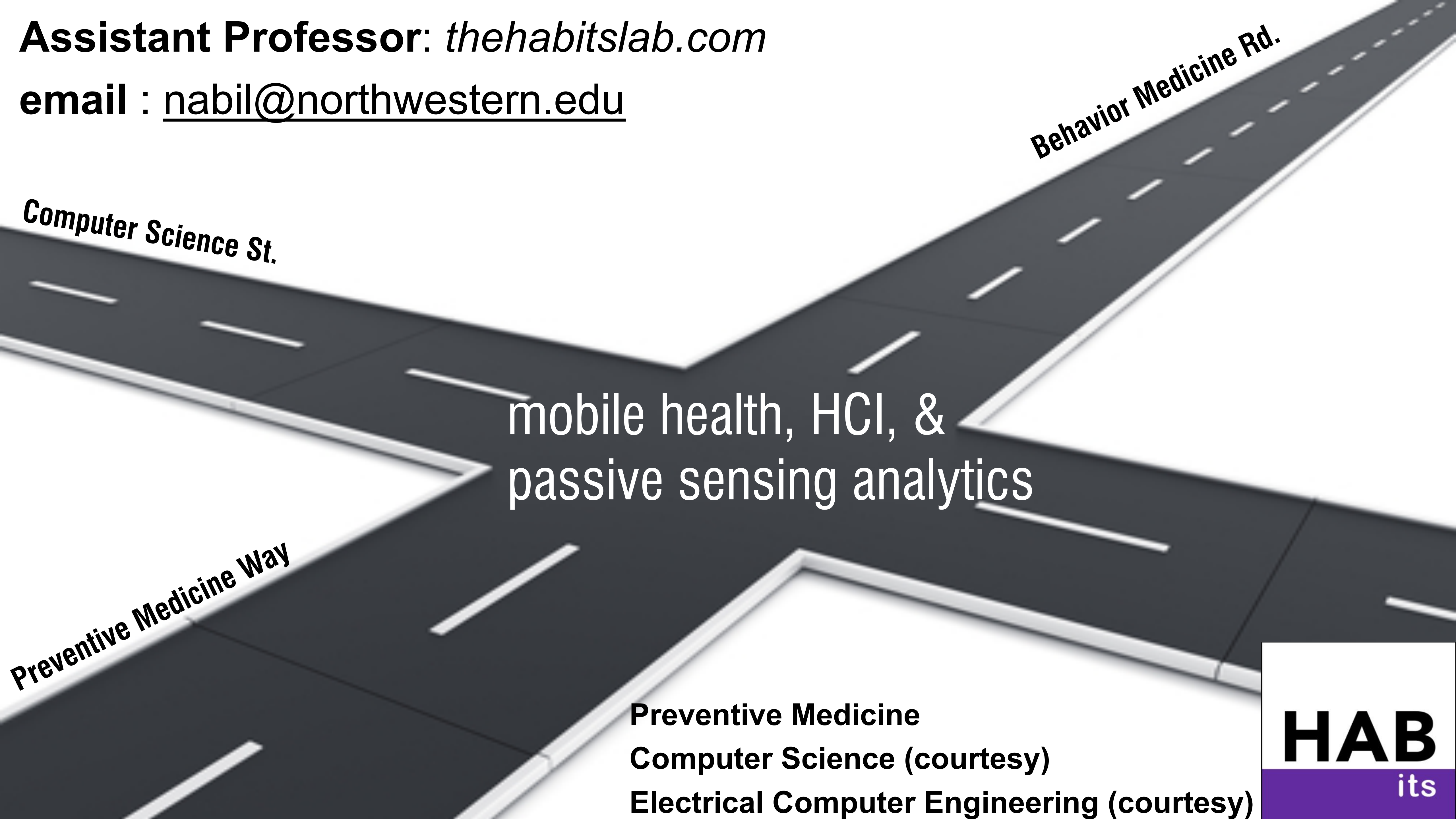
Assistant Professor: *thehabitslab.com*

email : nabil@northwestern.edu

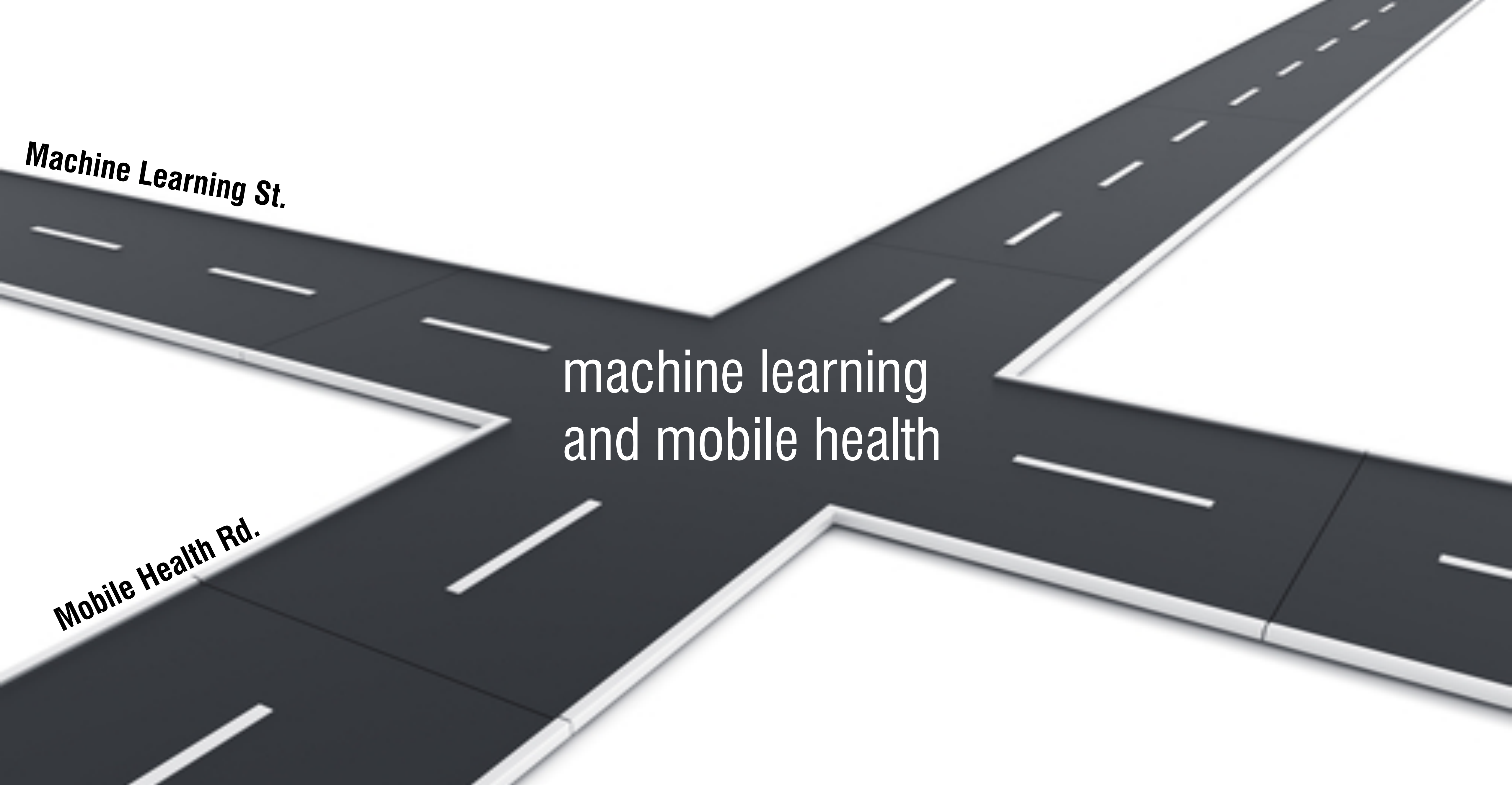


mobile health, HCI, &
passive sensing analytics

Preventive Medicine
Computer Science (courtesy)
Electrical Computer Engineering (courtesy)

HAB
its

Today we'll be discussing

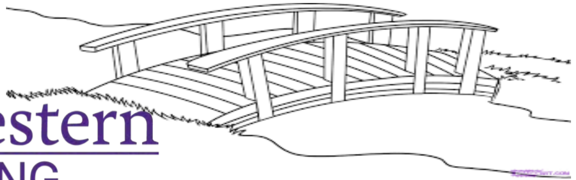


my story…

Northwestern Medicine

HABits Lab

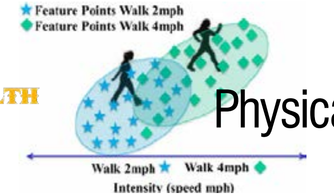
Health Aware Bits Lab



Northwestern ENGINEERING

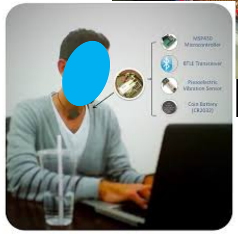
Northwestern Medicine

Wireless Health UCLA



Physical Activity

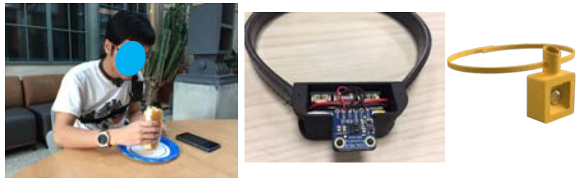
Sleep



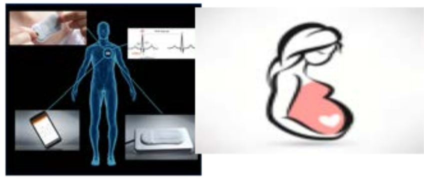
Eating

PhD in Computer Science (Wireless and mHealth)

Eating



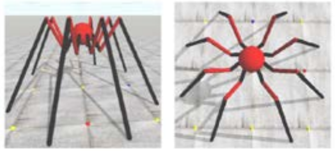
Stress



HABits Lab

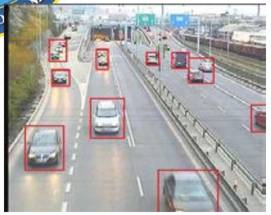
Faculty at Northwestern

Ucla



Masters in AI/Robotics

U.S. ARMY



Defense contractor for 8 years

Ucla

BS in CS and Minor in Sociology

NSF

NIH National Institutes of Health

Ann & Robert H. Lurie Children's Hospital of Chicago

Google

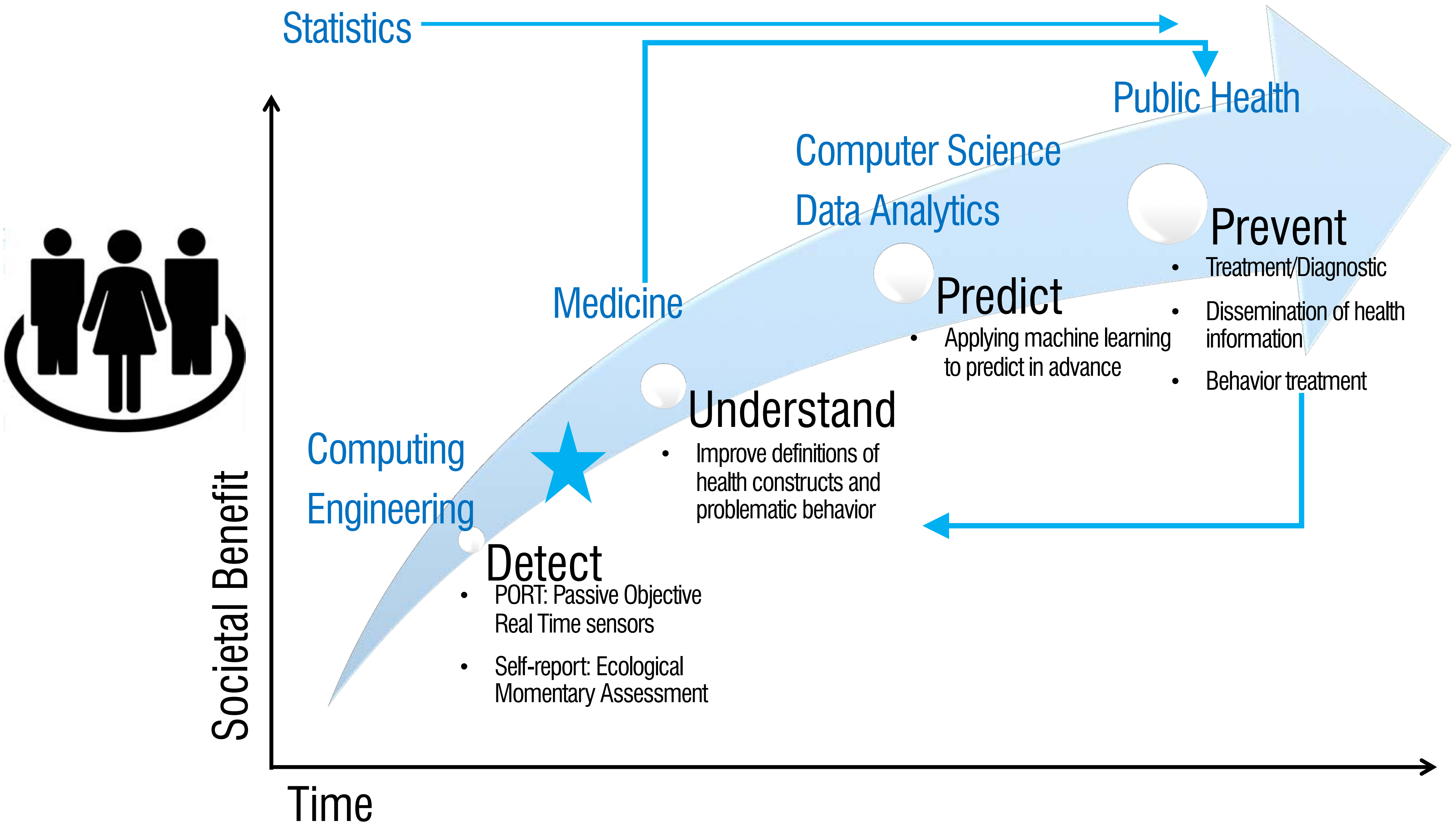
POPULAR SCIENCE

SAMSUNG

Symantec.

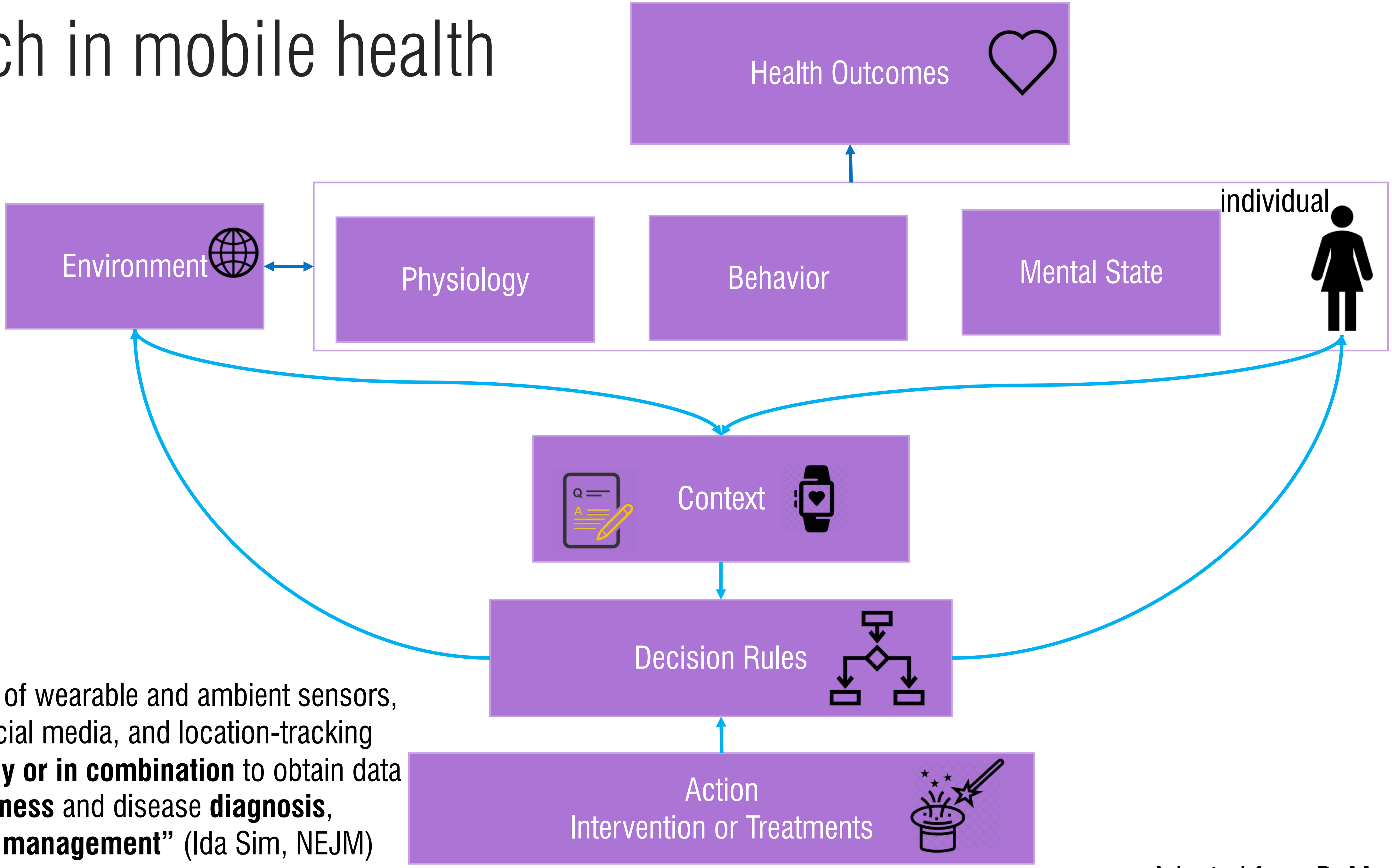
HAB its

stages of research in mobile health and prevention



Nabil Alshurafa and Josiah Hester. 2017. Personalized Medicine in the Wearable Era. ACM Sensys: HumanSys 2017

research in mobile health



“The application of wearable and ambient sensors, mobile apps, social media, and location-tracking technology **singly or in combination** to obtain data pertinent to **wellness** and disease **diagnosis**, **prevention**, and **management**” (Ida Sim, NEJM)

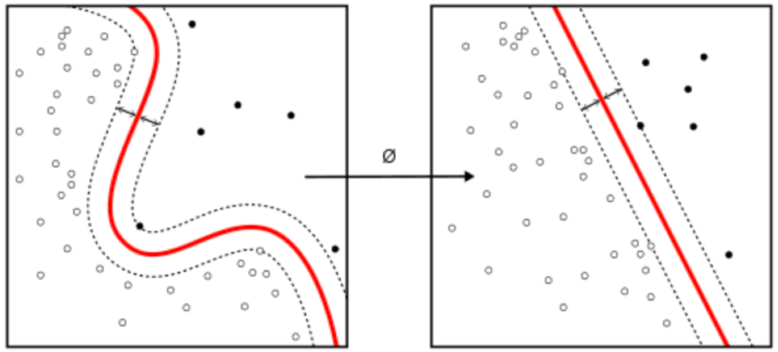
Adapted from B. Marlin

questions in mobile health

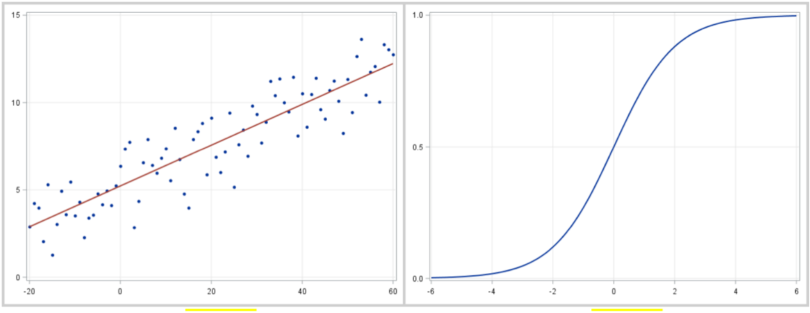
1. Measures: How do we assess or measure *outcome* or *context*?
   - Direct
   - Indirect (proxy)
2. Gold Standard Measure
3. Time Points: When and how often do we run observations and decision rules?
   - Continuous or not
   - Frequency/sample rate
   - Real-time or end of day
4. Decision Rule: How do I construct a data analytic pipeline?
5. Treatments: What should the set of treatment options or intervention component's be?

