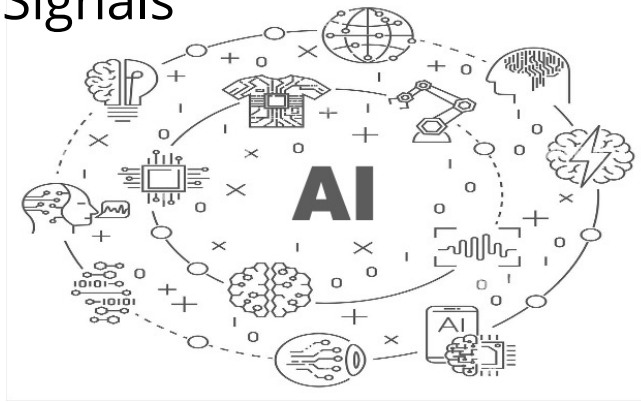
# CIS 7000-008: Special Topics on Wireless and Mobile Sensing

Mingmin Zhao (mingminz@cis.upenn.edu)

Lecture 5

Wireless Sensing: Physiological Signals




Penn
University of Pennsylvania

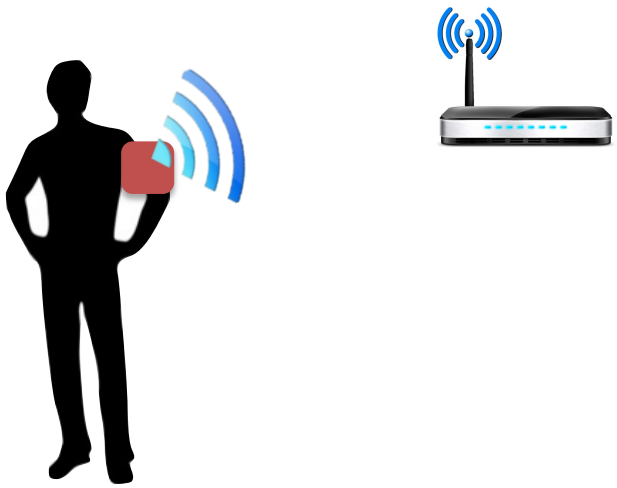
*Slides Courtesy of Prof. Fadel Adib

# Interest in Sensing the Human Body

## Heart Rate

## Breathing

## Locations

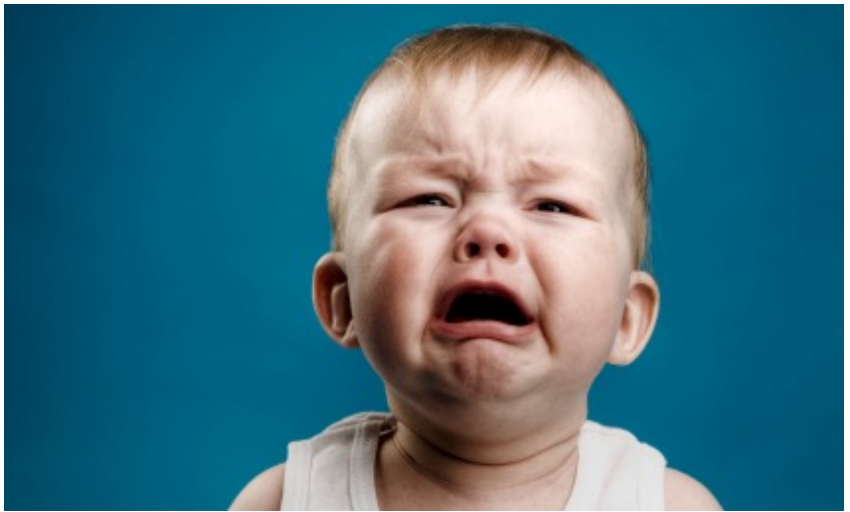


## Gestures

Heart Rate Breathing Locations Gestures

# On-body sensors can be cumbersome

Not suitable for elderly & babies



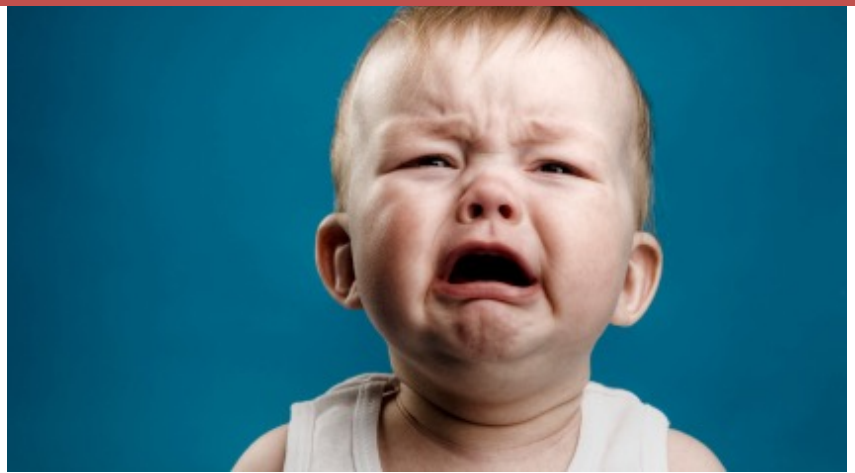
Heart Rate

Breathing

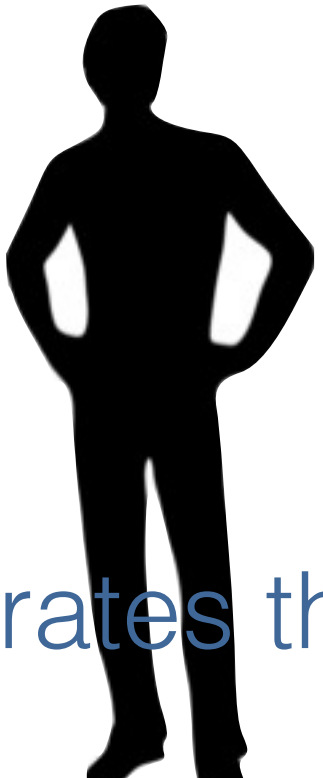
Locations

Gestures

Imagine enabling these applications without sensors on the human body



- Location
- Vital Signs
- Imaging



Operates through occlusions

## Last Lecture

**WiVi:** Sensing humans through walls with WiFi

- MIMO Nulling
- Inverse SAR

**WiTrack 1.0 & 2.0:** Localizing & Tracking through walls

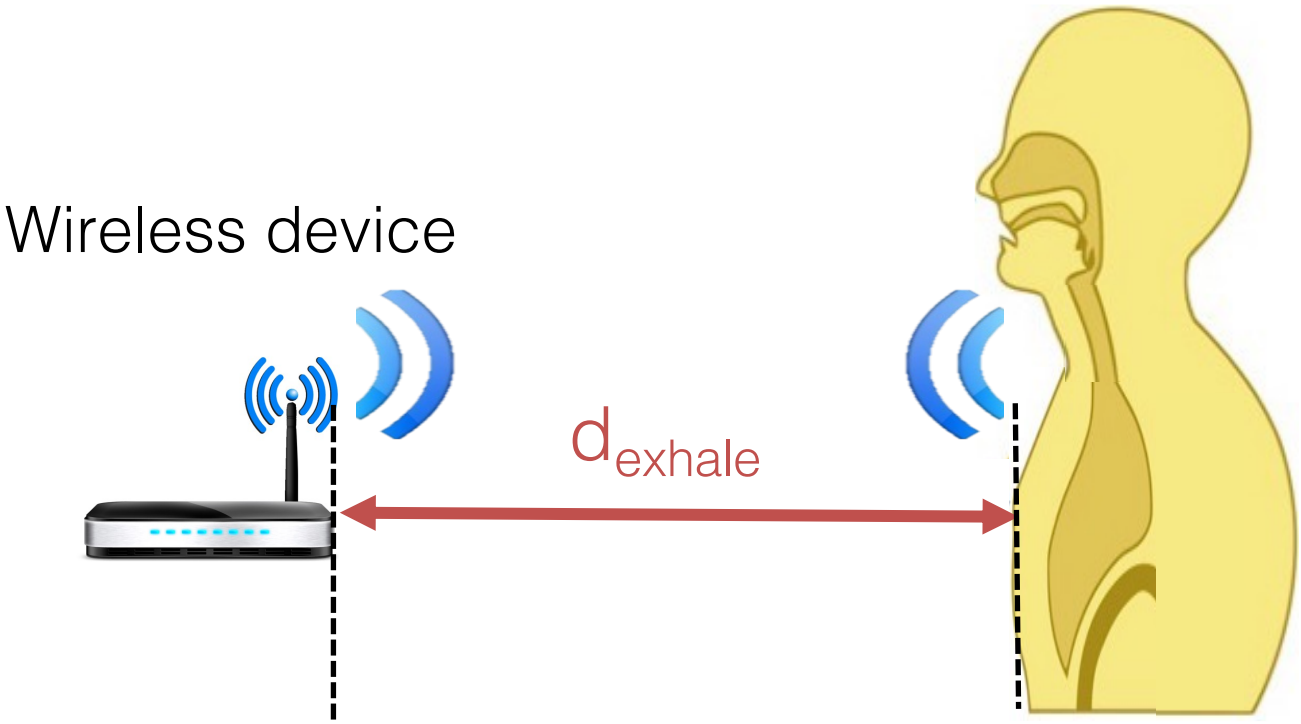
- FMCW
- Background Subtraction
- Dynamic Multipath
- Multi-Shift FMCW
- Successive Silhouette Cancellation
- Multi-Resolution Subtraction Window

