Lecture 1: From RF to Vital Signals

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Extracting Breathing and Heart Rate from RF Signals

Ubiquitous Health & Comfort Monitoring

Can smart homes monitor and adapt to our breathing and heart rates?

Can smart homes monitor and adapt to our breathing and heart rates?

Can smart homes monitor and adapt to our breathing and heart rates?

Personal Health

Baby Sleep

Elderly Health

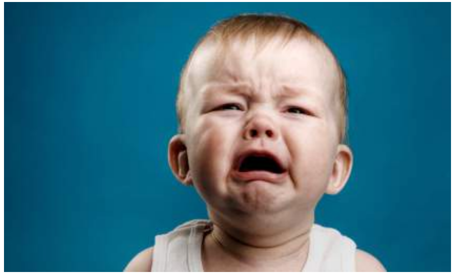
Adapt Lighting and Music to Mood

<u>But:</u> today's technologies for monitoring vital signs are cumbersome

Breath Monitoring

Heart Rate Monitoring

Not suitable for elderly & babies



Can we monitor breathing and heart rate from a distance?

Vital-Radio

- Technology that monitors breathing and heart rate remotely with 97% accuracy

- Can monitor multiple users simultaneously

- Operates through walls and can cover multiple rooms

Idea: Use wireless reflections off the human body

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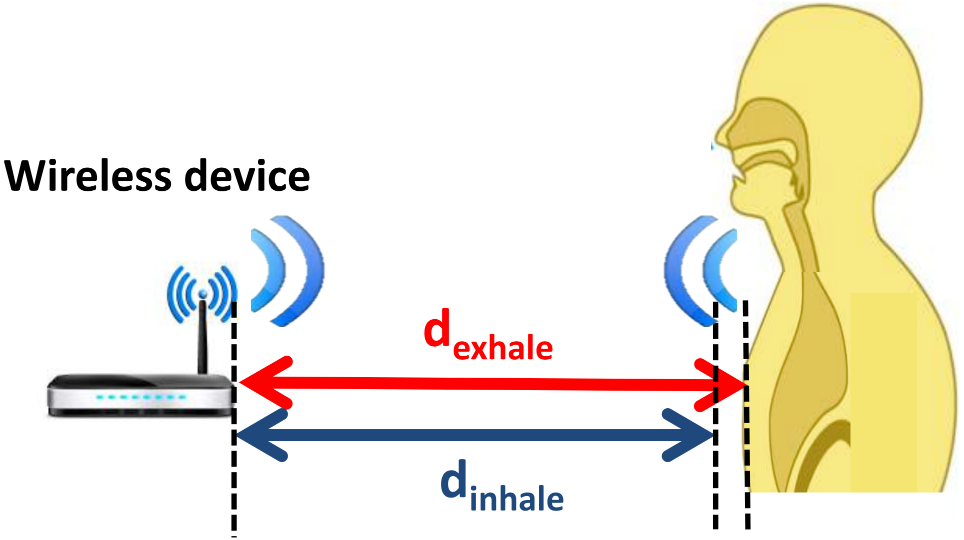


Wireless wave has a phase: $\phi = 2\pi \frac{\text{distance}}{\text{wavelength}}$

- Chest Motion changes distance
- Heartbeats also change distance

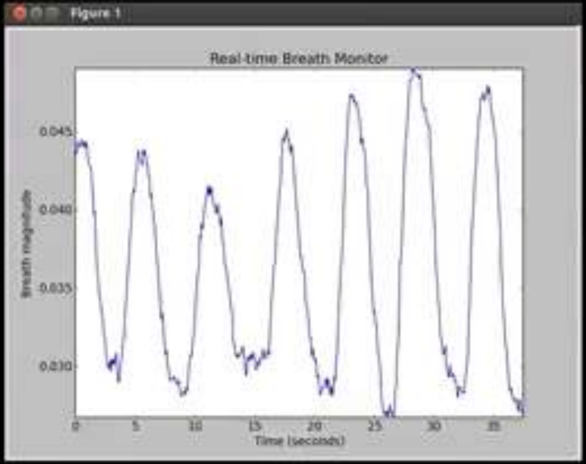
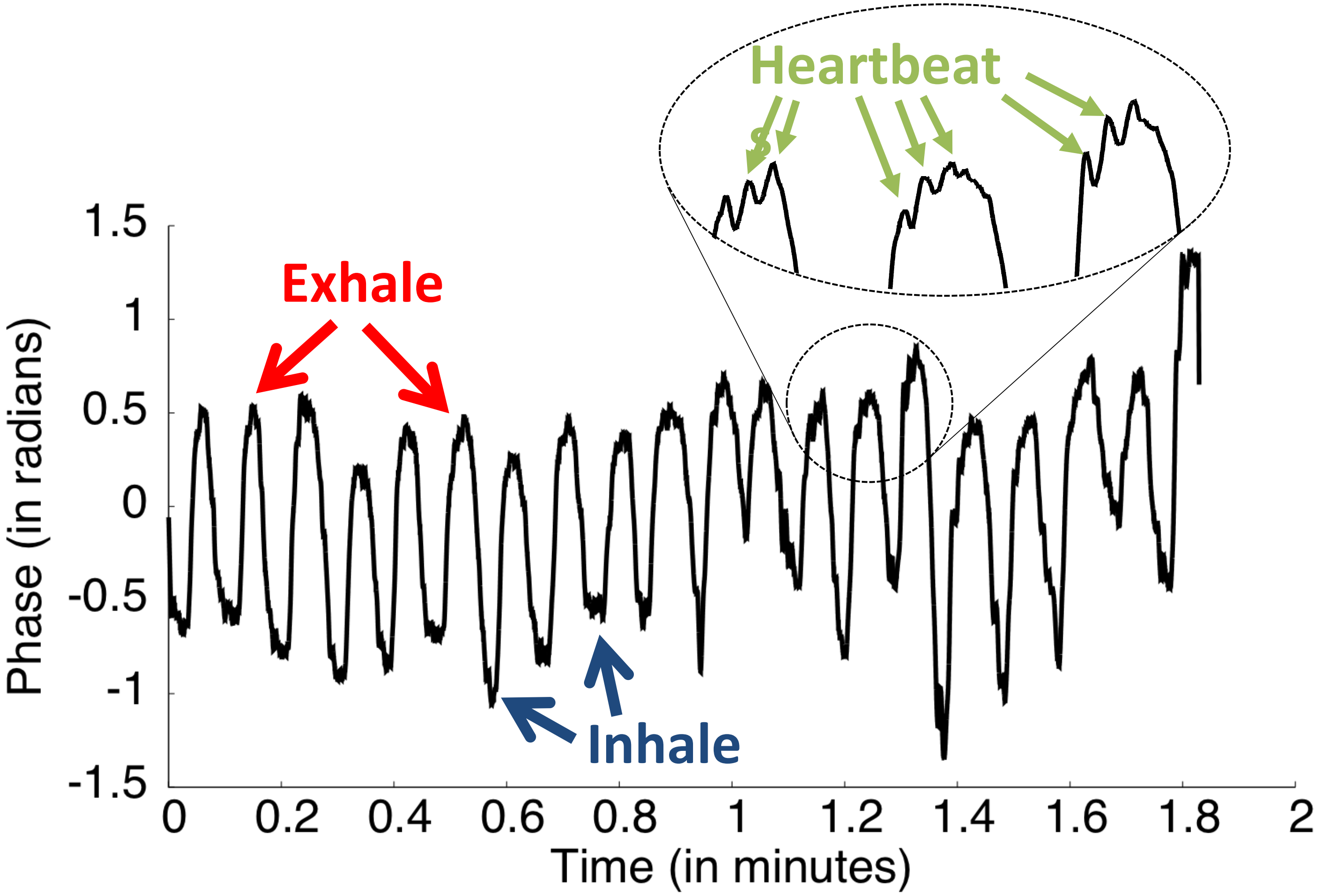


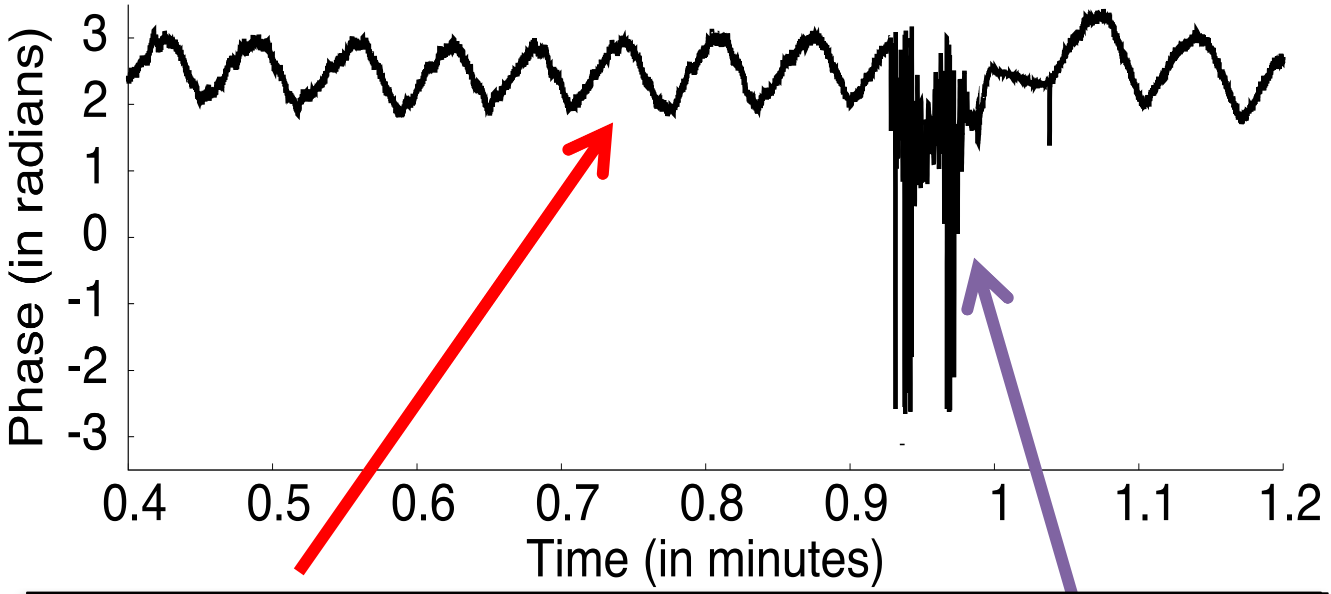
Figure 1
Real-time Breath Monitor
Breath magnitude
0.045
0.040
0.035
0.030
0
5
10
15
20
25
30
35
Time (seconds)


Let’s zoom in on these signals


Heartbeat
Exhale
Inhale
Phase (in radians)
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
Time (in minutes)

What happens when a person moves his limb?

