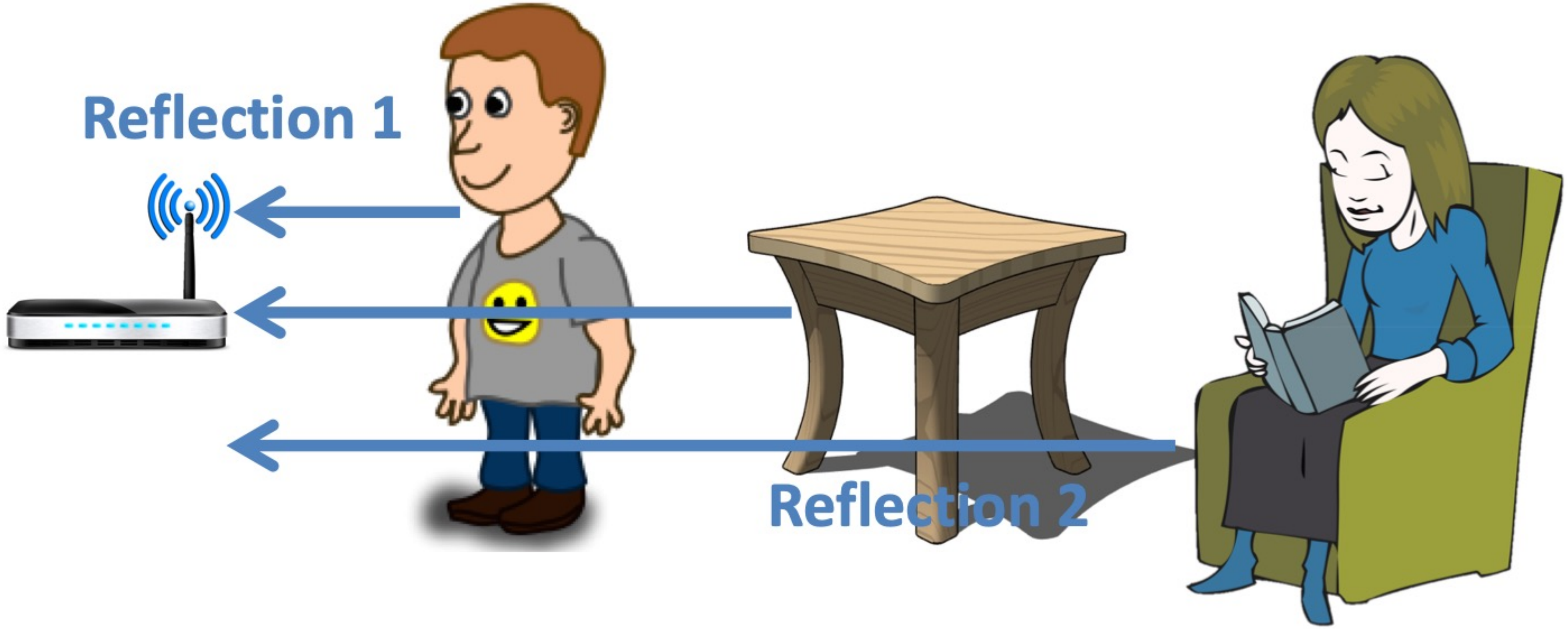
Problem: Phase becomes meaningless!