## This Lecture

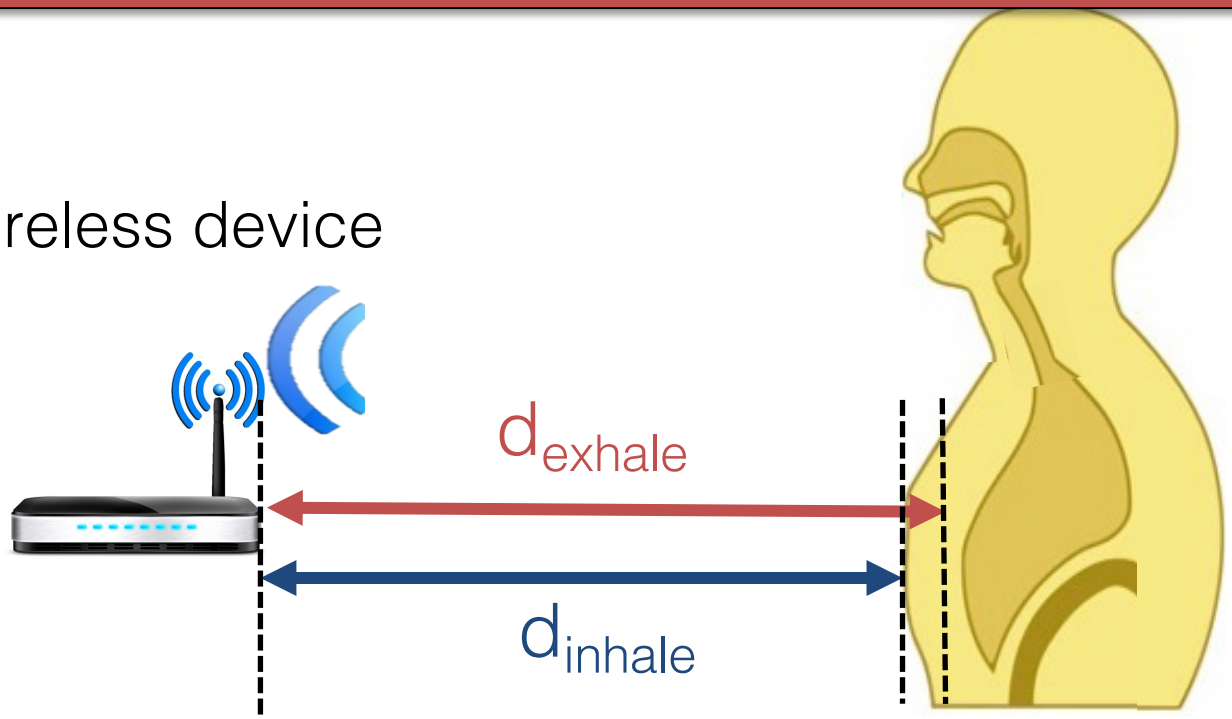
**Vital Radio:** Extracting vital signs

- Breathing Rate
- Heart Rate

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


Wireless device
$d_{exhale}$

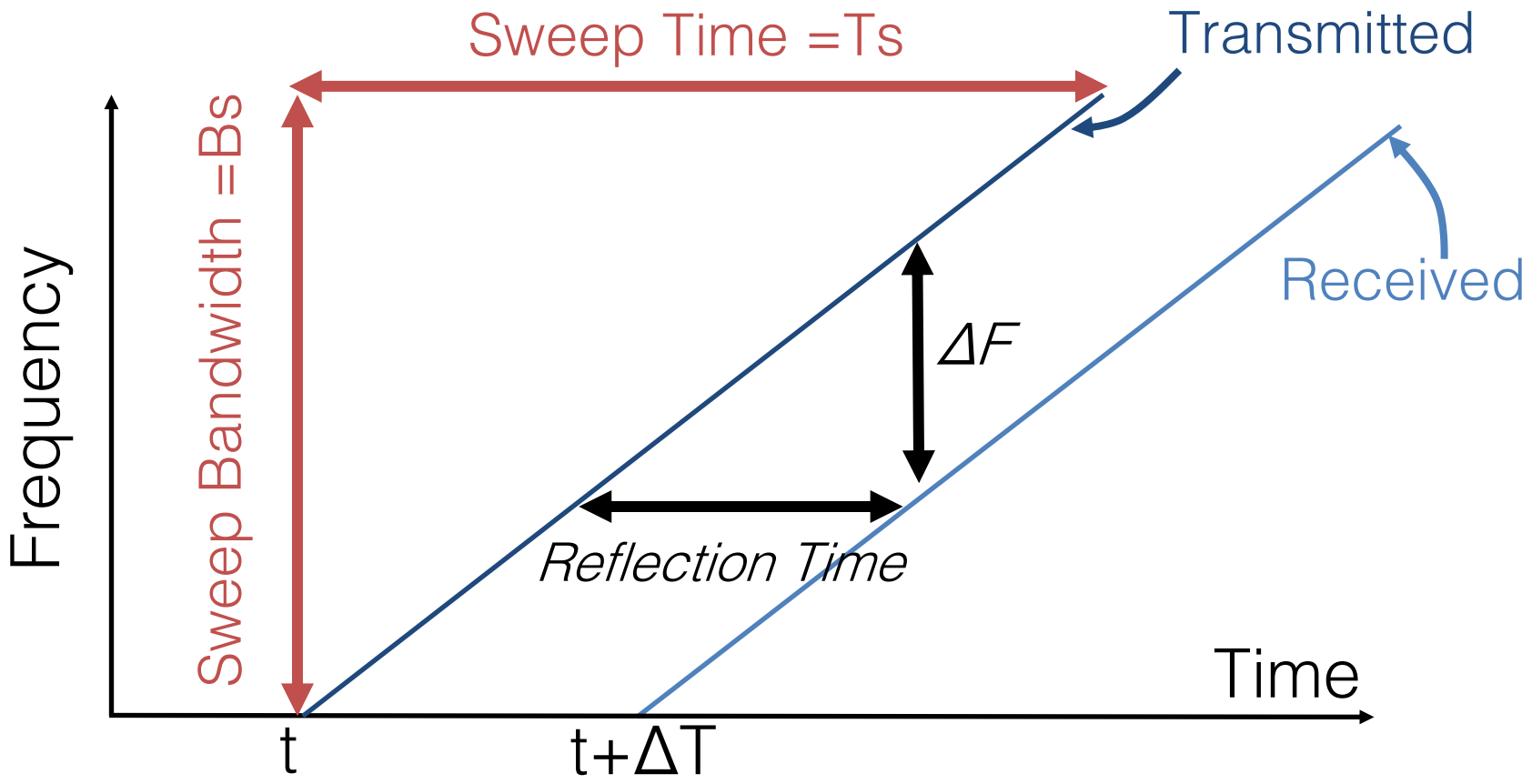
# Problem: Localization accuracy is only 12cm and cannot capture vital signs




Channel equation: $h = \frac{1}{d} e^{j2\pi \frac{d}{\lambda}}$

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

# FMCW: Measure time by measuring frequency




Slope = k = Bs/Ts

Reflection Time =ΔF/k

# FMCW

- FMCW Transmitted Signal:

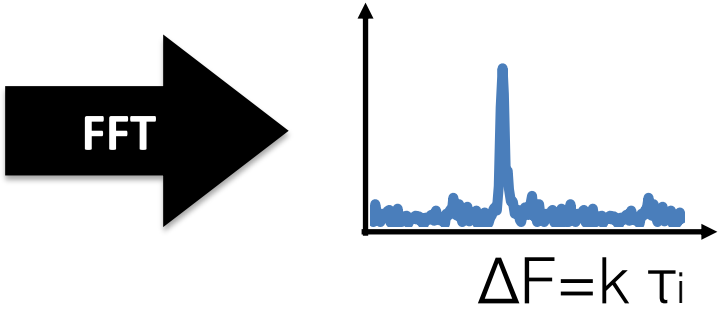
$$x(t) = e^{j2\pi(\frac{k}{2}\ t^2 + f_0 t)}$$

- 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 downconversion:

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



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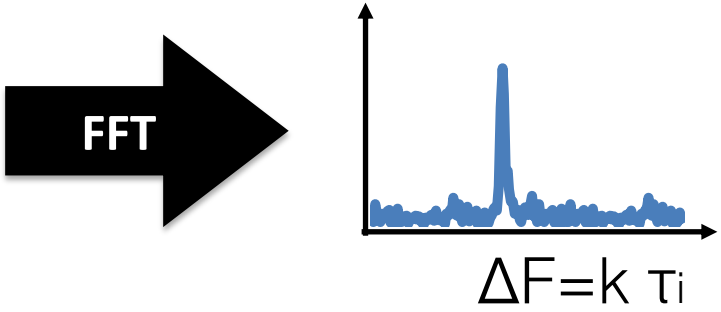


- Sampling Rate = B

ΔF < B ⟶ τmax = B/k = BxTs/Bs ⟶ dmax = cxBxTs/2Bs

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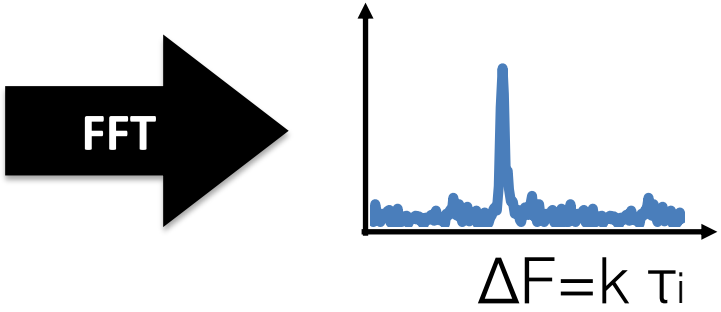


- Sampling Rate = B

ΔF < B ⟶ $\tau_{max}$ = B/k = BxTs/Bs ⟶ $d_{max}$ = cxBxTs/2Bs

- Sampling Window = Ts

ΔF > 1/Ts ⟶ $\tau_{min}$ = 1/(kxTs) =1/Bs ⟶ $d_{min}$ = c/2Bs

# FMCW

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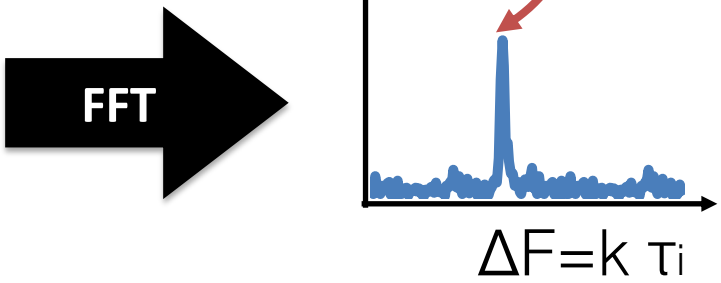
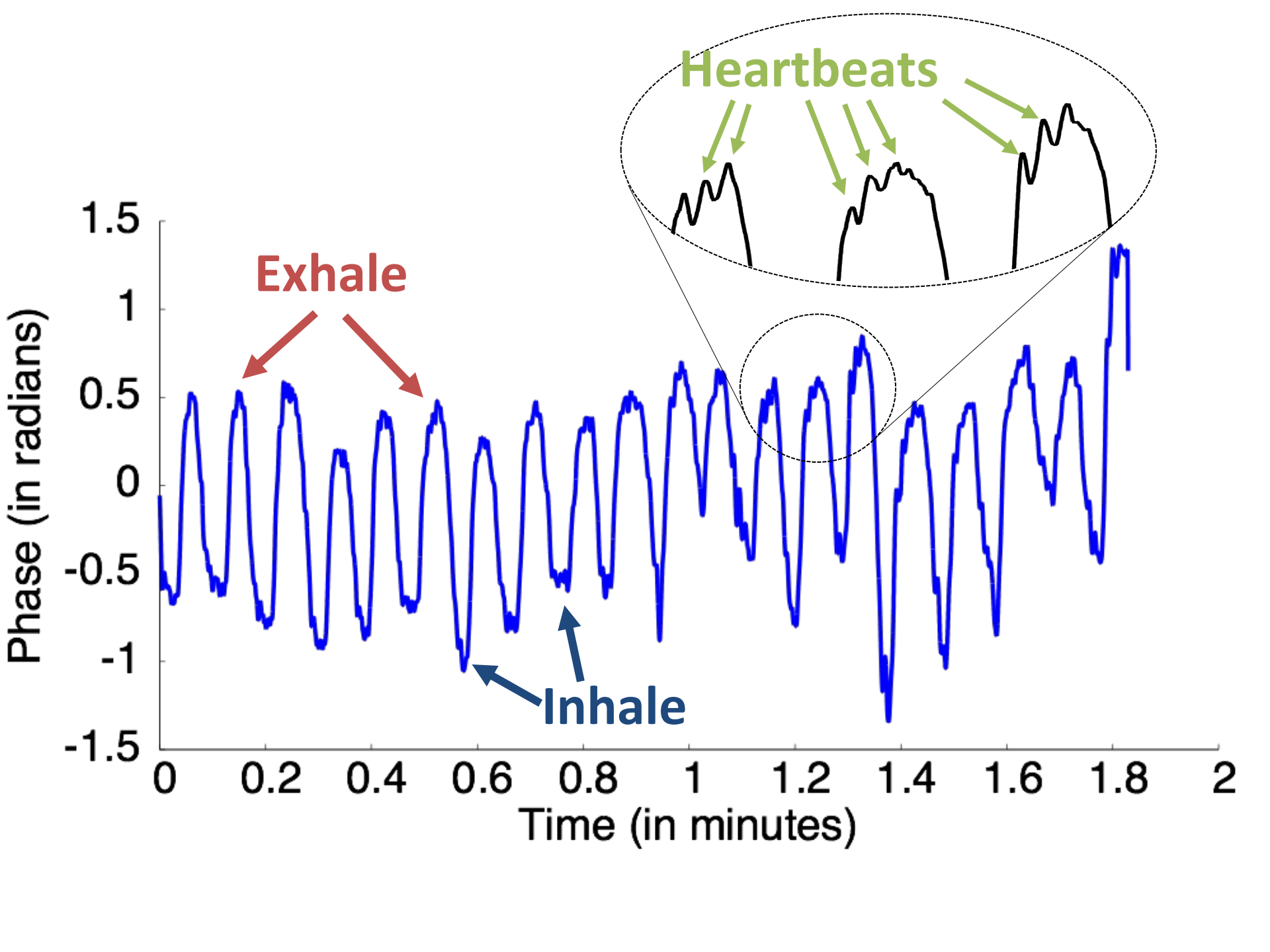



- Phase of peak = $f_0\tau_i$
  - Phase wraps around $2\pi$
  - Use peak position $\Delta F = k\,\tau_i$ for course estimate of $\tau_i$
  - Use peak phase $f_0\tau_i$ for fine estimate of $\tau_i$