Supervised …to detect and predict

Classification

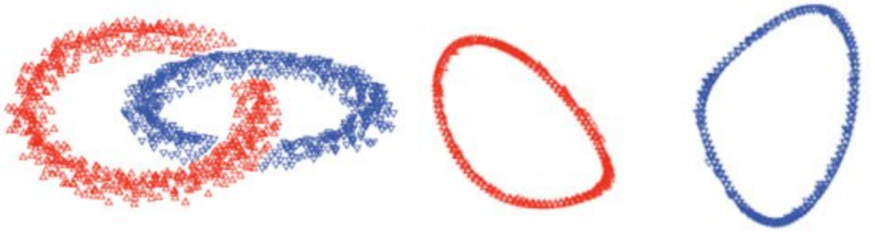


Regression

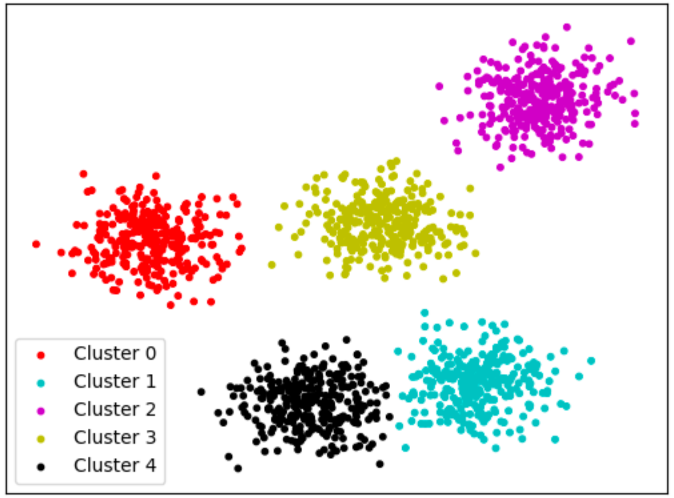


Unsupervised…to represent and organize

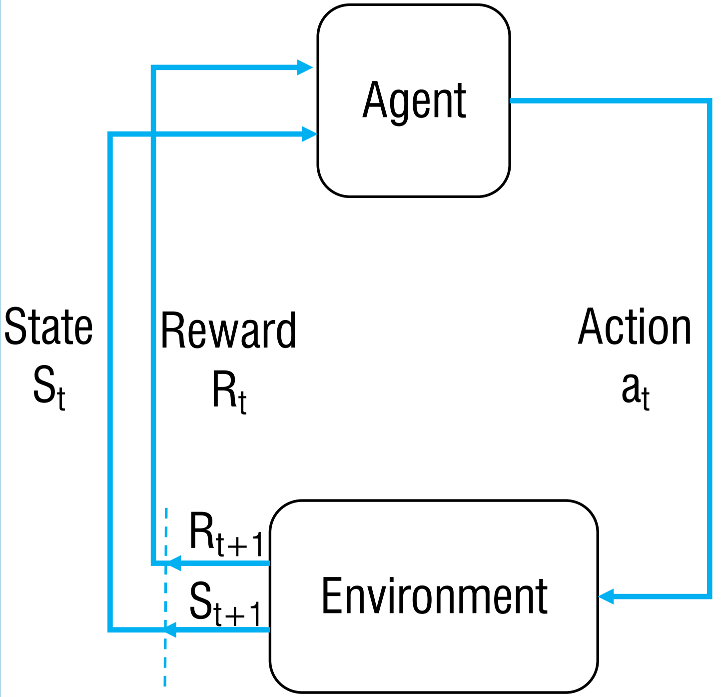
Dimensionality Reduction

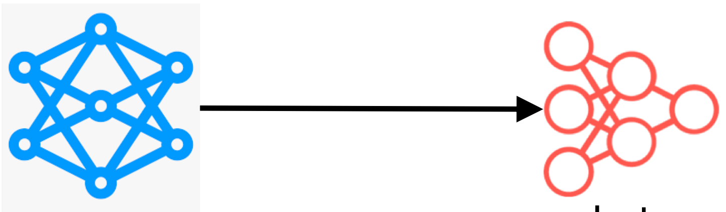


Clustering



Reinforcement Learning …to act optimally





Start: cold model

hot

Construct


Eating

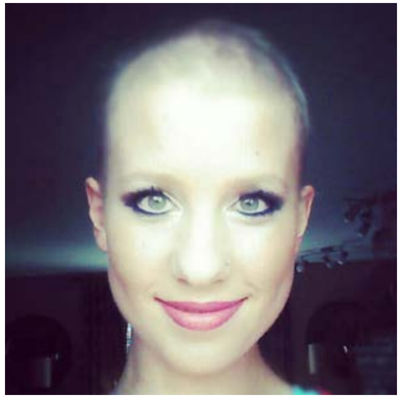

Stress


UV exposure

Population


Obesity


Pregnant women

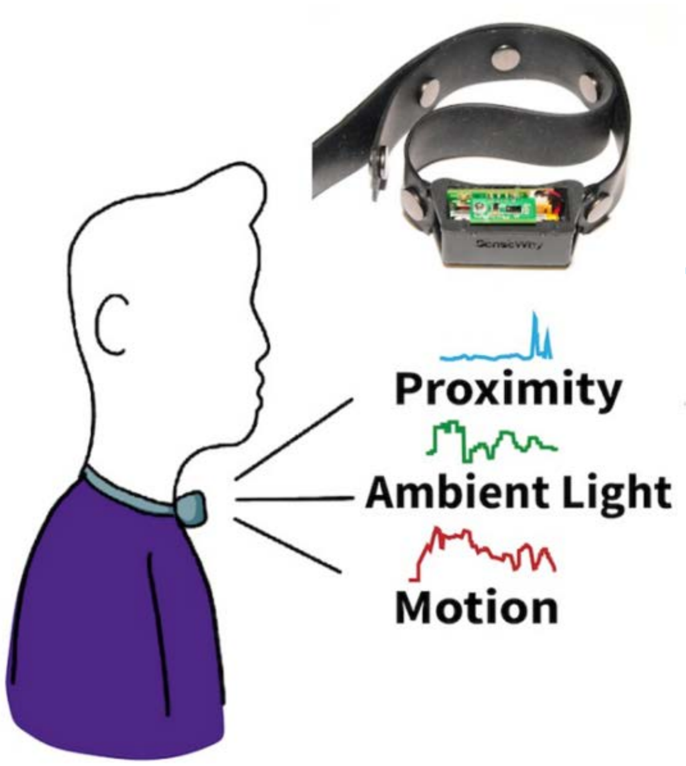

Melanoma Survivors

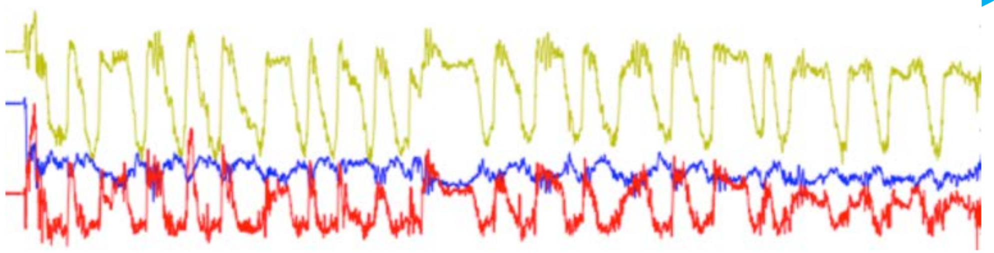
event detection problem

Def: Suppose we have a dynamical system in which an event of interest is either occurring or not occurring at each time instant t. Given a numerical representation x_t of the state of the system at time t, infer whether the event occurred at time t or not.

example

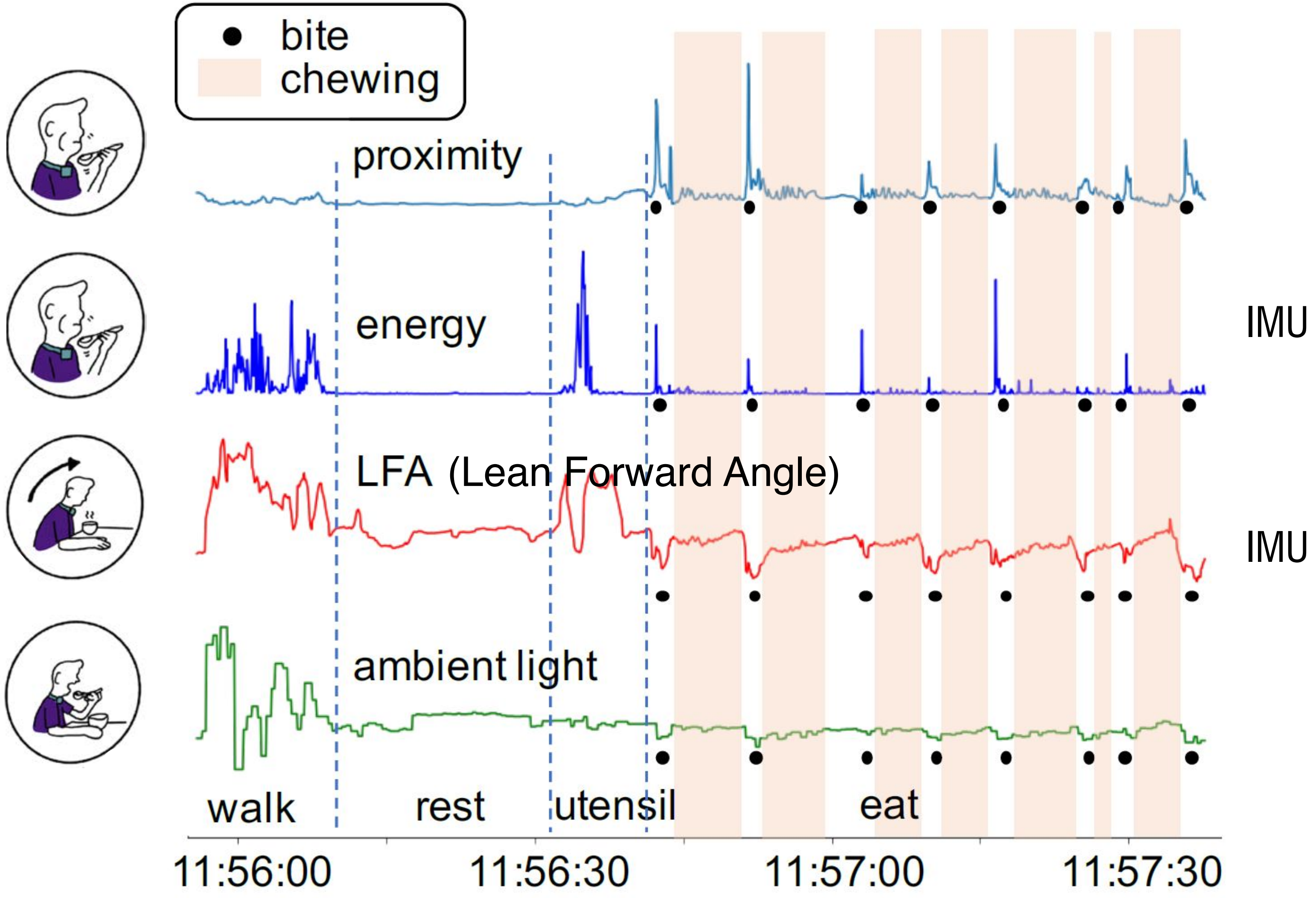
Suppose we have data from a wearable neckworn sensor. Based on the data from the proximity, ambient light, and motion sensor, within a given time segment Δt, determine whether that time segment involves chewing or not.

