

Toss 'N' Turn:

Smartphone as
Sleep and Sleep Quality Detector

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Computer Human Interaction: Mobility Privacy Security

Sensing Sleep for...

- Personal informatics
- UbiComp system
- Health monitoring



Current Practices

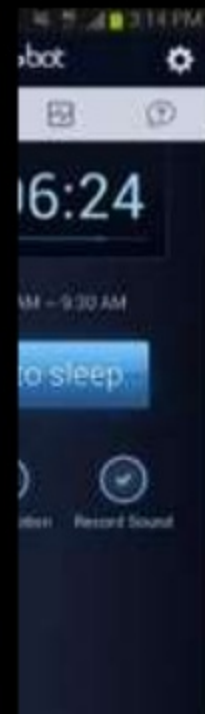


Last night, I feel asleep in:	Times I woke up during the night:	How I felt when I woke up:	Last night, I slept a total of:	My sleep was disturbed by:
45 minutes	3 times	TIRED	5 hours	couldn't get comfortable

A photograph of a person with dark hair lying in a hospital bed, covered with a blue blanket. They appear to be sleeping. The bed has blue sheets and a white pillow.

Opportunities

- We already have smartphones
 - 83% of millennials sleep with their phone
- Pew Internet

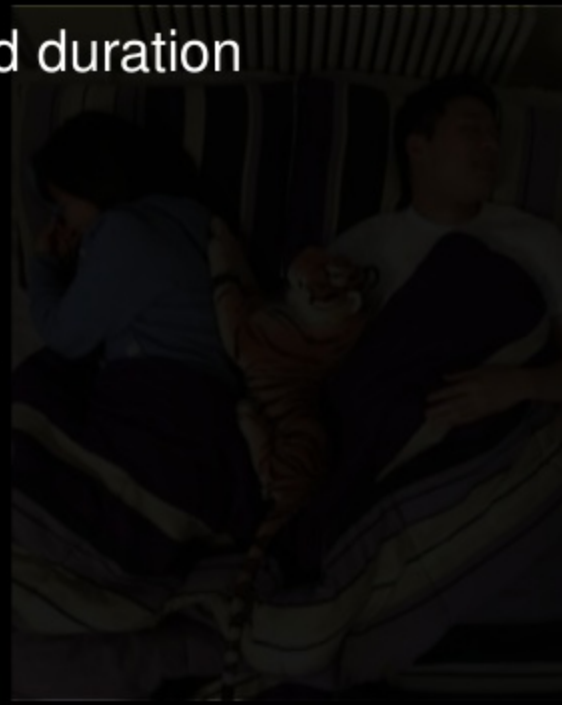
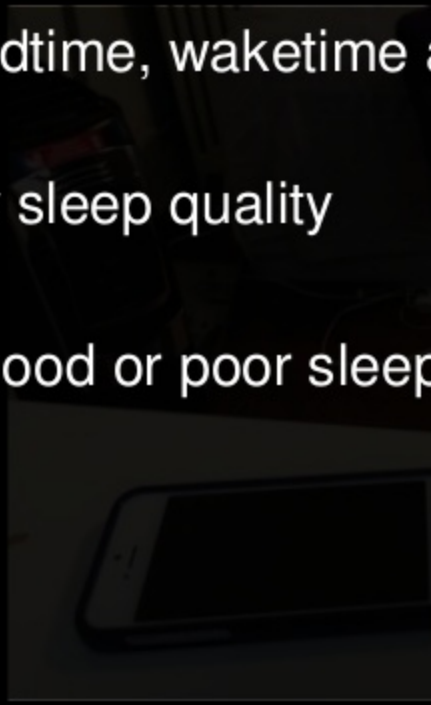
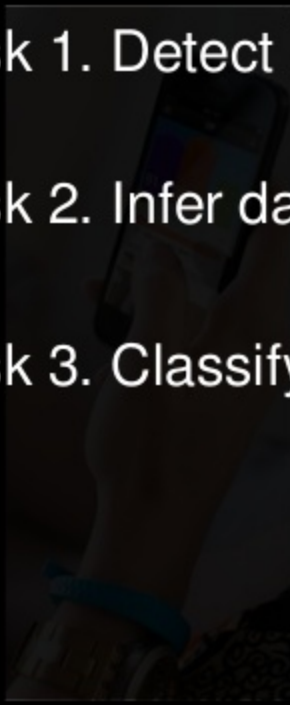


How well a **smartphone can sense sleep** without requiring changes in our behavior?

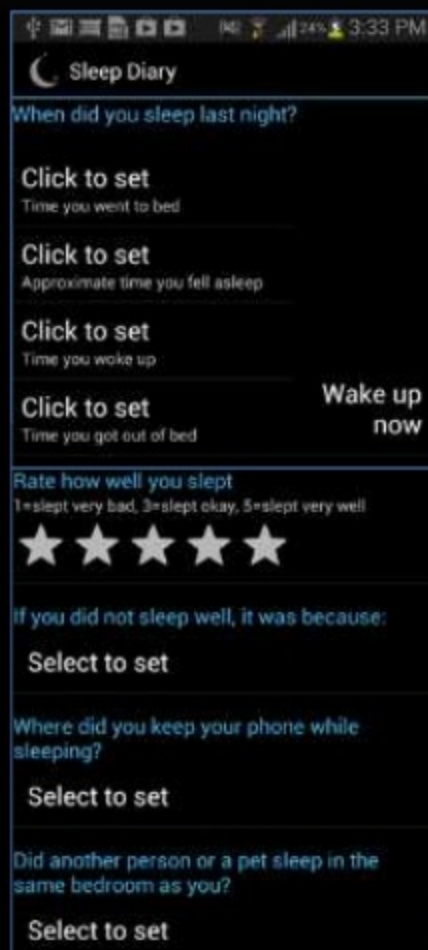
Task 1. Detect bedtime, waketime and duration