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

# What happens when a person moves his limb?

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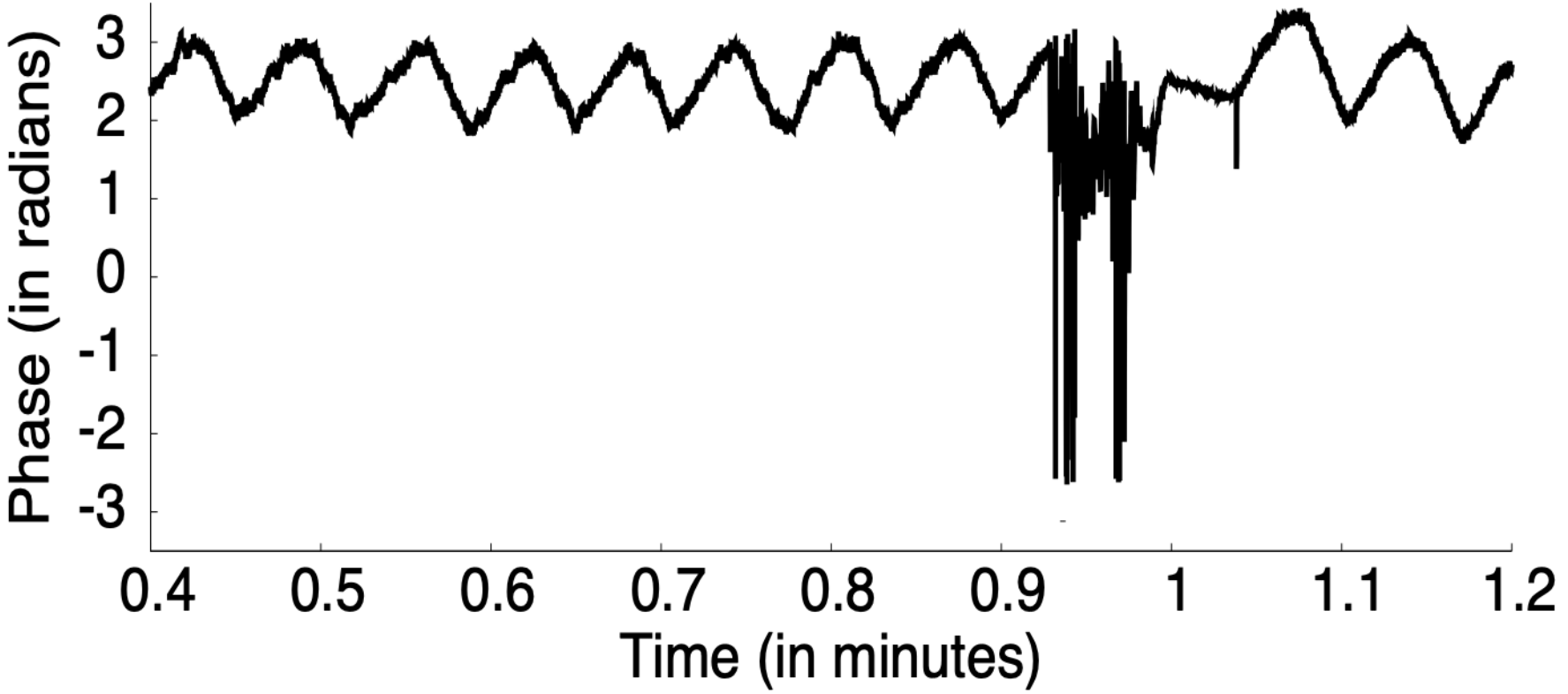

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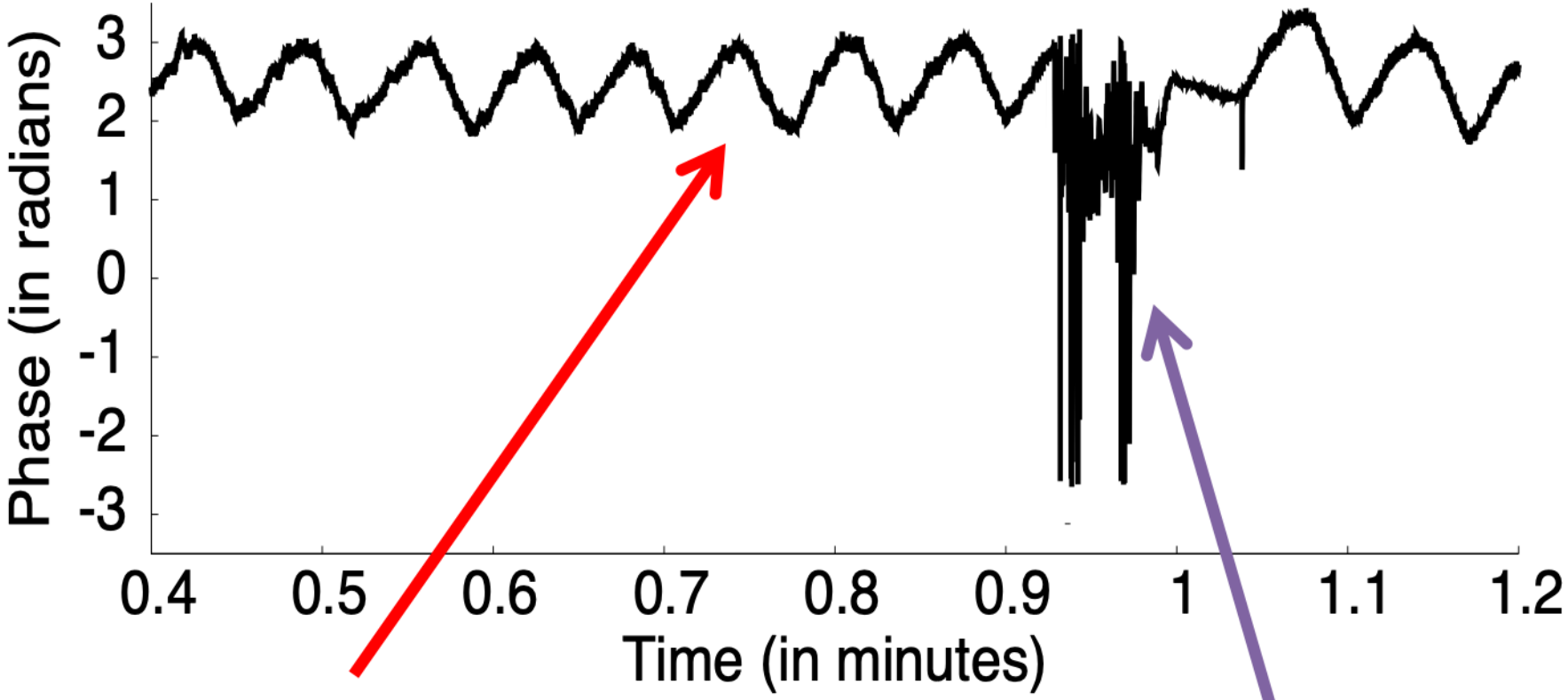