What happens when a person moves his limb?



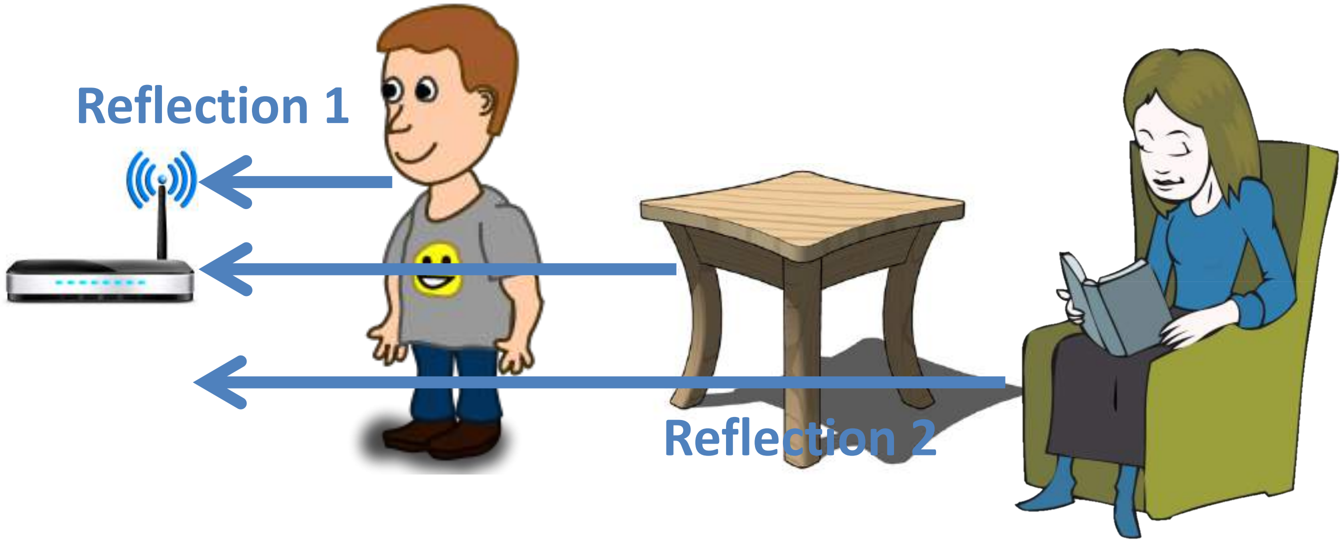
Band-pass filter the cleaned signals to extract breathing and heart rate

periodic

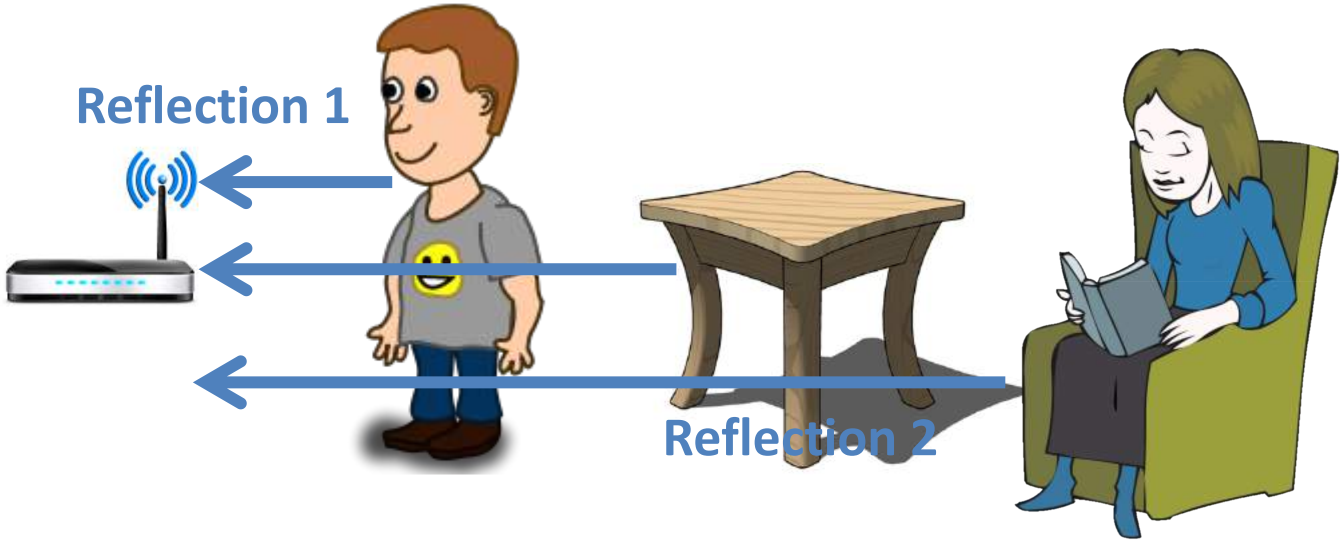
What happens with multiple users in the environment?

Reflections from different objects collide

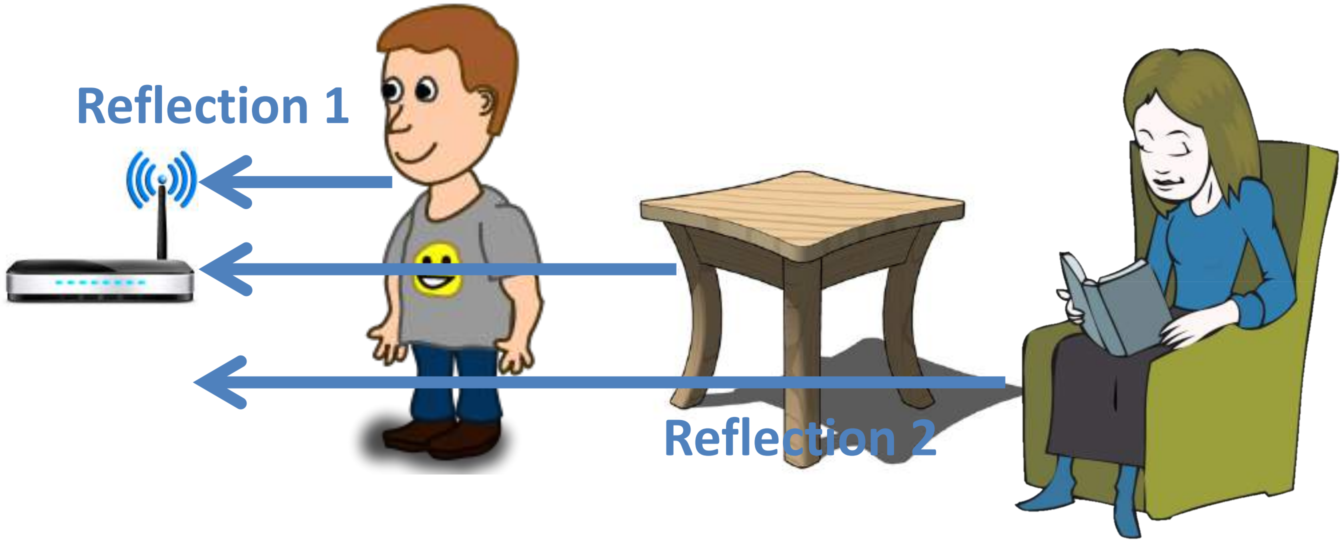
<u>Problem:</u> Phase becomes meaningless!



Idea: Wireless positioning can be used to locate various devices



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



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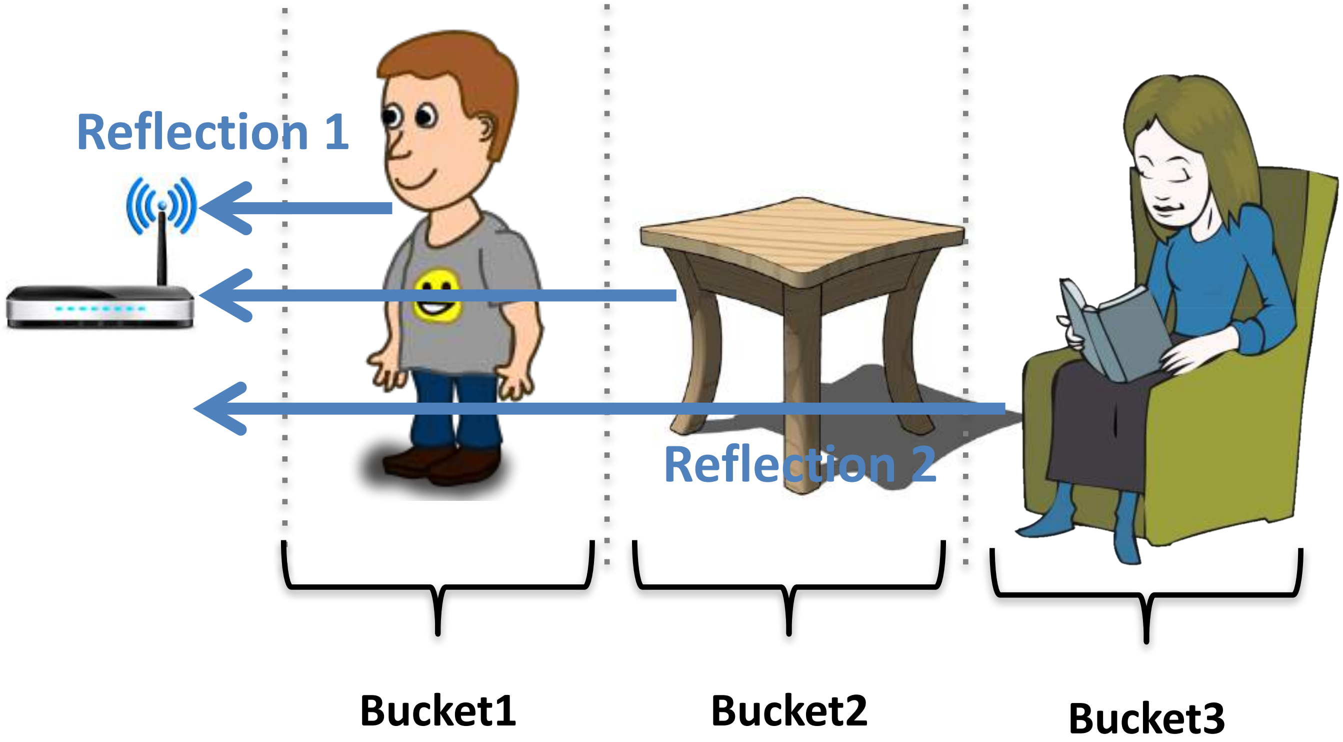