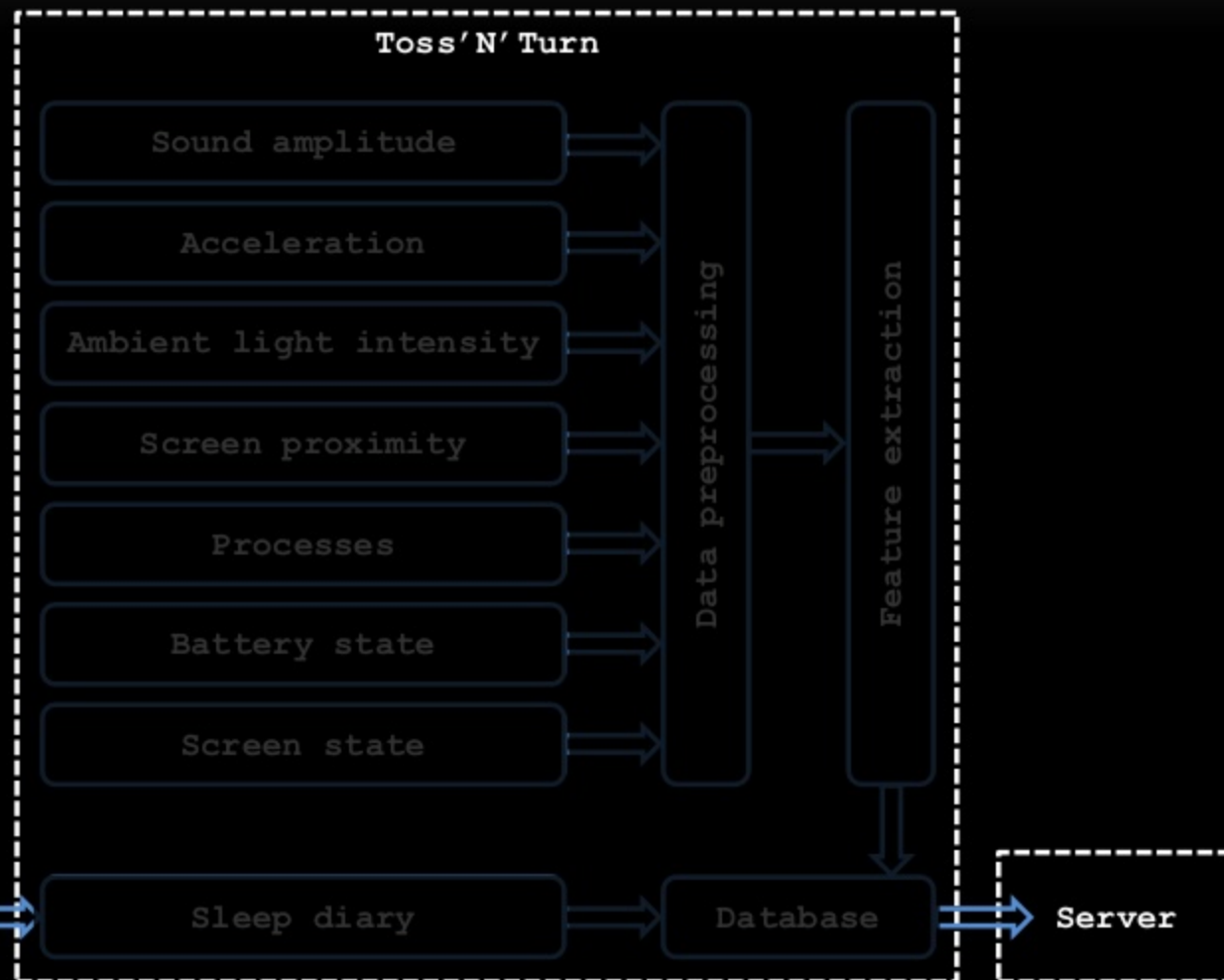
Task 2. Infer daily sleep quality

Task 3. Classify good or poor sleeper



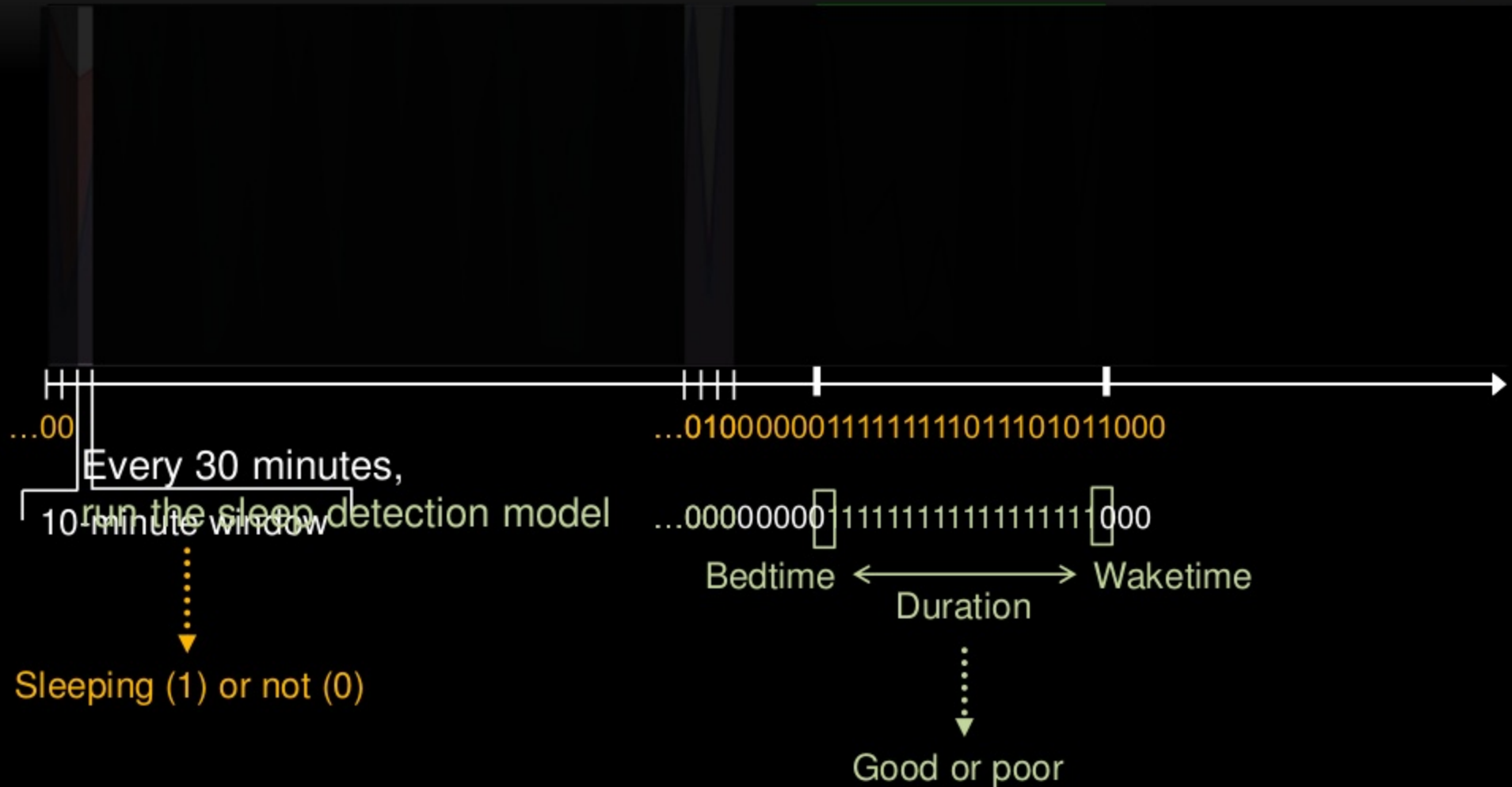
Toss 'N' Turn (Data Collection Ver.)

The image shows a mobile application interface titled "Sleep Diary". It includes several input fields for tracking sleep: "When did you sleep last night?", "Click to set" (Time you went to bed), "Click to set" (Approximate time you fell asleep), "Click to set" (Time you woke up), and "Click to set" (Time you got out of bed) with a "Wake up now" button. There is a section for "Rate how well you slept" with a star rating (1=very bad, 3=okay, 5=very well) and a section for "If you did not sleep well, it was because:" with a "Select to set" button. Another section asks "Where did you keep your phone while sleeping?" with a "Select to set" button. The final section asks "Did another person or a pet sleep in the same bedroom as you?" with a "Select to set" button. A blue arrow points from the bottom of the app interface to the "Sleep diary" box in the data flow diagram.



Modeling

Motion Sound Sleep



User Study

- Recruited good and poor sleepers
 - Living in US, age > 18
 - Pay \$2 USD for each diary entry (a maximum \$72)
- Collected sleep data for a month
- 30 participants signed up and 27 completed
 - Total 795 sleep-diary entries



User Study

Ground Truthing

PITTSBURGH SLEEP QUALITY INDEX (PSQI)

INSTRUCTIONS: The following questions relate to your usual sleep habits during the past month only. Your answers should indicate the most accurate reply for the majority of the nights in the past month. Please answer all questions.

1. During the past month, when have you usually gone to bed at night?
USUAL BED TIME _____

2. During the past month, how long (in minutes) has it usually take you to fall asleep each night?
NUMBER OF MINUTES _____

3. During the past month, when have you usually gotten up in the morning?
USUAL GETTING UP TIME _____

4. During the past month, how many hours of actual sleep did you get at night? (This may be different than the number of hours you spend in bed.)
HOURS OF SLEEP PER NIGHT _____

INSTRUCTIONS: For each of the remaining questions, check the one best response. Please answer all questions.