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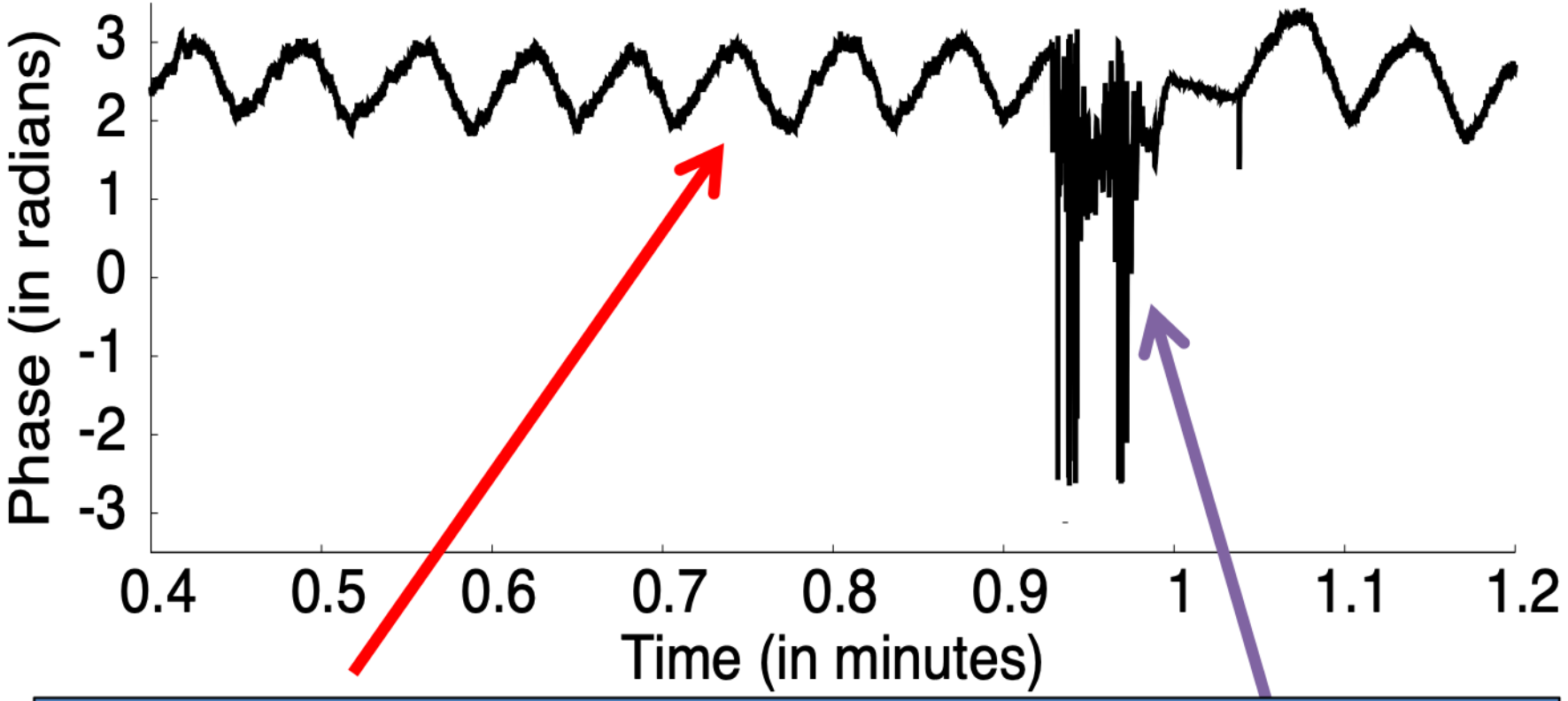
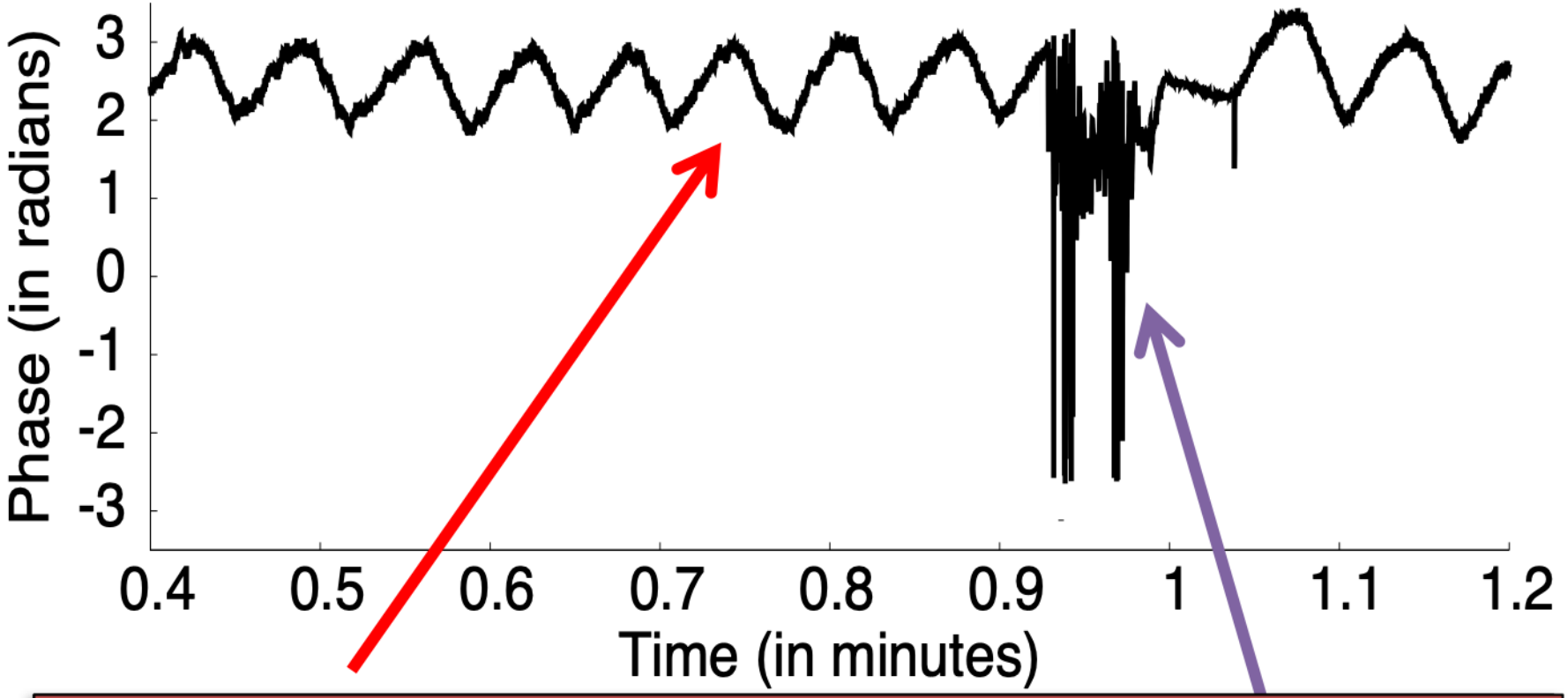



