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

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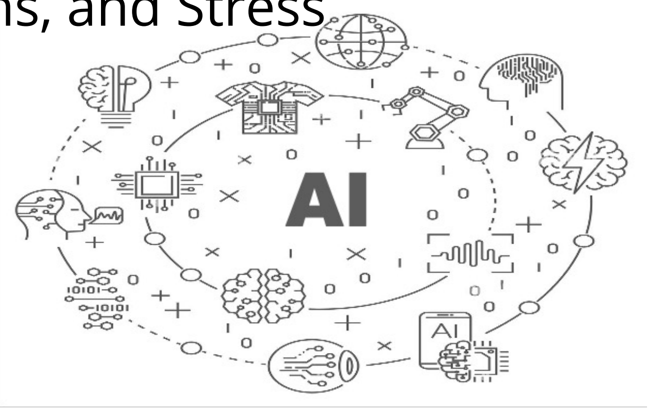
Lecture 6

Wireless Sensing: Heartbeats, Emotions, and Stress



University of Pennsylvania

Last Lecture

Vital Ratio: Extracting vital signs (average breathing rate and heart rate)

This Lecture

EQ-Radio: emotions from wireless signals

RF-SCG: seismocardiography from wireless signals

WiStress: stress level from wireless signals

Can you tell people's emotions even if they don't show up on their faces?

Smart Homes that adapt to our mood

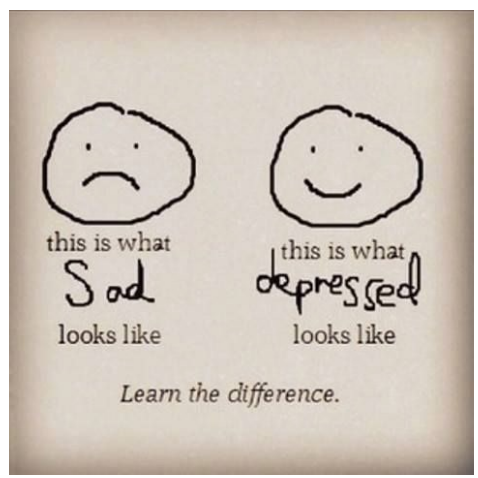
Did I get the Job? …. No

Does my advisor like my work?

Graduate student

Advisor

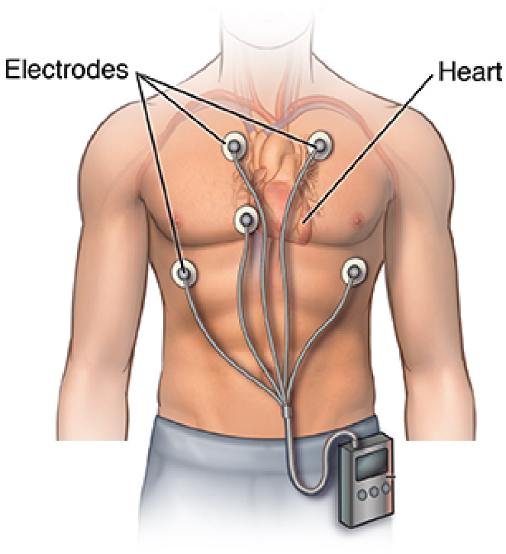
Combating Depression



Is the date going well!

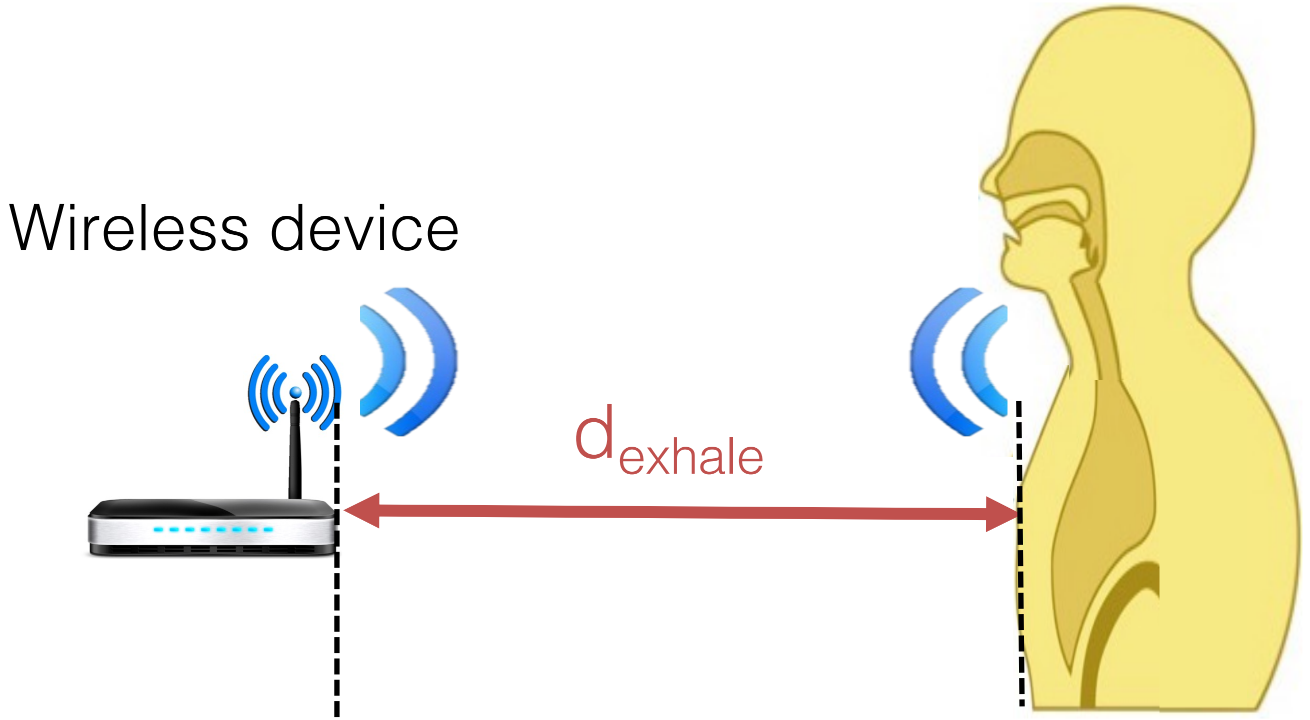
Existing approaches measure vital signs

- Use ECG to get very accurate heartbeats

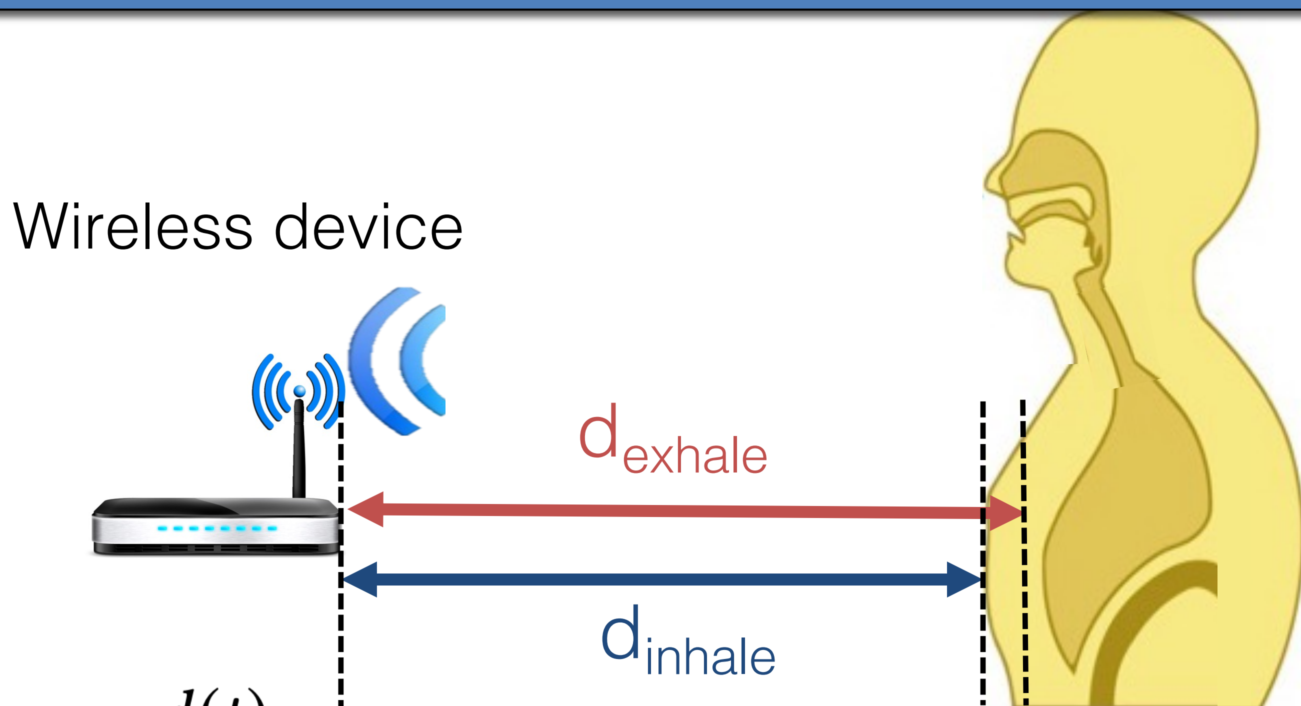


Use wireless reflections off the human body

Use wireless reflections off the human body



Solution: Use the phase of the wireless reflection

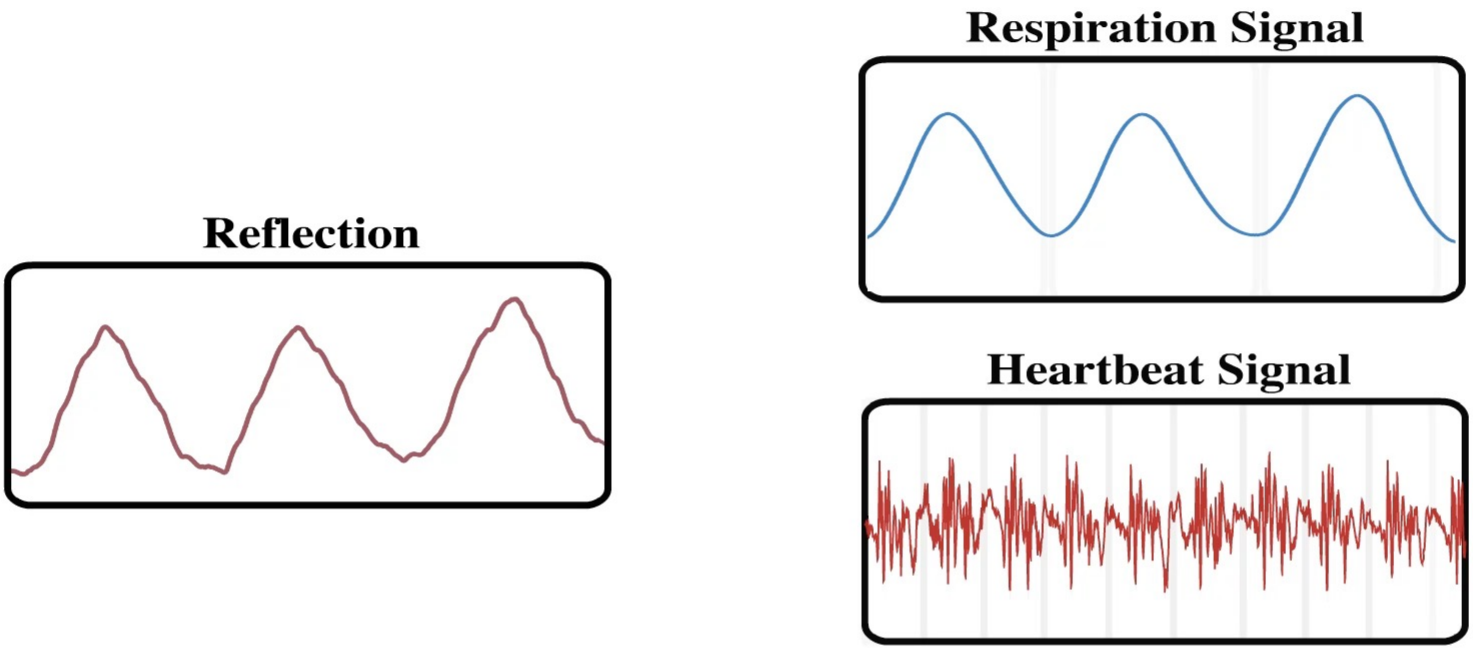


$$\phi(t) = 2\pi \frac{d(t)}{\lambda}$$

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

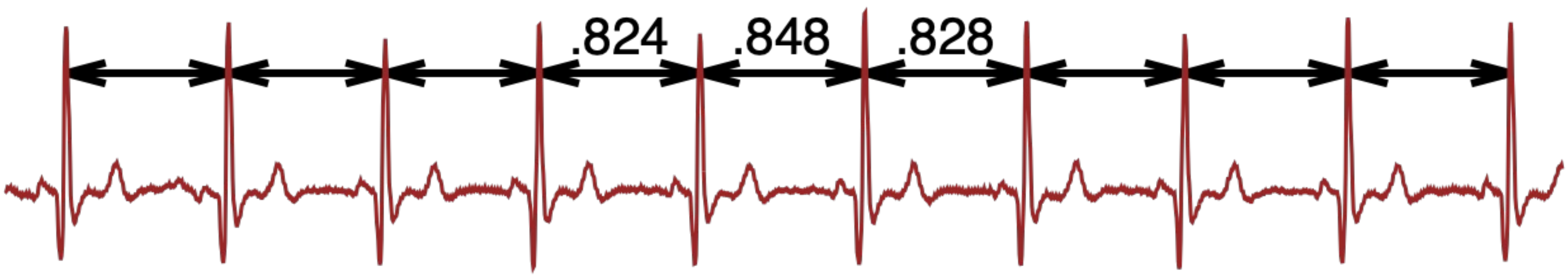
- Chest Motion changes distance
- Heartbeats also change distance