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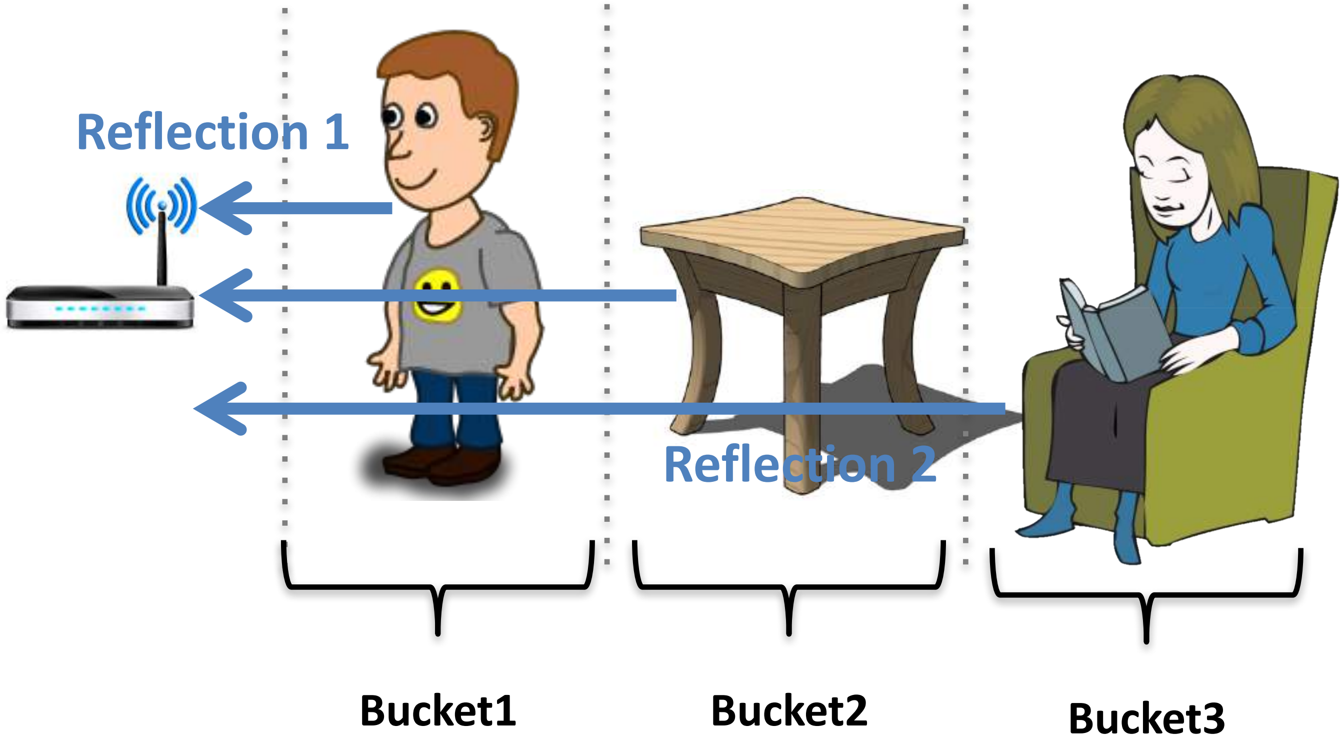


Putting It Together

Step 1: Transmit a wireless signal and capture its reflections

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

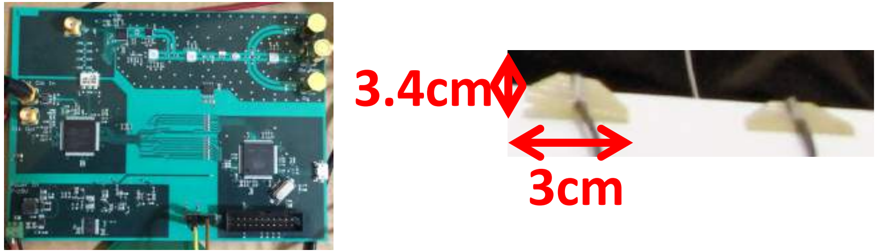
Step 3: Zoom in on each object’s reflection to obtain phase variations due to vital signs

Through-wall breath monitoring of multiple users

Through-wall breath monitoring of multiple users

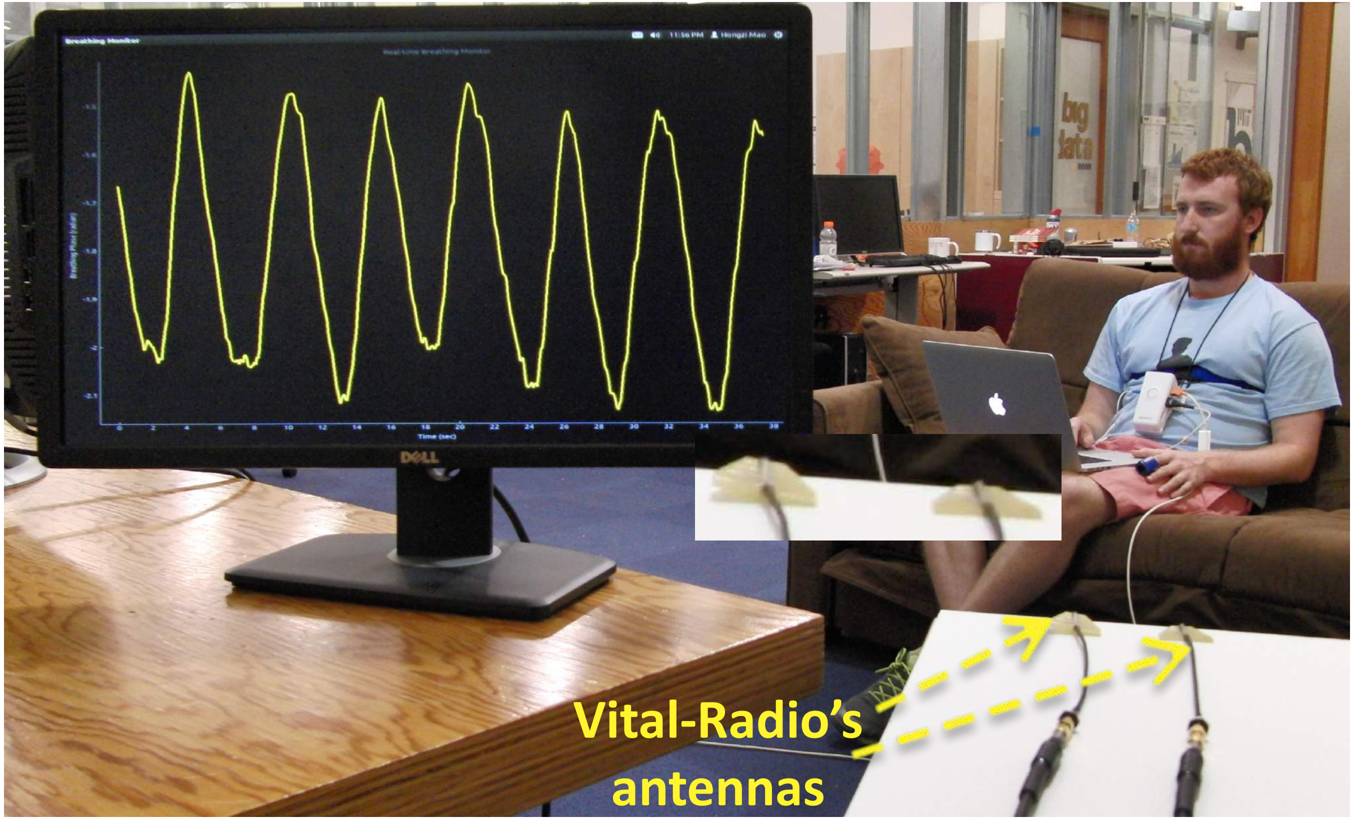
Vital-Radio Implementation

- 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

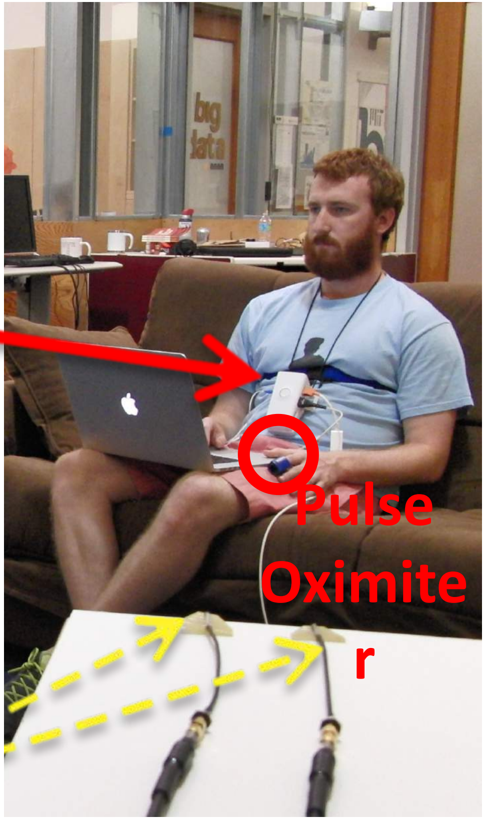


Vital-Radio Evaluation

Baseline:

- FDA-approved breathing and heart rate monitor

Chest Strap



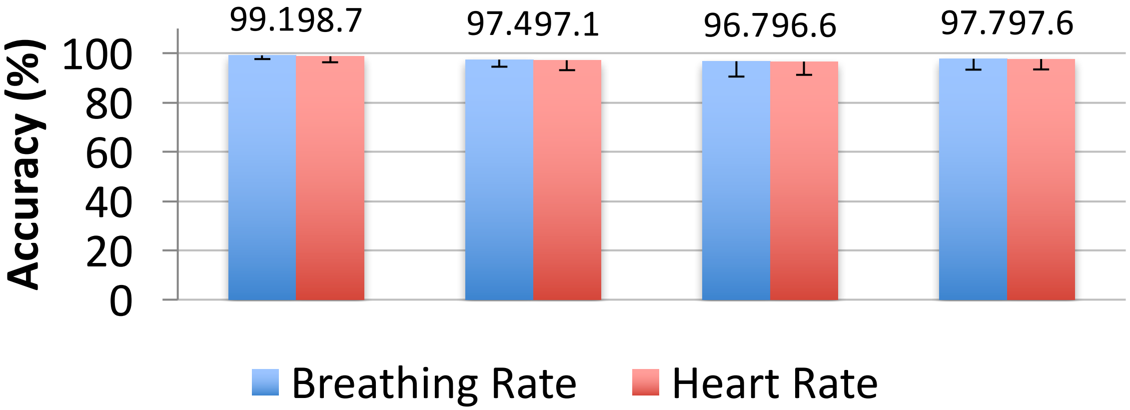
Experiments:

- 200 experiments
- 14 participants
- 1 million measurements

Accuracy vs. Orientation

User is 4m from device, with different orientations

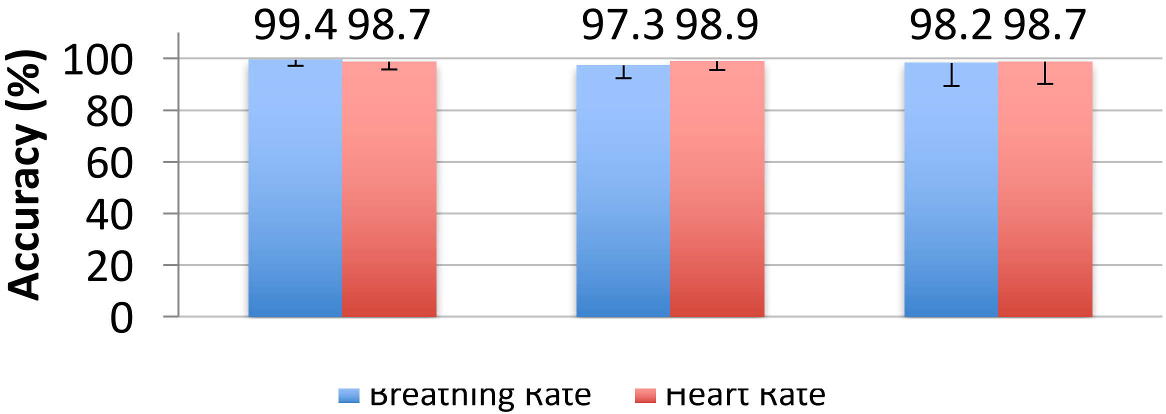
Forward **Right** **Backward** **Left**



Accuracy for Multi-User Scenario

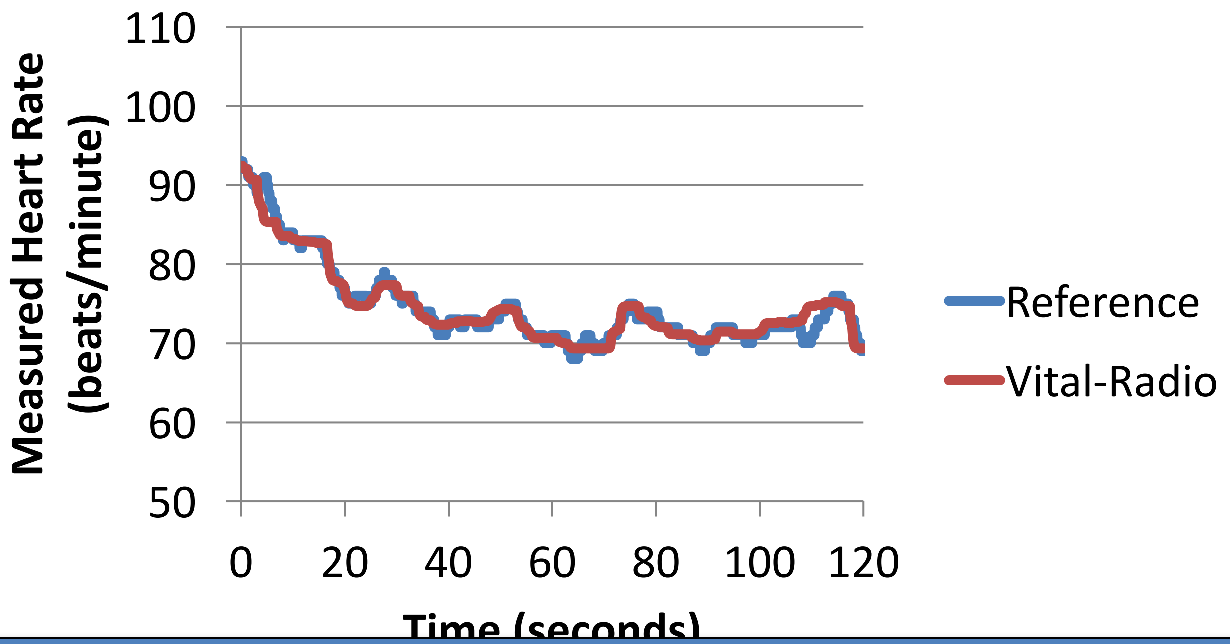
Multiple users sit at different distances

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

Related Work

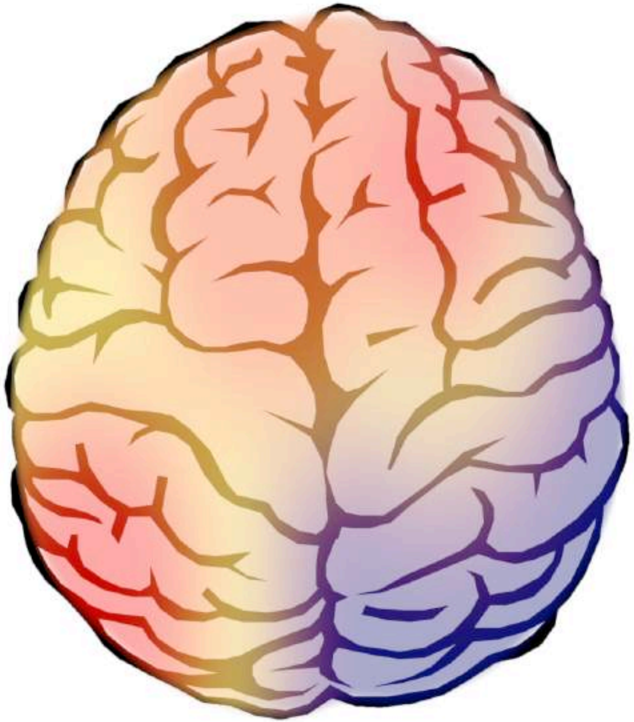
- Wearables
  – Require direct contact with user's body
- Vision-based techniques [SIGGRAPH'12, CVPR'13]
  – Require user to face device and line-of-sight
- Wireless-based techniques [MTT'04, MTT'09,

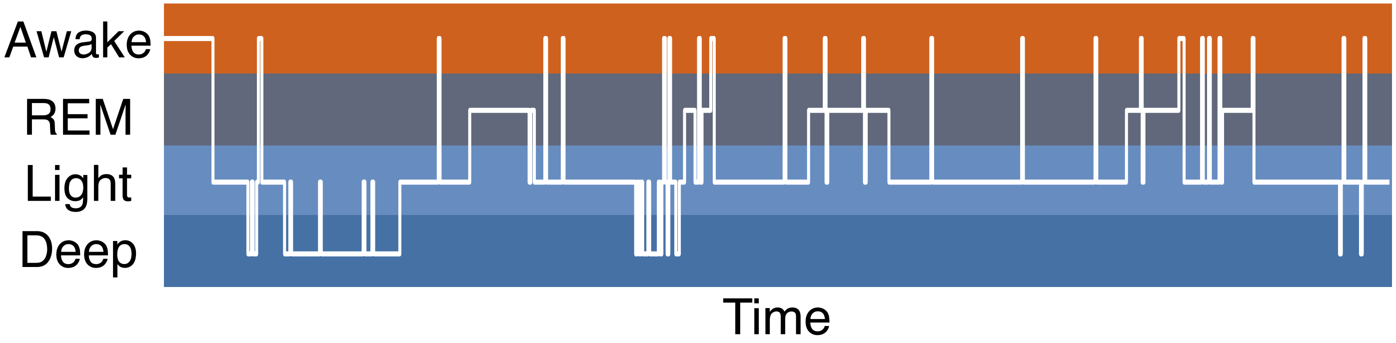
Vital-Radio operates through walls and monitors the vital signs of multiple users simultaneously in natural settings