**Use periodicity test to eliminate variations that are not due to breathing/heartbeats**

# What happens when a person moves his limb?

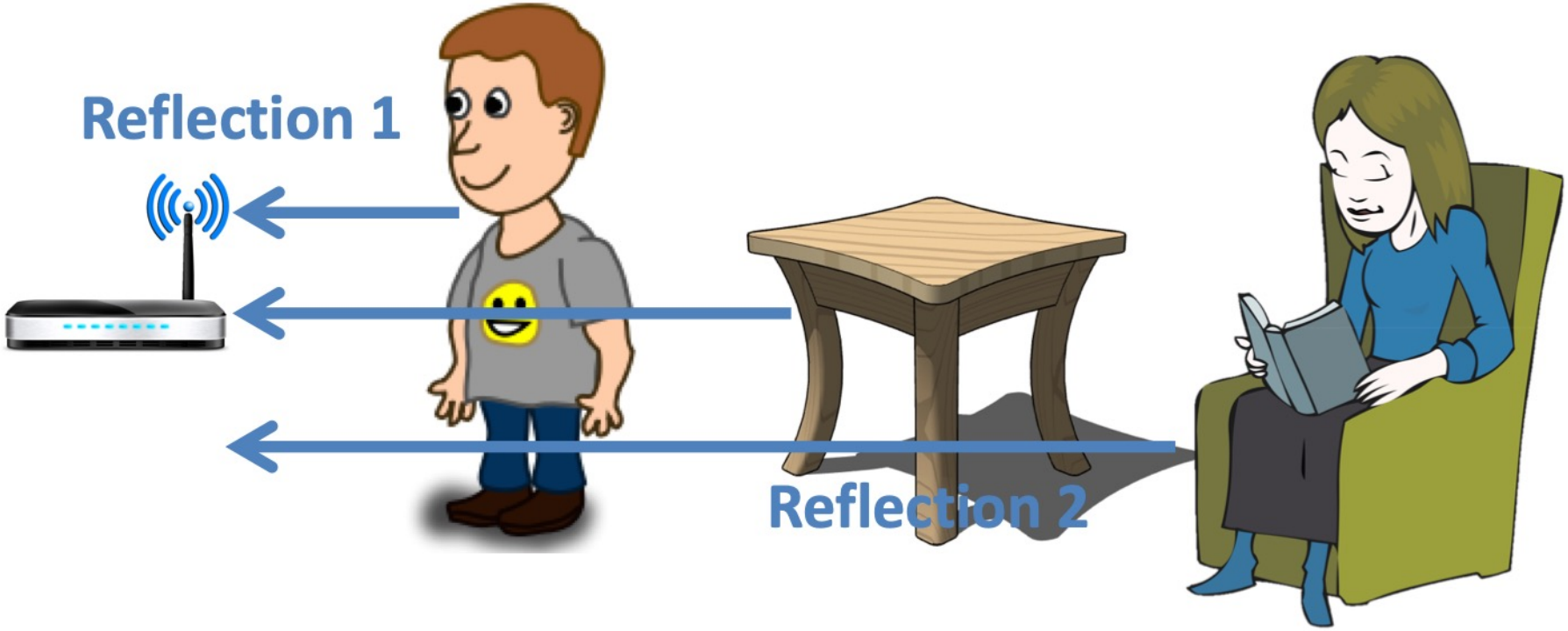



**Band-pass filter the cleaned signals to extract breathing and heart rate**

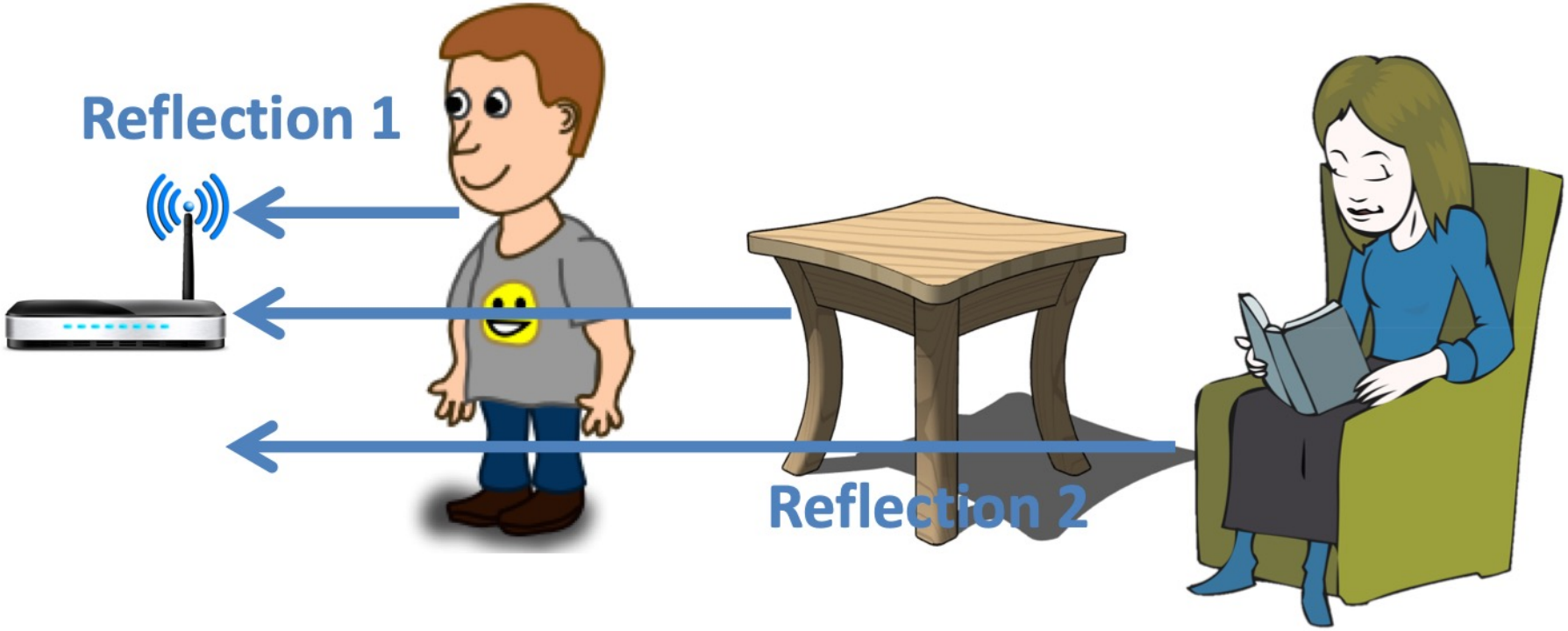
# What happens with multiple users in the environment?

# Reflections from different objects collide

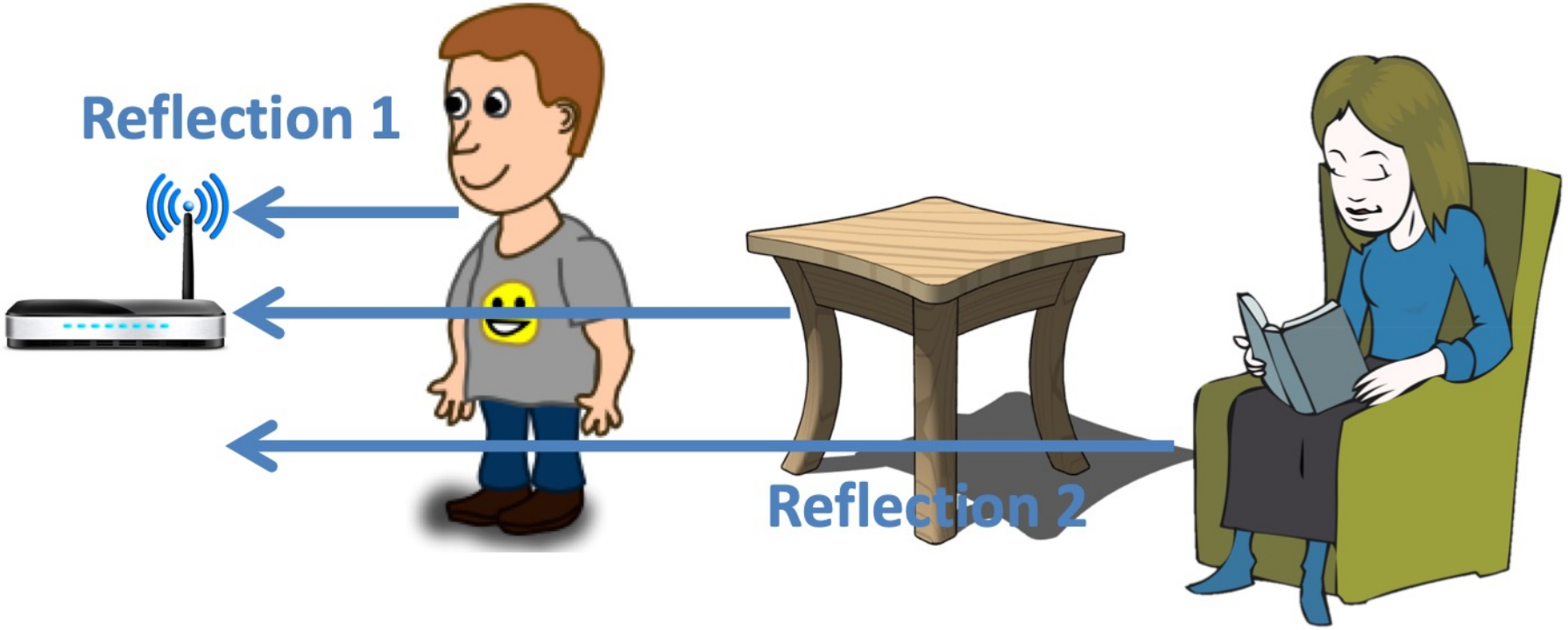
**<u>Problem:</u> Phase becomes meaningless!**



# Idea: Wireless localization can be used to locate various devices



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



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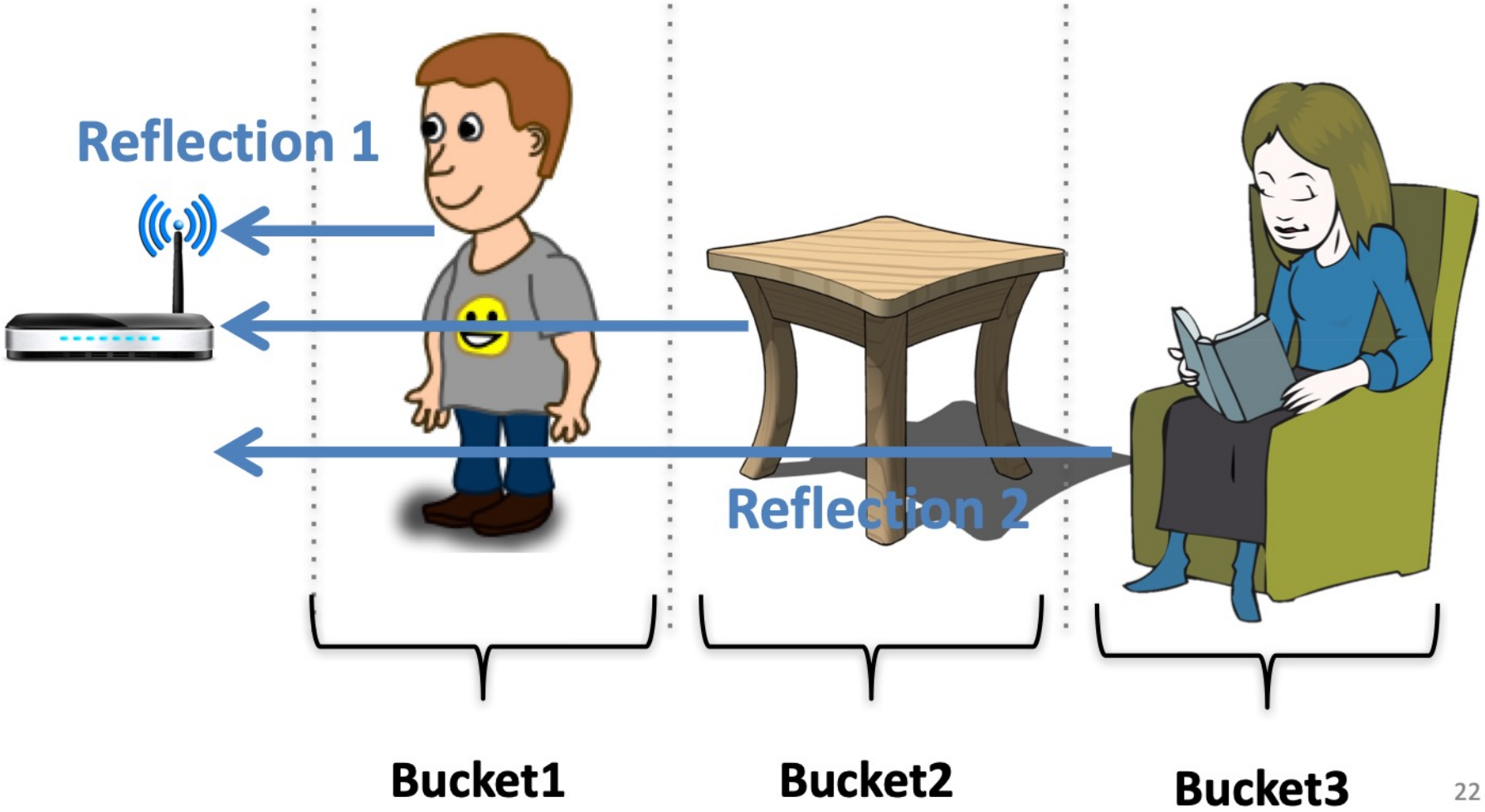