Emotion recognition using wireless signals



Key challenge: Inter-Beat Interval (IBI)

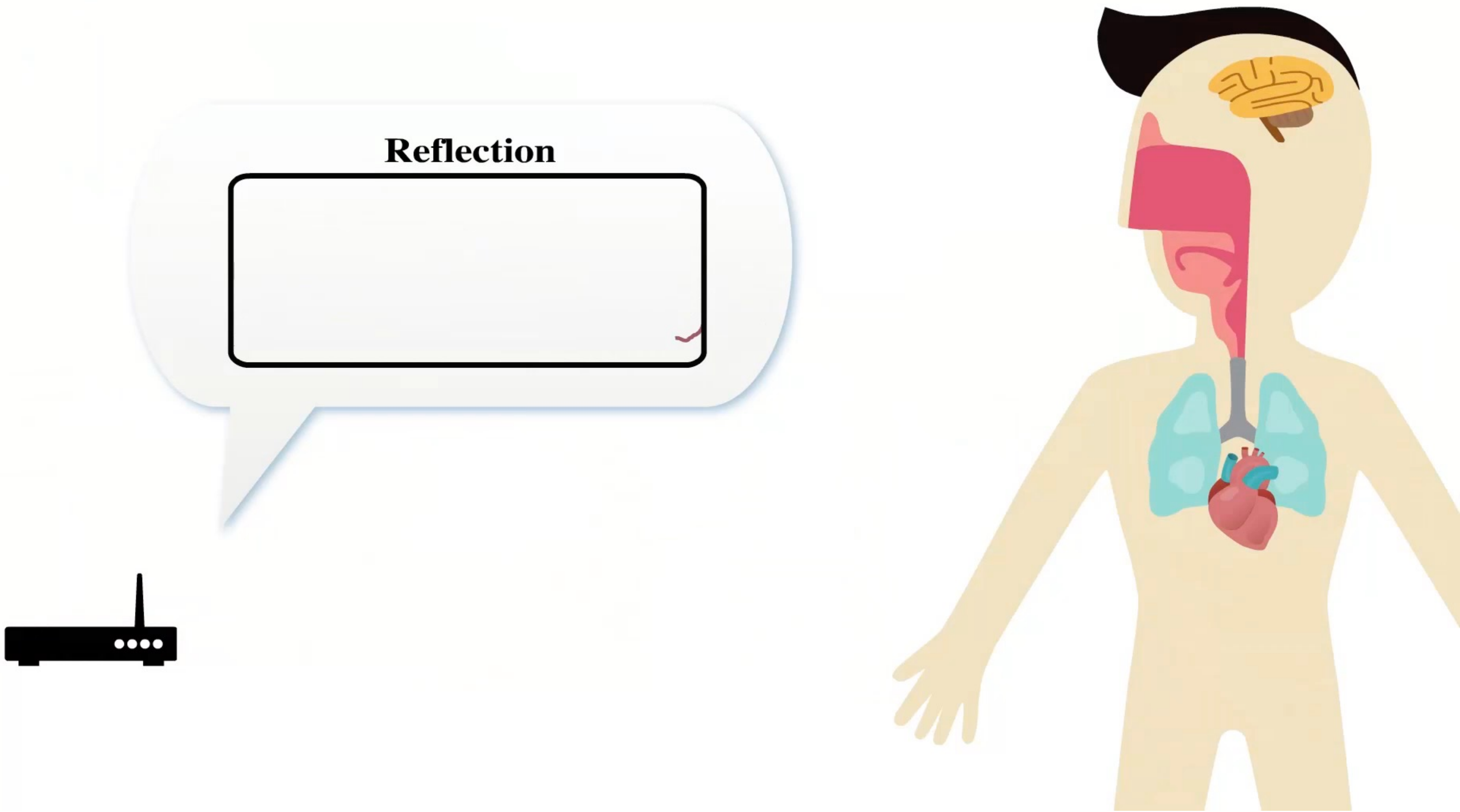
- Emotion recognition needs accurate measurements of the length of every single heartbeat



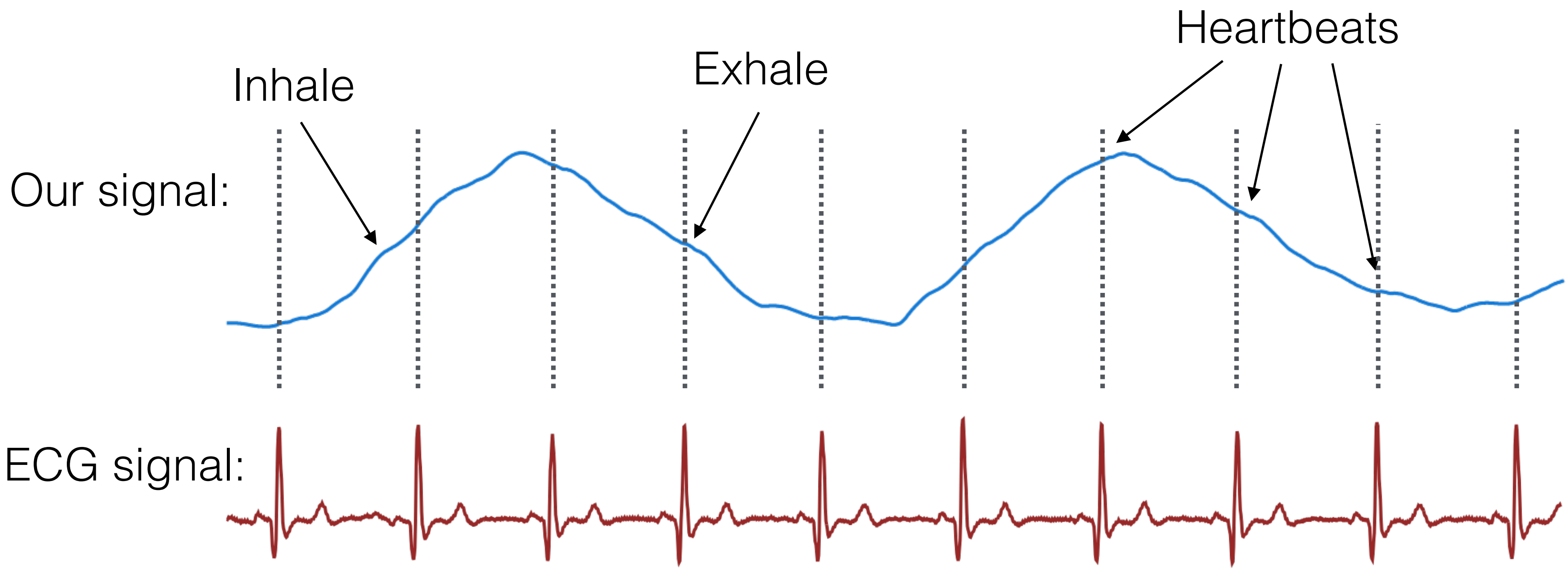
We need to extract IBI with accuracy over 99%

Input signal

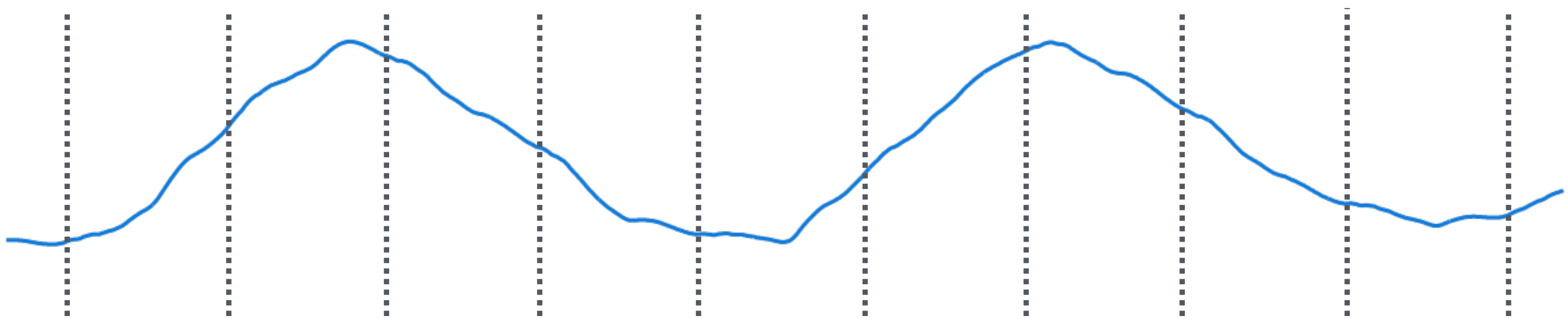
Wireless reflection of the human body



Input signal



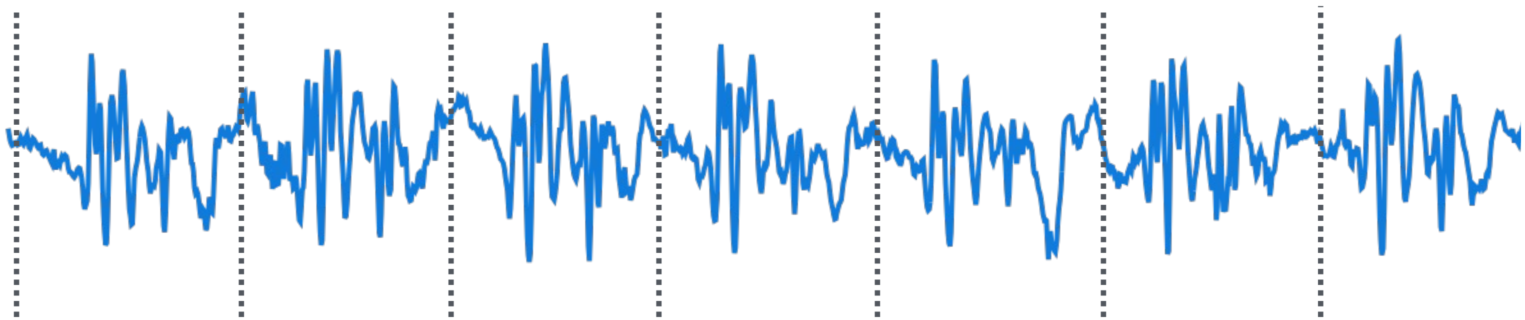
Step 1: Remove breathing signal



- Breathing masks heartbeats
- We use acceleration filter
    - Heartbeat involves rapid contraction of muscle
    - Breathing is slow and steady

Heartbeat signal

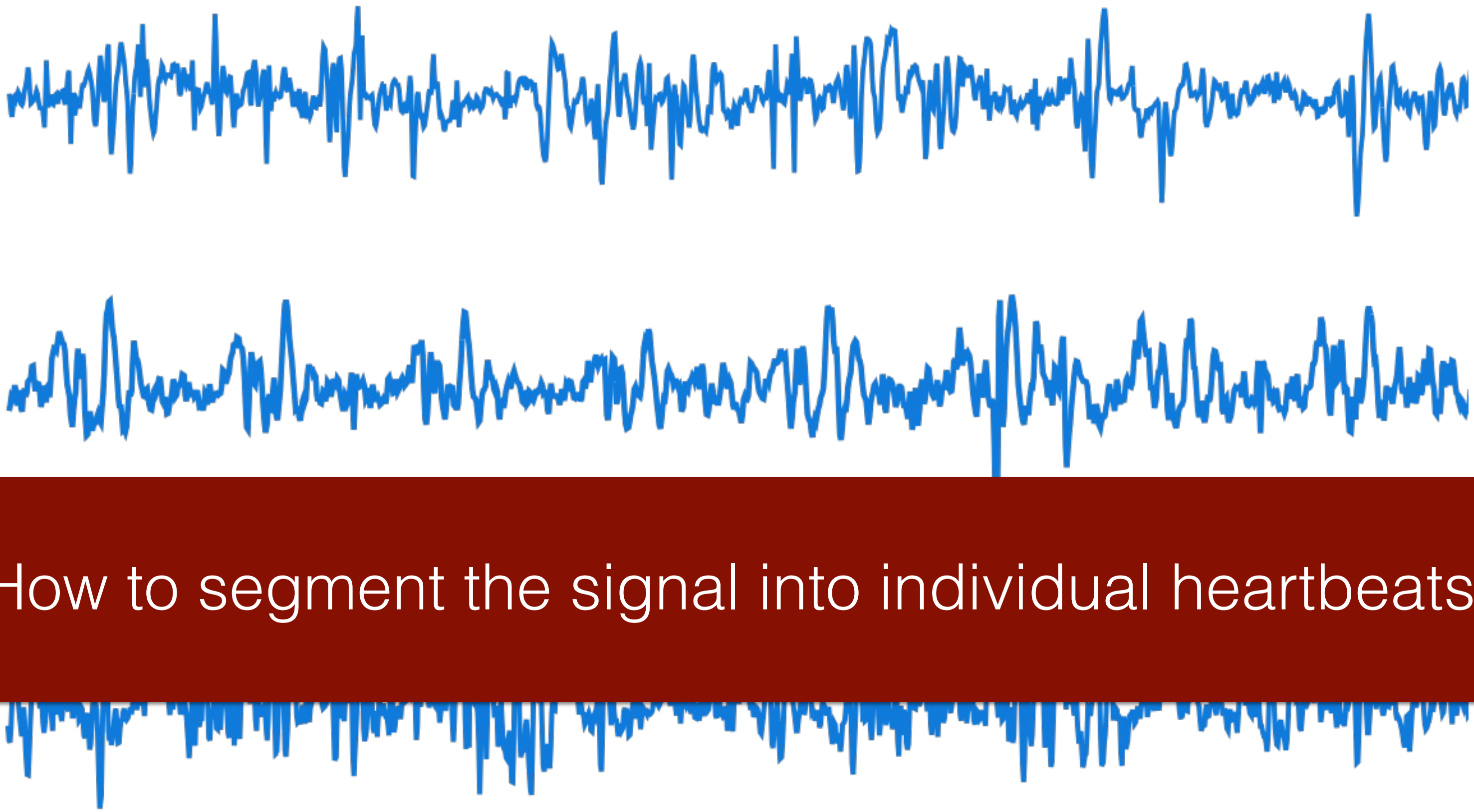
- Output of acceleration filter



- ECG signal

Heartbeat signal

- Other typical examples:



How to segment the signal into individual heartbeats?