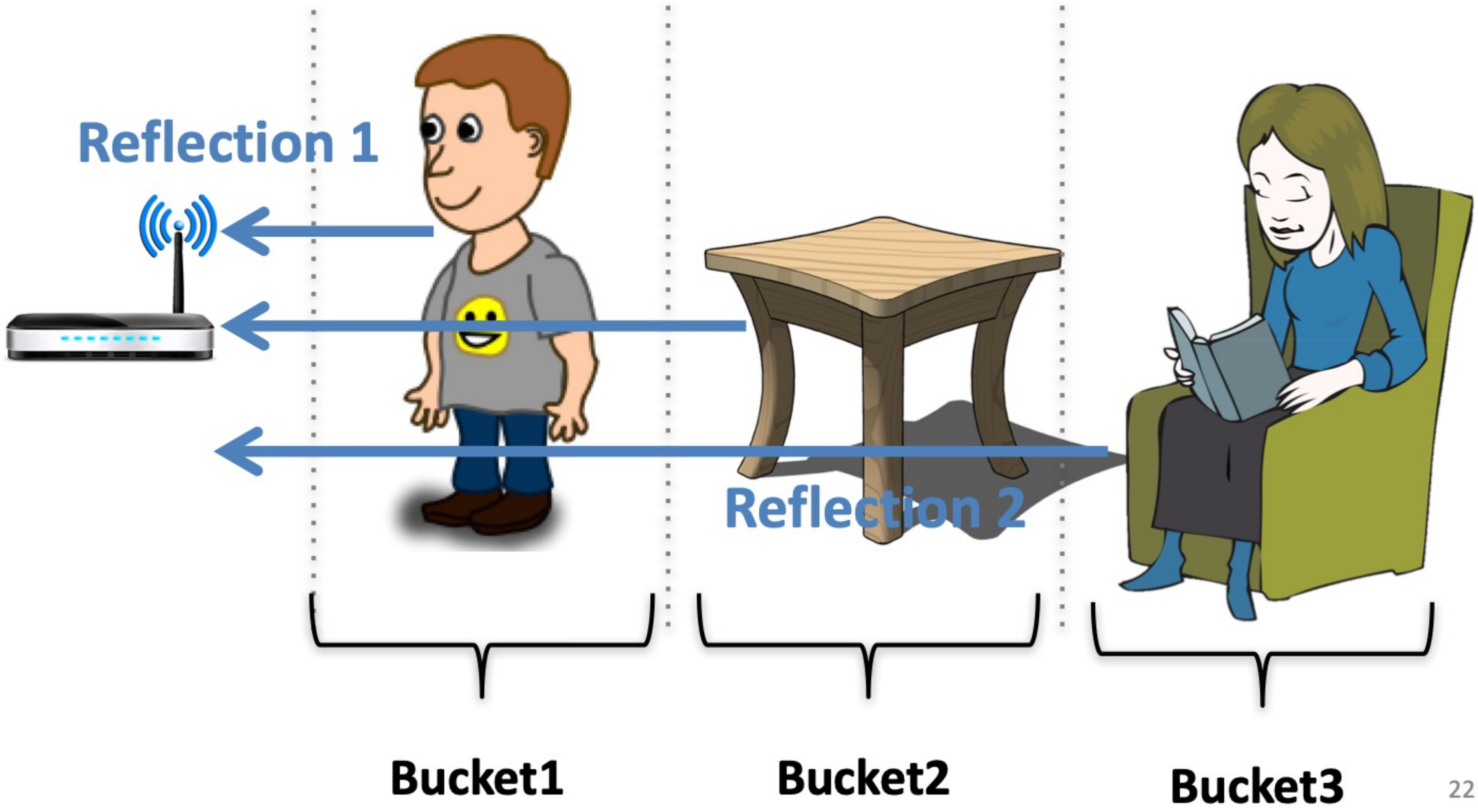
Idea: Wireless localization can be used to locate various devices



Solution: Use wireless localization as a filter to isolate reflections from different positions



Solution: Use wireless localization as a filter to isolate reflections from different positions