Baby Monitoring

Learning Sleep Stages from Radio Signals

Background



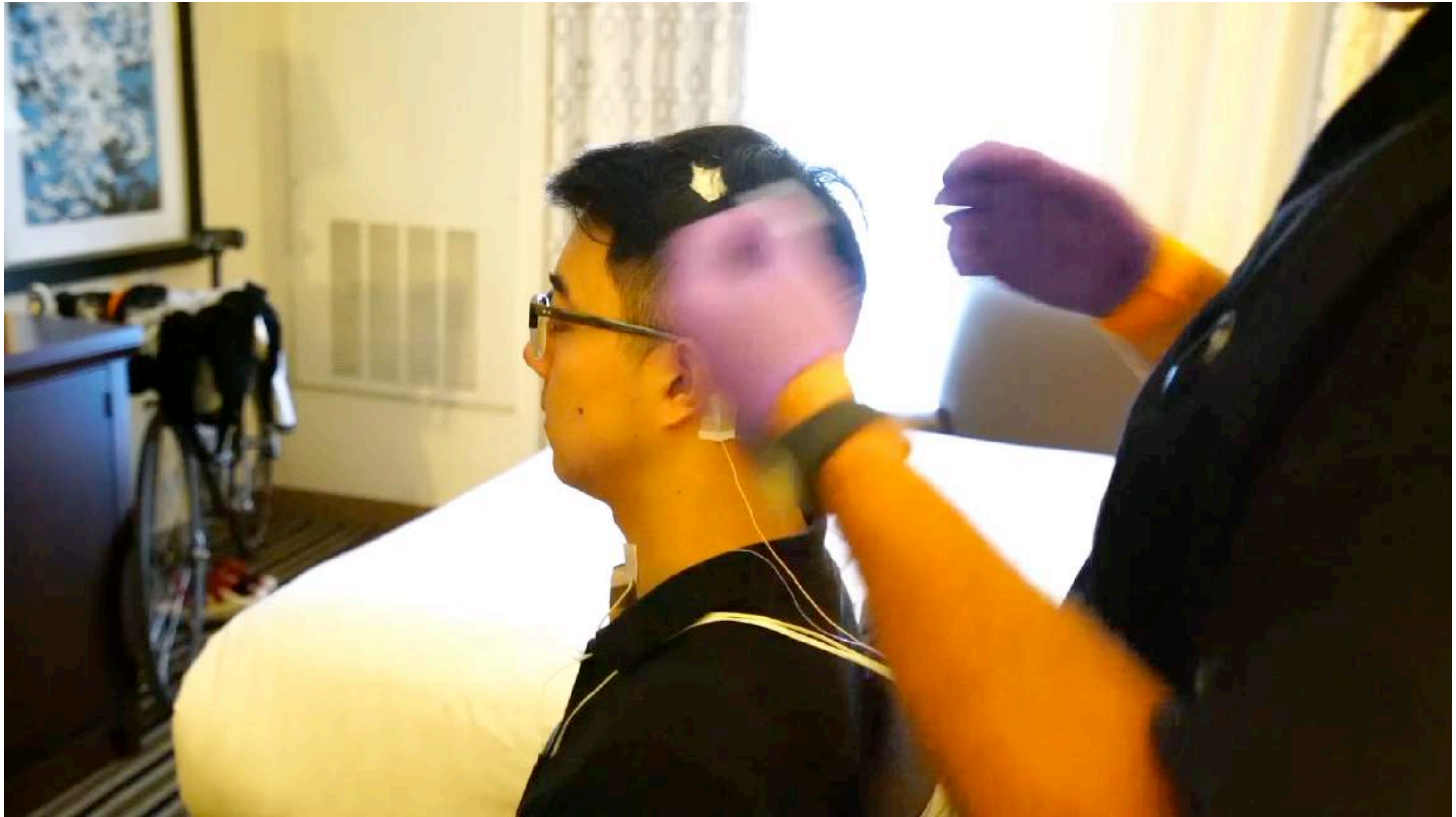

Awake
REM
Light
Deep
Time

Understanding Diseases with Sleep Stages

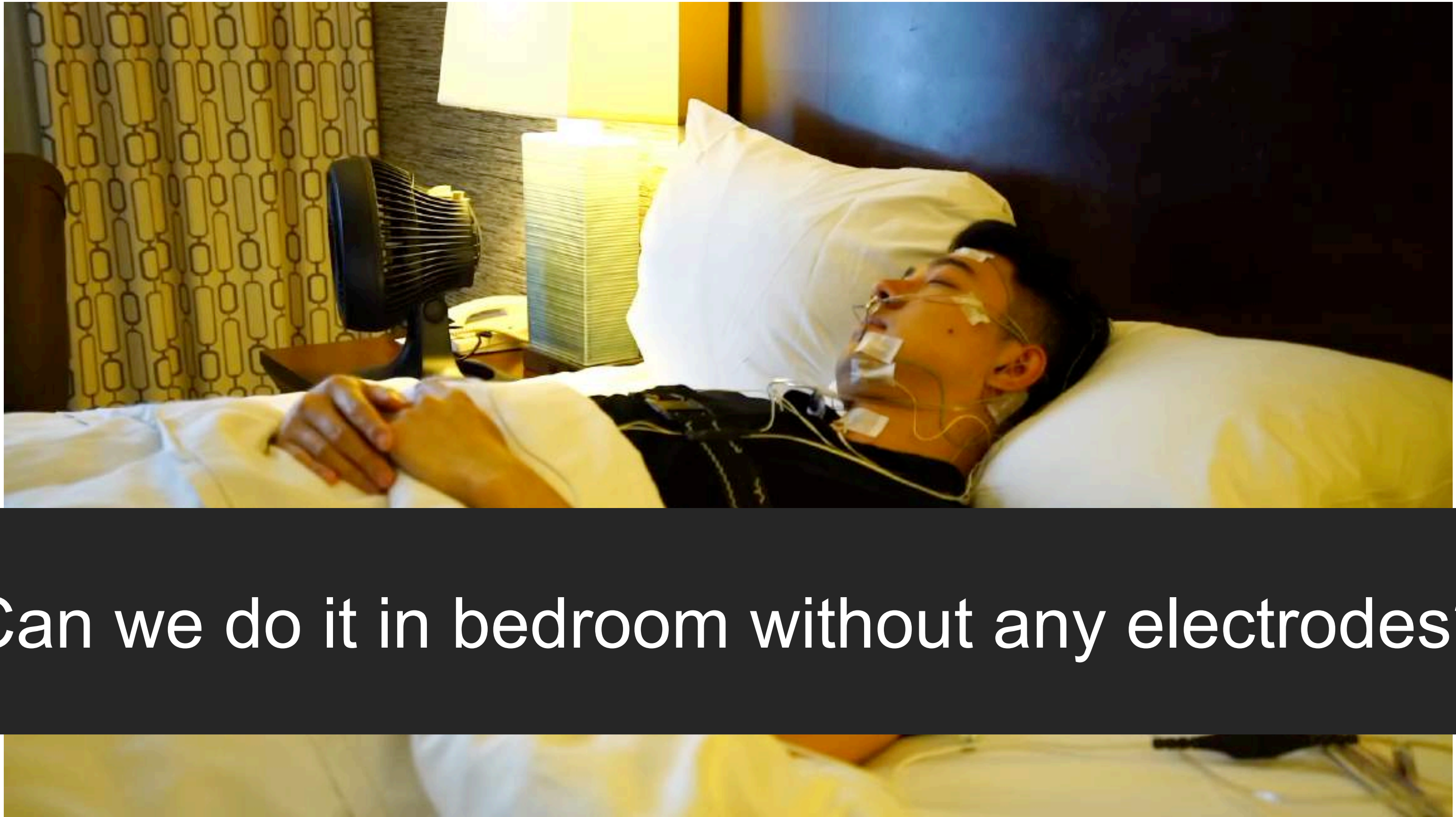
But, monitoring sleep stages is difficult …

done in hospital with many electrodes on the body

Sleep Lab

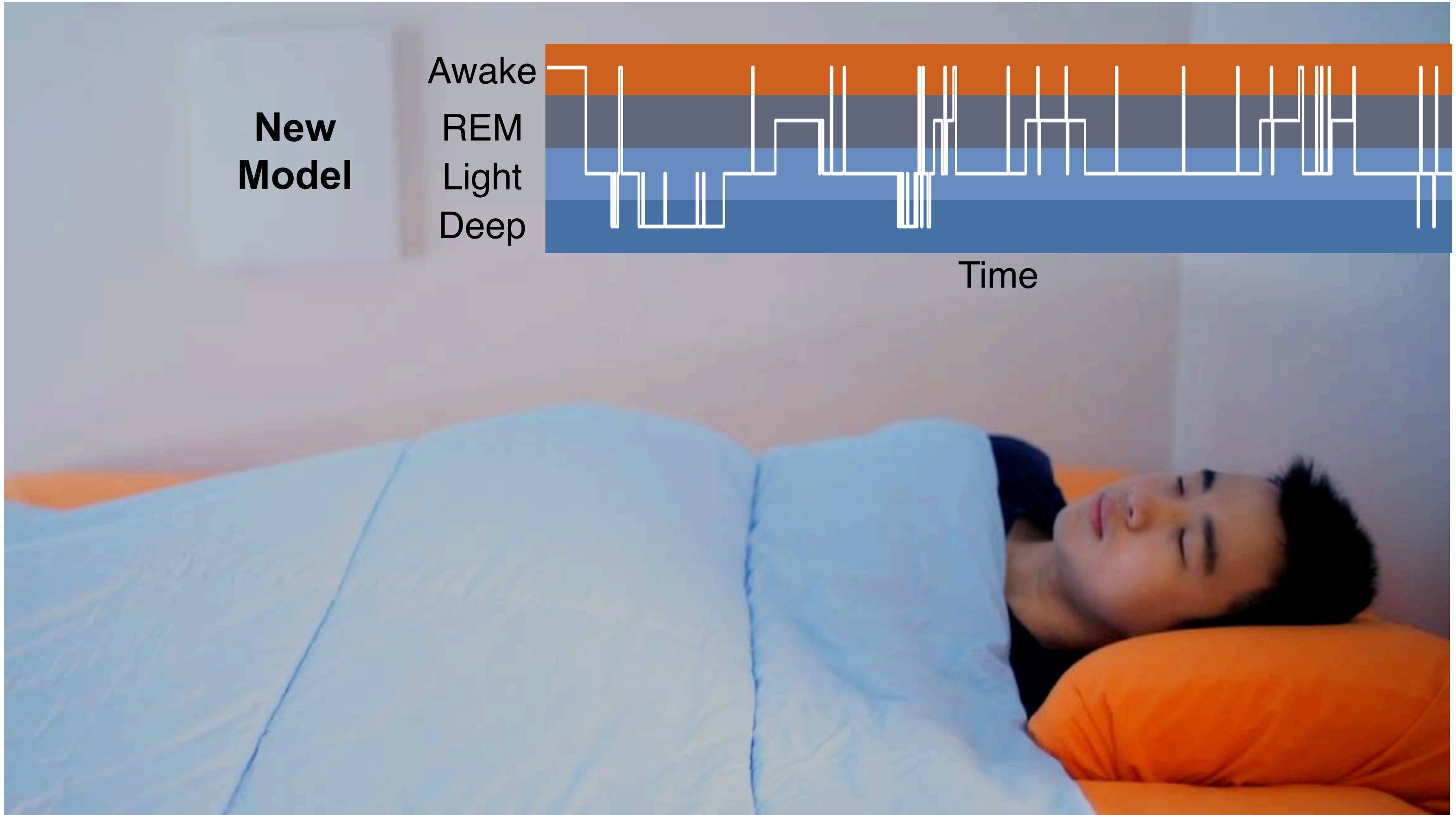


Sleep Lab



Can we do it in bedroom without any electrodes?