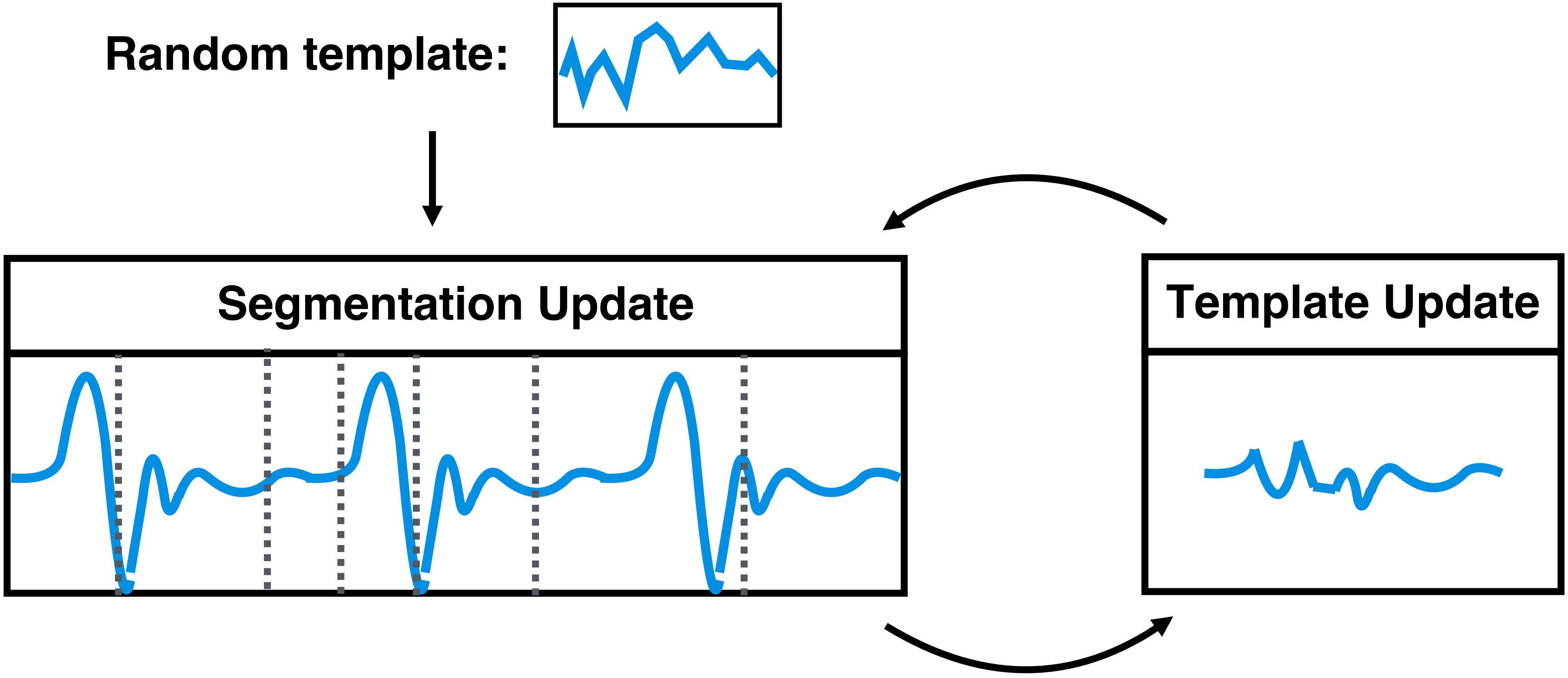
Step 2: Heartbeat segmentation

- **Intuition**: heartbeat repeats with certain shape (template)

- If we can somehow discover the template, then we can segment into individual heartbeats

Step 2: Heartbeat segmentation

- **Intuition**: heartbeat repeats with certain shape (template)



Step 2: Heartbeat segmentation

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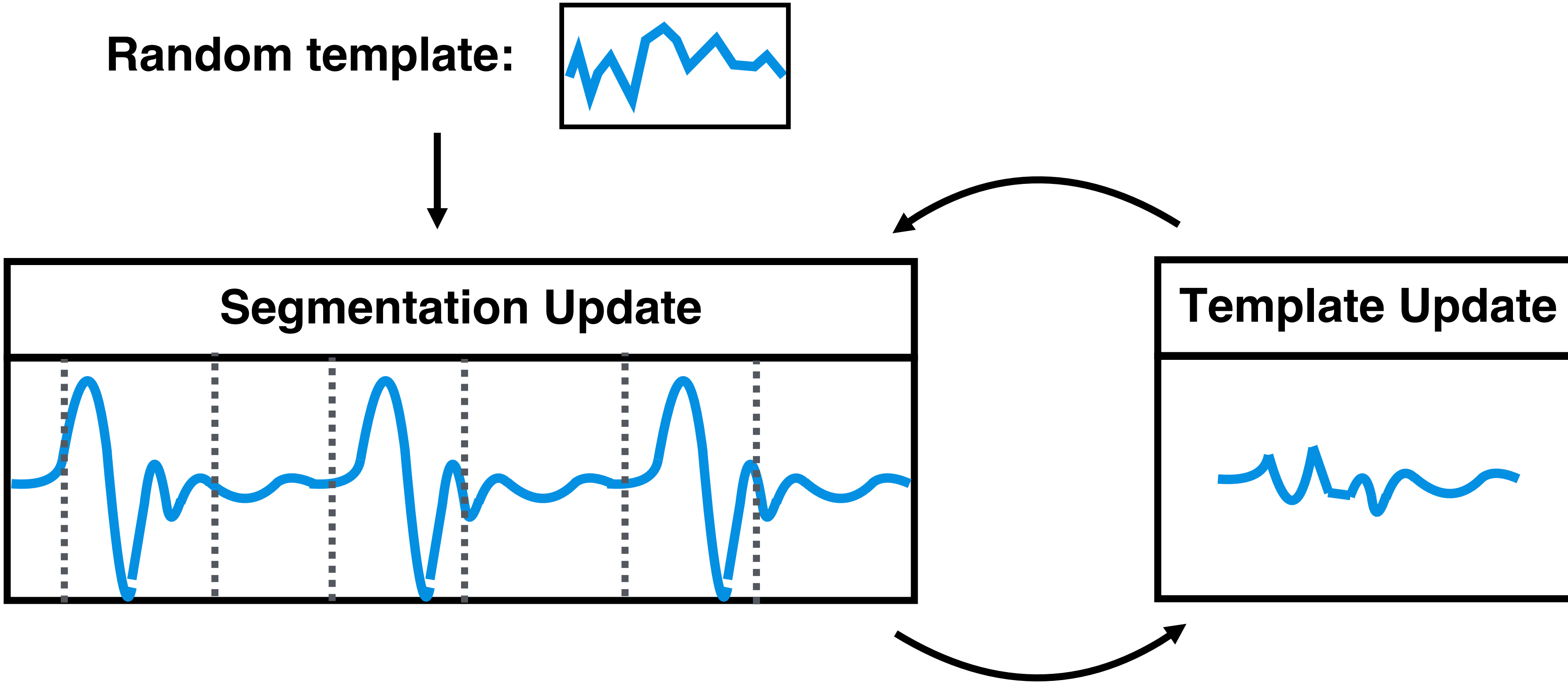

Step 2: Heartbeat segmentation

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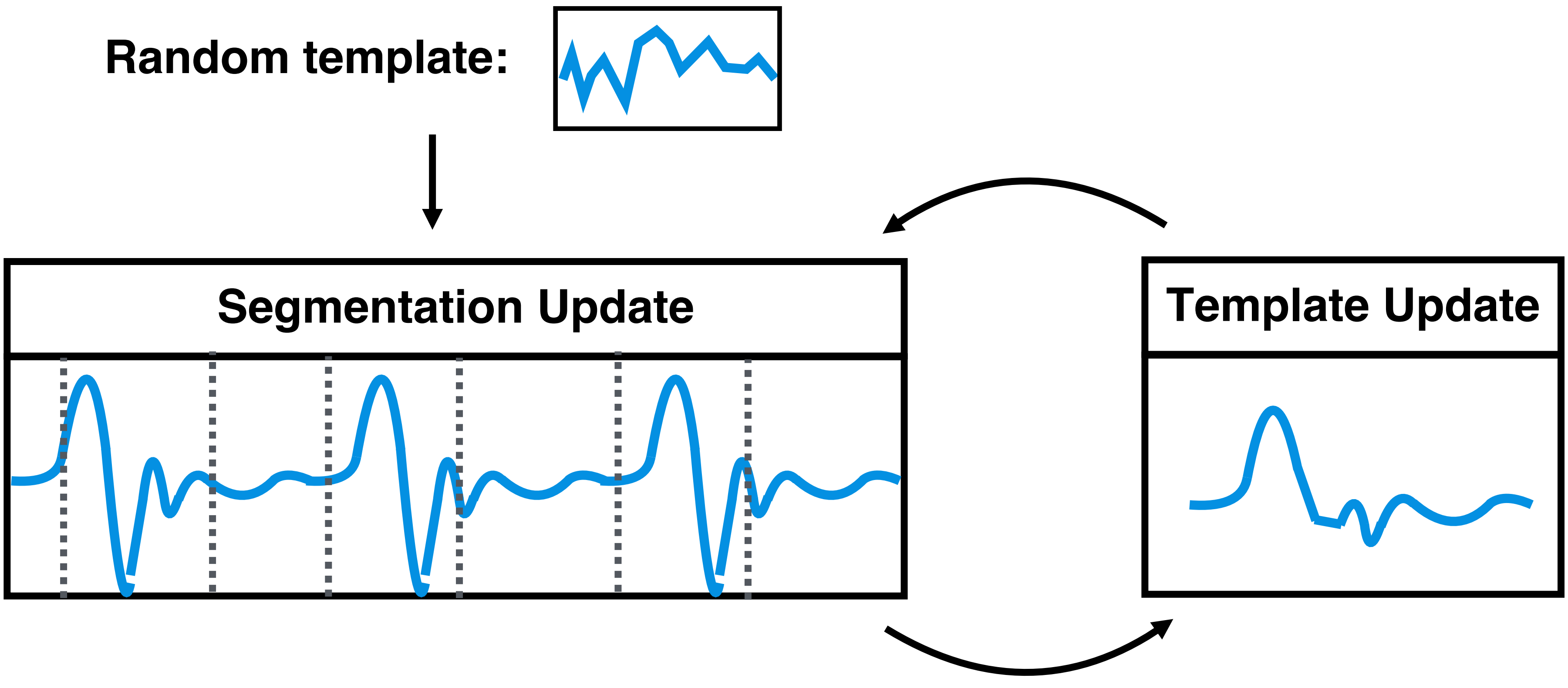