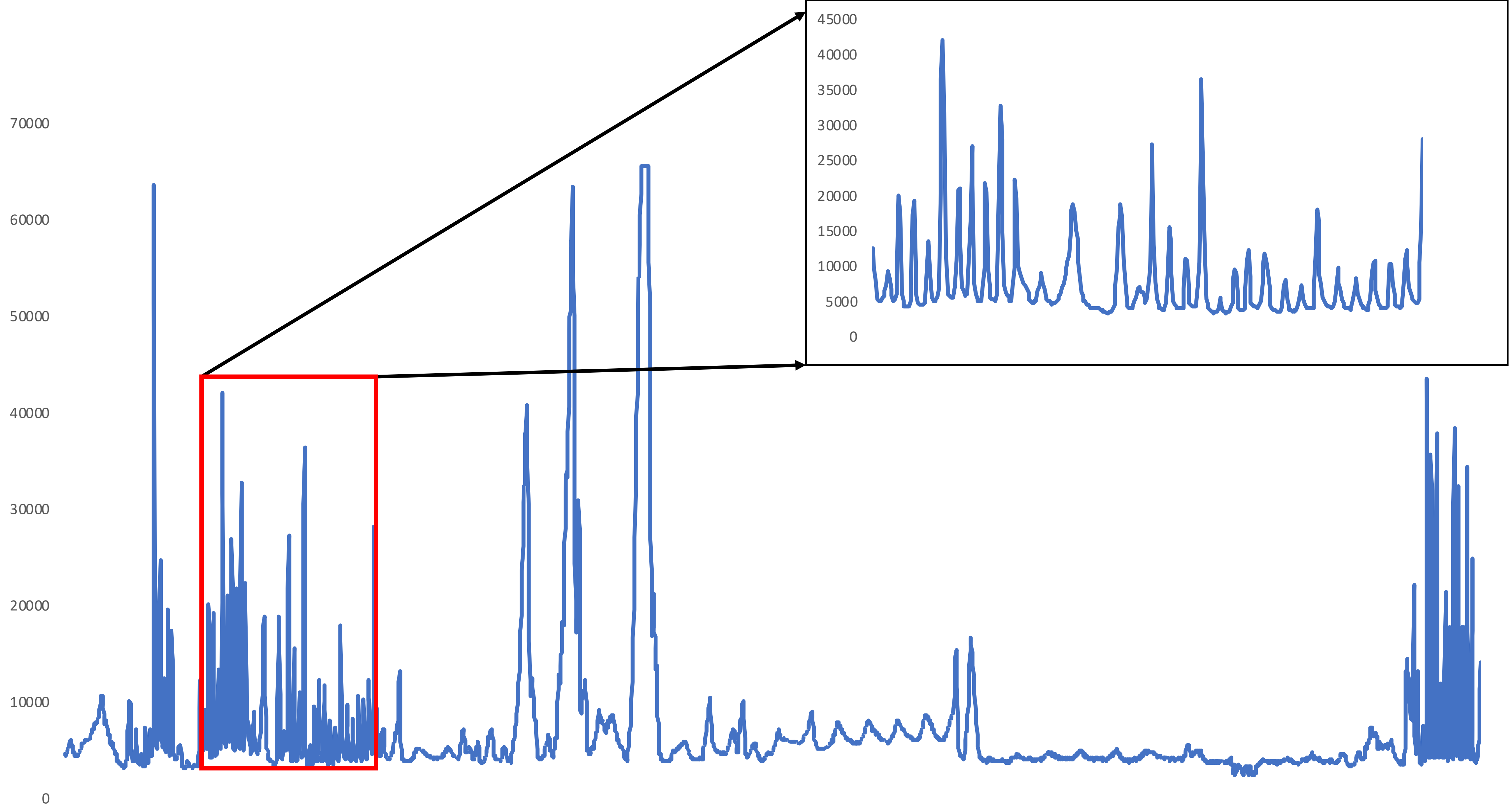




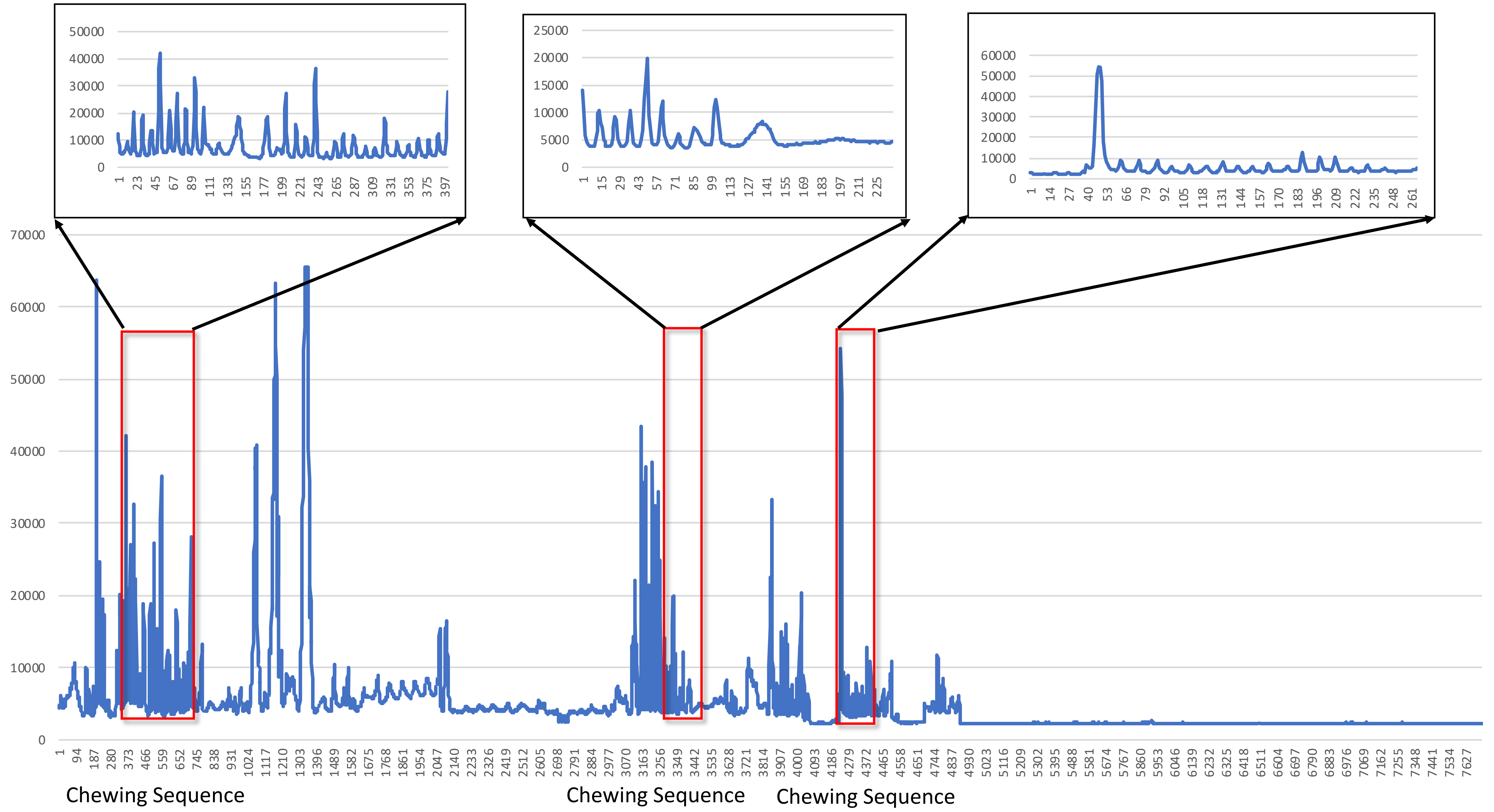
Chewing?

processing **four** signals from NeckSense

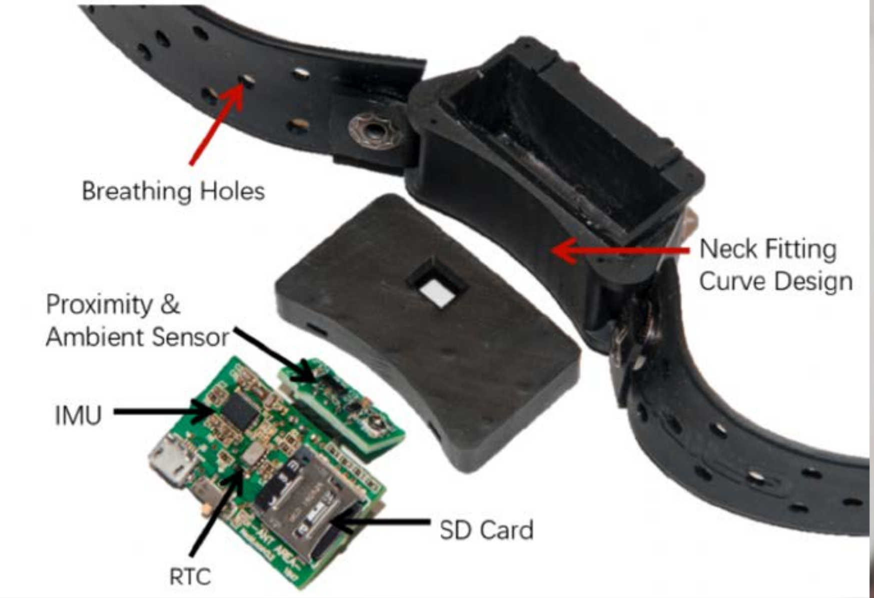




Chewing Sequence



Chewing Sequence
Chewing Sequence
Chewing Sequence



NeckSense

multi-sensor necklace for detecting eating activities
activities in free-living conditions

read our paper & learn about NeckSense: necksense.info

Shibo Zhang, Yuqi Zhao, Dzung Nguyen, Runsheng Xu, Sougata Sen, Josiah Hester, Nabil Alshurafa

ACM Ubicomp 2020

Northwestern
University

Won Brest Presentation (Runner Up) at Ubicomp 2020 novel **neck-worn** device with multiple embedded sensors

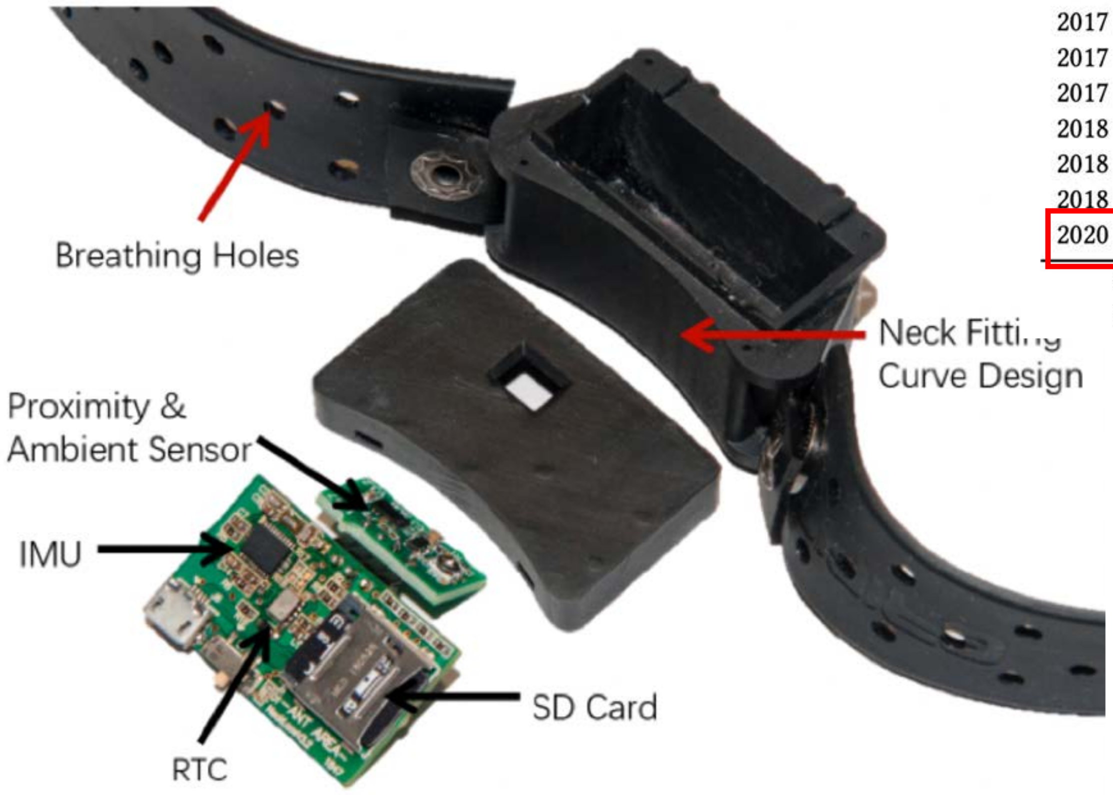
…**infer eating behavior** from **contactless** sensors

…**tested** on people with **obesity**

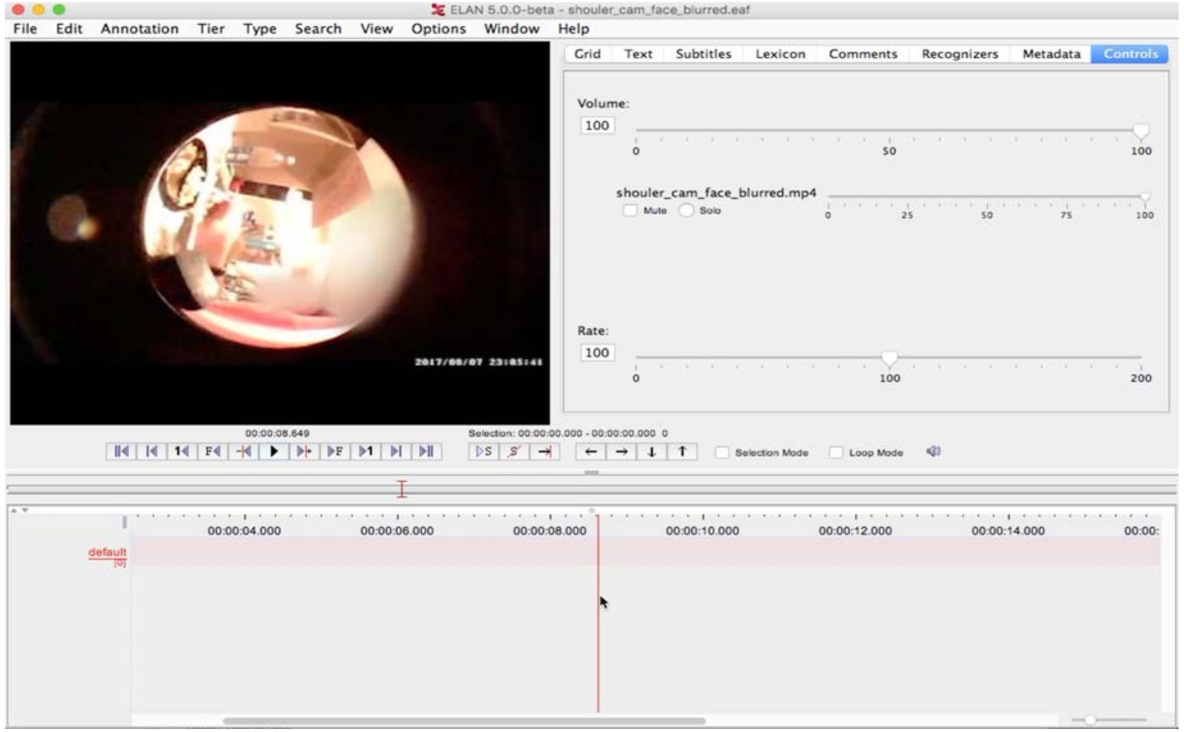
…tested in **real-world settings**

Year	Study	Sensors	On-body position	No. of participants	Avg hours per day	Validation video	Non-student	Obese
2014	Fontana et al. [22]	S1, S4, S6	Ear, wrist, chest	12	24.0	✗	✓	✓
2015	Thomaz et al. [55]	S1	Wrist	7+1	5.7/13.6	✗	✗	✗
2015	Bedri et al. [10]	S2, S5	Ear, head	6	6.0	✗	✓	✗
2016	Farooq et al. [21]	S4	Temple	8	3.0	✗	✓	✗
2017	Bedri et al. [9]	S1-S3, S5, S7	Neck, ear	10	4.5	✓	✓	✗
2017	Zhang et al. [60]	S8	Ear	10	6.1	✗	✗	✗
2017	Mirtchouk et al. [35]	S1-S3, S7	Ear, wrist, head	11	11.7	✗	✓	✗
2018	Sen et al. [49]	S1, S2, S10	Wrist	9	5.8	✗	✓	✗
2018	Chun et al. [15]	S5	Neck	17	4.6	✗	✗	✗
2018	Bi et al. [13]	S7	Ear	14	2.3	✓	✗	✗
2020	This work	S1-S3, S5, S9	Neck	10+10	4.9/9.5	✓	✓	✓

S1 - accelerometer, S2 - gyroscope, S3 - magnetometer, S4 - piezo, S5 - proximity, S6 - radio frequency, S7 - microphone, S8 - electromyography, S9 - light, S10 - camera



validated using a wearable video camera for **270 hours in-the-wild**
...provide **data** and **code** to the community



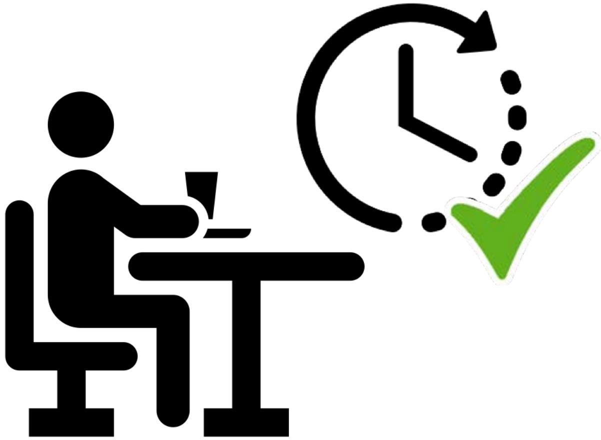
Zenodo: http://doi.org/10.5281/zenodo.3774395

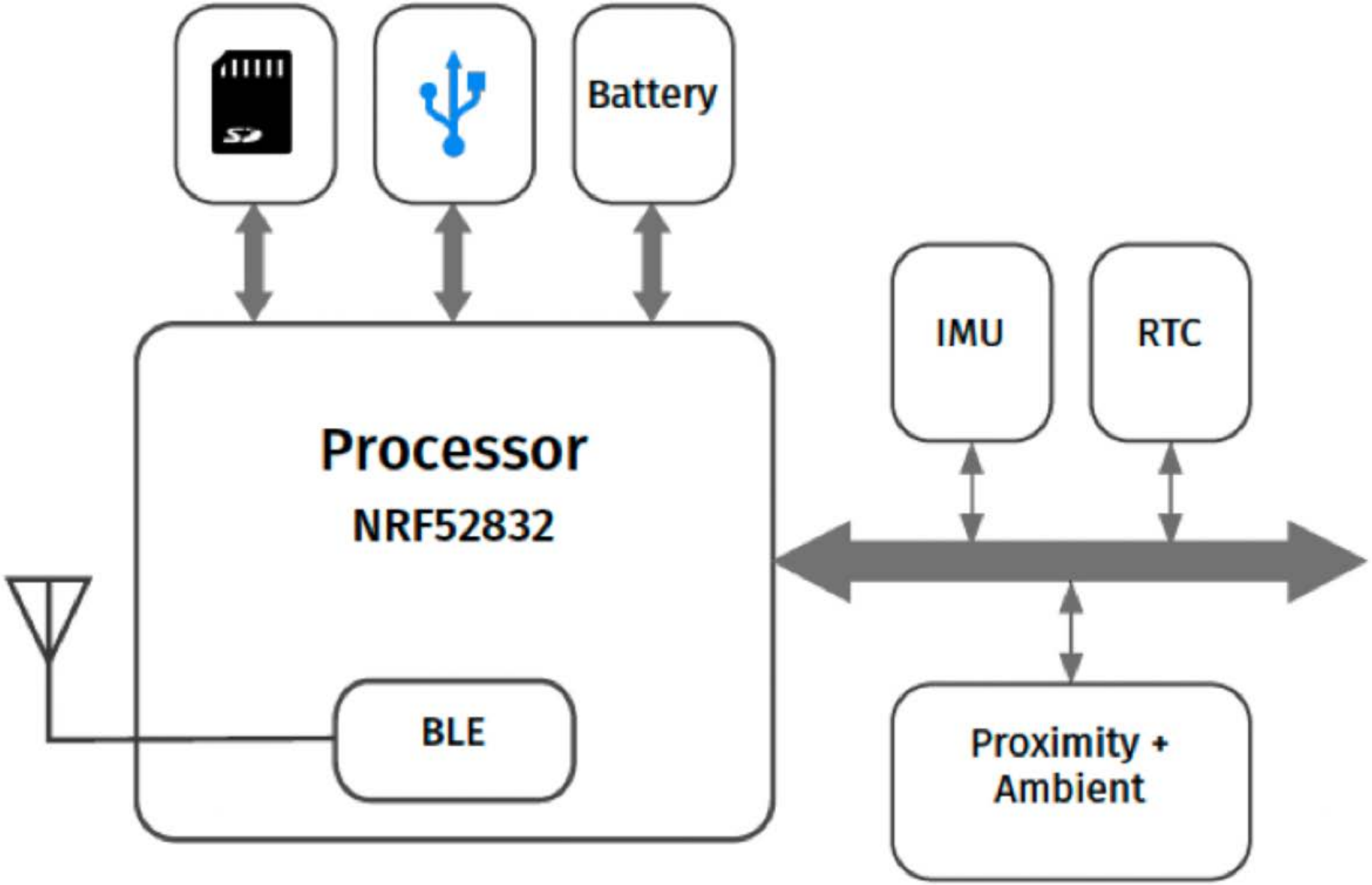
benefits to NeckSense

… understand characteristics of an eating episode

… **detect eating** in real-time

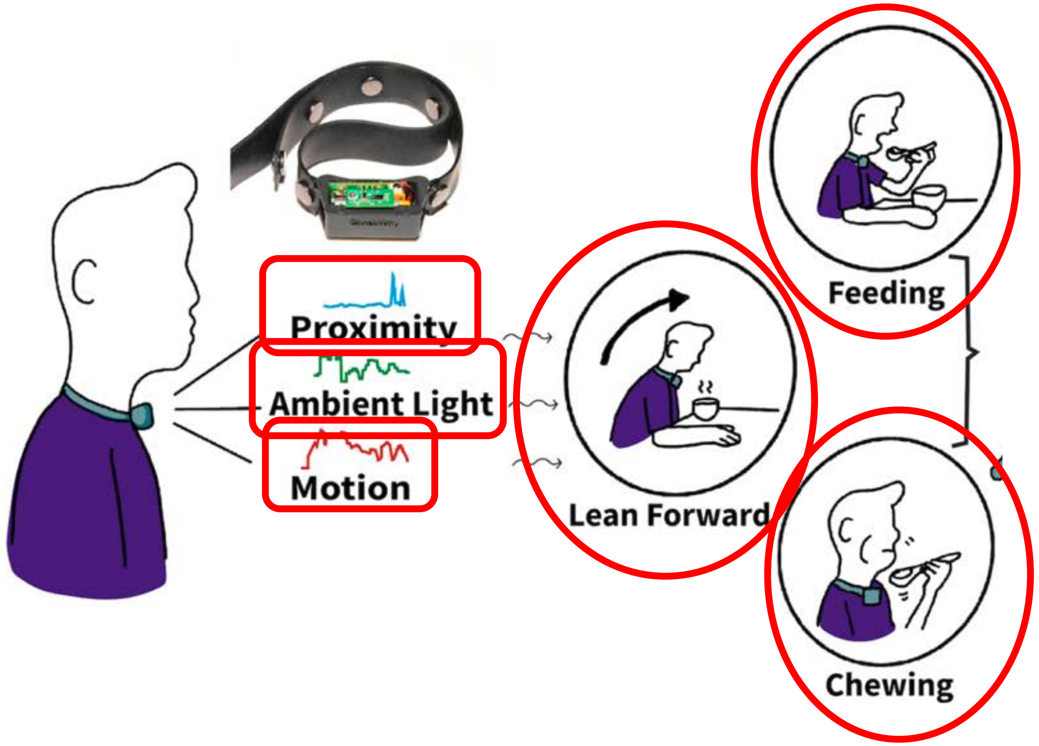
… **trigger timely interventions** for diet recall and behavior change