Through-wall breath monitoring of multiple users

It captures chest motion using wireless signal reflections

Device is behind the wall

Putting It Together

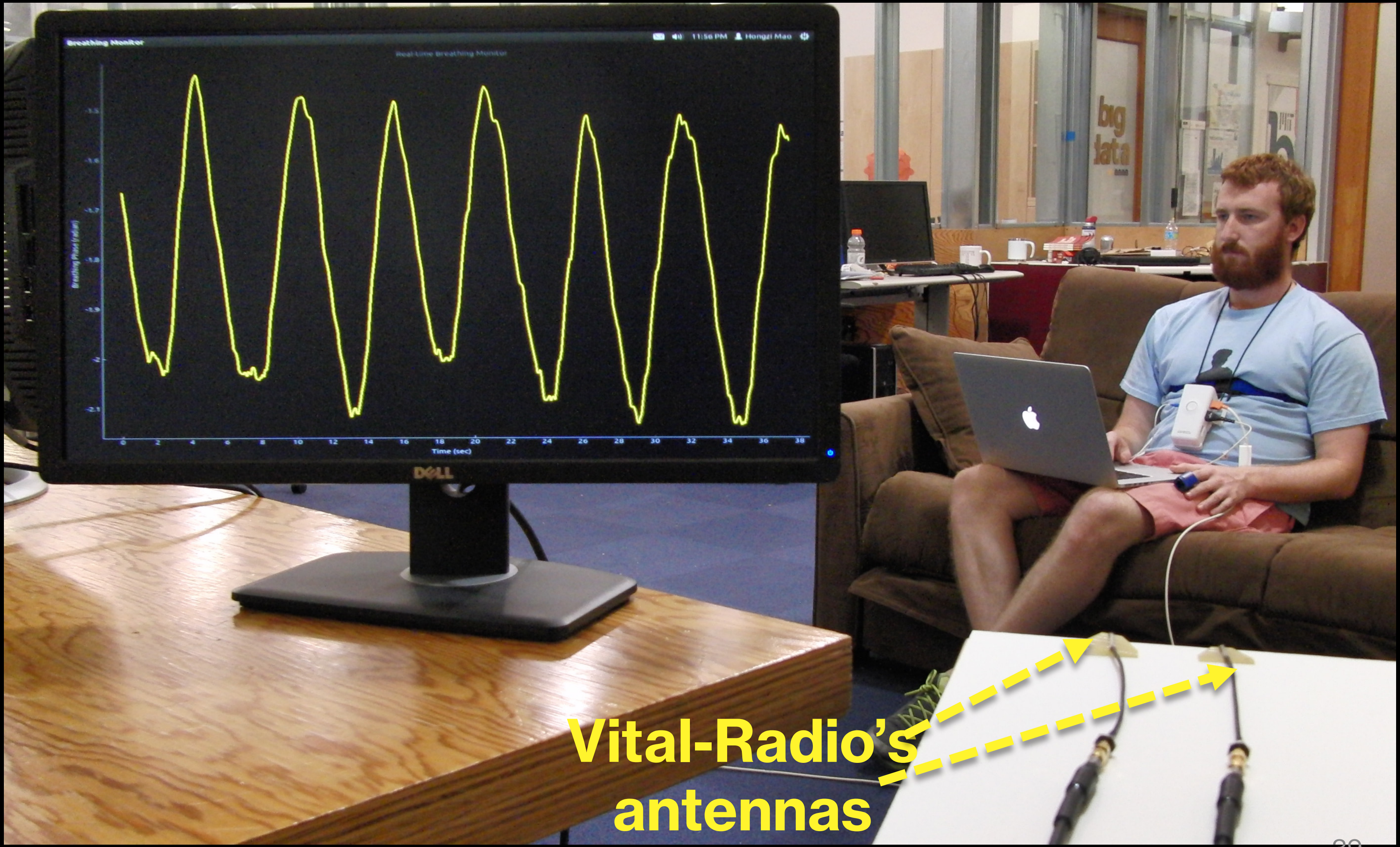
Step 1: Transmit a wireless signal and capture its reflection