# Putting It Together

**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

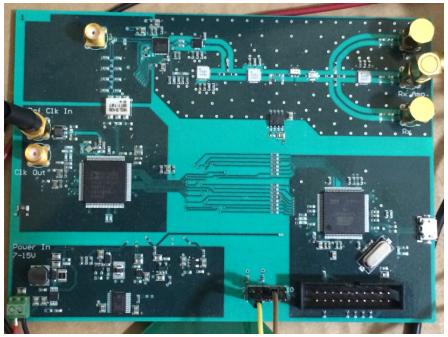
**Step 4:** Use frequency analysis to separate breathing and heart rate signals

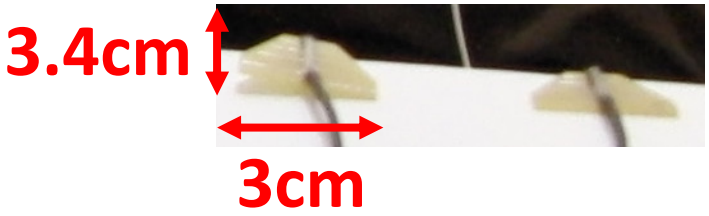
## It captures chest motion using wireless signal reflections


**Device is behind the wall**

# Vital-Radio Implementation

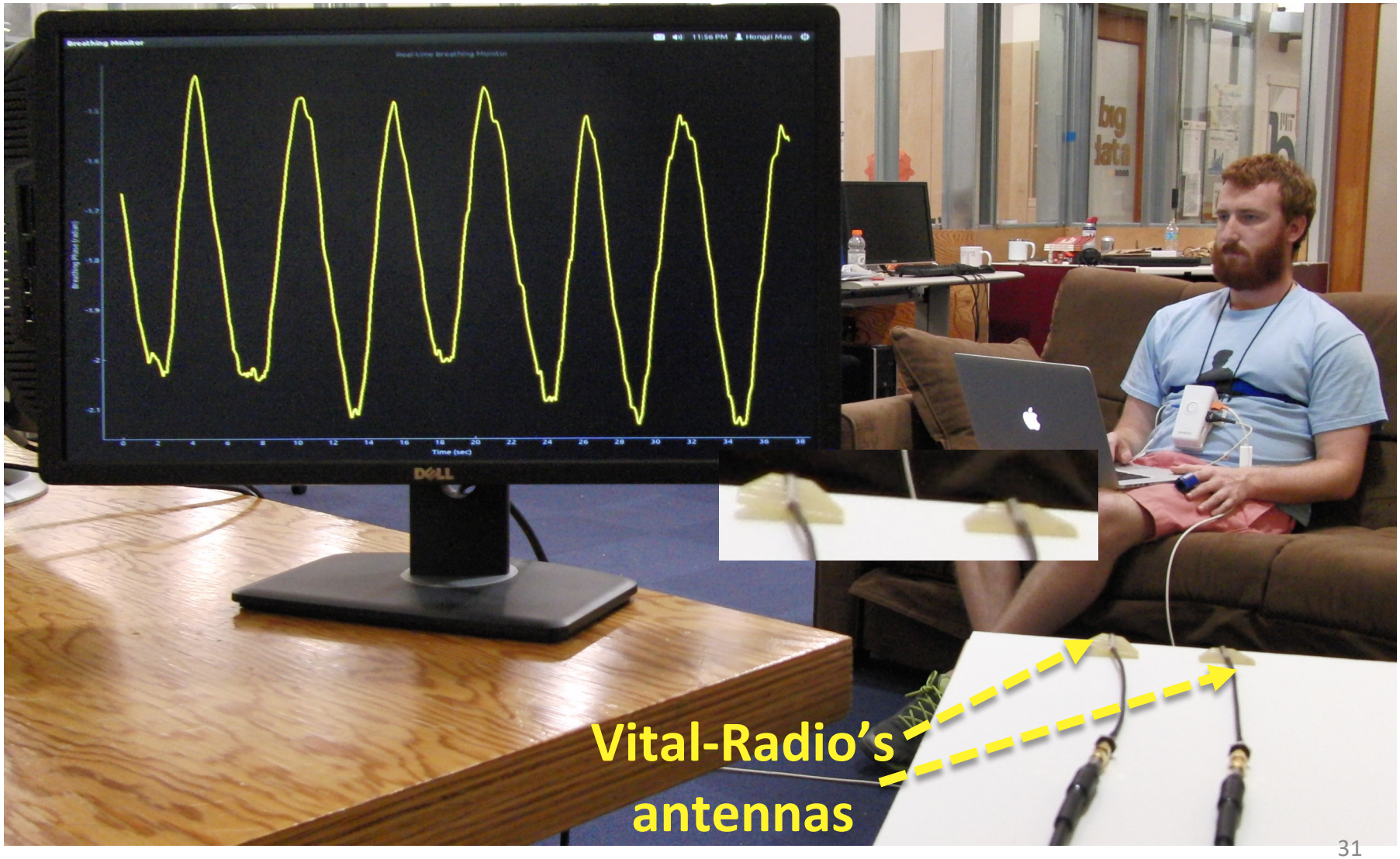
- Wireless positioning device to transmits and receives wireless signals
  - 10,000x lower power than cellphones
  - 1 transmit & 1 receive antenna






- Signal is analyzed in software to extract vital signs

# Vital-Radio Implementation



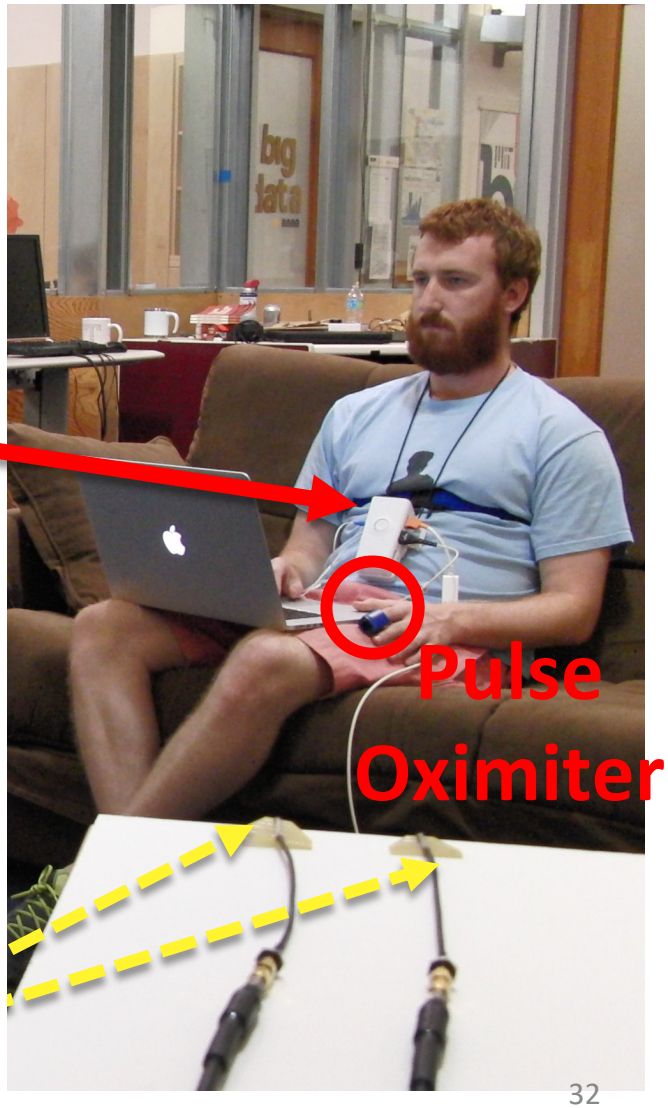
# Vital-Radio Evaluation

Baseline:

- FDA-approved breathing and heart rate monitor

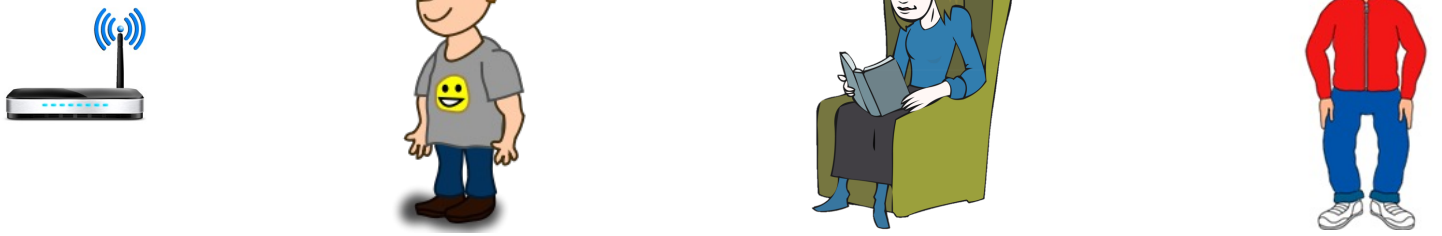
Experiments:

- 200 experiments
- 14 participants
- 1 million measurements

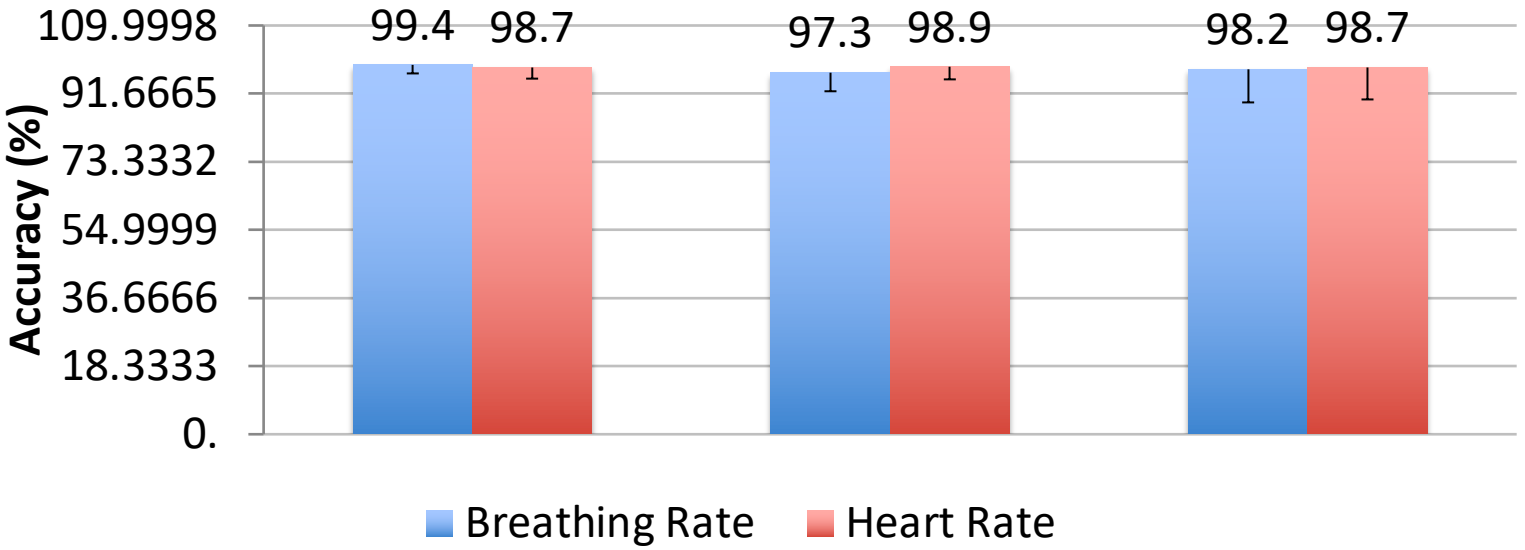


# Accuracy for Multi-User Scenario

Multiple users sit at different distances

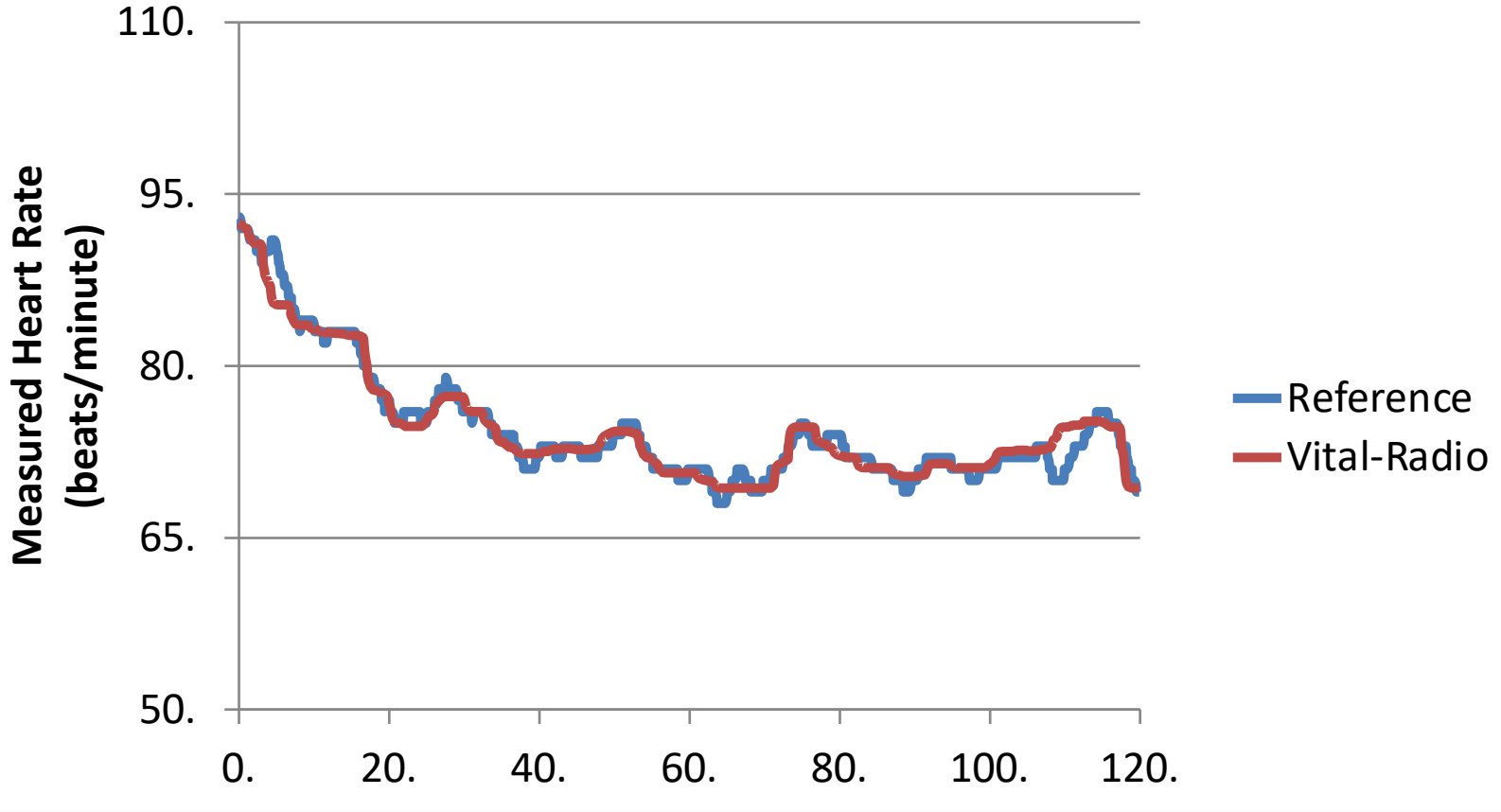


Nearest (at 2m) Middle (at 4m) Furthest (at 6m)



# 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


2014-03-14 21:50:30

# Introductions

- Name
- Program & Year
- Interests
- Project Ideas?

# Next class

- Wed Feb 1st
- ✓ Contactless physiological sensing
  - breathing and heart rate
- Next:
  - Heart beats, emotions, and stress