Step 2: Heartbeat segmentation

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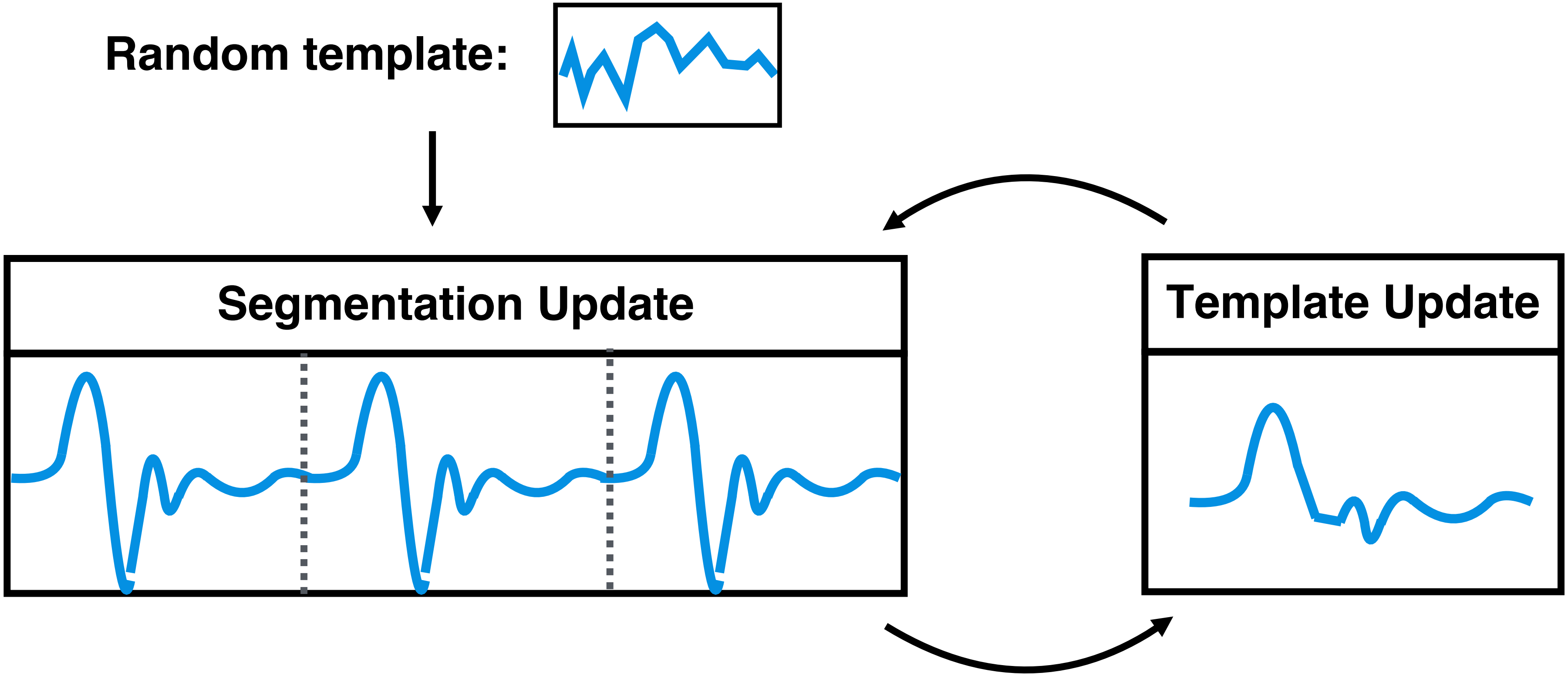

Step 2: Heartbeat segmentation

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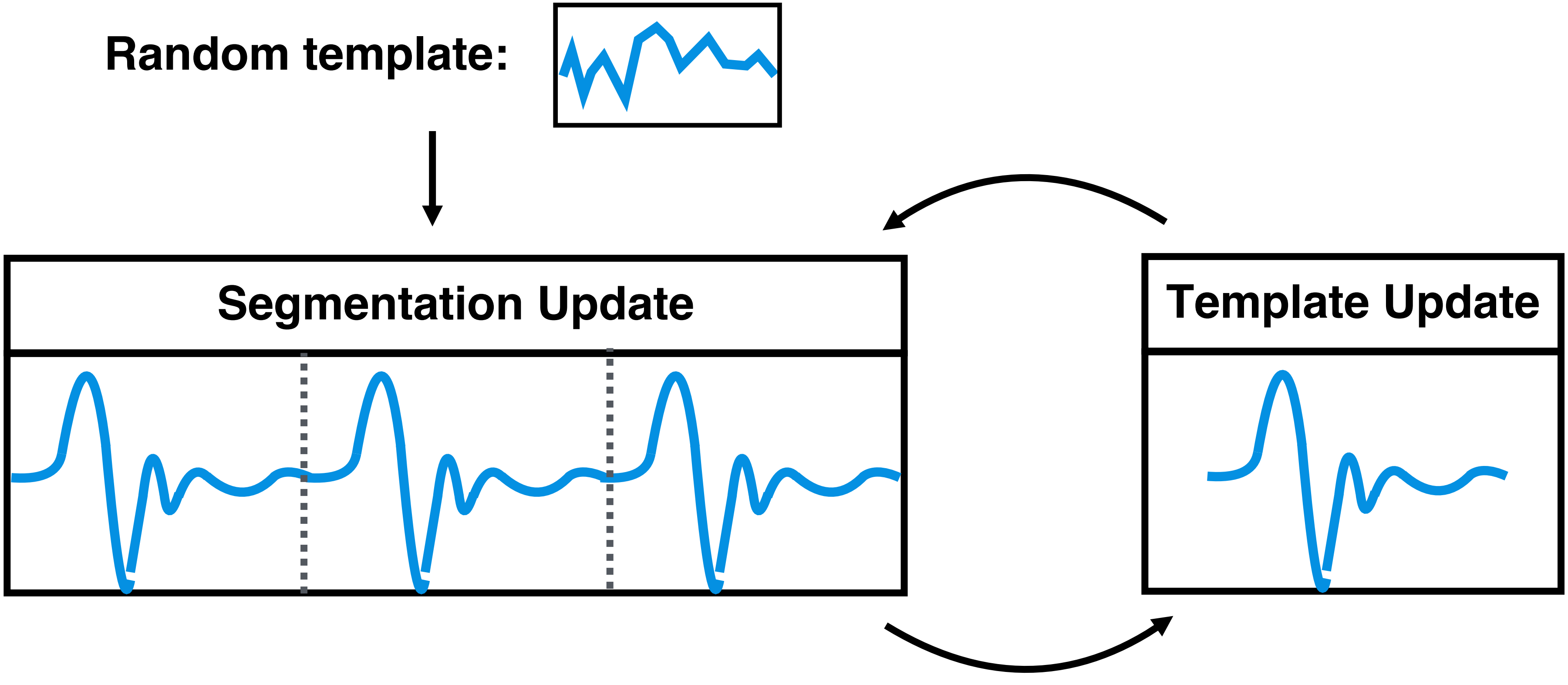
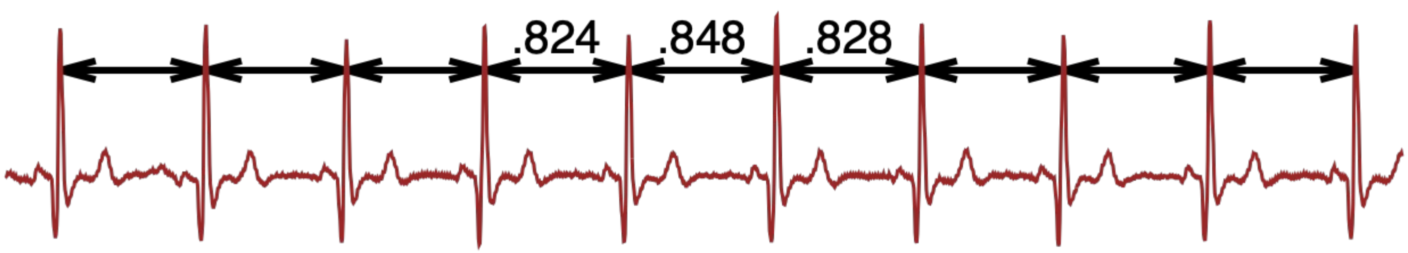


Caveat: Shrinking & Expanding

- IBI are not always the same



- Template subject to shrink and expanding
  - Linear warping

Algorithm

Need to recover both segmentation and template

- Joint optimization: $$\underset{\mathcal{S},\boldsymbol{\mu}}{\text{minimize}} \sum_{s_i \in \mathcal{S}} \|s_i - \omega(\boldsymbol{\mu}, |s_i|)\|^2$$

segmentation template warping

Segmentation Update	Template Update
$\mathcal{S}^{l+1} = \arg\min_{\mathcal{S}} \sum_{s_i \in \mathcal{S}} \|s_i - \omega(\boldsymbol{\mu}^l, |s_i|)\|^2$ (dynamic programming)	$\boldsymbol{\mu}^{l+1} = \arg\min_{\boldsymbol{\mu}} \sum_{s_i \in \mathcal{S}^{l+1}} \|s_i - \omega(\boldsymbol{\mu}, |s_i|)\|^2$ (weighted least squares)

Algorithm

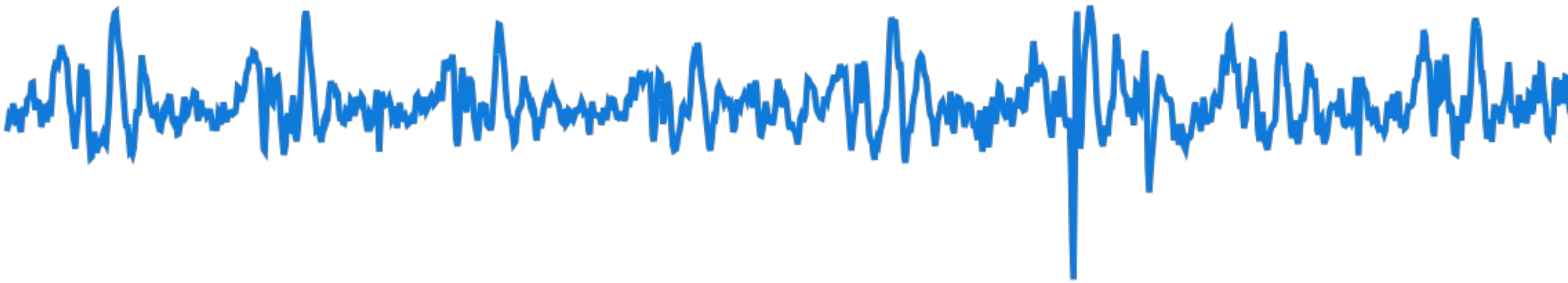
Need to recover both segmentation and template

- Joint optimization: $$\underset{\mathcal{S},\boldsymbol{\mu}}{\text{minimize}} \sum_{s_i \in \mathcal{S}} \|s_i - \omega(\boldsymbol{\mu}, |s_i|)\|^2$$

segmentation → $\mathcal{S}$; template → $\boldsymbol{\mu}$; warping → ω

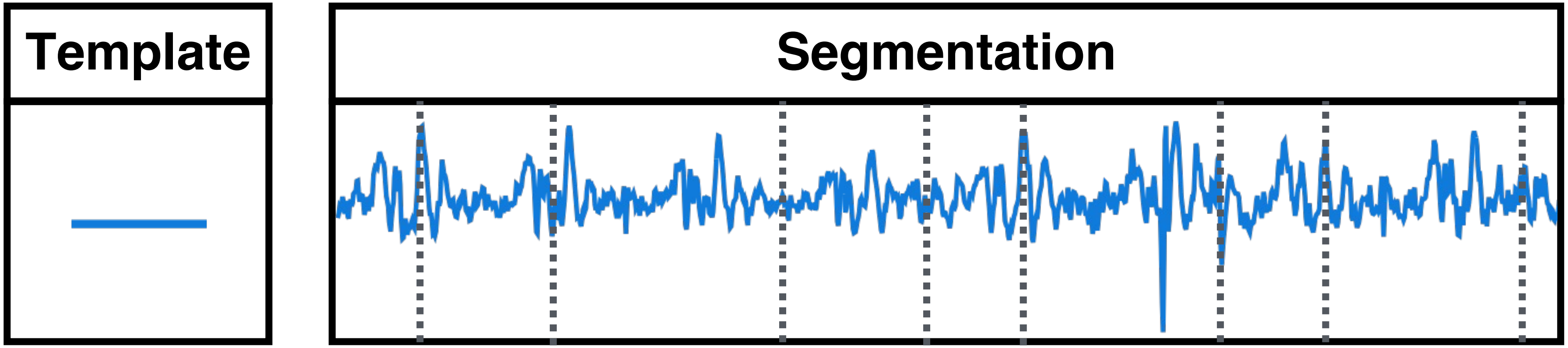
Segmentation Update	Template Update
$\mathcal{S}^{l+1} = \arg\min_{\mathcal{S}} \sum_{s_i \in \mathcal{S}} \|s_i - \omega(\boldsymbol{\mu}^l, \|s_i\|)\|^2$	$\boldsymbol{\mu}^{l+1} = \arg\min_{\boldsymbol{\mu}} \sum_{s_i \in \mathcal{S}^{l+1}} \|s_i - \omega(\boldsymbol{\mu}, \|s_i\|)\|^2$
(dynamic programming)	(weighted least squares)

Example run



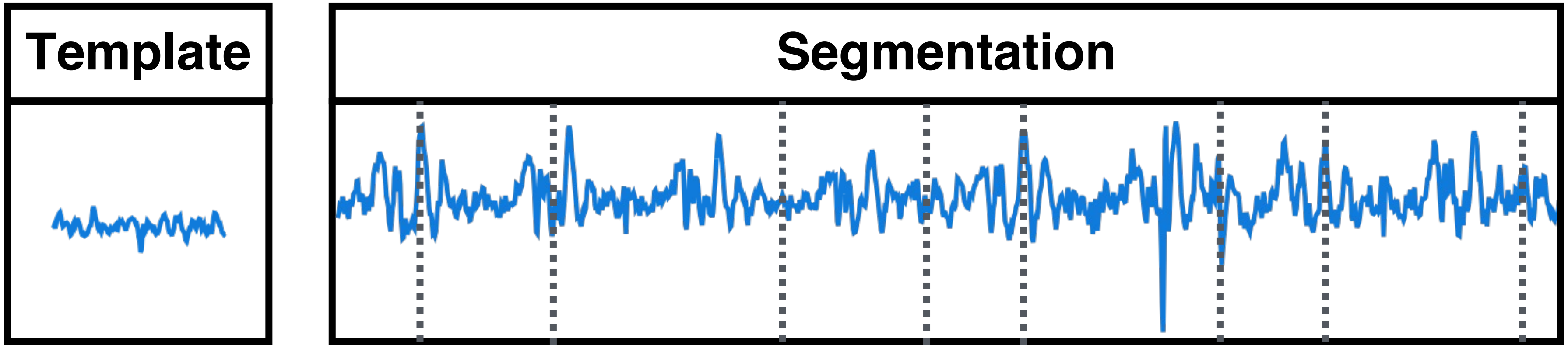
Example run

Iteration 1:



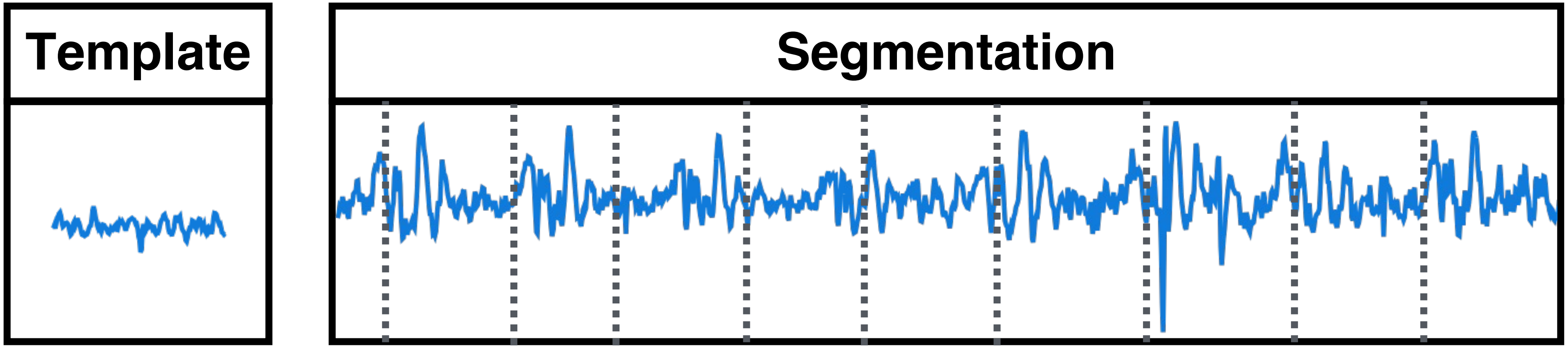
Example run

Iteration 2:



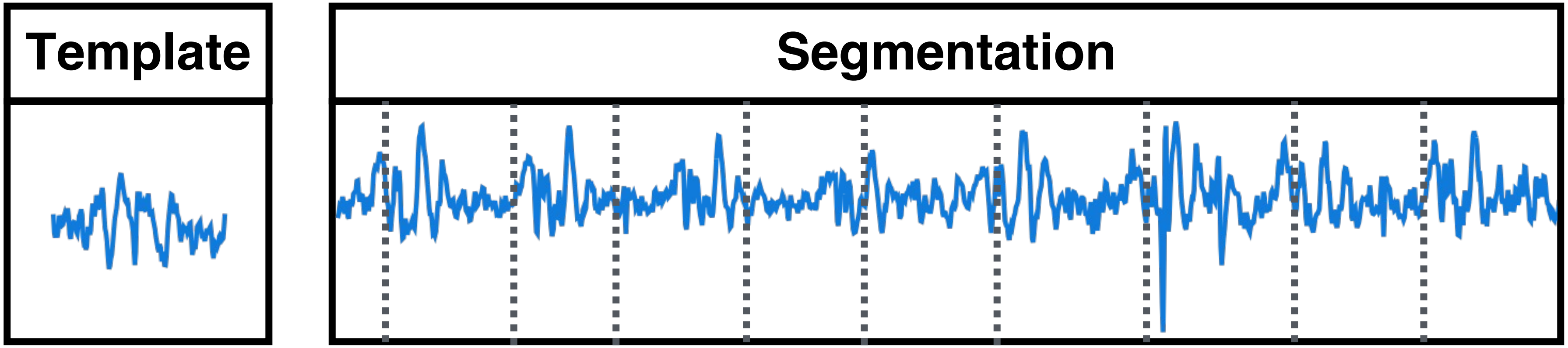
Example run

Iteration 2:



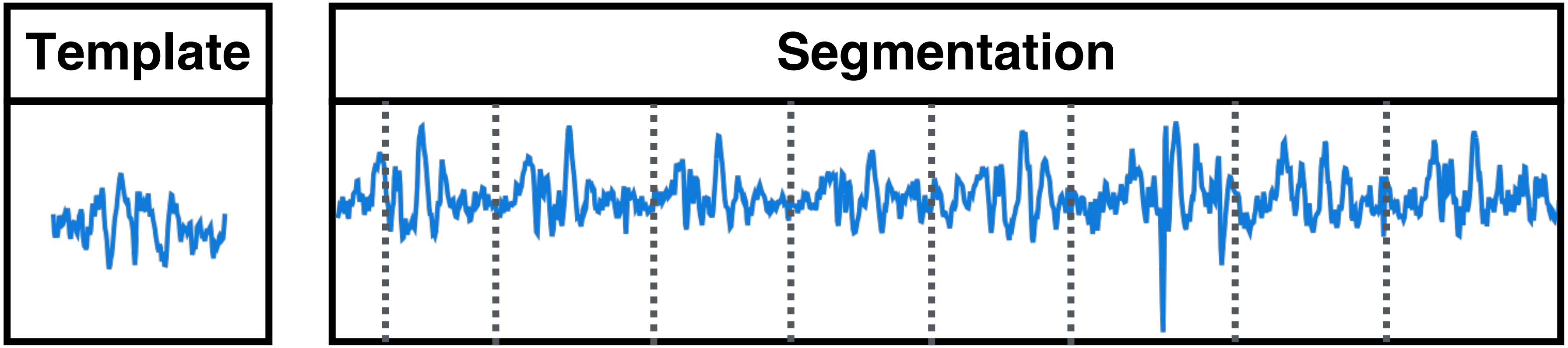
Example run

Iteration 3:



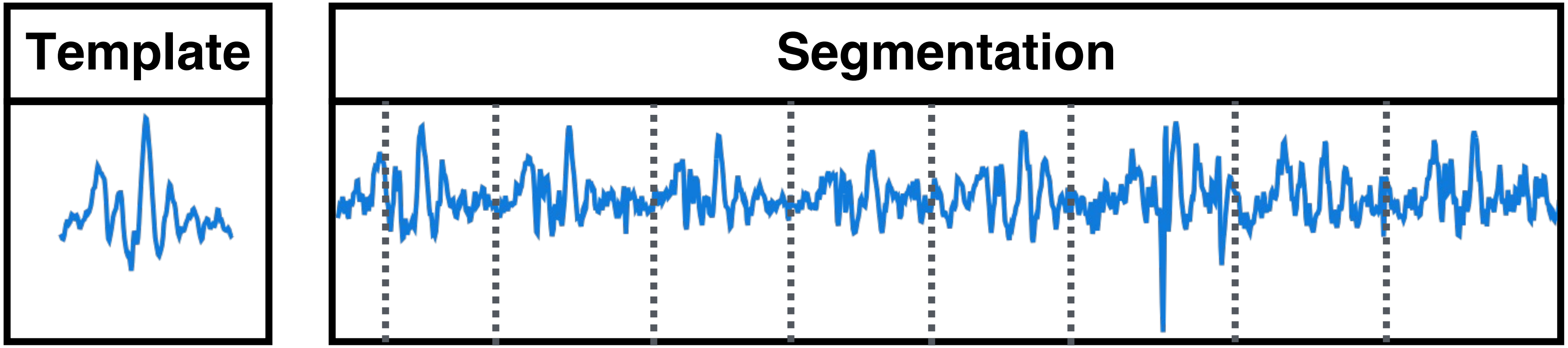
Example run

Iteration 3:



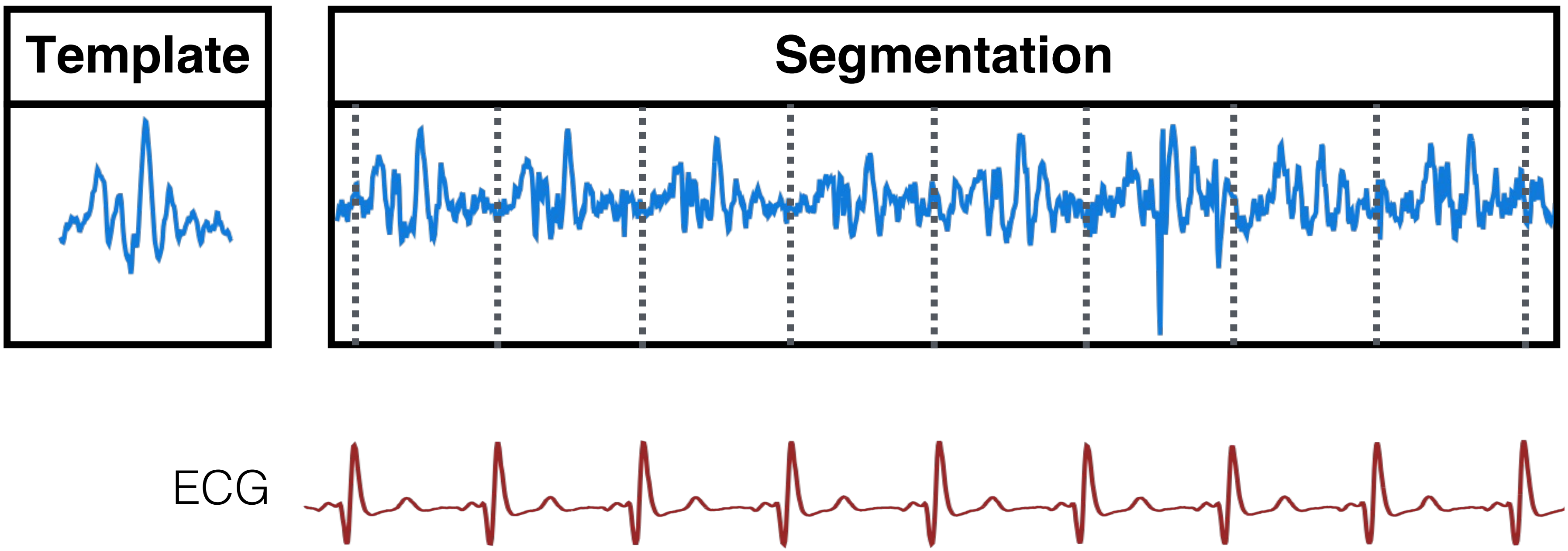
Example run

Iteration 7:



Example run

Iteration 7:



From vital signs to emotions

Physiological Features for Emotion Recognition

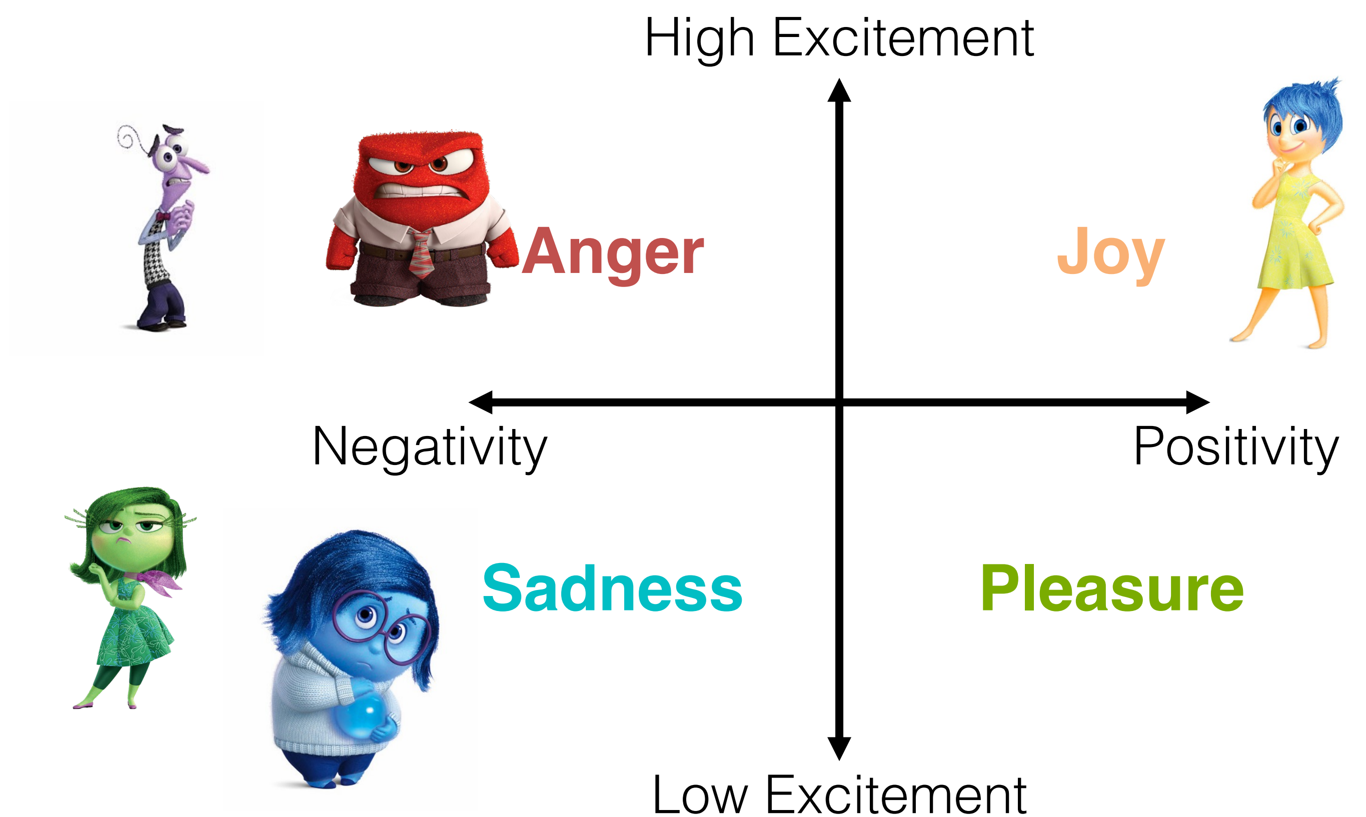
- 37 Features similar to ECG-based methods
  - Variability of IBI
  - Irregularity of breathing