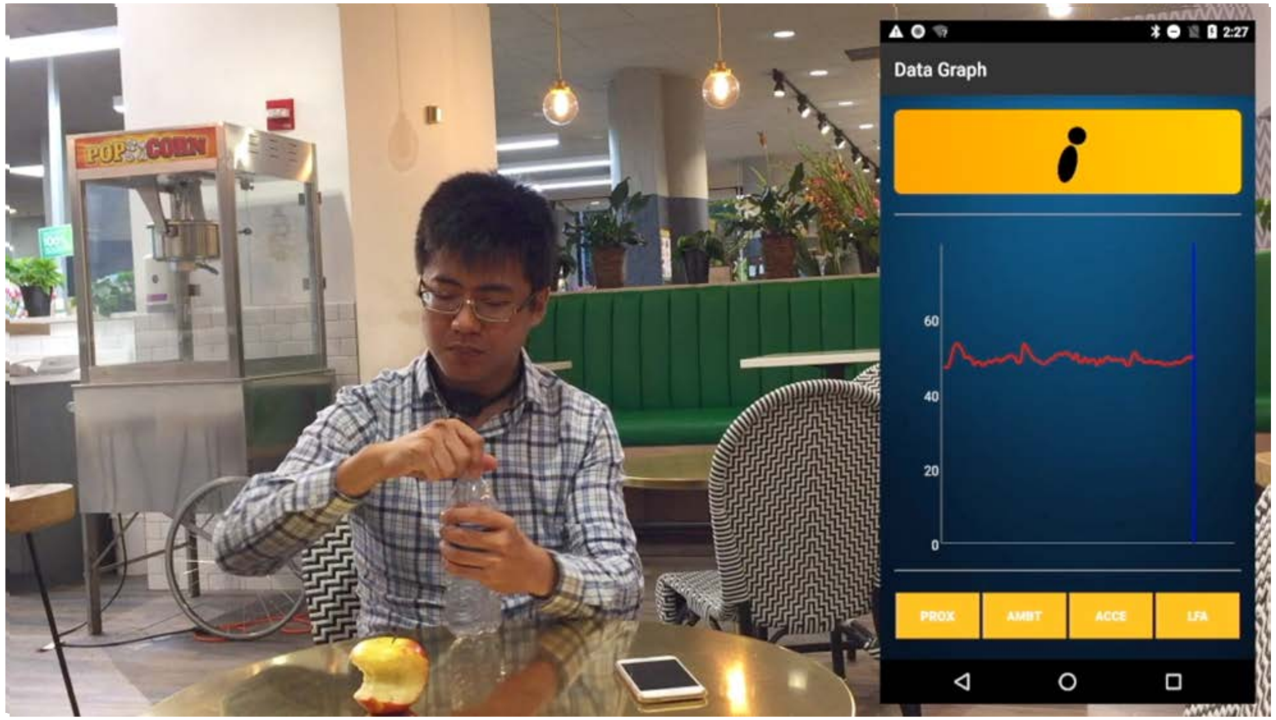



Battery
IMU
RTC
Processor
NRF52832
BLE
Proximity +
Ambient

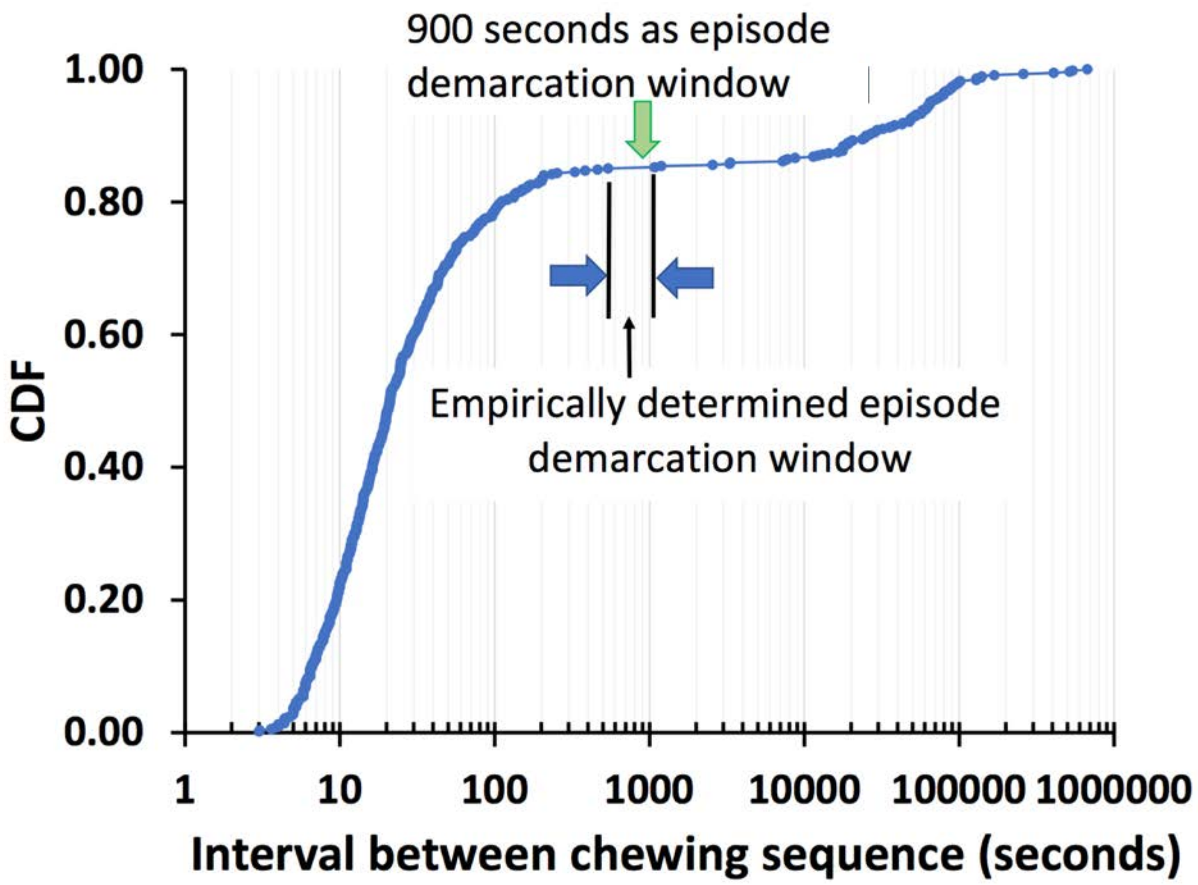
Multiple sensors capture eating

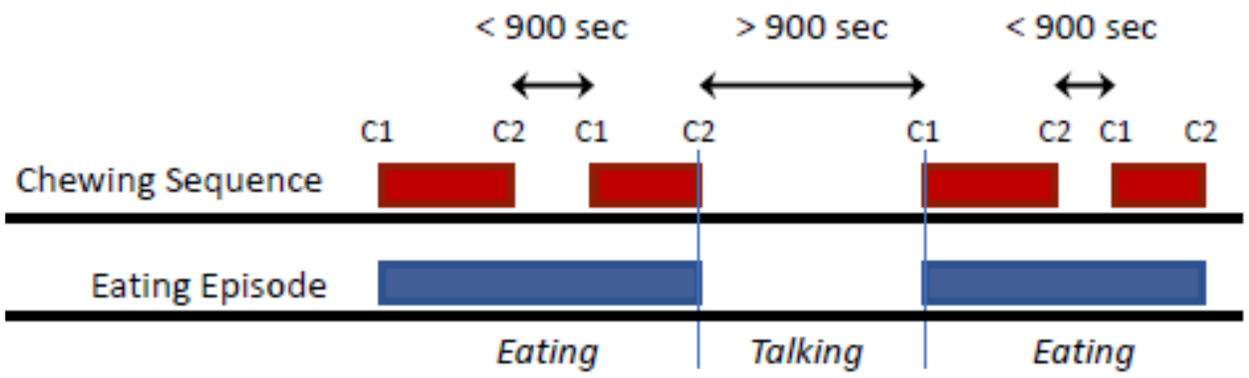
… **proximity signal** captures periodicity of chew
… **ambient light** as a proxy to feeding gestures
… **IMU** calculates leaning forward and backward angle to infer bite



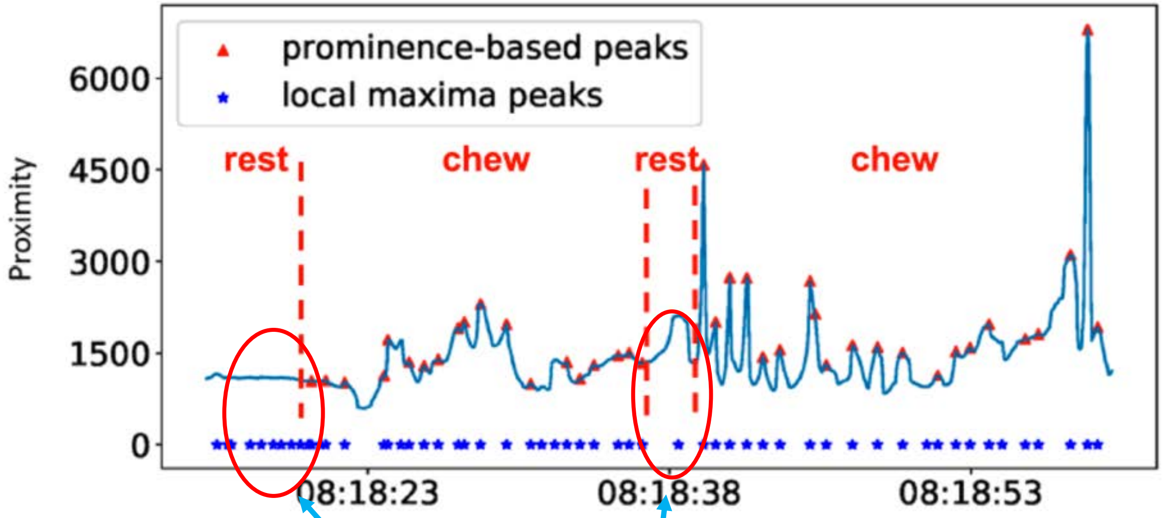


defining an **eating episode**





segmentation using proximity sensing signal



Local peaks but not prominent peaks

segmentation using proximity sensing signal

Definition 1. *ϵ**-periodic**: Given a sequence of increasing timestamps t_i, where $i \in \{1 \ldots N\}$, the difference between consecutive numbers is $p_i = t_{i+1} - t_i, \forall i = \{1 \ldots (N-1)\}$, if p_{min} and p_{max} are the smallest and largest values of these differences, respectively, then the sequence is defined to be ϵ-periodic if:*

$$\frac{p_{max}}{p_{min}} < 1 + \epsilon$$

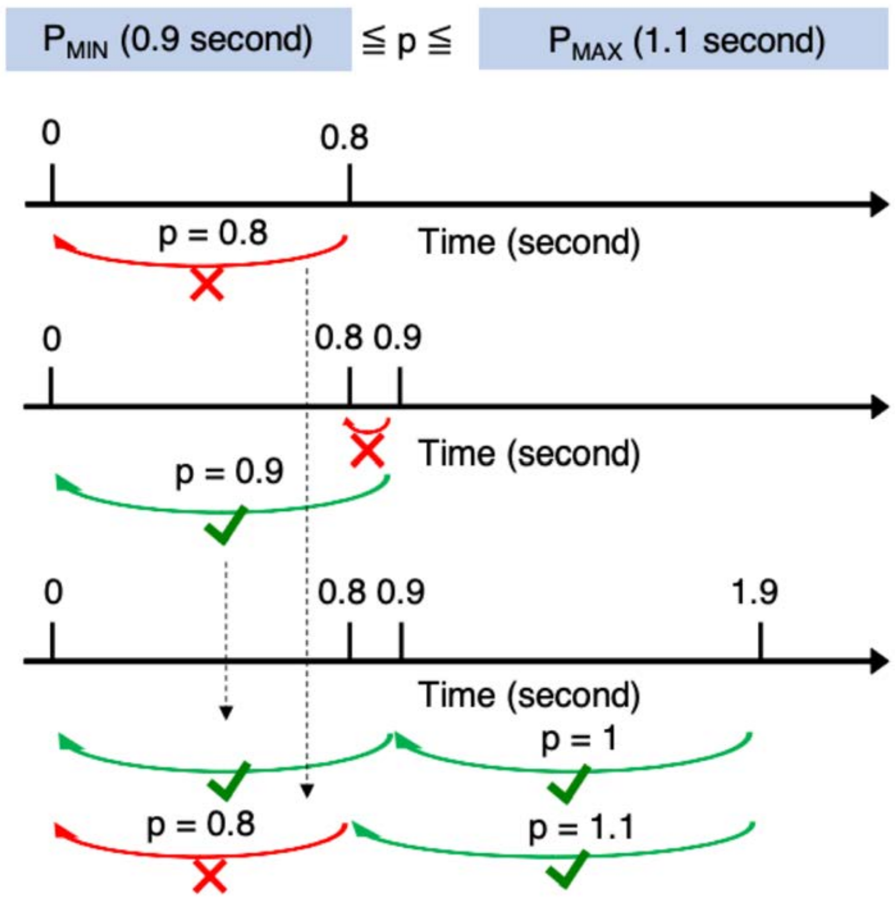
Problem 1. ***Relative error periodic subsequence**: Given a sequence of increasing numbers t_i, find all longest subsequences that are ϵ-periodic.*

Problem 2. ***Absolute error periodic subsequence**: Given a sequence of increasing numbers t_i, find all longest subsequences such that consecutive differences are bounded by p_{min} and p_{max}.*

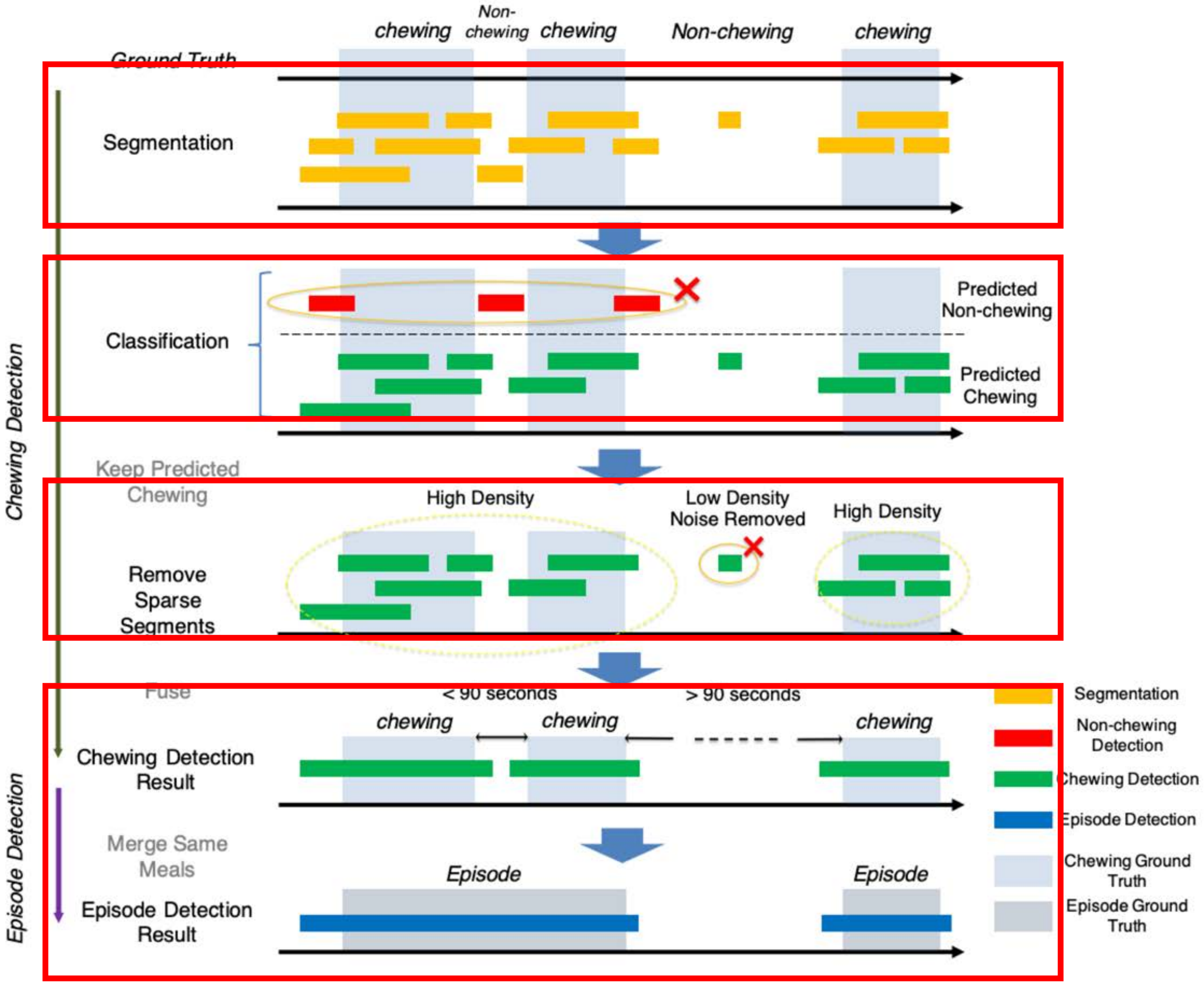
- Beat Gfeller. 2011. Finding longest approximate periodic patterns. In Workshop on Algorithms and Data Structures (WADS). Springer, 463–474. https://doi.org/10.1007/978-3-642-22300-6_39
- Shibo Zhang, Yuqi Zhao, Dzung Tri Nguyen, Runsheng Xu, Sougata Sen, Josiah Hester, and Nabil Alshurafa. 2020. NeckSense: A Multi-Sensor Necklace for Detecting Eating Activities in Free-Living Conditions. Proc. ACM Interact. Mob. Wearable Ubiquitous Technol. 4, 2, Article 72 (June 2020), 26 pages. https://doi.org/10.1145/3397313

segmentation using proximity sensing signal

$\boldsymbol{\epsilon}$-periodic: $\frac{p_{max}}{p_{min}} < 1 + \boldsymbol{\epsilon}$