5. During the past month, how often have you had trouble sleeping because you...

- (a) ...cannot get to sleep within 30 minutes
- (b) ...wake up in the middle of the night or early morning
- (c) ...have to get up to use the bathroom
- (d) ...cannot breathe comfortably
- (e) ...cough or snore loudly
- (f) ...feel too cold
- (g) ...feel too hot
- (h) ...had bad dreams
- (i) ...have pain
- (j) Other reason(s), please describe _____

How often during the past month have you had trouble sleeping because of this? ☐ ☐ ☐ ☐

Subjective sleep quality
+ Sleep latency
+ Sleep efficiency
+ Sleep duration
+ Use of medication
+ Sleep disturbances

= Global sleep quality

Global score > 5 indicates
a subject is having poor sleep

Very good ☐ Fairly good ☐ Fairly bad ☐ very bad ☐

Less than once a week ☐ Once or twice a week ☐ Three or more times a week ☐

☐ ☐ ☐

☐ ☐ ☐

No problem at all ☐ Only a very slight problem ☐ Somewhat of a problem ☐ A very big problem ☐

☐ ☐ ☐

partner or roommate ☐ Partner/roommate in other room ☐ Partner in same room, but not same bed ☐ Partner in same bed ☐

☐ ☐ ☐

in the past month you have had...

Less than once a week ☐ Once or twice a week ☐ Three or more times a week ☐

☐ ☐ ☐

☐ ☐ ☐

☐ ☐ ☐

☐ ☐ ☐

☐ ☐ ☐

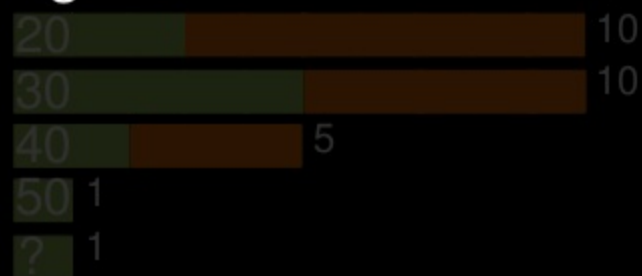
☐ ☐ ☐

Demographics

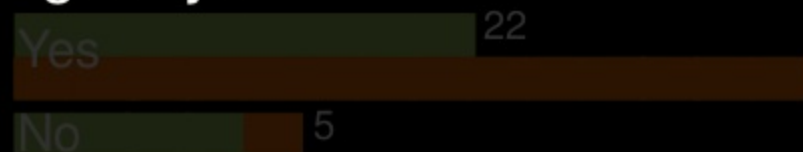
Sex



Age



Regularly work

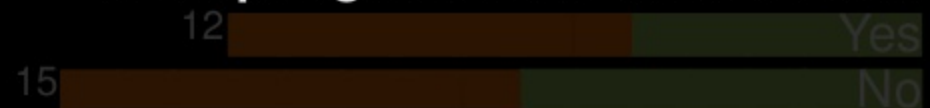


Share bed with



Traffic
Neighbors
Family/roommate/pet

Disrupting noises in the bedroom



Good sleeper
(PSQI global score ≤ 5)

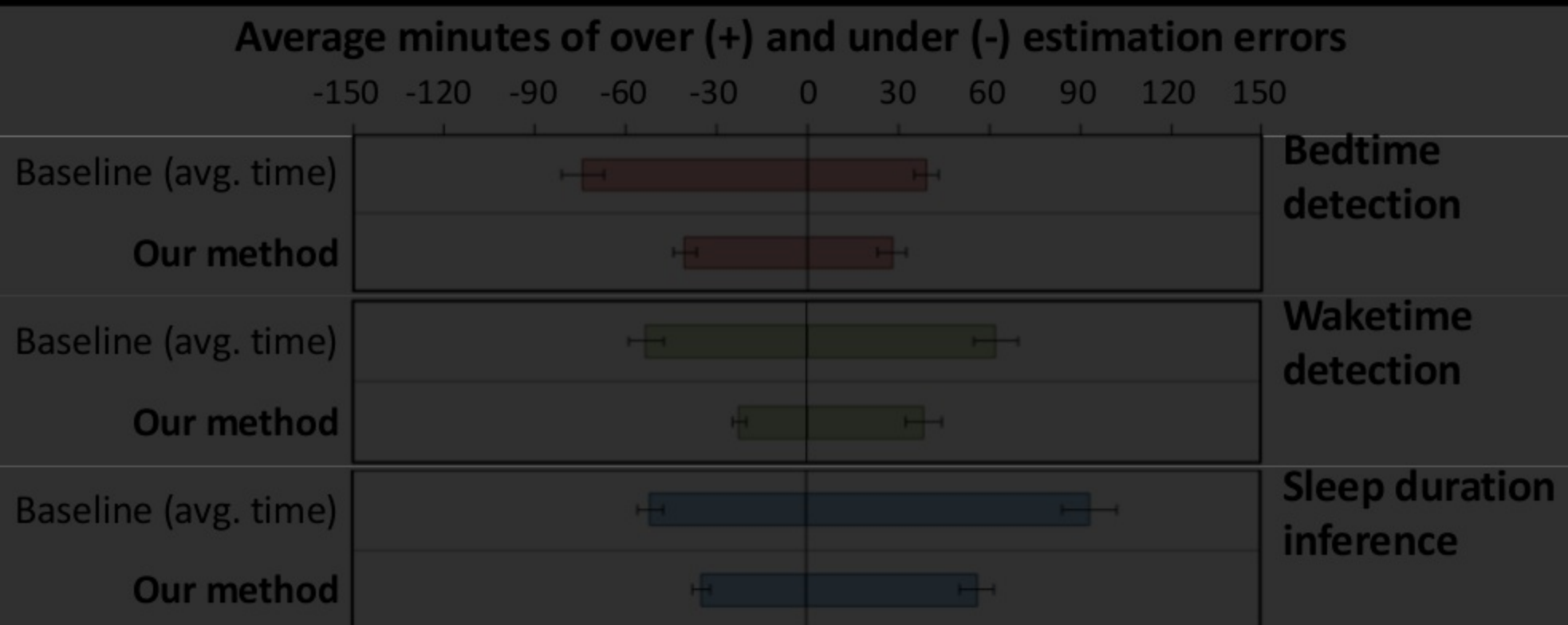
Poor sleeper
(PSQI global score > 5)