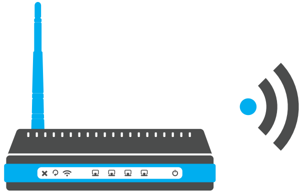
RF-Based Sleep Staging



Contributions

- Predict sleep stages from radio signals without contact
- Conditional adversary for domain adaptation
- User study and dataset of 100 night of sleep

Background on RF Sensing

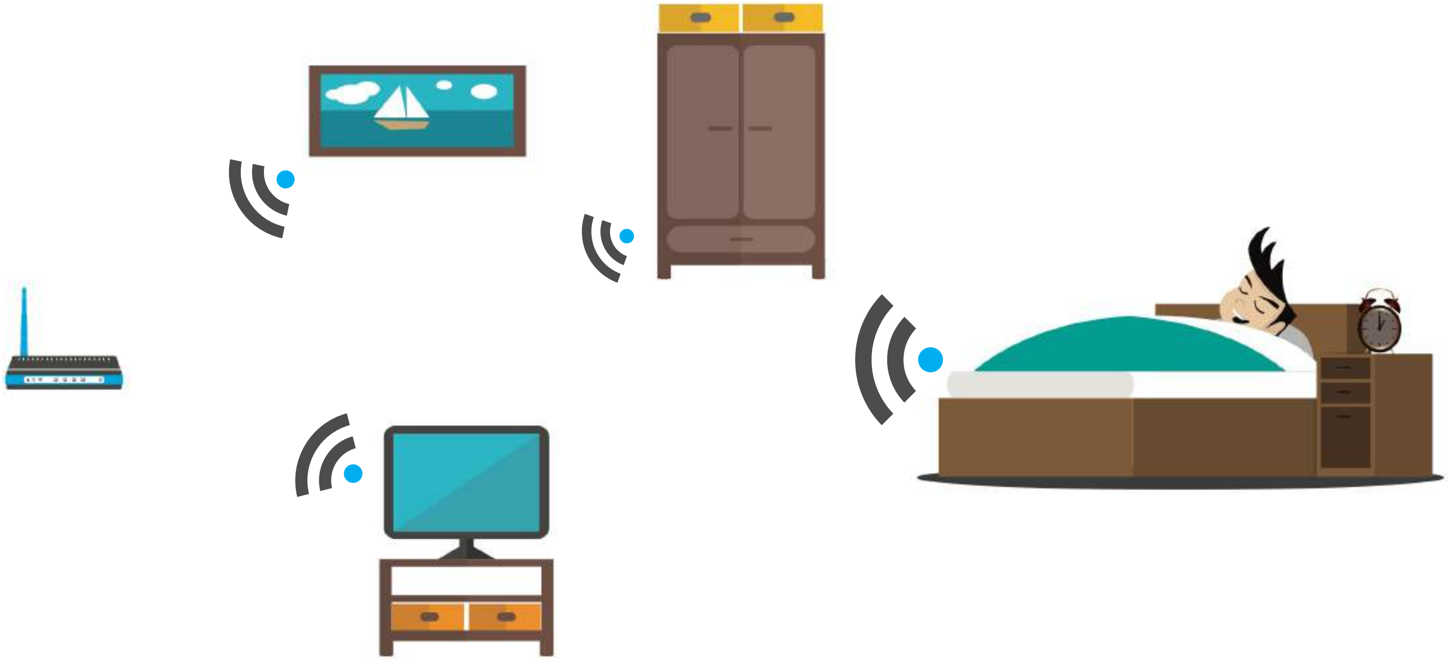


RF signals reflect off body and change with physiological signals

Our objective: High accuracy on par with sleep lab, but in one's bedroom and without electrodes on the body

Key Challenge

RF reflections are highly dependent on the **measurement conditions** and the **individuals**.



Need to remove such extraneous information!





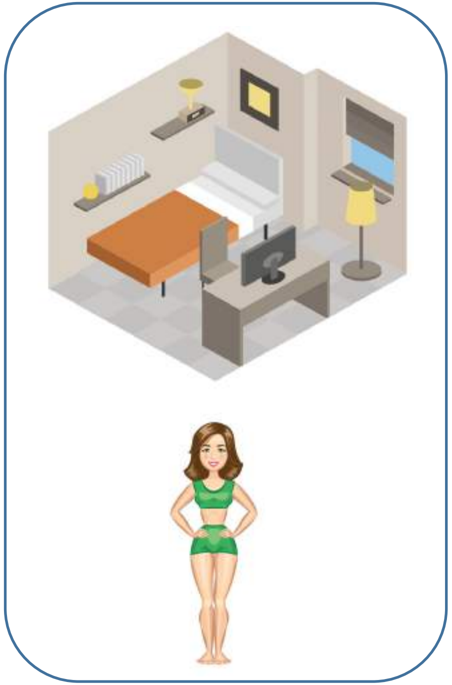

Multi-Source Domain Adaptation

domain = measurement condition + individual

Source domain A

Source domain B

Target domain C



Multi-Source Domain Adaptation

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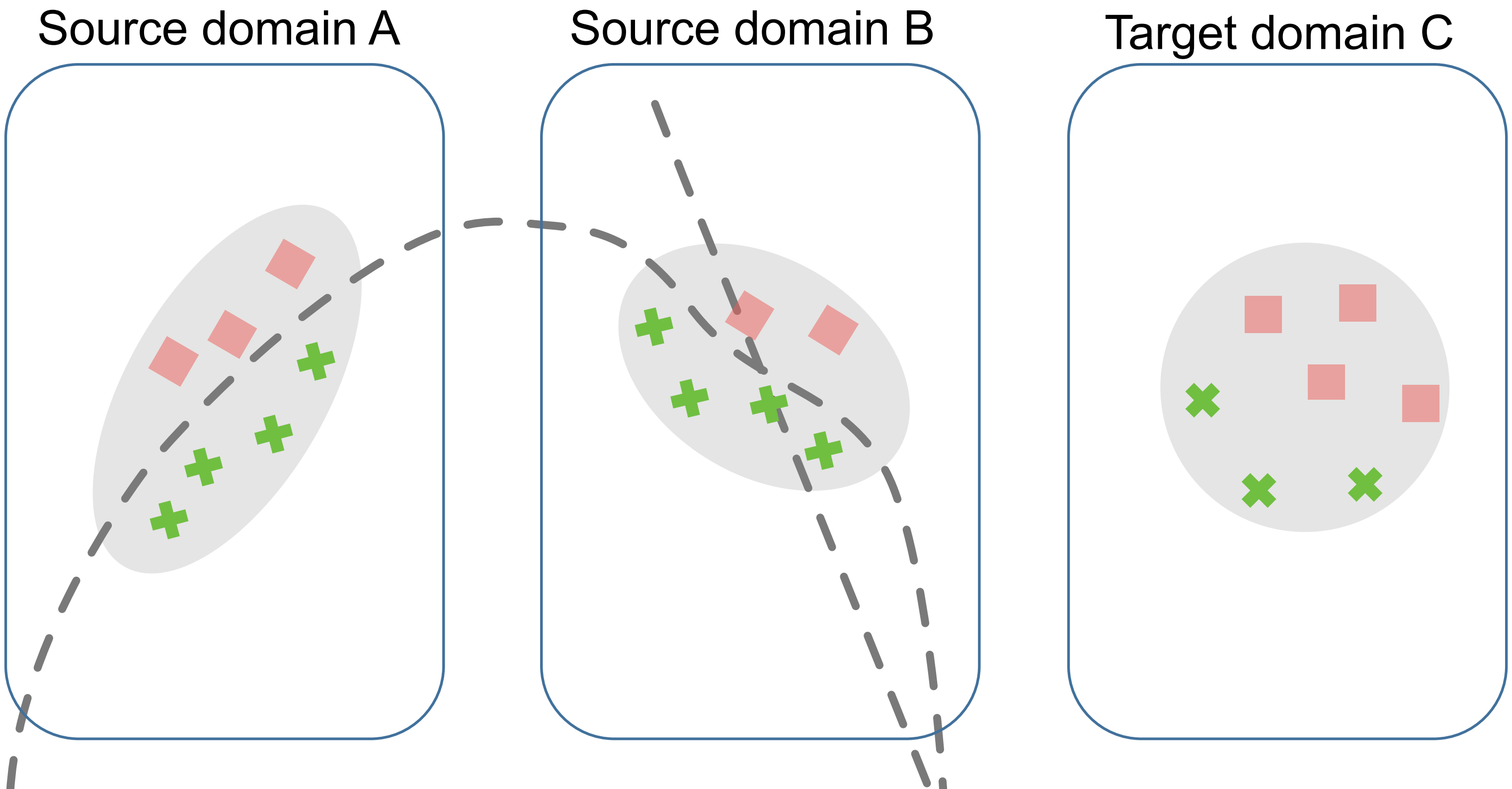
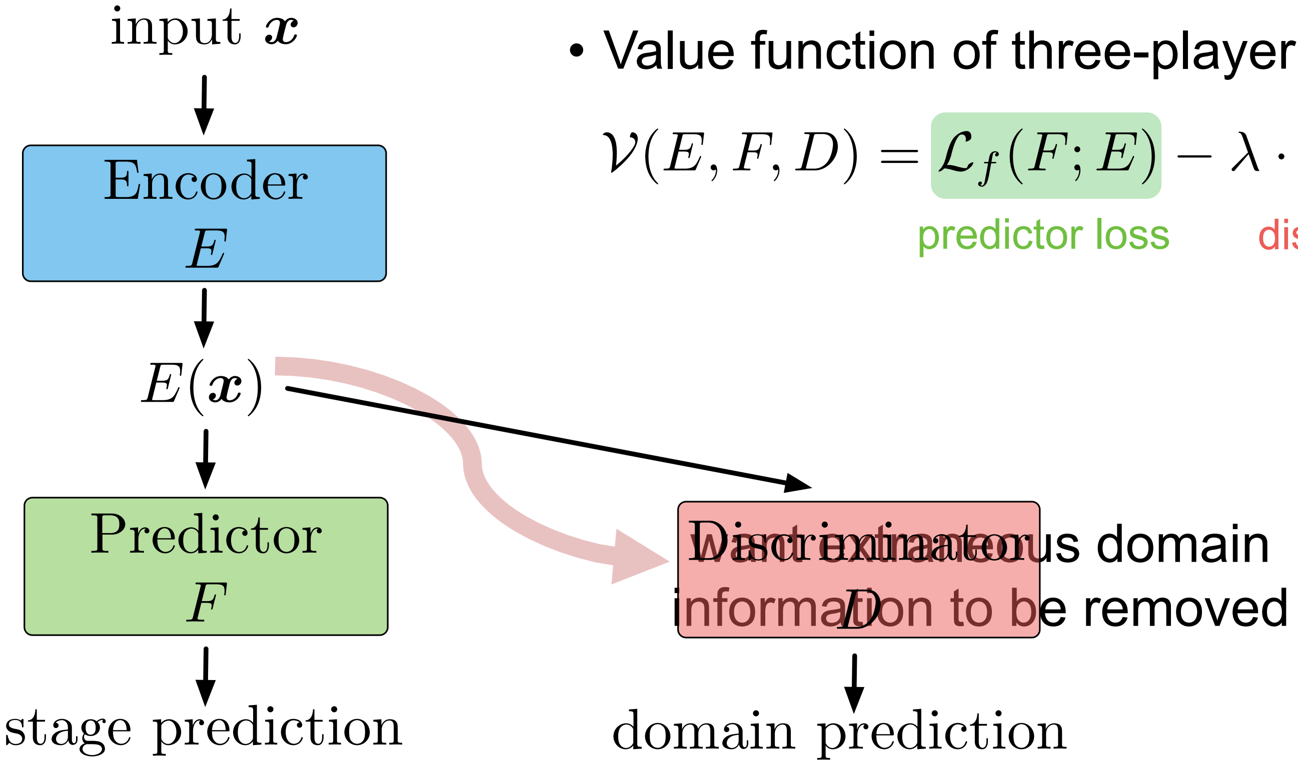