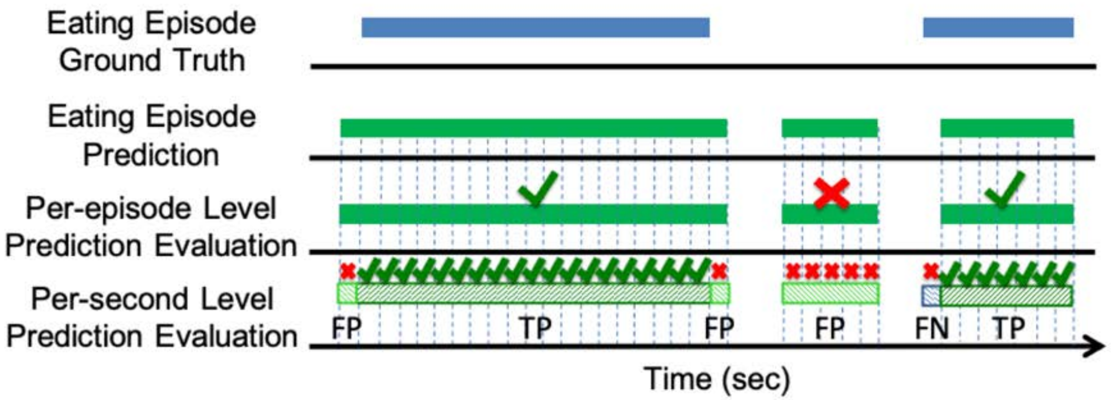


pipeline



chewing
Non-chewing
chewing
Non-chewing
chewing
Ground Truth
Segmentation
Predicted Non-chewing
Classification
Predicted Chewing
Chewing Detection
Keep Predicted Chewing
High Density
Low Density Noise Removed
High Density
Remove Sparse Segments
Fuse
< 90 seconds
> 90 seconds
chewing
chewing
chewing
Chewing Detection Result
Merge Same Meals
Episode
Episode
Episode Detection Result
Episode Detection
Segmentation
Non-chewing Detection
Chewing Detection
Episode Detection
Chewing Ground Truth
Episode Ground Truth

Evaluation criteria (fine-grained and coarse grained)



feature extraction

Category	Features
Statistics	Max, min, mean, median, standard deviation, RMS, correlation, skewness, kurtosis, 1st and 3rd quartile, interquartile range
Frequency	Frequency amplitude of 0.25 Hz, 0.5 Hz, 0.75 Hz, 1 Hz, 1.25 Hz, 1.5 Hz, 1.75 Hz, 2 Hz, 2.25 Hz, 2.5 Hz
Statistics of Frequency	Skewness and kurtosis of spectrum from frequency features
Time-series	Count below/above mean First location of min/max Longest strike below/above mean Number of peaks
Periodic subsequence	p_{min}, p_{max}, ϵ, length
Time	Hour of datetime

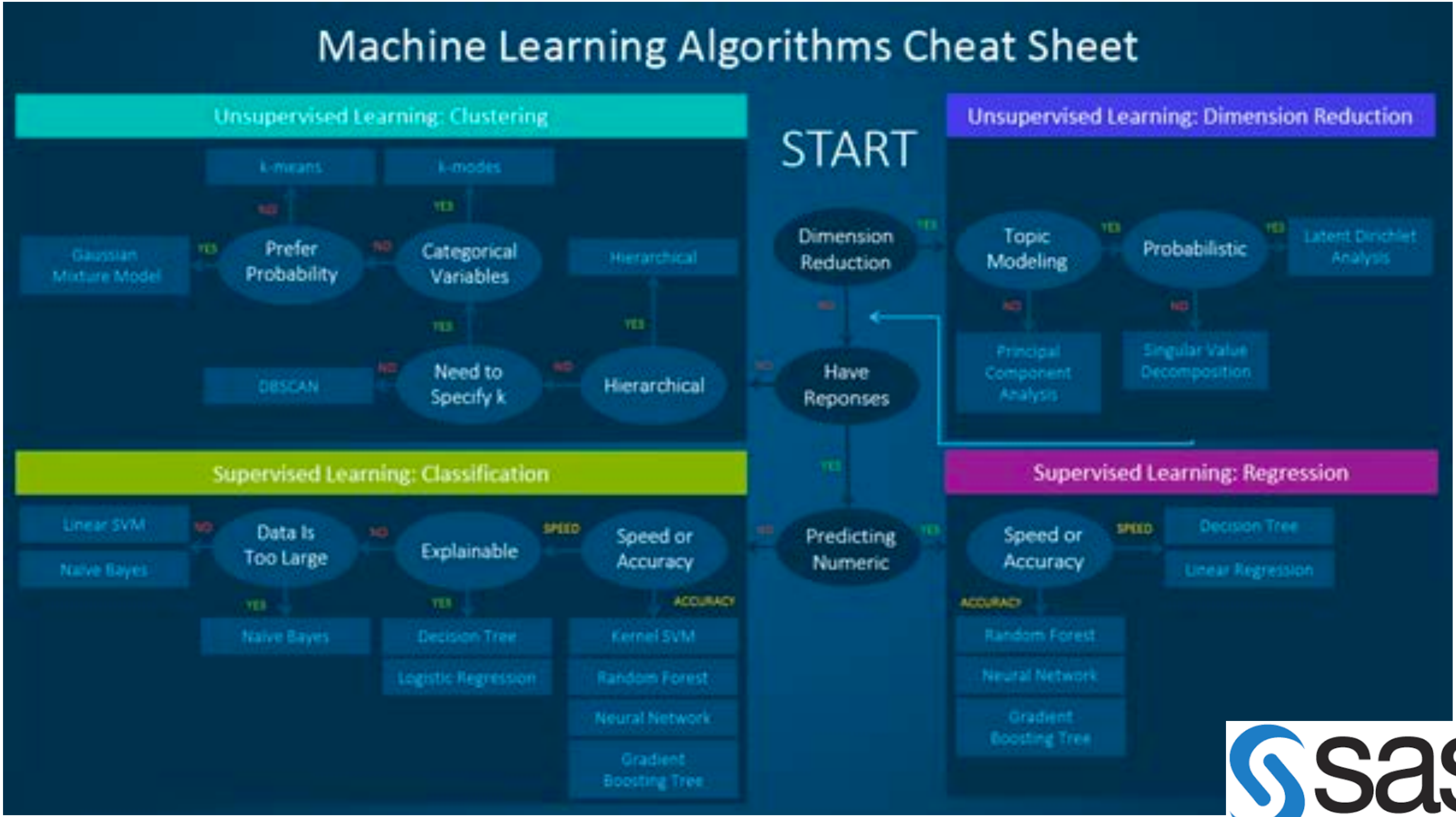
Chewing Sequence?

XGBoost Classifier

Eating episode?

Fusion

Yes? No?



Machine Learning Algorithms Cheat Sheet
Unsupervised Learning: Clustering
Unsupervised Learning: Dimension Reduction
START
k-means
k-modes
Gaussian Mixture Model
Prefer Probability
Categorical Variables
Hierarchical
DBSCAN
Need to Specify k
Hierarchical
Dimension Reduction
Topic Modeling
Probabilistic
Latent Dirichlet Analysis
Principal Component Analysis
Singular Value Decomposition
Have Reponses
Supervised Learning: Classification
Supervised Learning: Regression
Linear SVM
Naive Bayes
Data Is Too Large
Explainable
Speed or Accuracy
Predicting Numeric
Speed or Accuracy
Decision Tree
Linear Regression
Naive Bayes
Decision Tree
Logistic Regression
Kernel SVM
Random Forest
Neural Network
Gradient Boosting Tree
Random Forest
Neural Network
Gradient Boosting Tree
SPEED
ACCURACY
SPEED
ACCURACY

sas

XGBoost (eXtreme Gradient Boosted trees)

wins Kaggle competitions (easy to use, fast)
ensemble method
…each tree introduces a weak learner or boosts attributes that led to
misclassifications of the previous tree
regularized boosting (prevents overfitting)
parallel processing
cross validation at each iteration
…evaluate performance at each step of training (early stopping)
…incremental training (stop training, save, and re-run later)
can plug own optimization objective
Dmatrix
…structure used to hold features and labels---easy to create from a numpy array

XGBoost (eXtreme Gradient Boosted trees) hyperparameters

booster
…gbtree (classification) or gblinear (regression)
objective
…multi:softmax or multi:softprob
eta (learning rate –adjusts weights on each step)
max_depth (depth of the tree)
min_child_weight
…can control overfitting
GridSearchCV
AWS SageMaker: hyperparameter tuning

we performed the following **exploratory** study…

Total Hours: 134 hours

in-the-wild

- Camera wear
- Data transfer and delete
- 24-hour diet recall

Baseline | **14 partial days (2 weeks)** | **Assessment**

- Taught to use technology
    - Told to **wear during eating episodes**
- Pre-study questionnaire

- Returned technology
- Post-study questionnaire
- Trained Labelers Annotate using ELAN

we performed the following **free-living** study…

Total Hours: 137 hours

in-the-wild

- Camera wear
- Data transfer and delete
- 24-hour diet recall

Baseline → **2 complete days** → **Assessment**

- Taught to use technology
    - Told to **wear all day**
- Pre-study questionnaire

- Returned technology
- Post-study questionnaire
- Trained Labelers Annotate using ELAN

in the exploratory study… **81.6% Average F-score**
in the free-living study… **77.1% Average F-score**

When trained on people without obesity,
show **poor** test performance on people with obesity

		Test	
		Obese	Non-obese
Train	Obese	71.21%	75.33%
	Non-obese	$\boxed{66.75\%}$	79.88%

Per-episode LOPO evaluation

results

Sensor(s) used	Exploratory Study	Free-Living Study
Proximity only (ref)	73.4%	66.4%
Proximity + IMU*	81.5%	78.7%
Proximity + ambient light	72.7%	70.3%
All Sensors*	**81.6%**	**77.1%**

*Post hoc analyses with Bonferroni correction show statistically significant improvement of Proximity+IMU and All Sensors over Proximity only at the $P<.05$ level.

NeckSense is …

- designed to detect eating episodes in the real-world for long-term wear
- validated using longest periodic subsequence algorithm
- validated on people with and without obesity and solely in free-living settings

Data set available and device available upon request (www.necksense.info)

Let’s make sure we validate our wearables on people we are designing it for !

nabil@northwestern.edu

@HABitsLab

Passive Sensing Data Analytic Chain (PASDAC)

High Level

Start with the end in mind → Evaluation

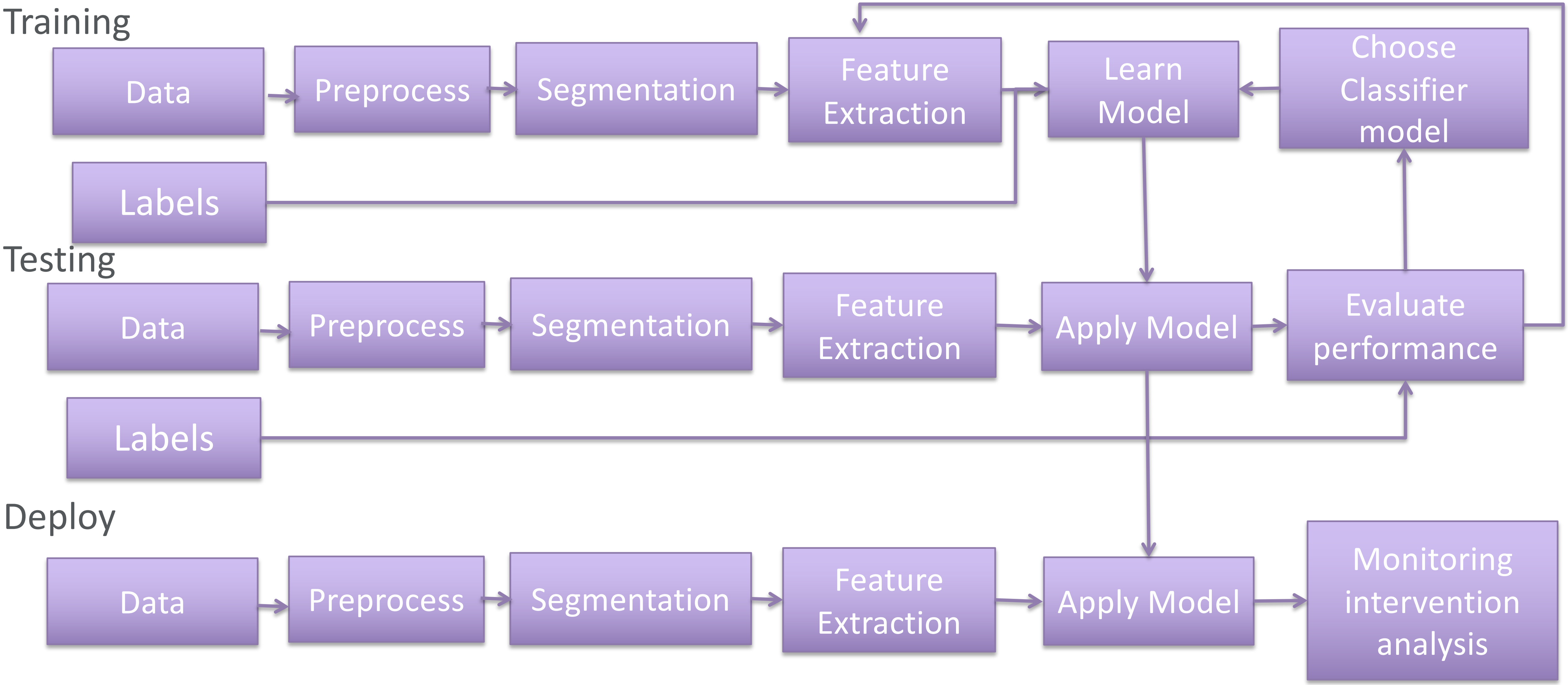
System Design → Raw Data → Preprocessing → Segmentation → Feature Extraction → Classification → Evaluation

Signal Processing

Domain Knowledge

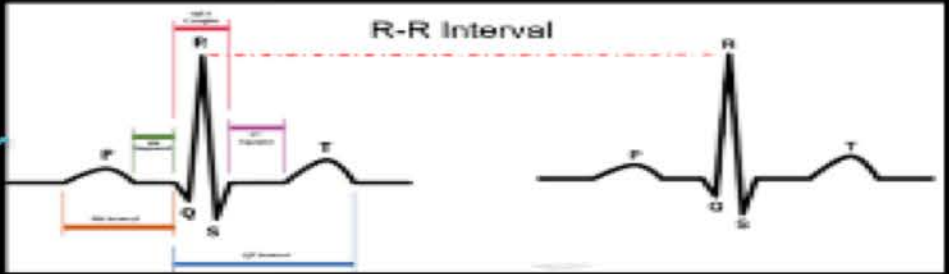
Machine Learning

Full model learning process for detection



ACM Ubicomp 2020

Ann & Robert H. Lurie Children's Hospital of Chicago



microStress-EMA

Passive Sensing Framework for Detecting in-the-wild Stress in Pregnant Mothers

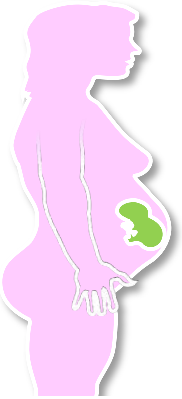
Northwestern University

Zachary King, Judith Moskowitz, Begum Egilmez, Shibo Zhang, Lida Zhang, Michael Bass, John Rogers, Roozbeh Ghaffari, Laurie Wakshlag, **Nabil Alshurafa**

ACM Distinguished Paper Award

Promoting Healthy Brain Project

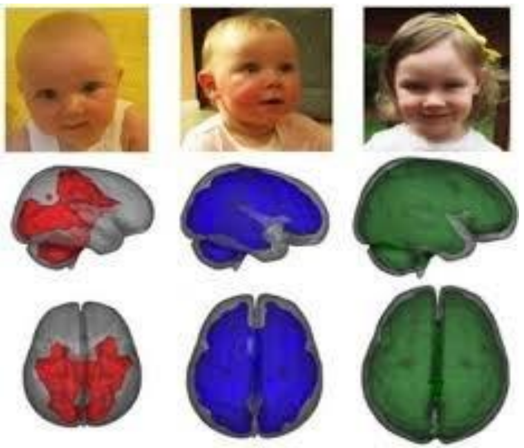
Ann & Robert H. Lurie Children's Hospital of Chicago℠



Randomized Clinical Trial (RCT): Prenatal Stress Reduction

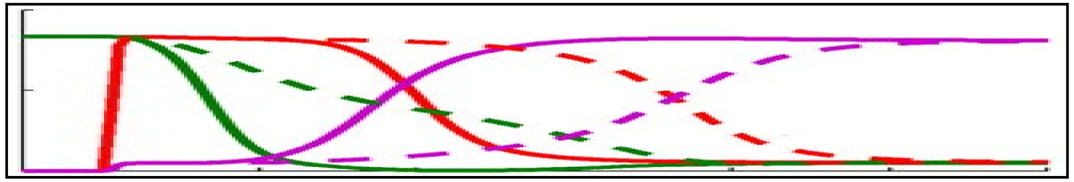
Improve Neurodevelopmental Health

Neurodevelopmental Brain:Behavior Trajectories:
Birth, 6 mos. & 12 mos.