Evaluation

- Classifier
 - Bayesian network (BN) with correlation-based feature selection
- Task 1. Detect bedtime, waketime and duration
- Task 2. Infer daily sleep quality
 - Train the model individually (leave-one-day-out cross validation)
- Task 3. Classify good or poor sleeper
 - Leave-one-person-out cross validation

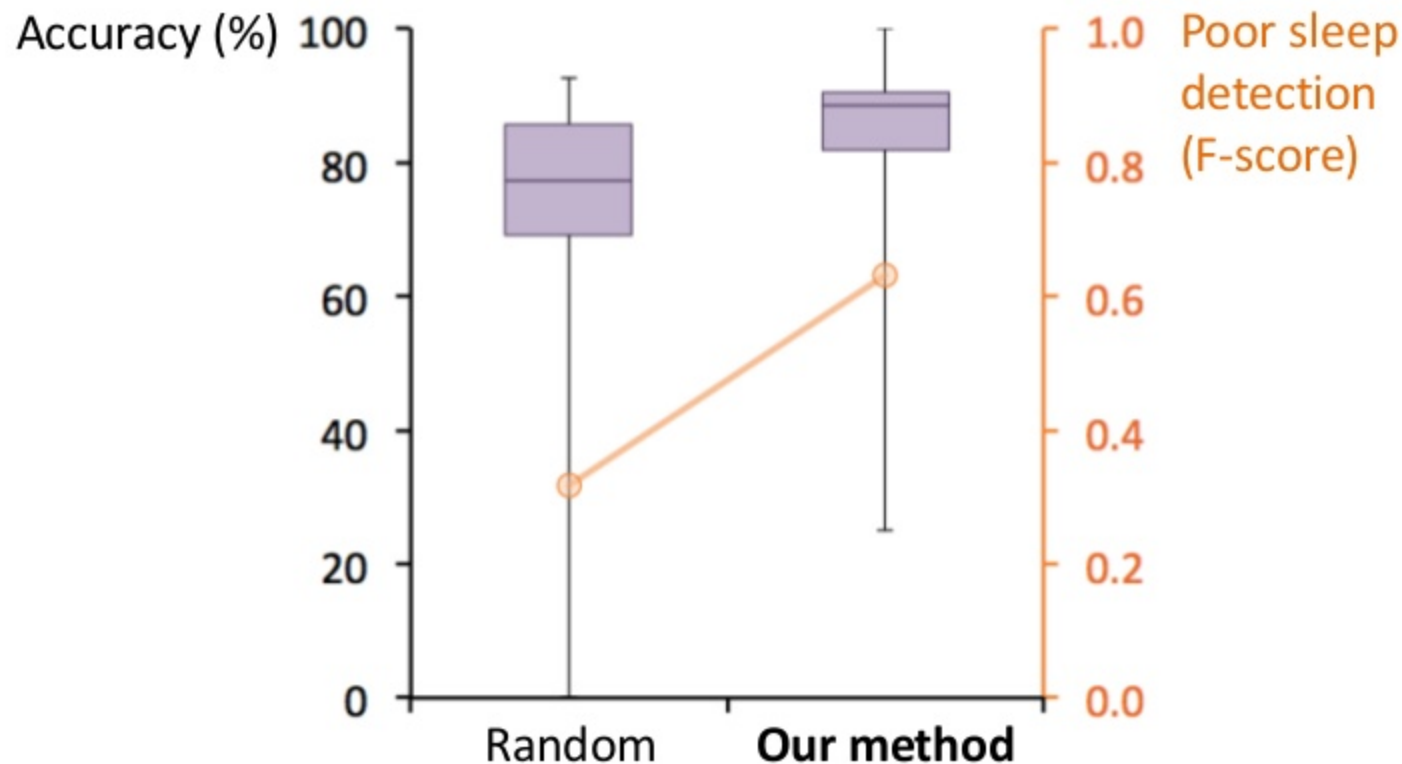
Task 1: Sleep Detection

- Detect sleep windows → Detect sleep time
- 94.5% in classifying sleep/not-sleep windows