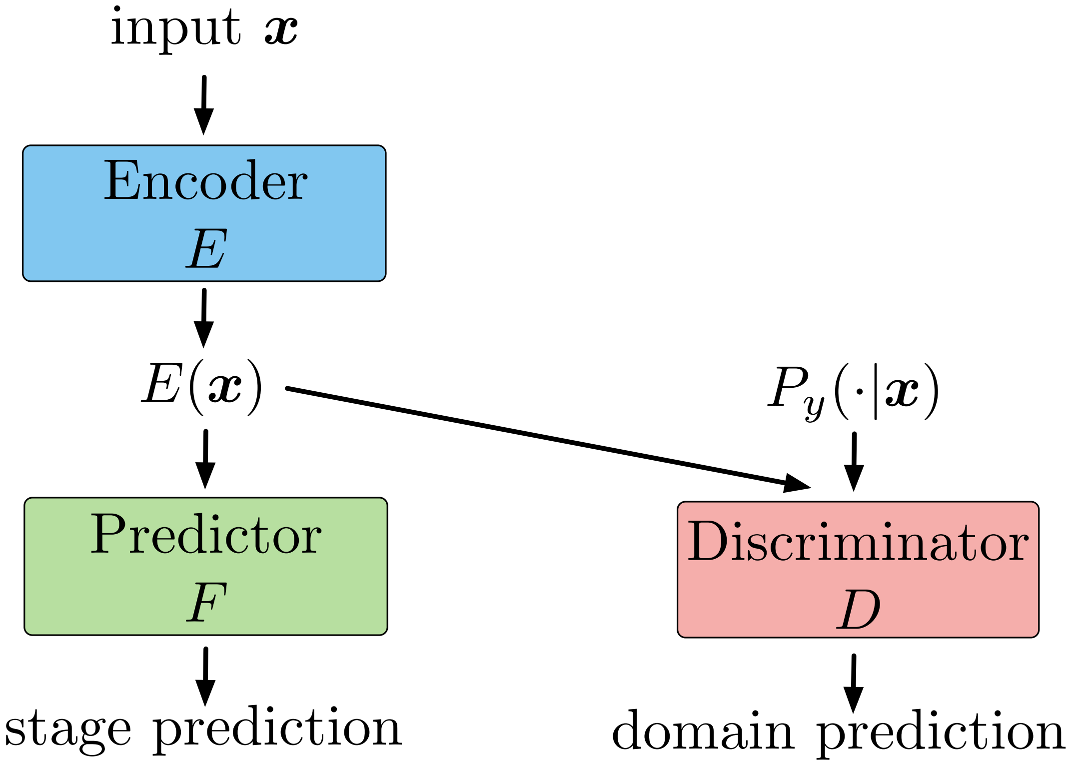
Problem: Discriminator removes both extraneous and useful information

- Value function of three-player game:

$$\mathcal{V}(E, F, D) = \underbrace{\mathcal{L}_f(F; E)}_{\text{predictor loss}} - \lambda \cdot \underbrace{\mathcal{L}_d(D; E)}_{\text{discriminator loss}}$$



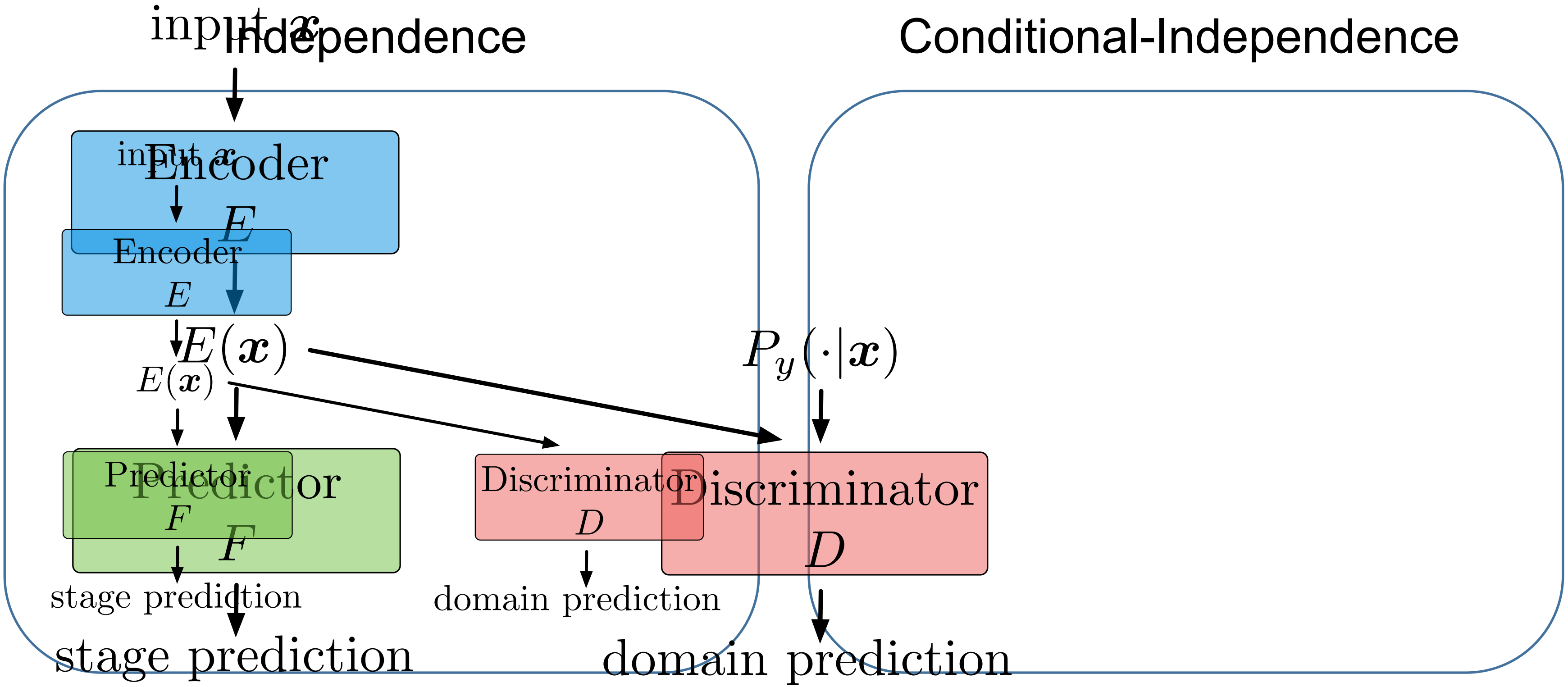
Conditional Adversary



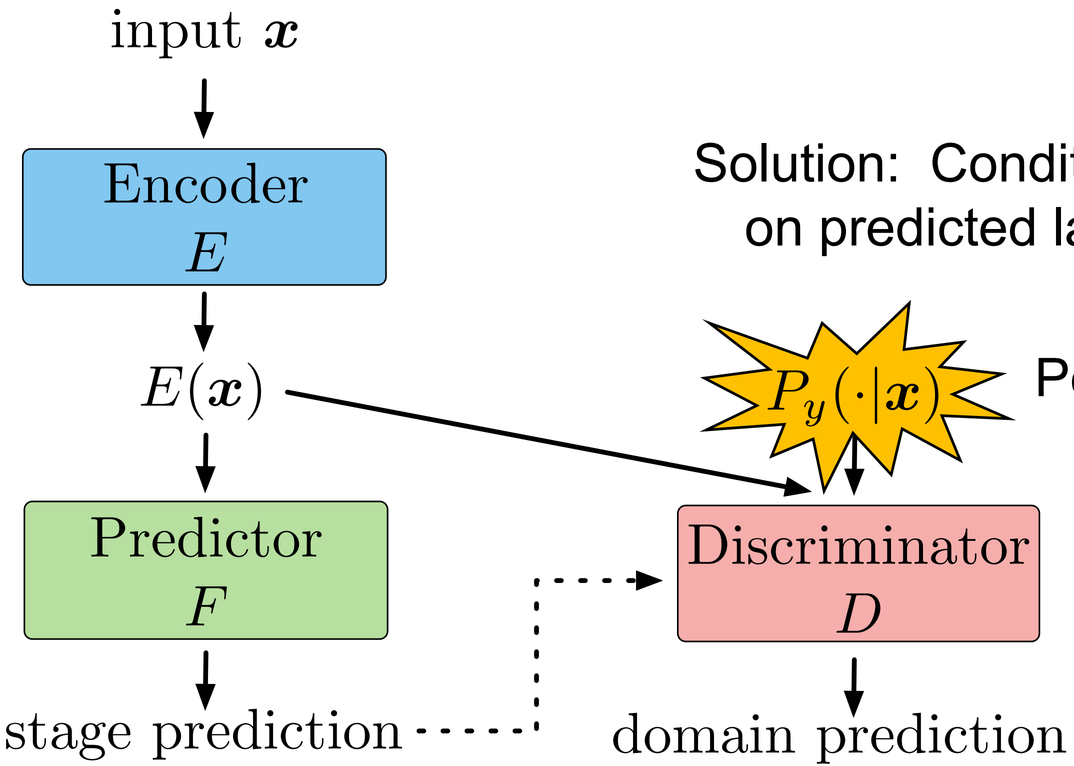
Role of Adversary

Independence

Conditional-Independence



Does it work?