Emotion Classification

- Recognize emotion using physiological features
- Used L1-SVM classifier
    - select features and train classifier at the same time

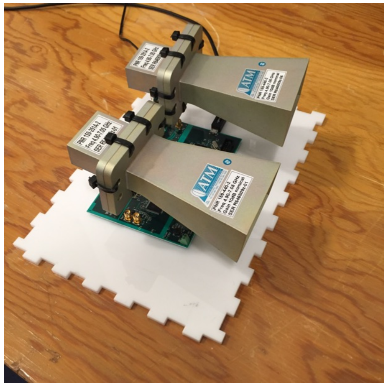
Emotion Model

- Standard 2D emotion model
- Classify into **anger**, **sadness**, **pleasure** and **joy**



Implementation

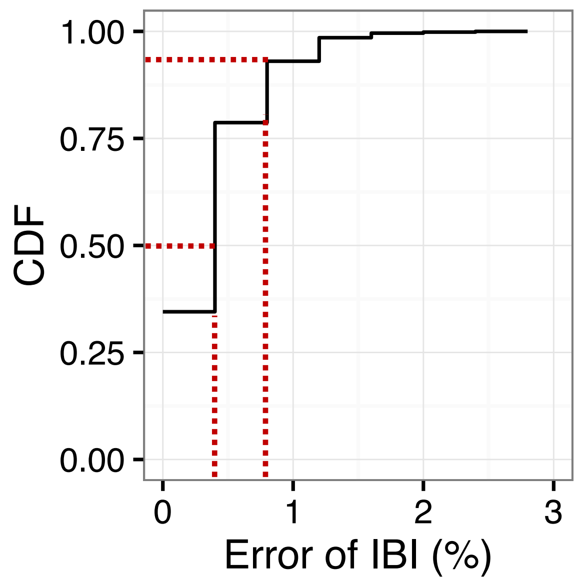
- FMCW radio
  - sweeps from 5.5 GHz to 7.2 GHz every 4ms
  - sub-mW power in compliance with FCC regulations



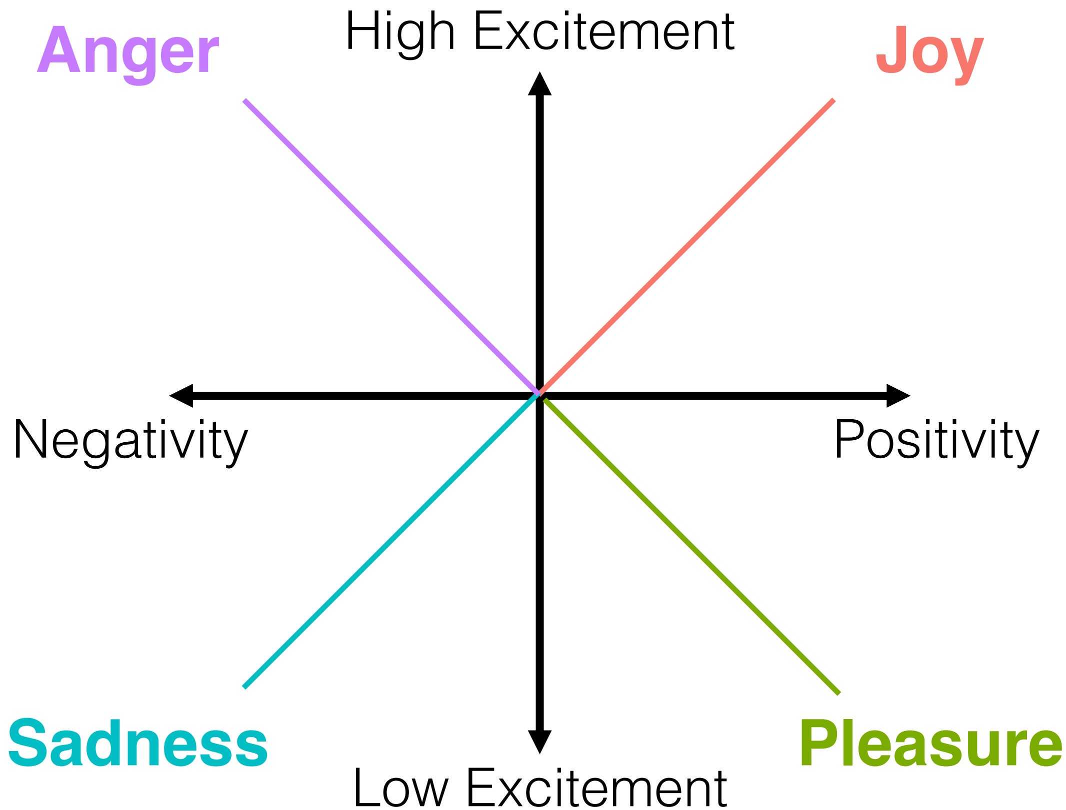
Does it capture IBI accurately?

Median IBI estimation error: 0.4%
90th percentile error: 0.8%

- Ground truth: ECG
- 30 subjects, over 130,000 heartbeats

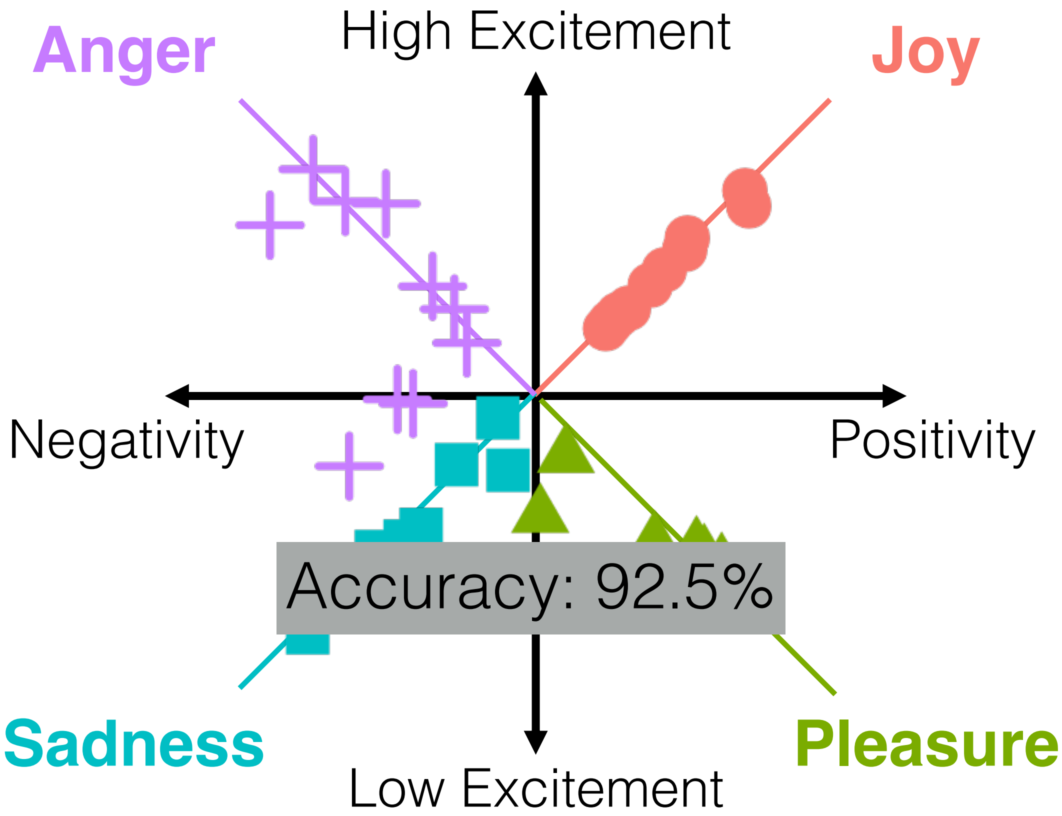


Does it detect emotion accurately?