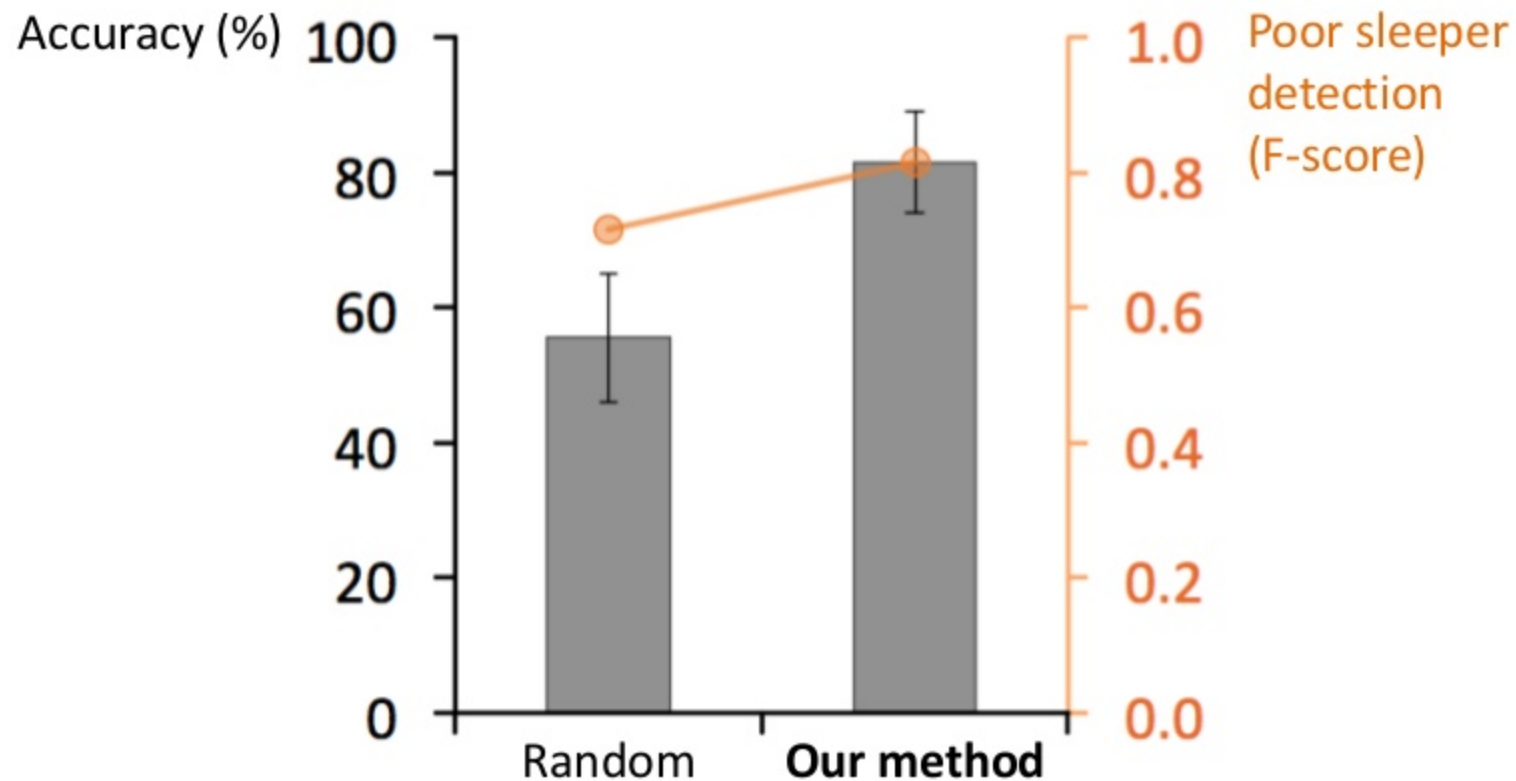
Task 2: Daily Sleep Quality Inference

- Detect sleep \rightarrow Classify the quality of sleep
- 84.0% in classifying good/poor sleeps



Task 3: Good/Poor Sleeper Classification

- Infer daily qualities → Classify the sleeper type
- 81.5% in classifying good/poor sleepers



Discussion

How well a **smartphone can sense sleep** without requiring changes in our behavior?

Task 1. Detect bedtime, waketime and duration within 35, 31, and 49 minutes of errors, respectively