Step 2: Isolate reflections from different objects based on their positions

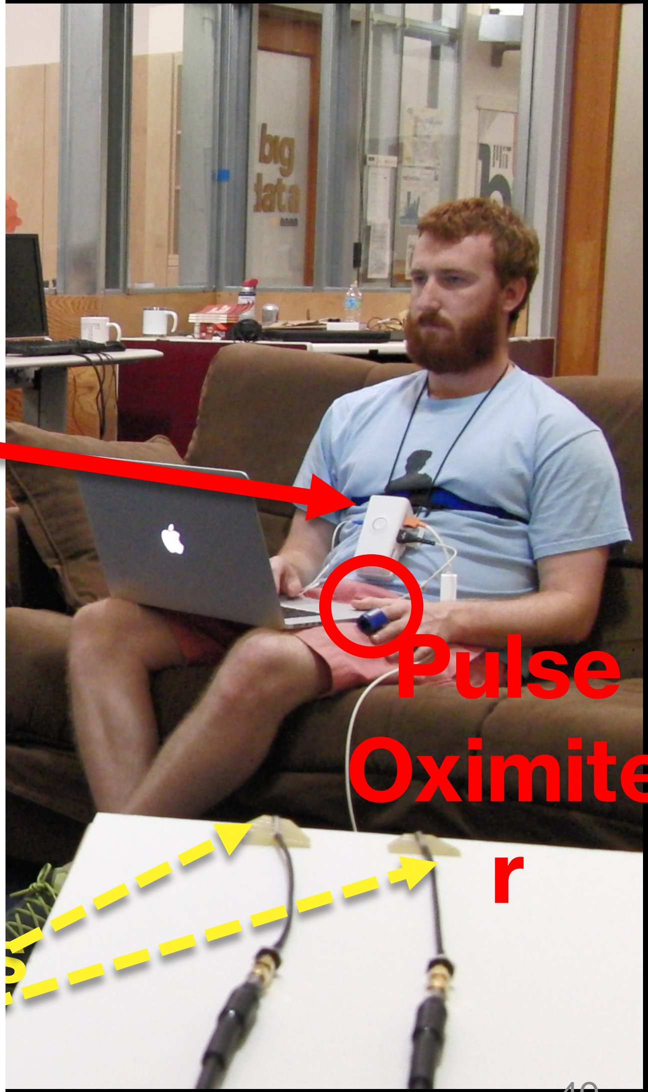
Step 3: Zoom in on each object's reflection to obtain phase variations due to vital signs