Infant Natural Sleep MRI & EEG

Task-Based Executive Function



?

Measure Stress

Tailored Messaging

Customization

PI: Lauren Wakschlag

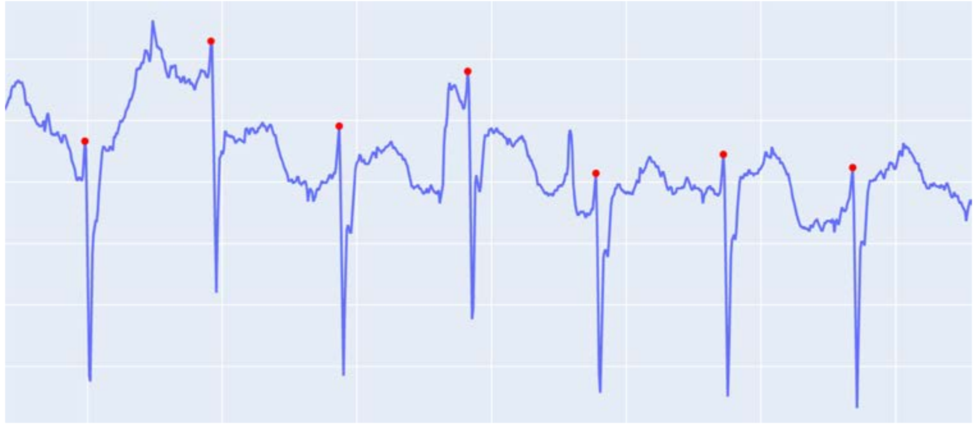
Biostamp Research Connect

event detection problem

Def: *Suppose we have a dynamical system in which an event of interest is either occurring or not occurring at each time instant t. Given a numerical representation x_t of the state of the system at time t, infer whether the event occurred at time t or not*.

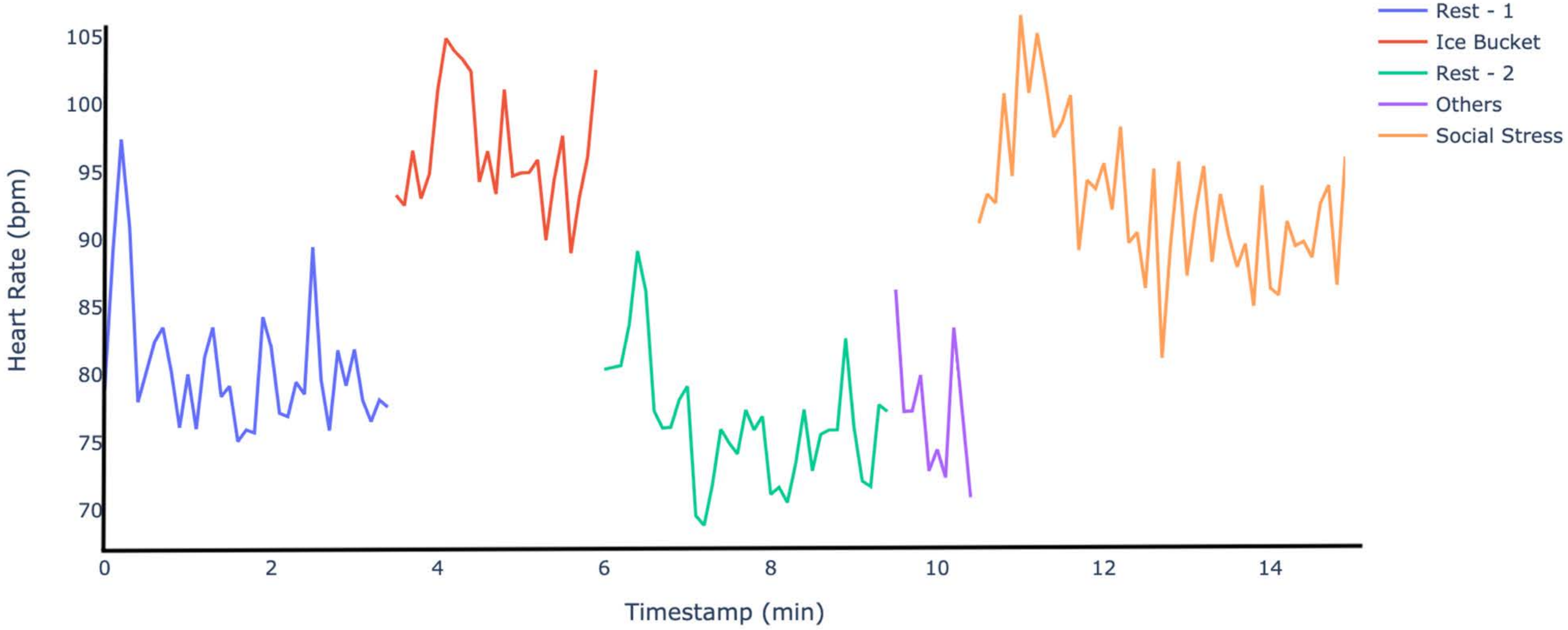
example

Suppose we have data from a wearable ECG sensor. Based on the data from the ECG sensor, within a given time segment Δt, determine whether the wearer is exhibiting stress or not.

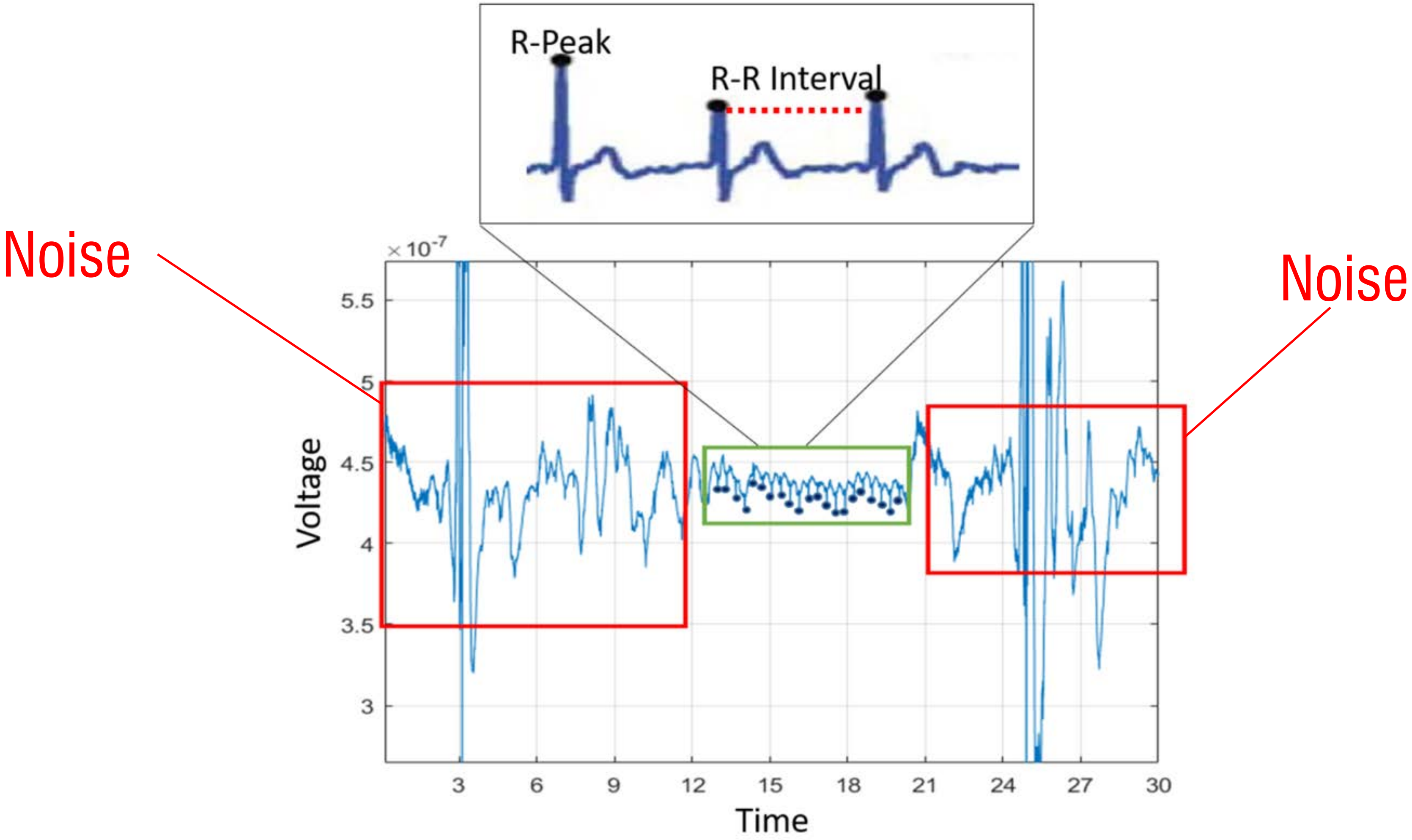


Stress?

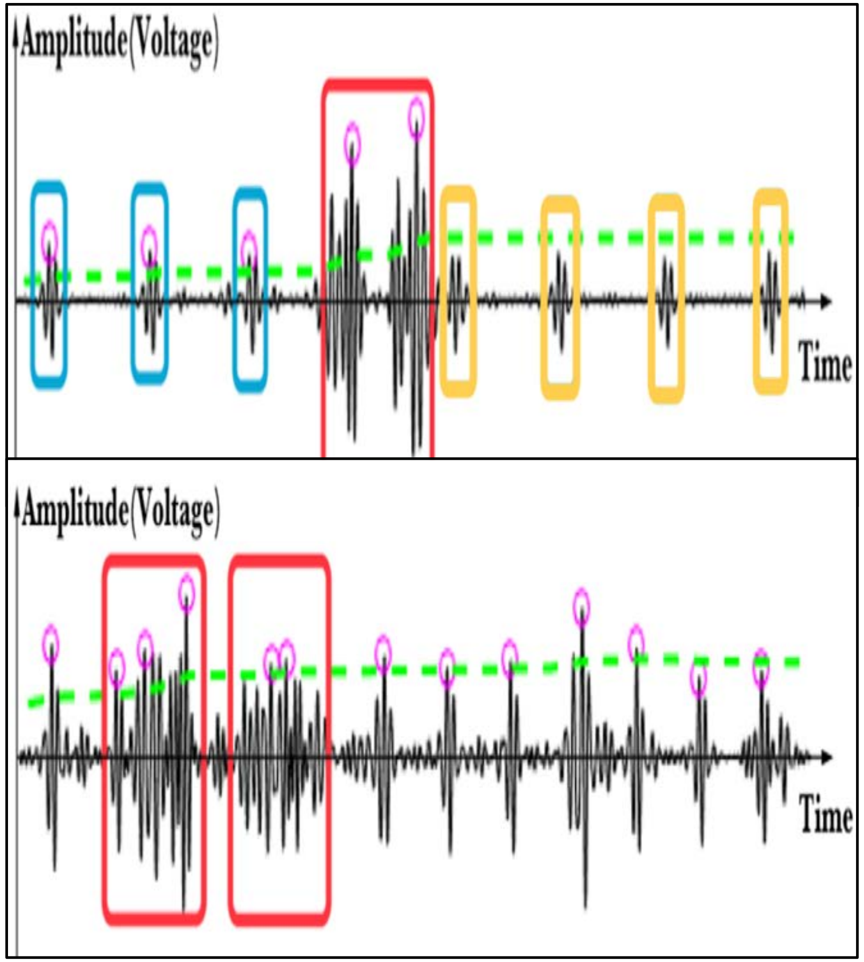
heart rate estimates from Biostamp data



Noise in ECG data



noise effects Pan Tompkins



noise effects the detection of R-peaks by the Pan-Tompkins algorithm

new study to build a pre-processing module that detects noise

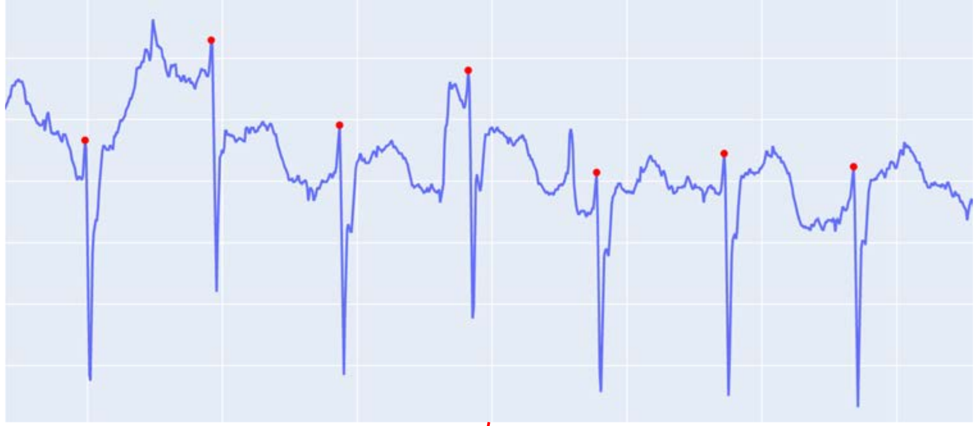
16 activities that involved stretching

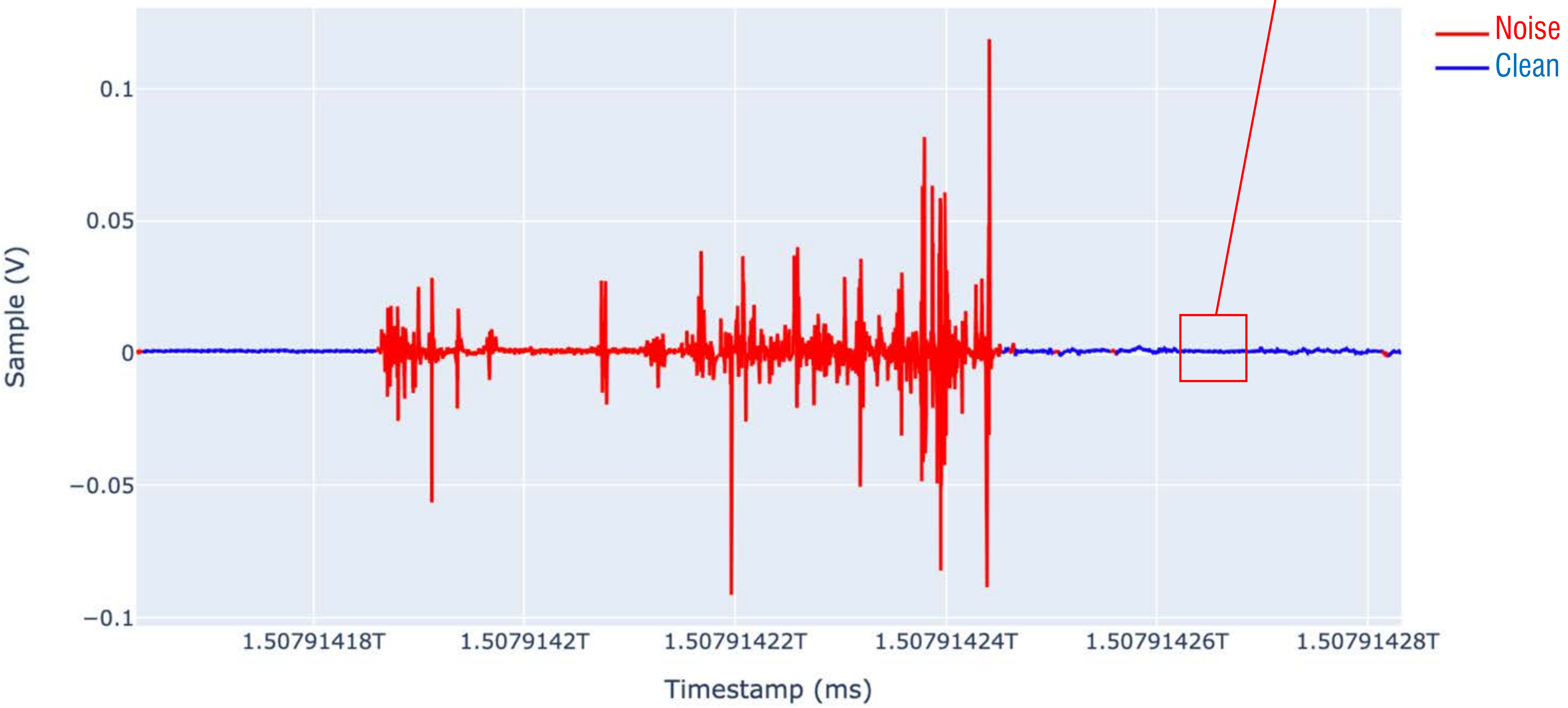
Task	Description	Label
Dressing & Grooming	Dress yourself	stretching
Rest	Have a talk.	non-stretching
Arising	Stand up from a chair. Get in and out of bed.	stretching
Rest	Check social media/email/text.	non-stretching
Walking	Carry a backpack, walk and climb.	non-stretching
Rest	Rest on the chair	non-stretching
Hygiene	Wash hands. Use toilet. Brush teeth.	stretching
Rest	Work on laptop	non-stretching
Reaching	Get down stuffs from above head. Dust the bookshelf. Pick up clothing from the floor.	stretching
Rest	Read a book	non-stretching
Gripping	Open house door and jars. Turn faucets on and off.	stretching
Rest	lie down on couch	non-stretching
Teaching	Write on a blackboard and clean it.	stretching
Rest	Take notes on a paper.	non-stretching
Cleaning	Vacuum the living room. Wipe down the dining table.	stretching
Stretching	Stretch your body.	non-stretching