Task 2. Infer daily sleep quality with 84% accuracy

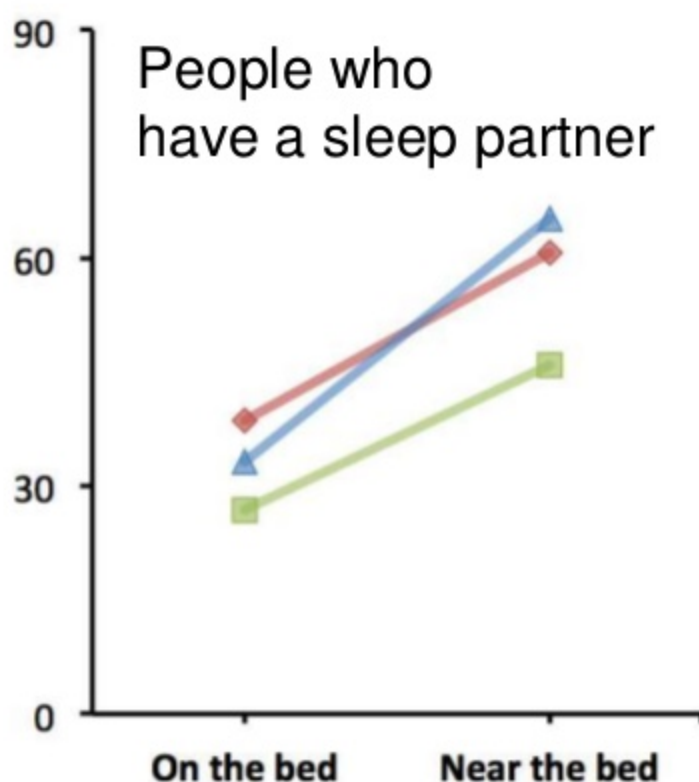
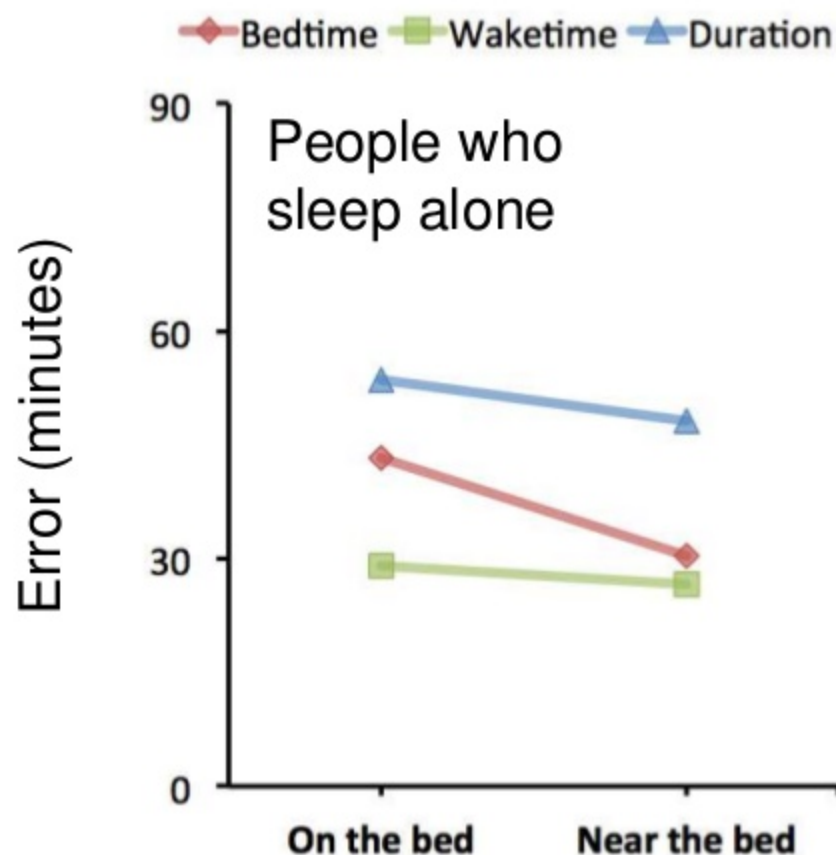
Task 3. Classify good or poor sleeper with 81% accuracy

Top Five Features

- Sleep detection
- Time
 - Battery charging / not-charging
 - Min. movement
 - Std. sound amplitude
 - Q3 sound amplitude

- Sleep quality inference
- Bedtime
 - Waketime
 - Sleep duration
 - Std. movement
 - Yesterday's sleep quality