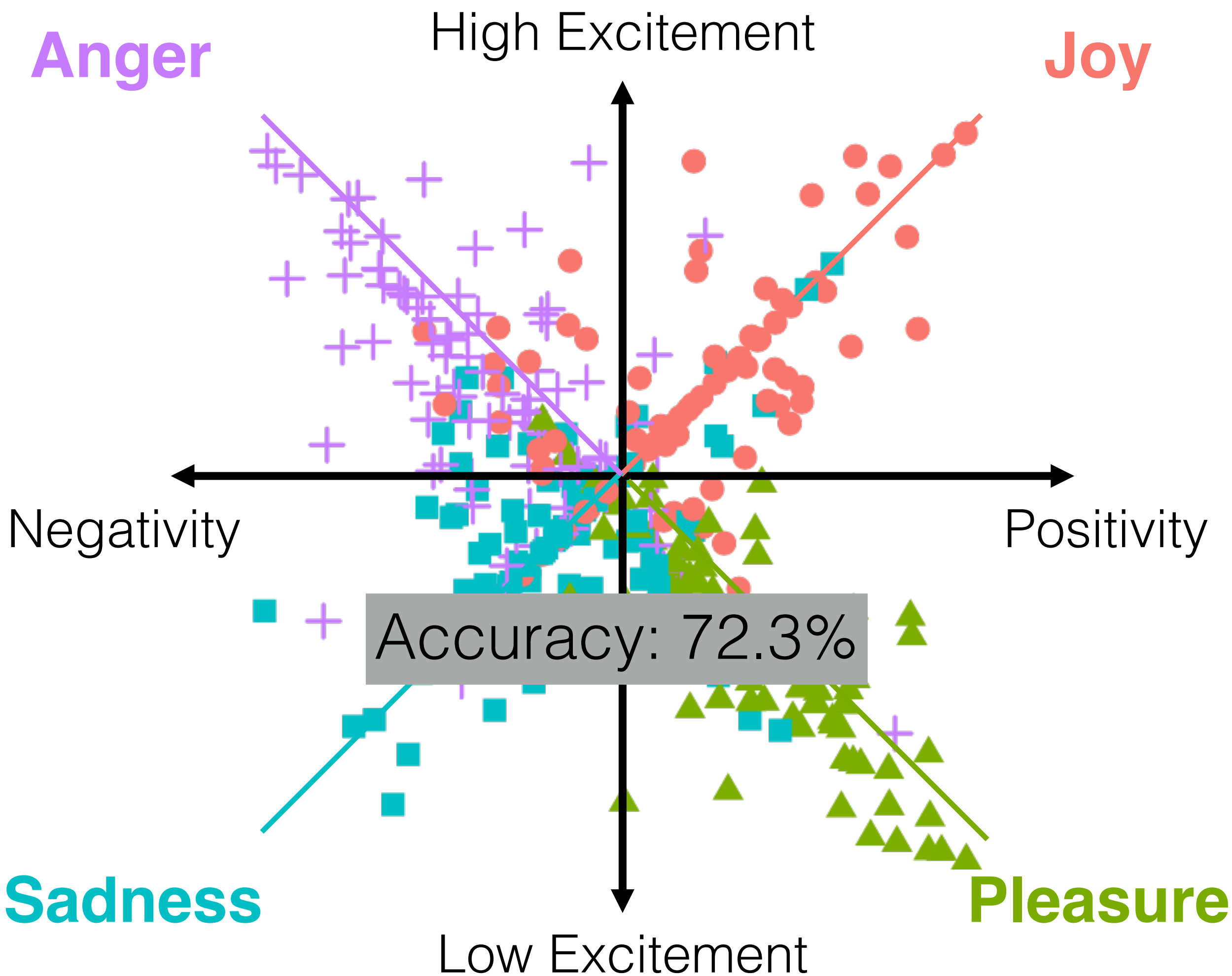
Person-dependent Classification

- Train and test on the same person

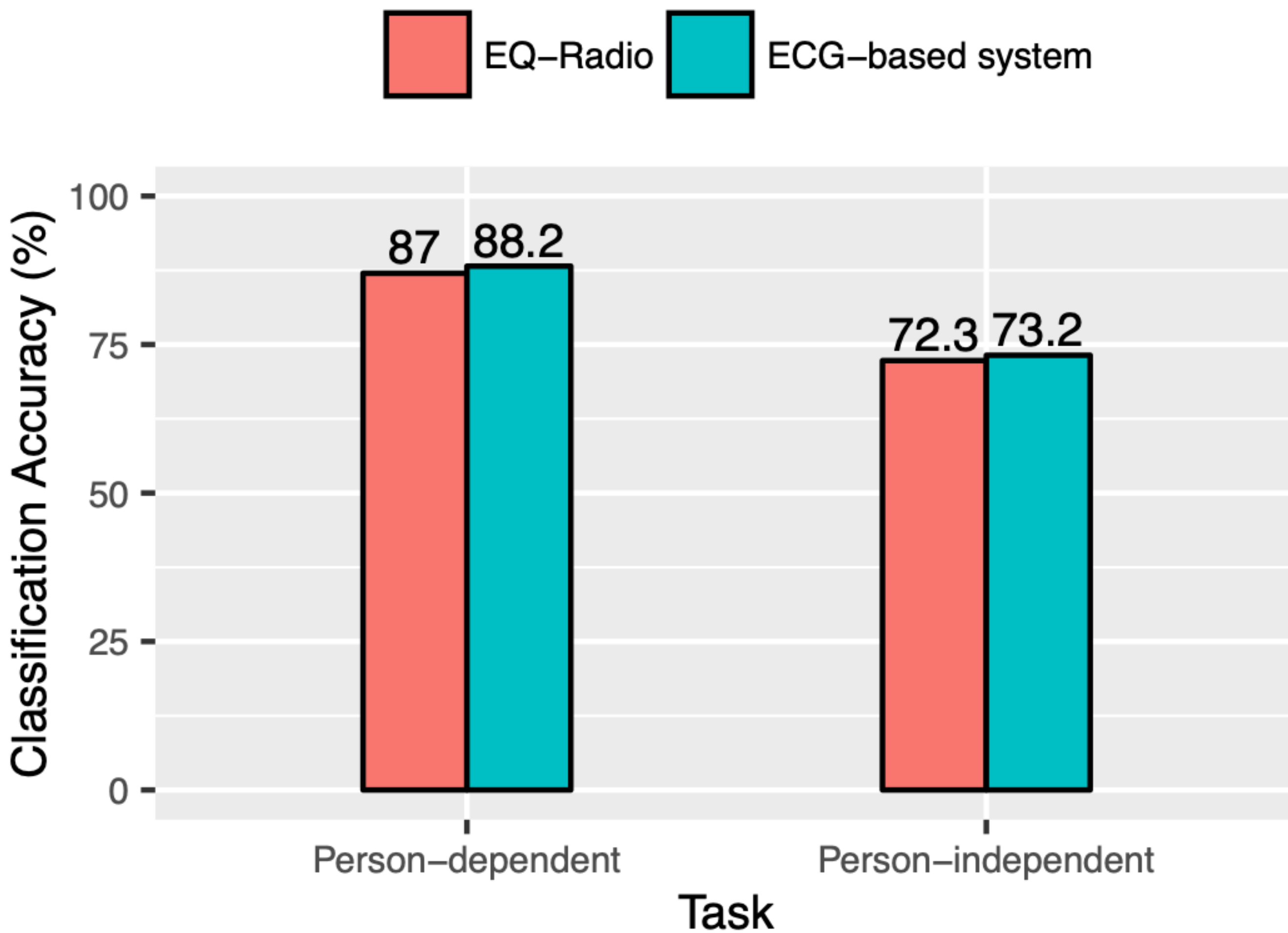


Person-independent Classification

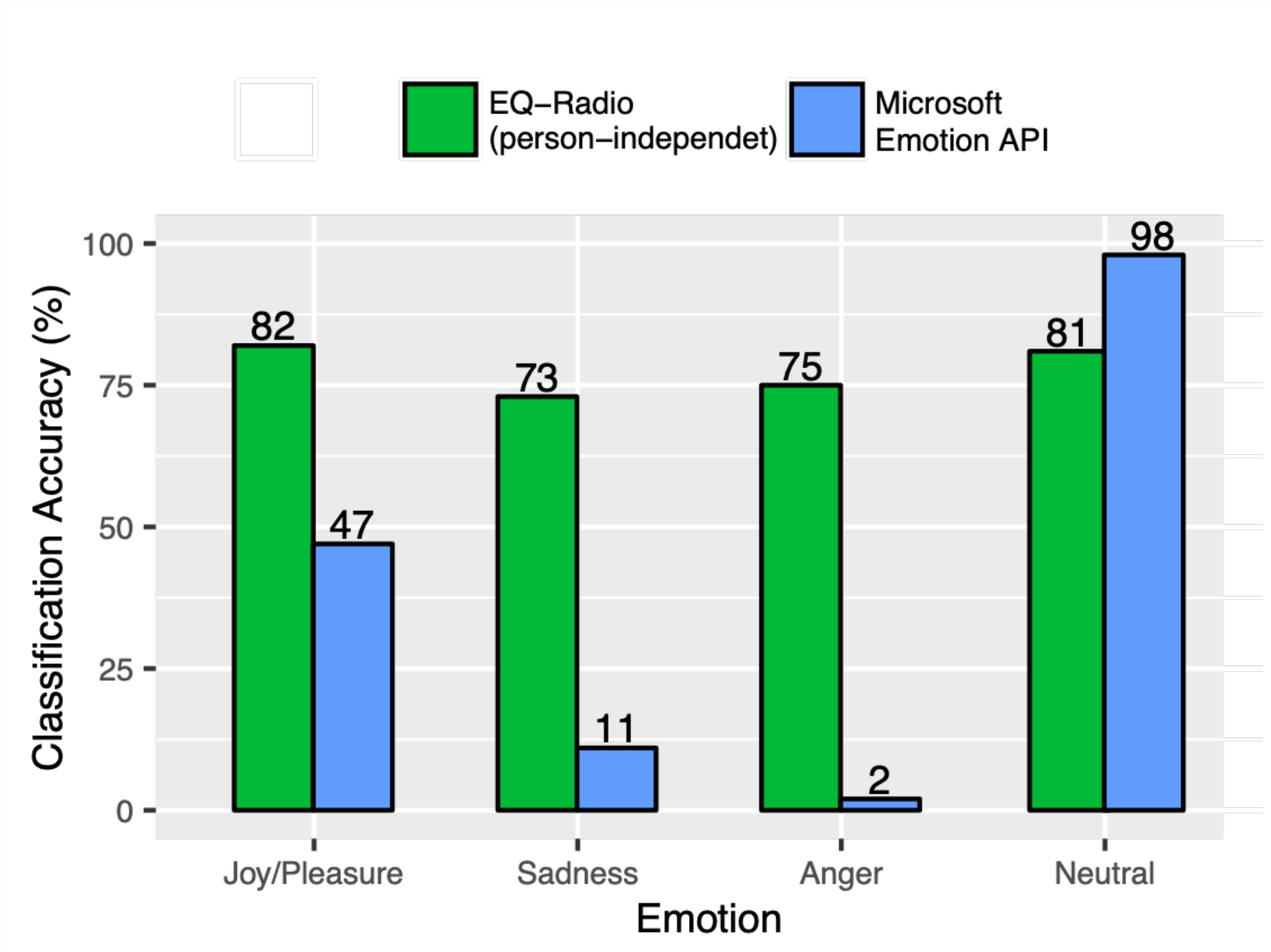
- Train and test on the different person



Comparison with ECG-based system



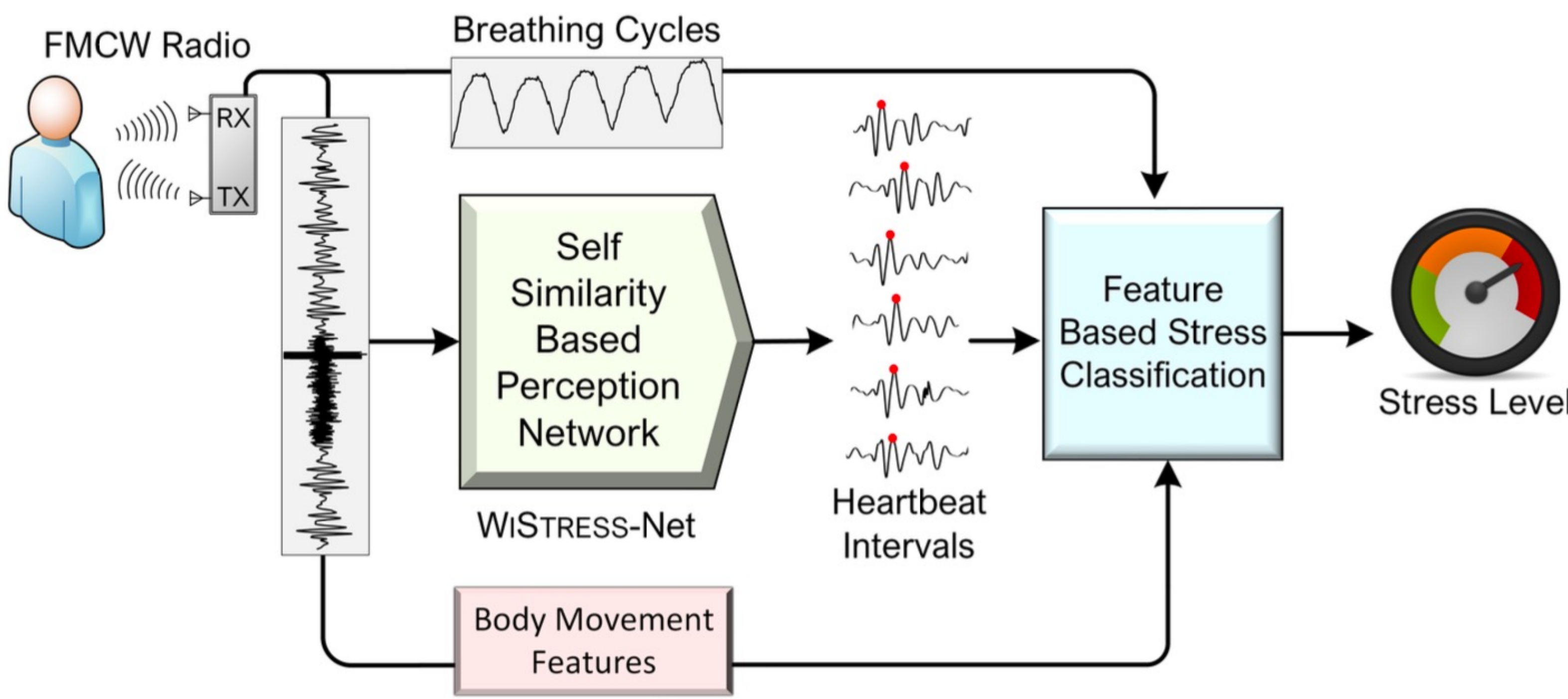
Comparison with Image-based system



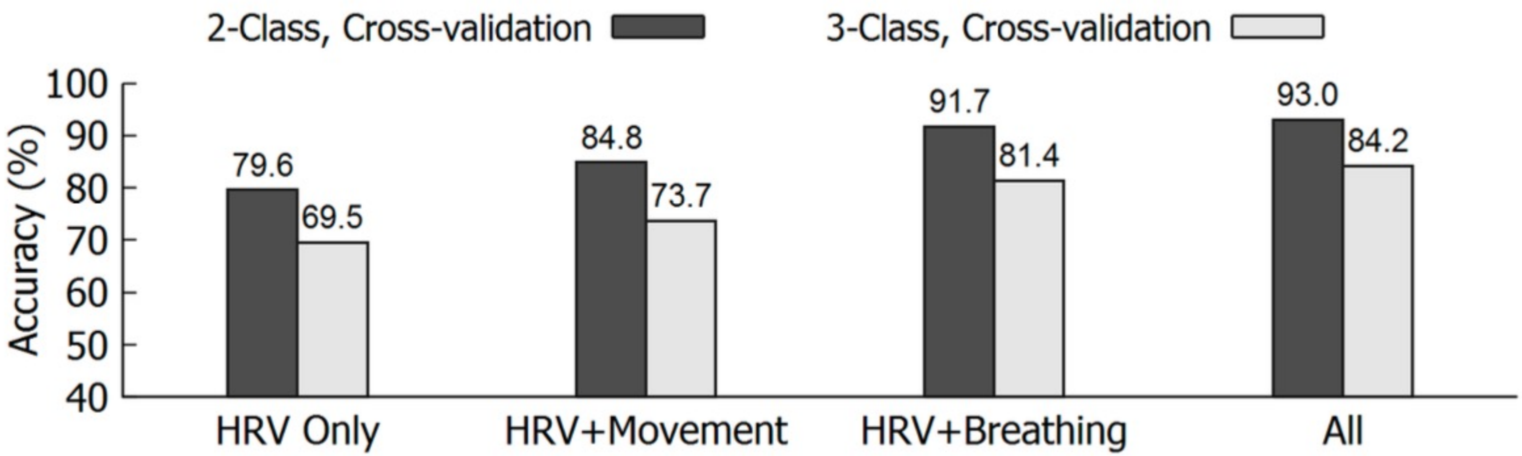
You know, I just read that a team at MIT developed a device

Stress level Monitoring

- HRV, Movement, and Breathing are used for stress level classification.