+ 1 pitcher

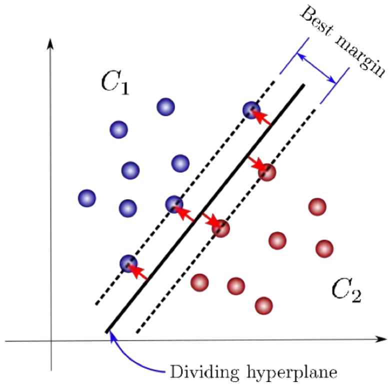
Zhang, L., King, Z., Egilmez, B., Reeder, J., Ghaffari, R., Rogers, J. A., ... Alshurafa, N. (2018). Measuring fine-grained heart-rate using a flexible wearable sensor in the presence of noise. In 2018 IEEE 15th International Conference on Wearable and Implantable Body Sensor Networks, BSN 2018 (Vol. 2018-January, pp. 160-164)

consensus noise model





SVM



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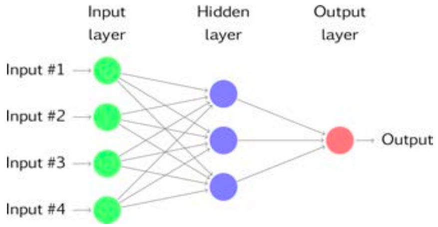
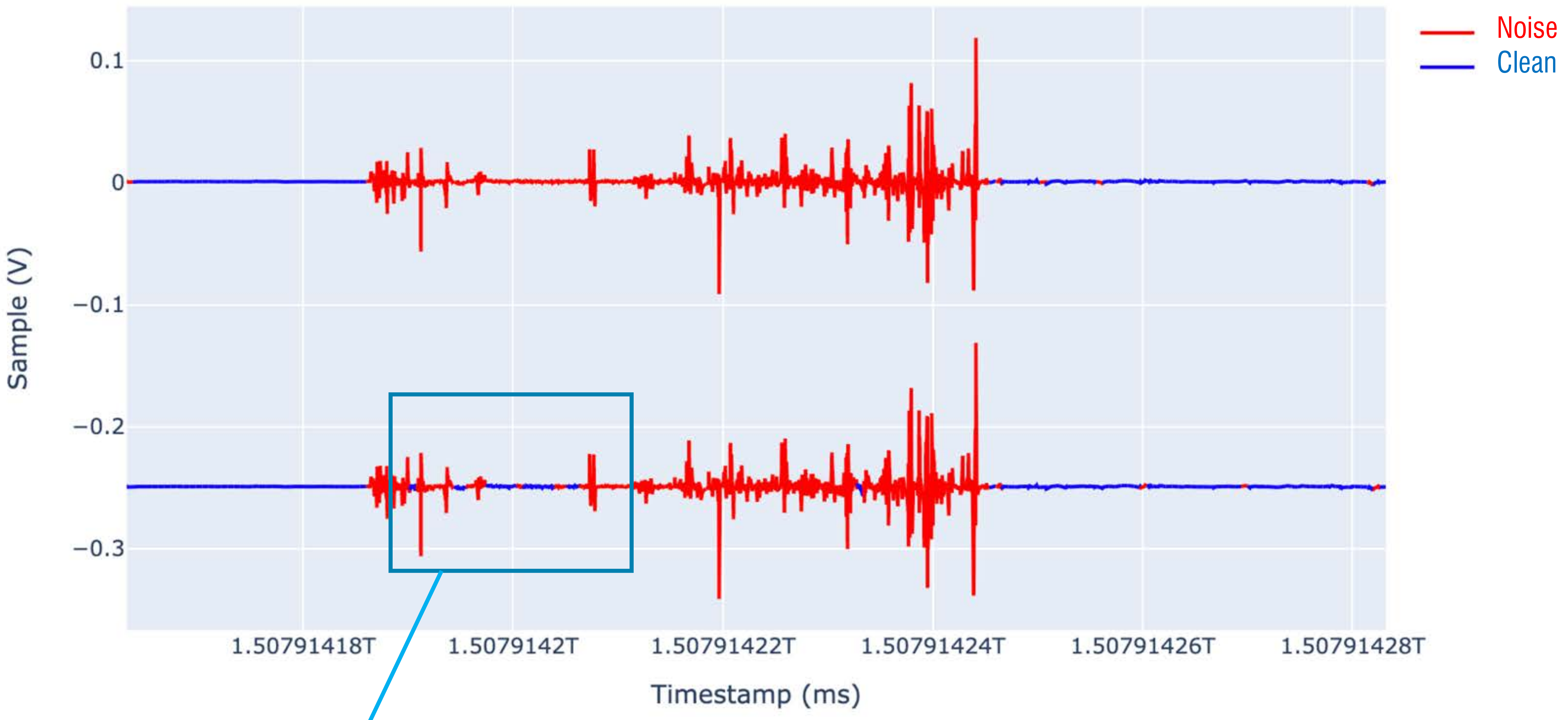
NN



93.2% improvement in heart-rate estimation

Zhang, L., King, Z., Egilmez, B., Reeder, J., Ghaffari, R., Rogers, J. A., ... Alshurafa, N. (2018). Measuring fine-grained heart-rate using a flexible wearable sensor in the presence of noise. In 2018 IEEE 15th International Conference on Wearable and Implantable Body Sensor Networks, BSN 2018 (Vol. 2018-January, pp. 160-164)

noise model corrects labeler

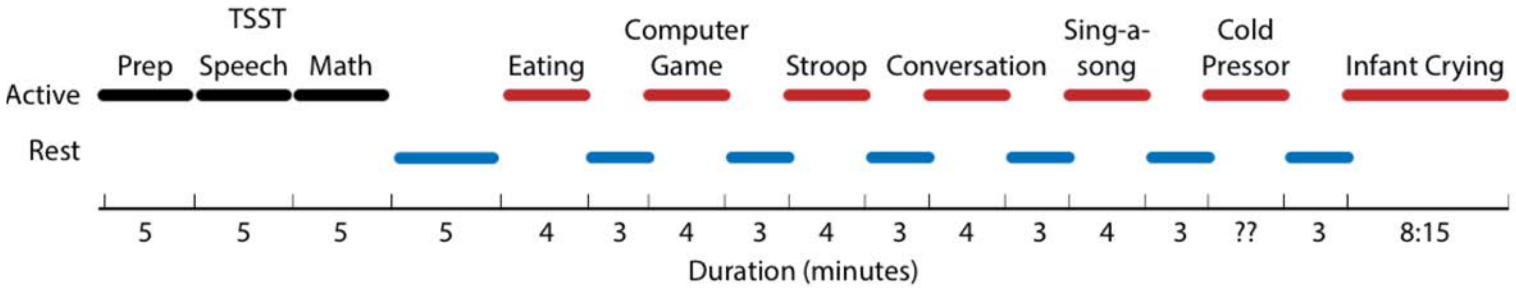


Noise model corrects

stress induction to detect physiological stress

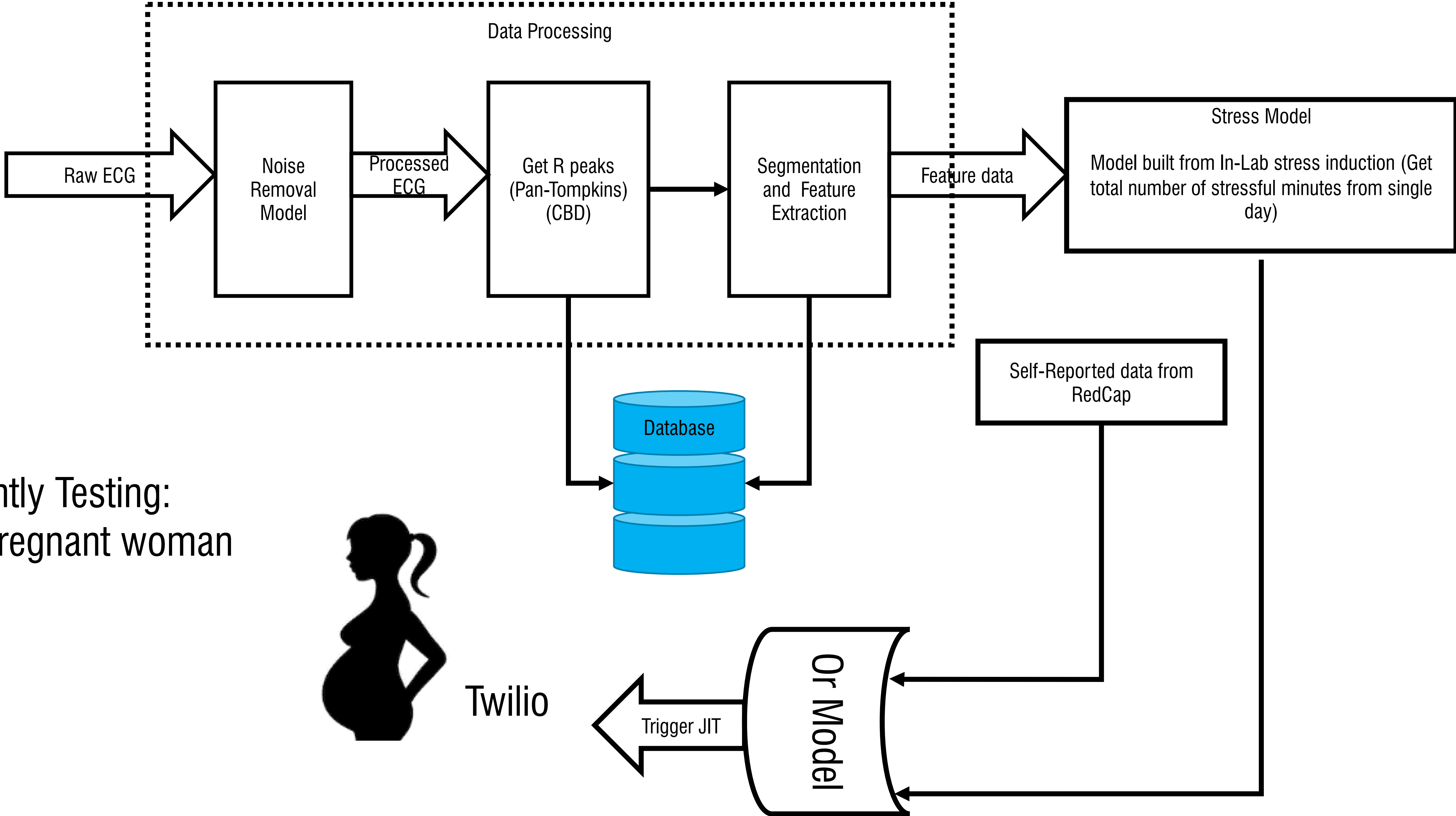
Before and After every activity

Definition	Question
Intended (-)	Based on whether the activity was intended to cause stress
LikertStress (-)	How Stressed were you?(0-6)
BinaryStress (-)	Were you Stressed?(yes/no)
PSS-Control (-)	Did you feel you could not control important things?(0-4)
PSS-Overcome (-)	Did you feel difficulties piling up so you cannot overcome them?(0-4)
WorriedStress (-)	How Worried were you?(0-100)
SadStress (-)	How Sad were you?(0-100)
IrritableStress (-)	How Irritable/Angry were you?(0-100)
PSS-Confident (+)	Did you feel confident in your ability to handle problems?(0-4)
PSS-Your Way (+)	Did you feel things are going your way?(0-4)
ContentStress (+)	How Content were you?(0-100)
HappyStress (+)	How Happy were you?(0-100)
ExcitedStress (+)	How Excited were you?(0-100)



model flow pipeline

Currently Testing:
100 pregnant woman



combining self-report and sensor data

- Self-reported stress model from EMA (PSS-Q4)
- Physiological stress model built using signal processing, machine learning, & domain knowledge

Self-Report


In the past hour, how stressed were you feeling?
* must provide value
not at all
very much
reset

In the past hour, did you feel you could not control important things?
* must provide value
not at all
very much
reset

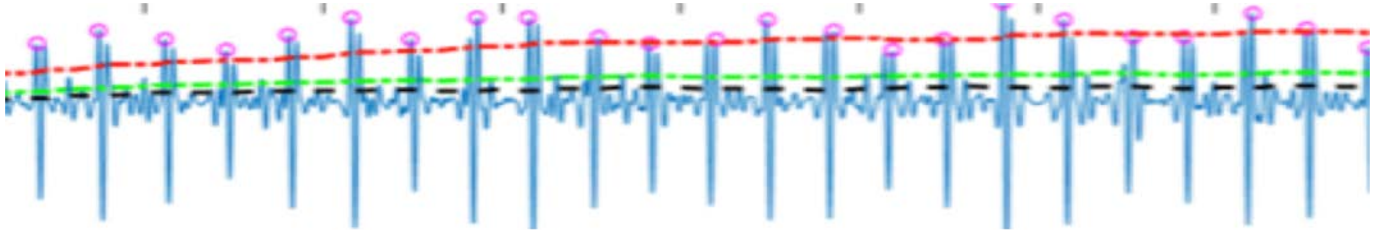
In the past hour, did you feel confident in your ability to handle problems?
* must provide value
not at all
very much
reset

In the past hour, did you feel things are going your way?
* must provide value
not at all
very much
reset

$P_{self\text{-}report}(Stress)$

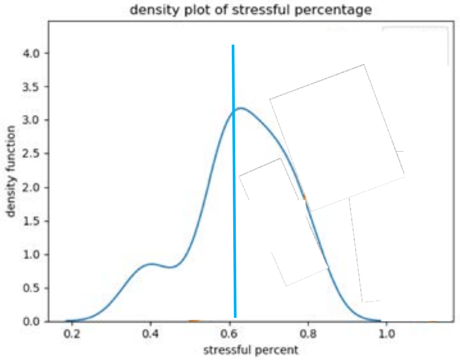
$P_{physiology}\ (Stress)$

Stress Probability



Non-Stress

Stress



$P_{self\text{-}report}(Stress)$ > *National PSSQ-4 Threshold*

OR

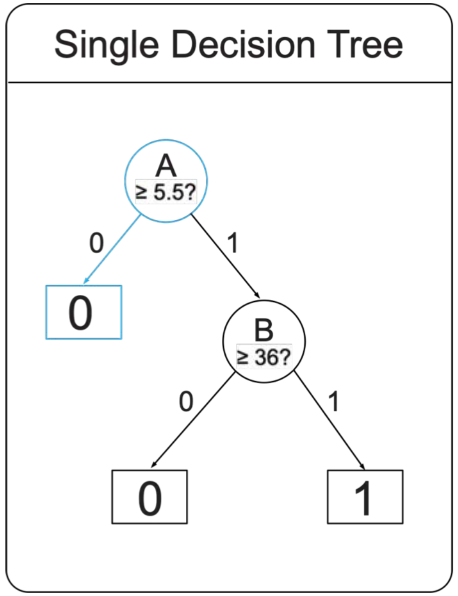
$P_{physiology}(Stress)$ > *Mean Threshold (Minutes a day)*

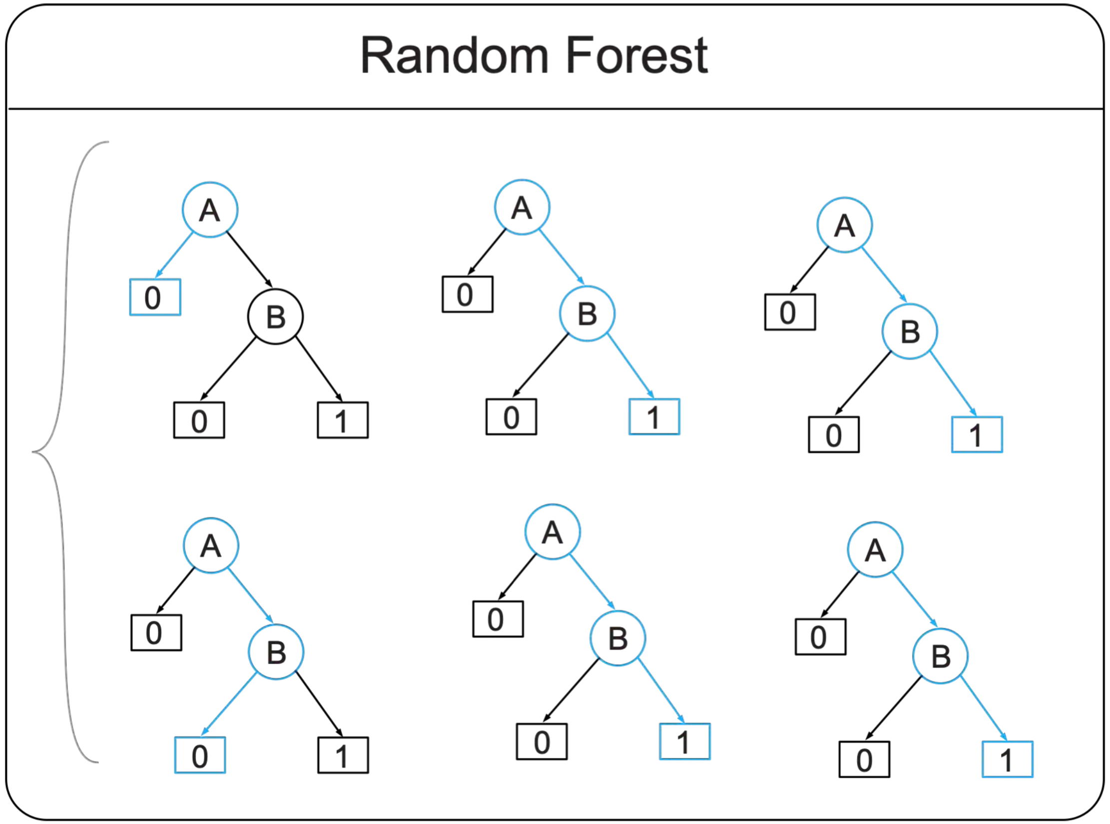
challenges and opportunities

1. Explainability AI: How do I take a black box ML-based algorithm and make it interpretable?
2. Interactive ML: E.g., Active Learning
3. Sample Size: How do I know when I have enough data?
4. Speed/Real-time: Fast Machine Learning for Science
5. Optimization: Trade-off between Accuracy and {Battery Lifetime, Privacy, Engagement/Adherence}
6. Symbolic Reasoning VS. or WITH Deep Learning
7. Have we reached a dead-end with certain sensing modalities?