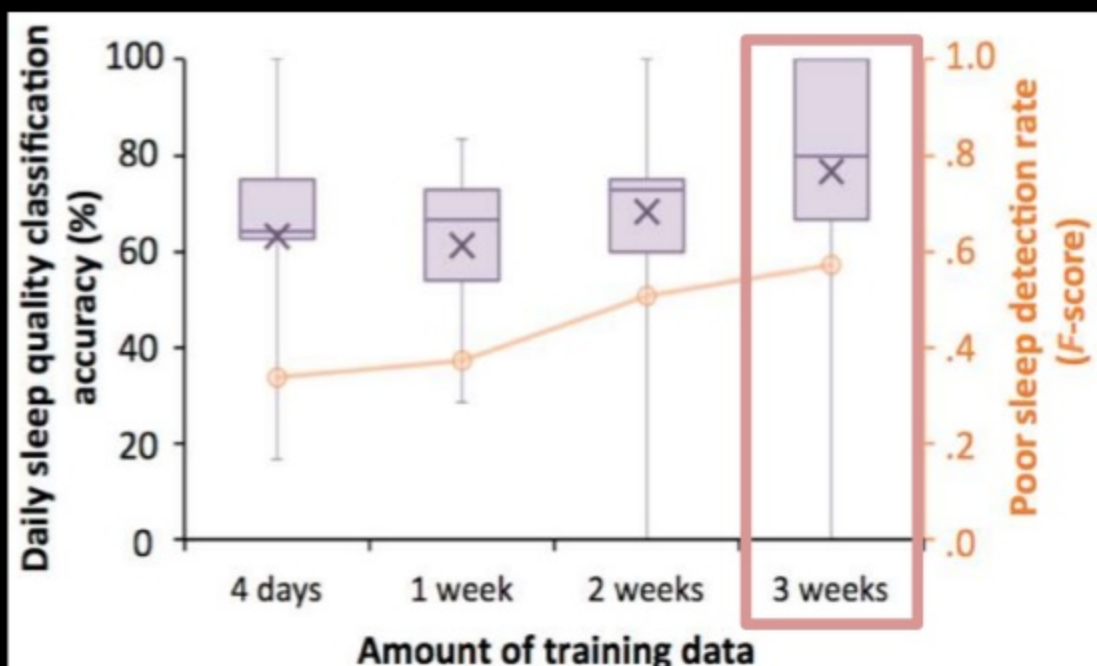
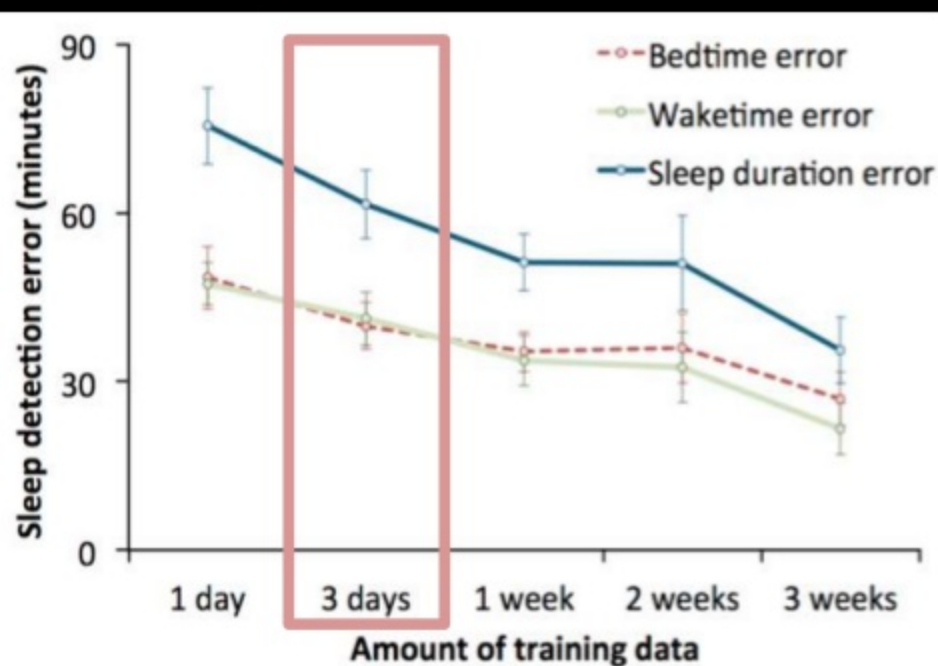
Sleep Detection Errors



Phone location

General vs. Individual Models

- Sleep detection: 93.06% vs. **94.52%**
 - Need 3 days of ground truthing to train an individual model
- Sleep quality inference: 77.23% vs. **83.97%**
 - Need 3 weeks of ground truthing to train an individual model



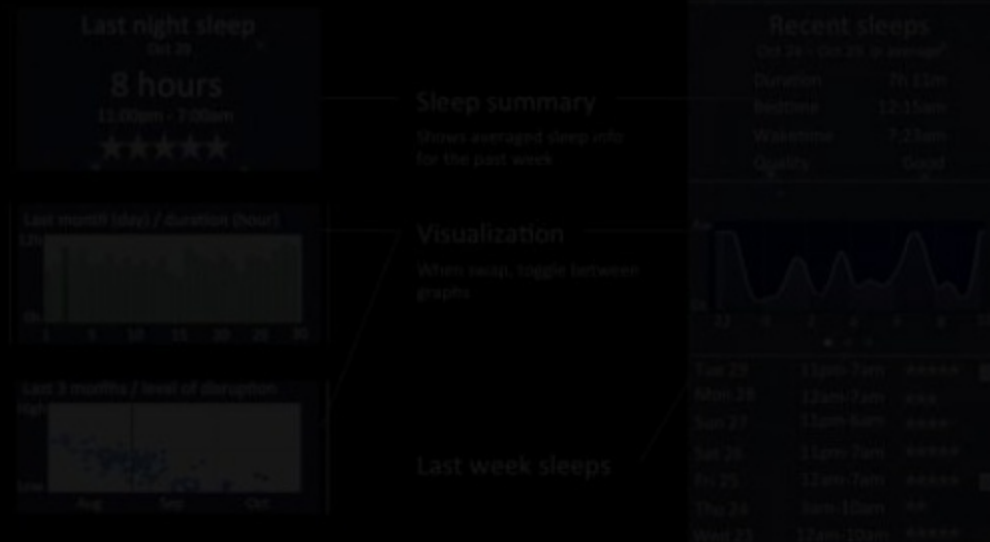
Limitations

- Subjective vs. objective sleep quality
 - “How was your sleep last night? Rate it on a one to five scale score” does not capture the full extent of a sleep session
- People tend to over / underestimate their sleep
- Small sample size of poor-quality sleep

Thanks!

- More info at cmuchimps.org or email loomlike@cs.cmu.edu
- Special thanks to:
 - DARPA, Google

Toss 'n' Turn (ver. 2) will be available soon



**Carnegie
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CHIMPS Lab

Computer Human Interaction: Mobility Privacy Security