Solution: Condition Discriminator on predicted label distribution

Posterior not available when training!

It Works

Theorem (informal): Given enough capacity, the encoder at equilibrium discards all extraneous information specific to domains, while retaining the relevant information for the predictive task.

Evaluation

- 25 different bedrooms and 100 nights
- Ground-truth: FDA-approved EEG-based sleep profiler provides sleep stage labels
- ~90k 30-sencond pairs of RF measurements and corresponding sleep stages

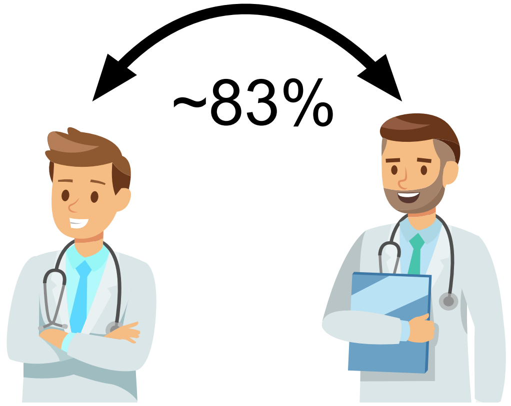
Accuracy

Accuracy of sleep lab
Inter-rater agreement: 83%

Our accuracy 79.8%
(Tested on new subjects not in training, i.e., new domains)

Previous solutions: 64%

Labelling sleep stages is subjective

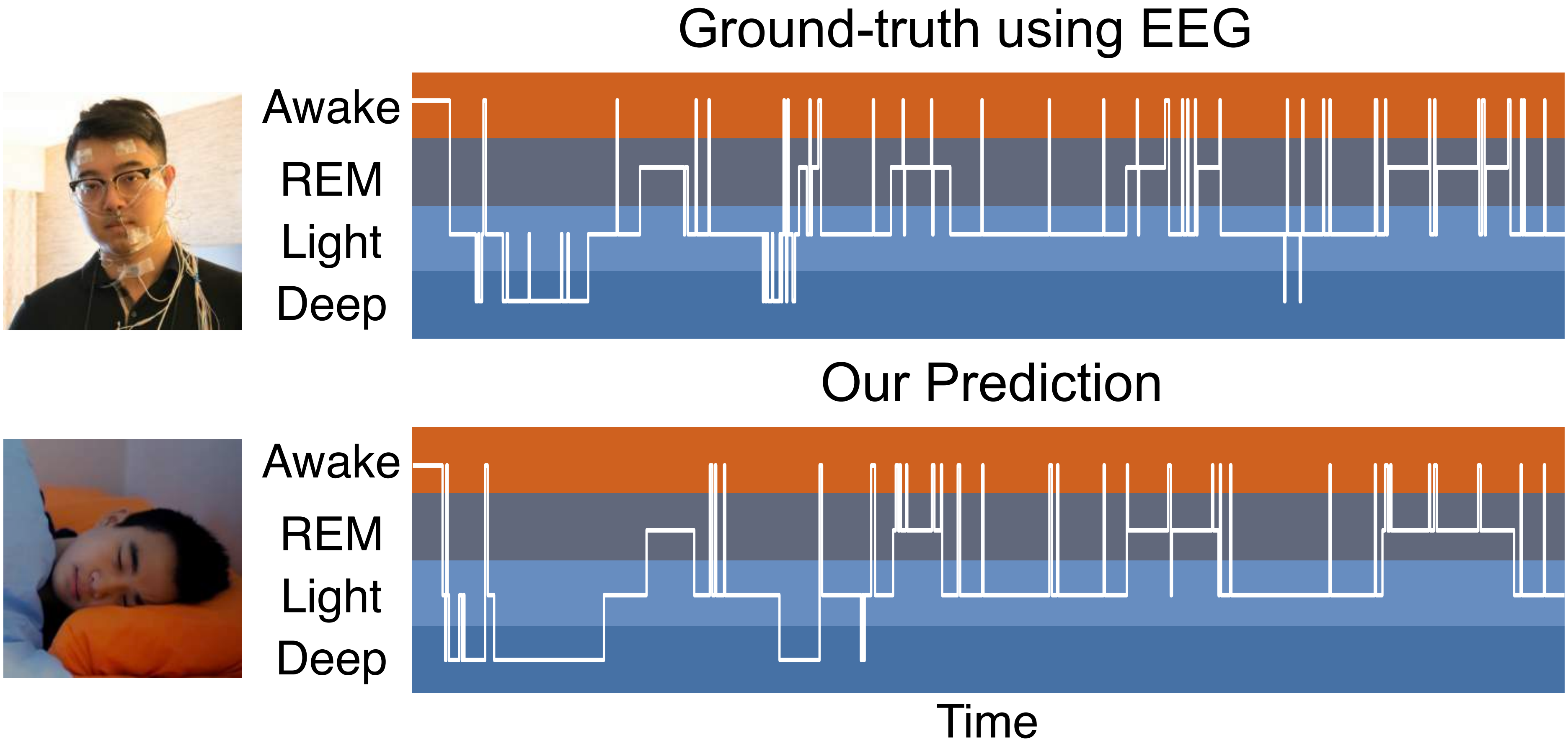


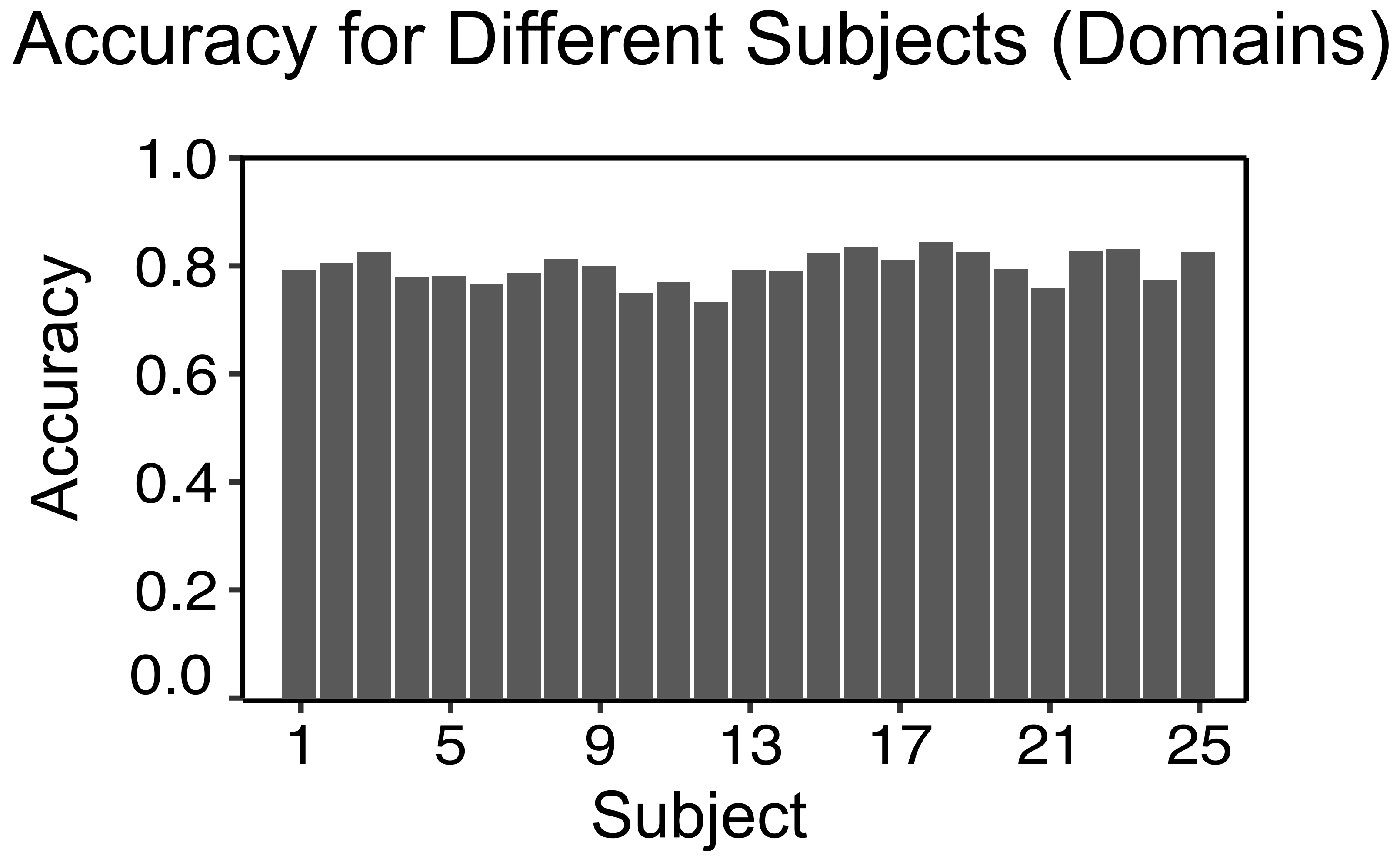
Comparison with Past Work

Average and Cohen's Kappa

Approach	*Accuracy*	κ
Tataraidze et al. (2016b)	0.635	0.49
Zaffaroni et al. (2014)	0.641	0.45
Ours	**0.798**	**0.70**

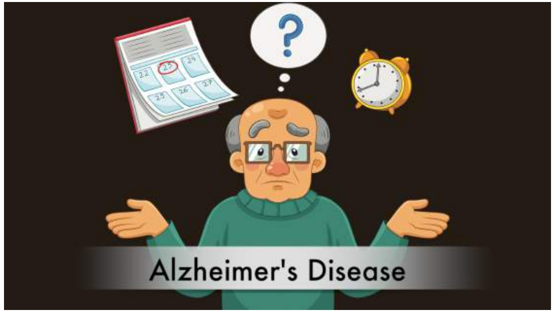
Representative Example Acc = 80%




Accuracy for Different Subjects (Domains)
Accuracy
1.0
0.8
0.6
0.4
0.2
0.0
1
5
9
13
17
21
25
Subject

Conclusion

Learning sleep stages from wireless signals



Learning Sleep Stages from Radio Signals: A Conditional Adversarial Architecture

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ICML 2017

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