Explainable AI

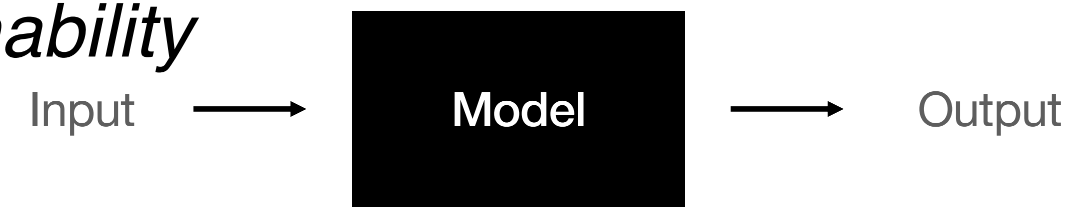
What? Why? Interpretability vs Explainability



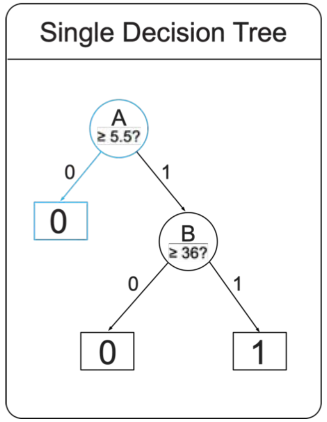


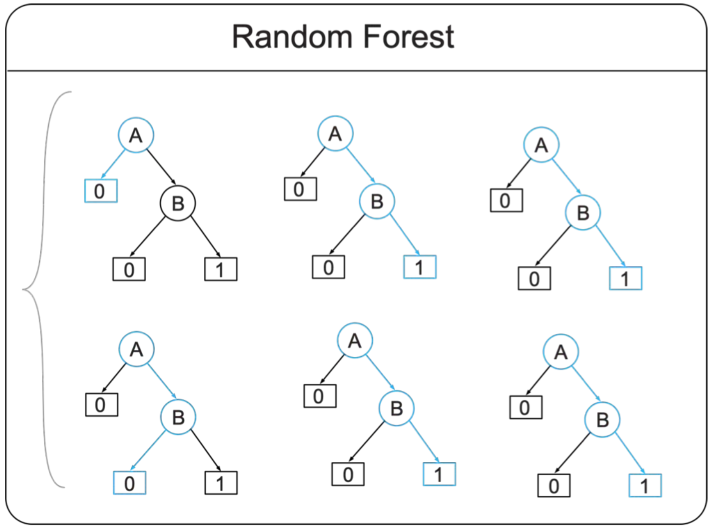
Explainable AI

What? Why? Interpretability vs Explainability



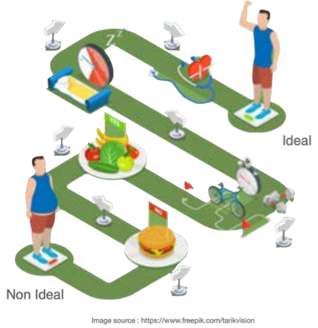
- Developing Methods and Techniques => Results of AI solution can be understood by humans
- Biases and Risks

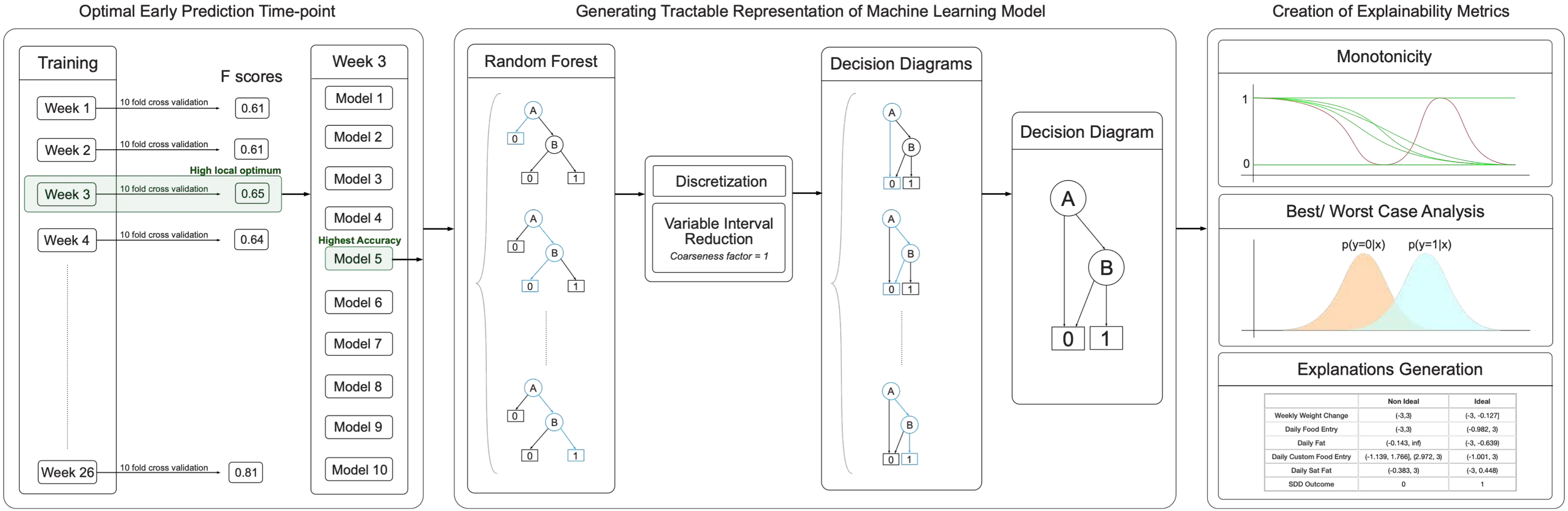




Explainable AI

Overview of work

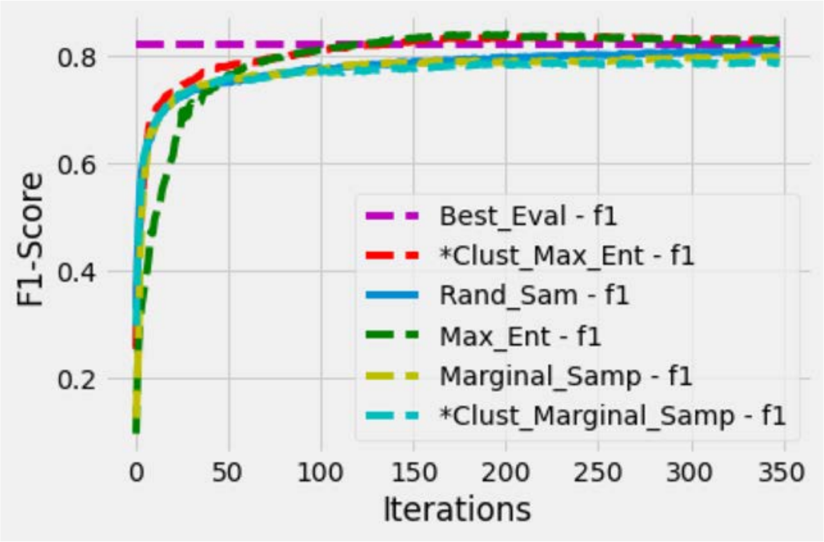




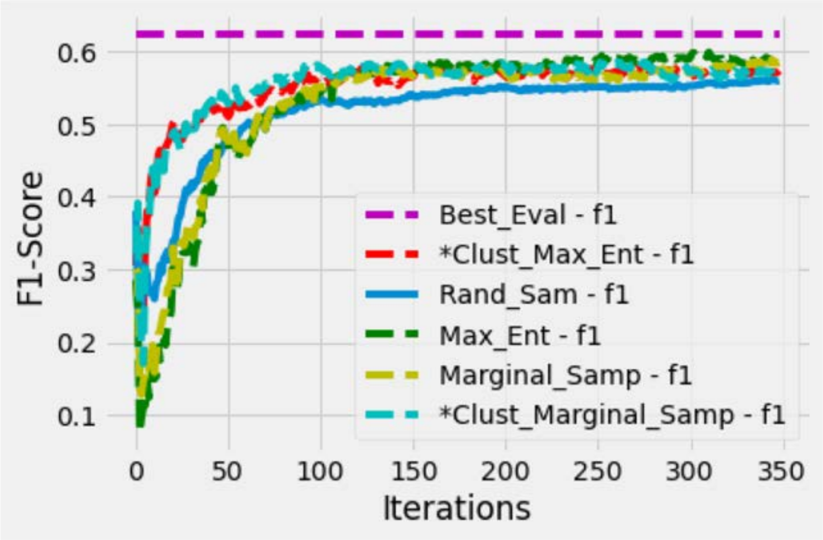
	Non Ideal	Ideal
Weekly Weight Change	(-3,3)	(-3, -0.127]
Daily Food Entry	(-3,3)	(-0.982, 3)
Daily Fat	(-0.143, inf)	(-3, -0.639)
Daily Custom Food Entry	(-1.139, 1.766], (2.972, 3)	(-1.001, 3)
Daily Sat Fat	(-0.383, 3)	(-3, 0.448)
SDD Outcome	0	1

Active Learning and Sample Size

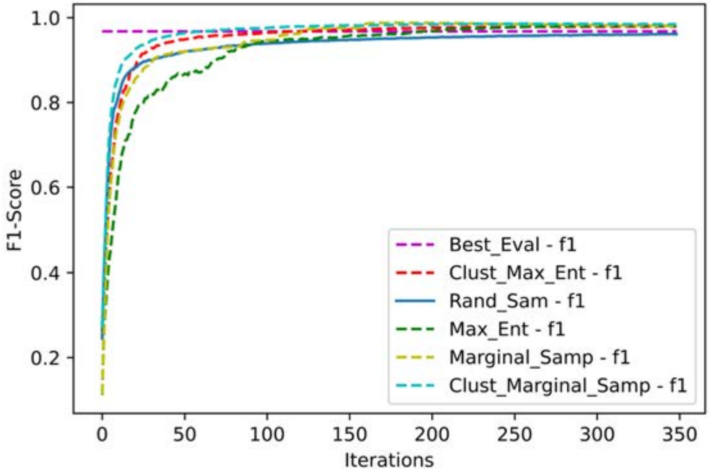
WISDM Dataset



FIC Dataset



UCI HAR Dataset



ACM IMWUT

RESEARCH-ARTICLE

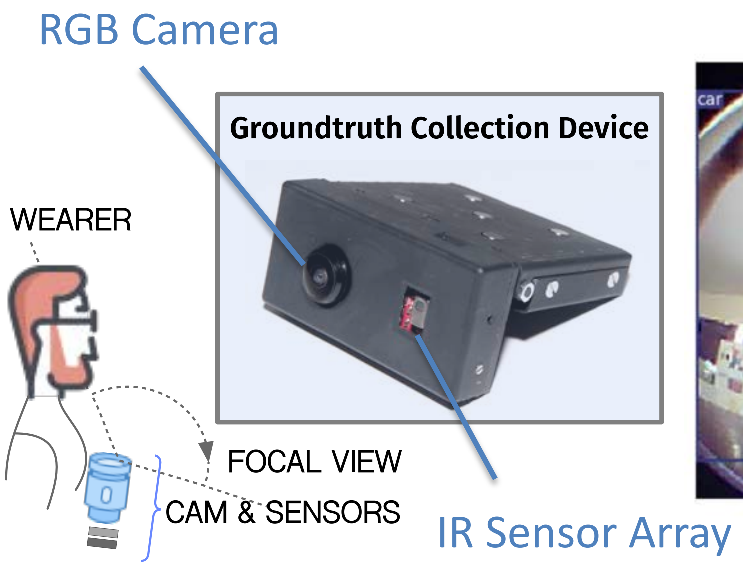
To Mask or Not to Mask?: Balancing Privacy with Visual Confirmation Utility in Activity-Oriented Wearable Cameras

Authors: Rawan Alharbi, Mariam Tolba, Lucia C. Petito, Josiah Hester, Nabil Alshurafa

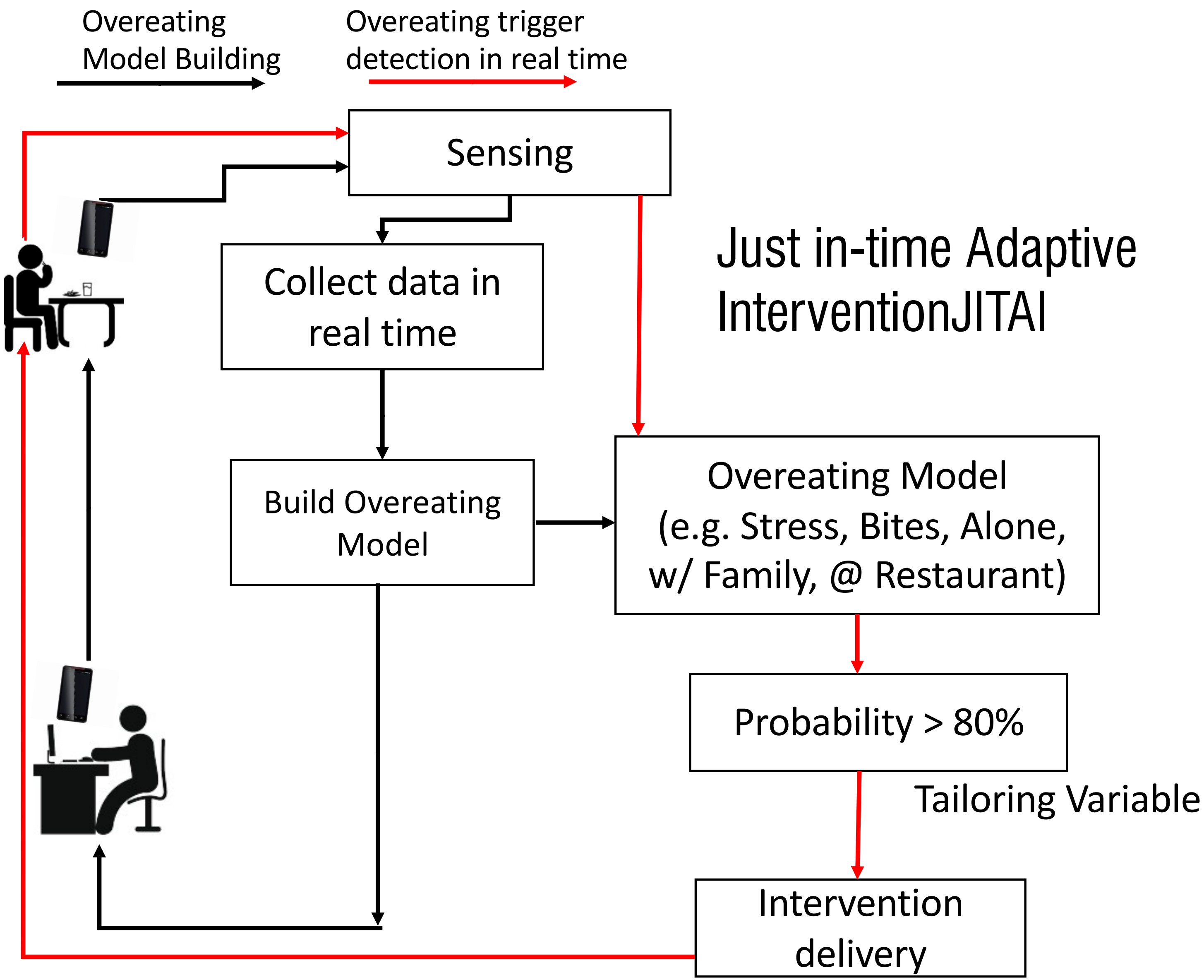
Authors Info & Affiliations

Publication: Proceedings of the ACM on Interactive, Mobile, Wearable and Ubiquitous Technologies • September 2019 • Article No.: 72 • https://doi.org/10.1145/3351230

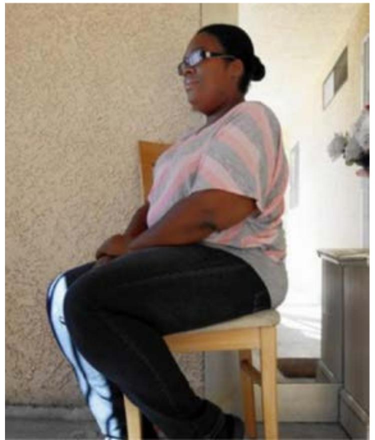
National Institute of Biomedical Imaging and Bioengineering



SenseWhy: Overeating in Obesity Through the Lens of Passive Sensing, K25



- Entirely passive sensing of factors that relate to overeating
- Computer Science
  - Optimization of machine-learned models
- Behavior Science
  - Understanding human behavior through passive sensing



Personalized Medicine

NIH NIDDK

from the lab to the wild

Summary

"The best solution could be an algorithmic model, or maybe a data model, or maybe a combination……

But the trick to being a scientist is to be open to using a wide variety of tools."

L. Breiman

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HABits Lab Students (PhD, Masters, Undergrads)

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Health Aware Bits Lab

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Mentors

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- Lauren Wakschlag, Northwestern University
- John Rogers, Northwestern University
- June Robinson, Northwestern University
- Angela Pfammatter, Northwestern University
- Tammy Stump, Northwestern University

Northwestern Medicine

Northwestern ENGINEERING

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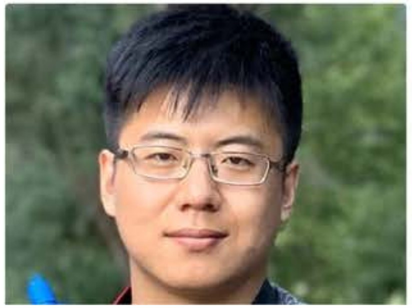

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Health Aware Bits Lab

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