Stress level Monitoring

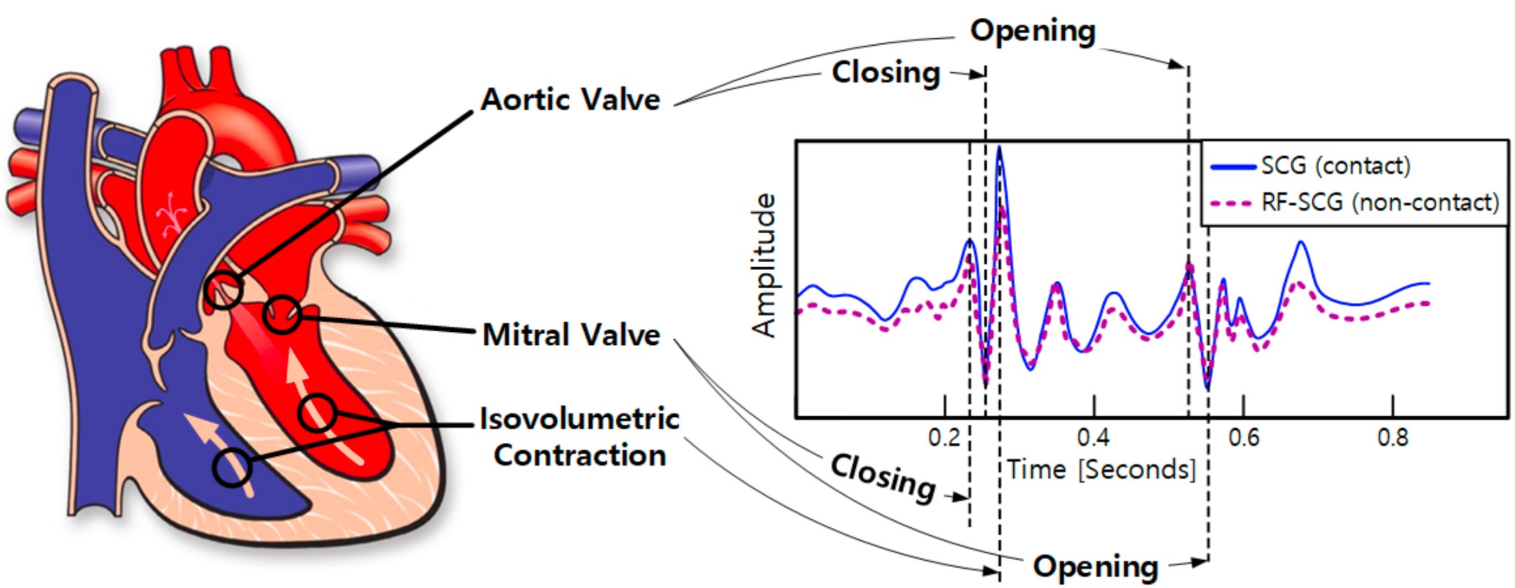


Morphology of Heartbeat Signals

- EQ-Radio leverage the HRV (segmentation) to capture emotional state.
- What about the shape of heartbeat signal (template)? Does it tell us something interesting?

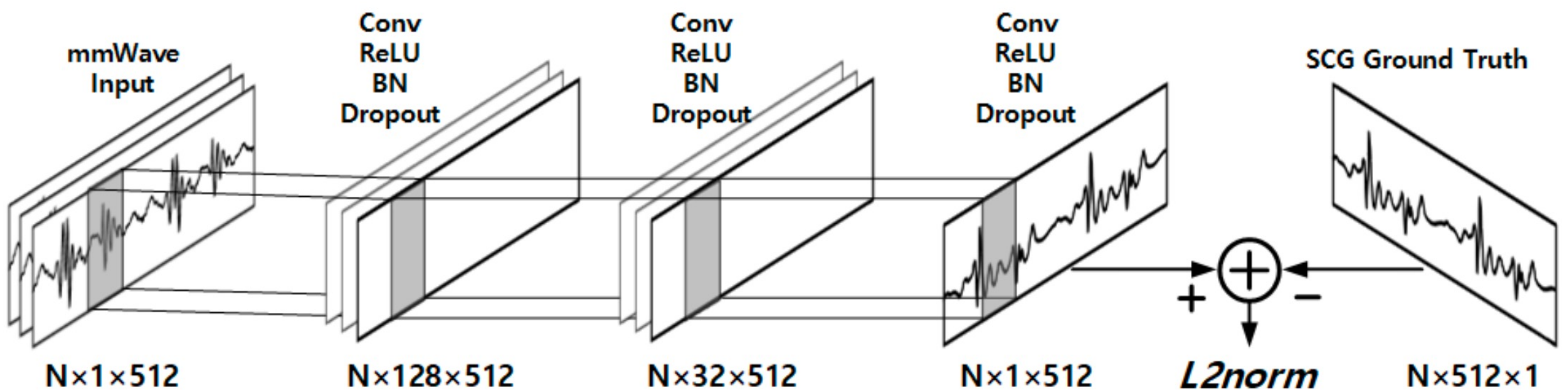
Contactless Seismocardiography

- The shape of the template captures five micro-cardiac movements: opening and closing of the aortic valve, opening and closing of the mitral valve, and isovolumetric contraction (of the ventricles)

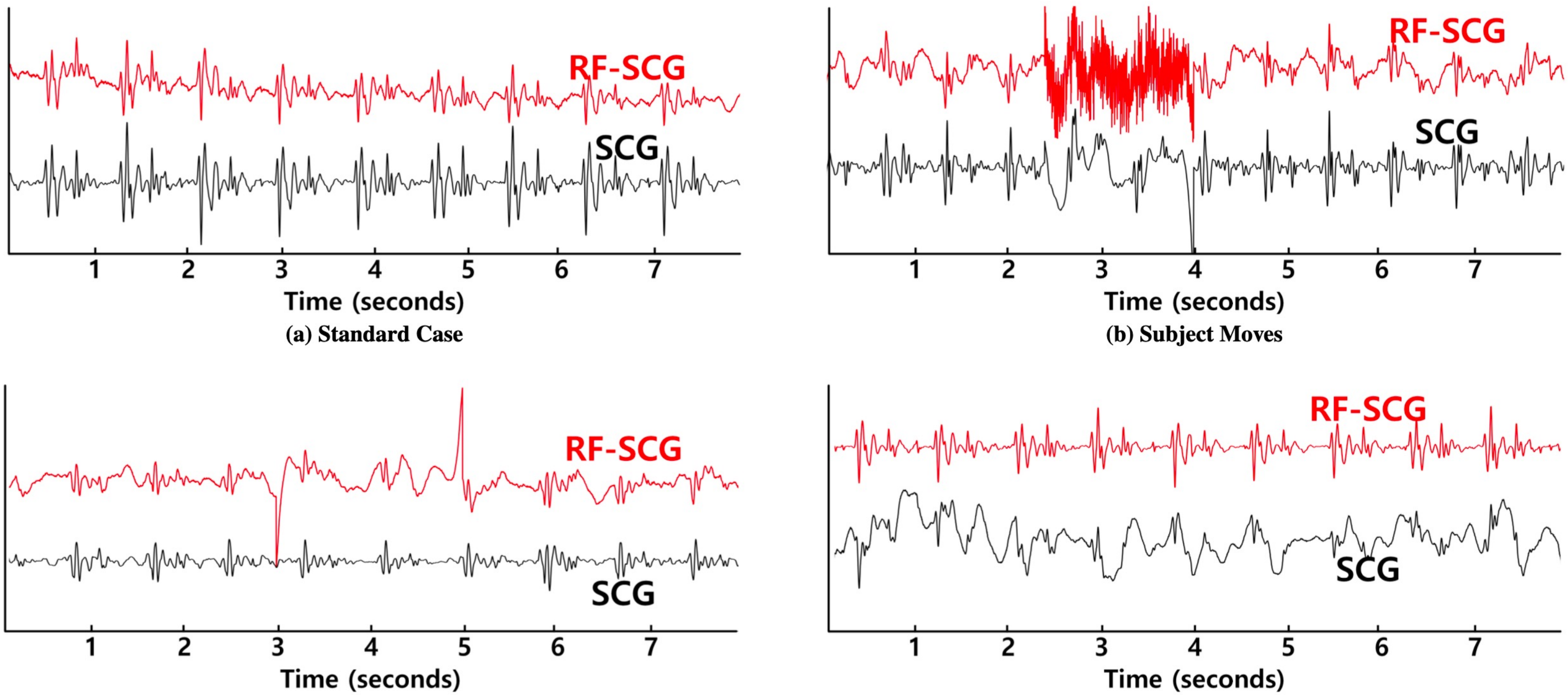


RF-to-SCG Translation

- Supervised 1D signal translation with paired time series.



RF-to-SCG Translation



(a) Standard Case

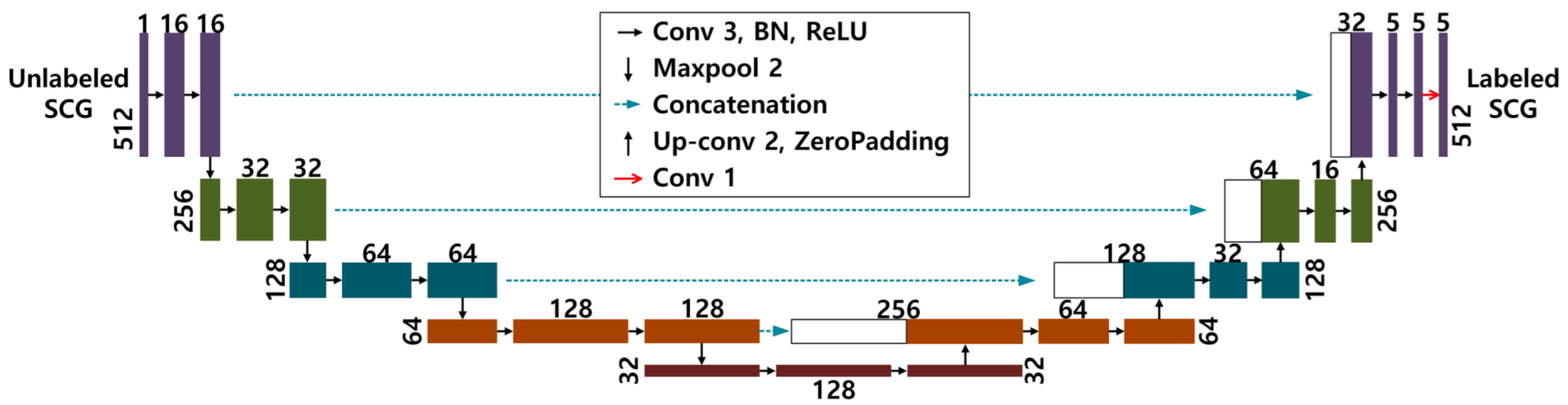
(b) Subject Moves

(c) Nearby Object Moves

(d) Accelerometer Attachment Problem

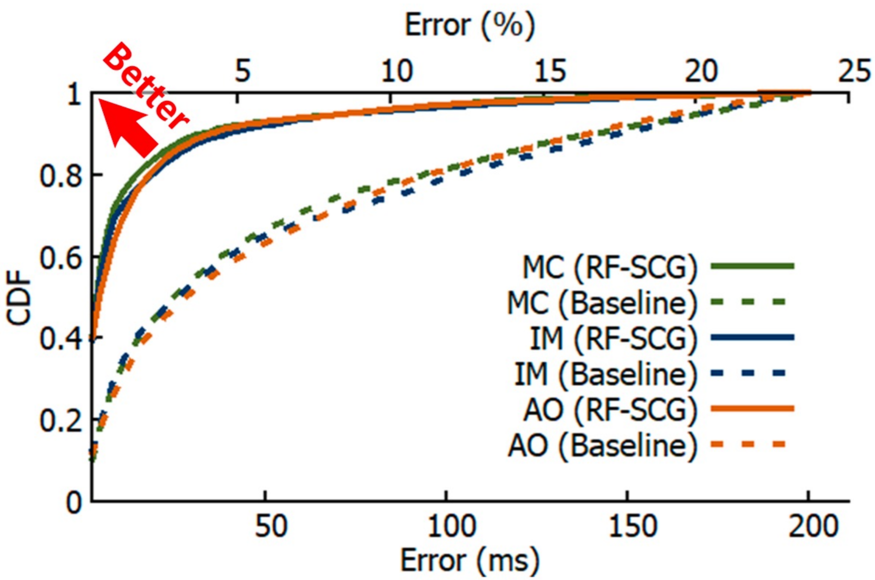
SCG Labeling:
Micro-Cardiac Movements Detection

- 1D U-Net produces 5-channel outputs corresponding to 5 micro-cardiac events.
- 5-channel outputs represent probabilities of micro-cardiac events at each sample point.

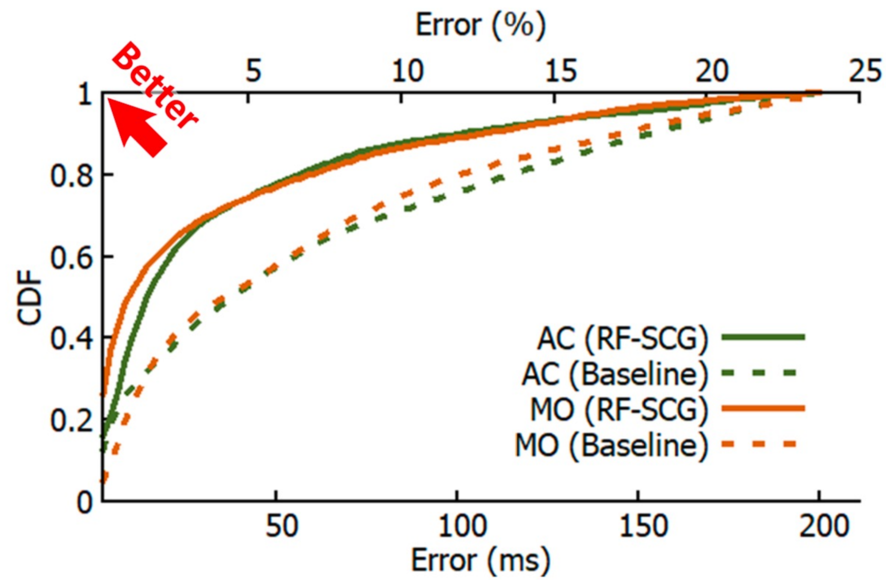


SCG Labeling:
Micro-Cardiac Movements Detection

- Systolic micro-cardiac movements: MC, IM, and AO
- Diastolic micro-cardiac movements: AC and MO



(a) CDF of Accuracies for Systolic Fiducial Points.



(b) CDF of Accuracies for Diastolic Fiducial Points.