Step 4: Use frequency analysis to separate breathing and heart rate signals

Vital-Radio Implementation



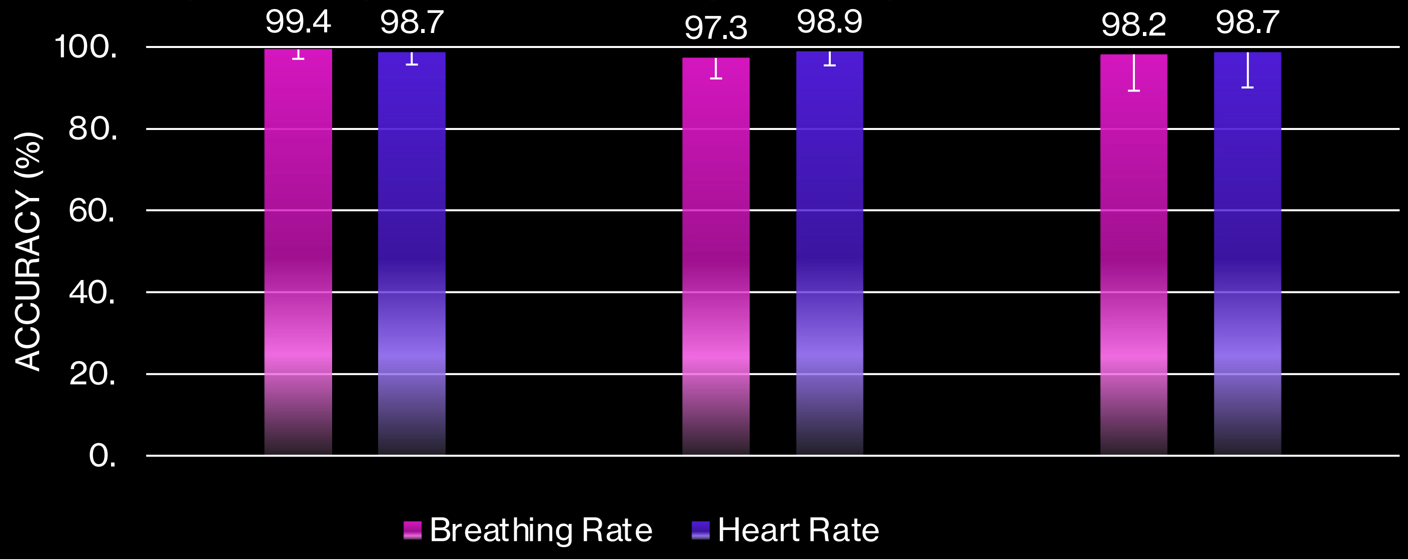
Vital-Radio Evaluation



Accuracy for Multi-User Scenario

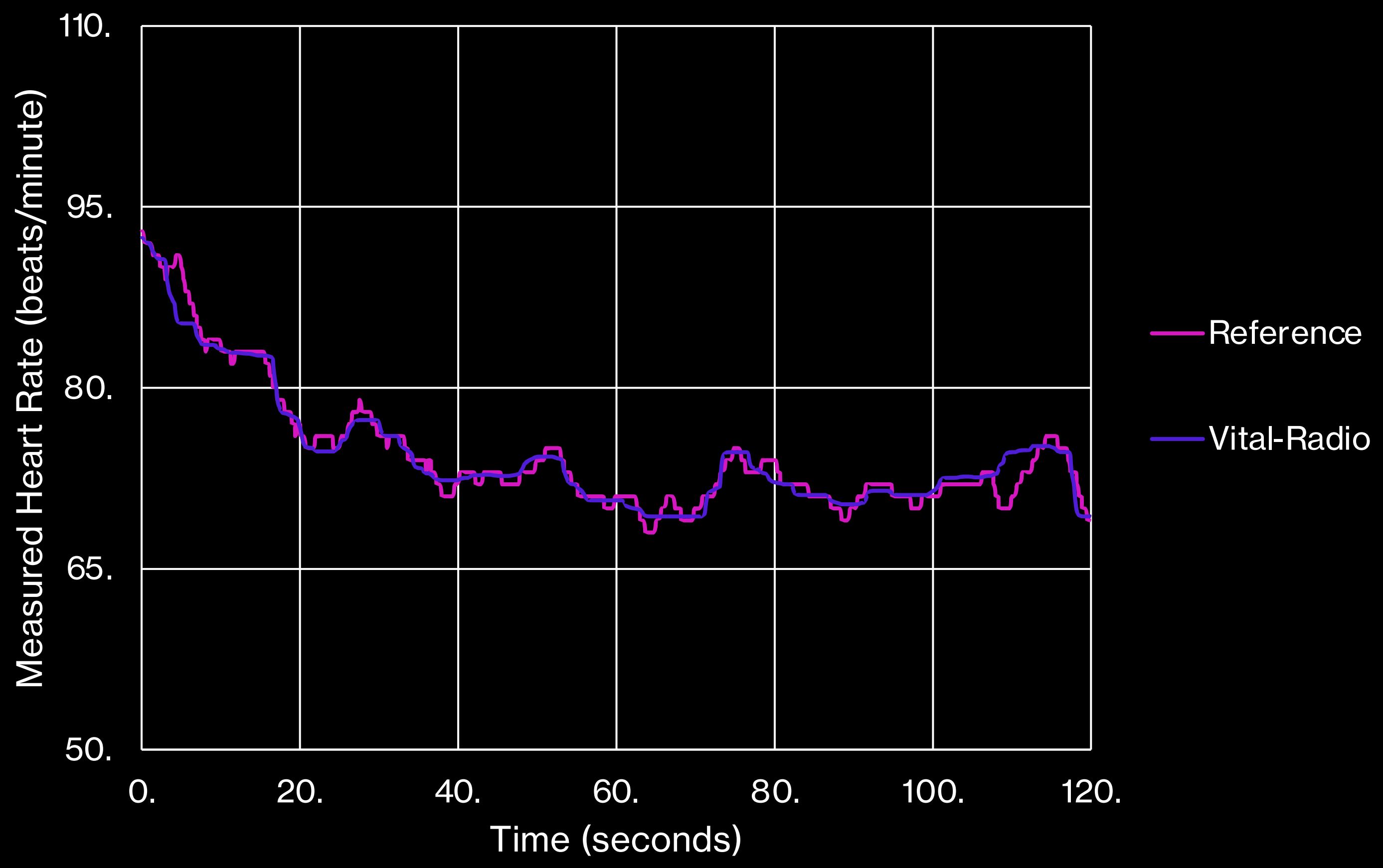
Multiple users sit at different distances

Nearest (at 2m) | Middle (at 4m) | Furthest (at 6m)



Accuracy for Tracking Heart Rate

Measure user's heart rate after exercising



Vital-Radio accurately tracks changes in vital signs

Vital-Radio Limitations

- Minimum separation between users: 1-2m
- Monitoring range: 8m
- Collects measurements when users are quasi-static

Next Lecture

- Time: Mon Feb 12th
- Topic: Inertial Sensing and Smart Cities