Towards Integration of Wearable Sensors for Clinical Outcomes Research

Bobak Mortazavi
Systems & Technology for Medicine & Internet of Things Lab (STMI)
bobakm@tamu.edu
http://stmi.engr.tamu.edu/

Outline

- Acute Myocardial Infarction and Heart Failure
- Clinical Outcomes Research in Acute Myocardial Infarction Procedures
- Small Data from Big Data for Remote Sensing

NSF ERC

PATHS-UP

Precise Advanced Technologies and Health Systems for Underserved Populations

Vision — To change the paradigm for the health of underserved populations by developing revolutionary and cost-effective technologies and systems at the point-of-care (POC).

Mission

1) To engineer transformative, robust, and affordable, technologies and systems to improve healthcare access, enhance the quality of service and life, and reduce the cost of healthcare in underserved populations.
2) To recruit and educate a diverse group of scientists and engineers who are ready to lead the future in developing enabling technologies to improve health in underserved communities.

Impact — Bringing affordable point-of-care healthcare technologies and systems to urban and rural underserved communities that lack access to care.

Envisioned Transformative Engineered Systems

Lab on a wrist

- Robust and accurate readings
- data provided to the right stakeholder at the right time
- continuous monitoring
- easy to use

Lab in your palm

- accurate and sensitive
- minimal sample preparation
- remote diagnostic capability
- inexpensive

TEXAS A&M UNIVERSITY | UCLA | RICE | FIU FLORIDA INTERNATIONAL UNIVERSITY | NSF

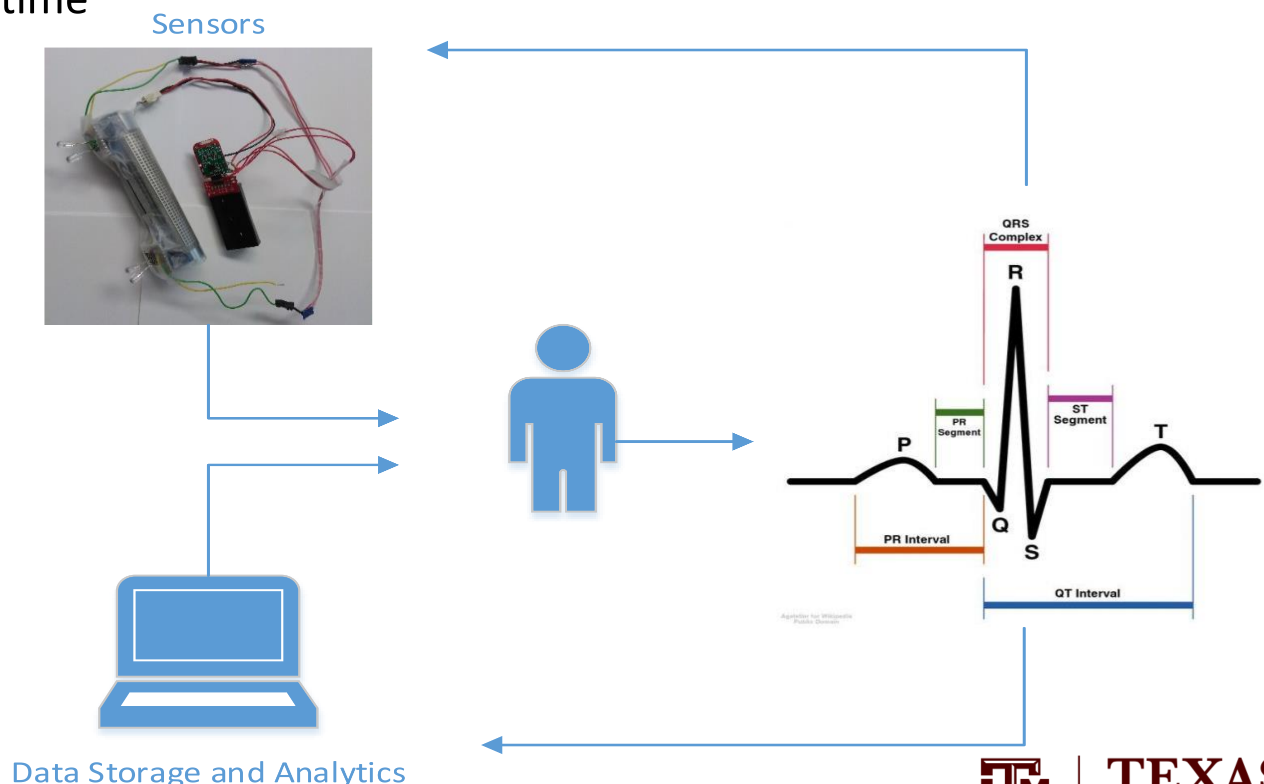
STMI

TEXAS A&M UNIVERSITY

Systems for Personal IOT

Use machine learning models on clinical data to inspire new sensing modalities.

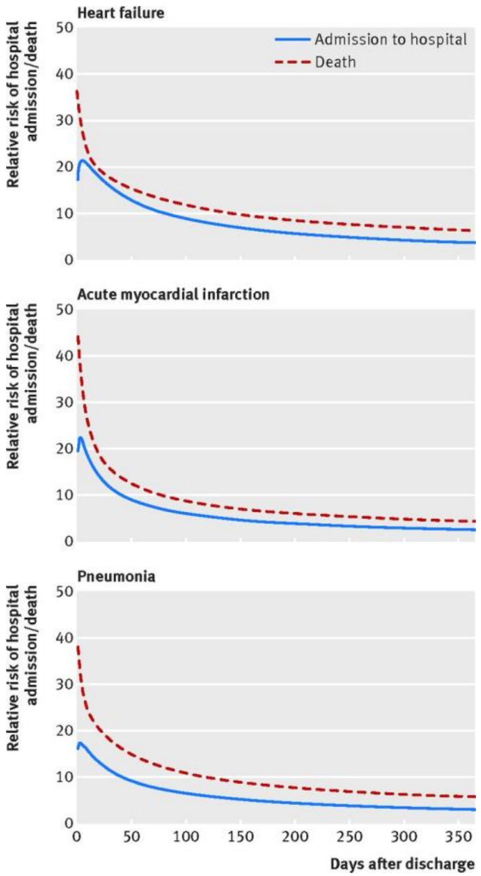
Use personalized data to understand and update models in real-time



STMI

TEXAS A&M UNIVERSITY

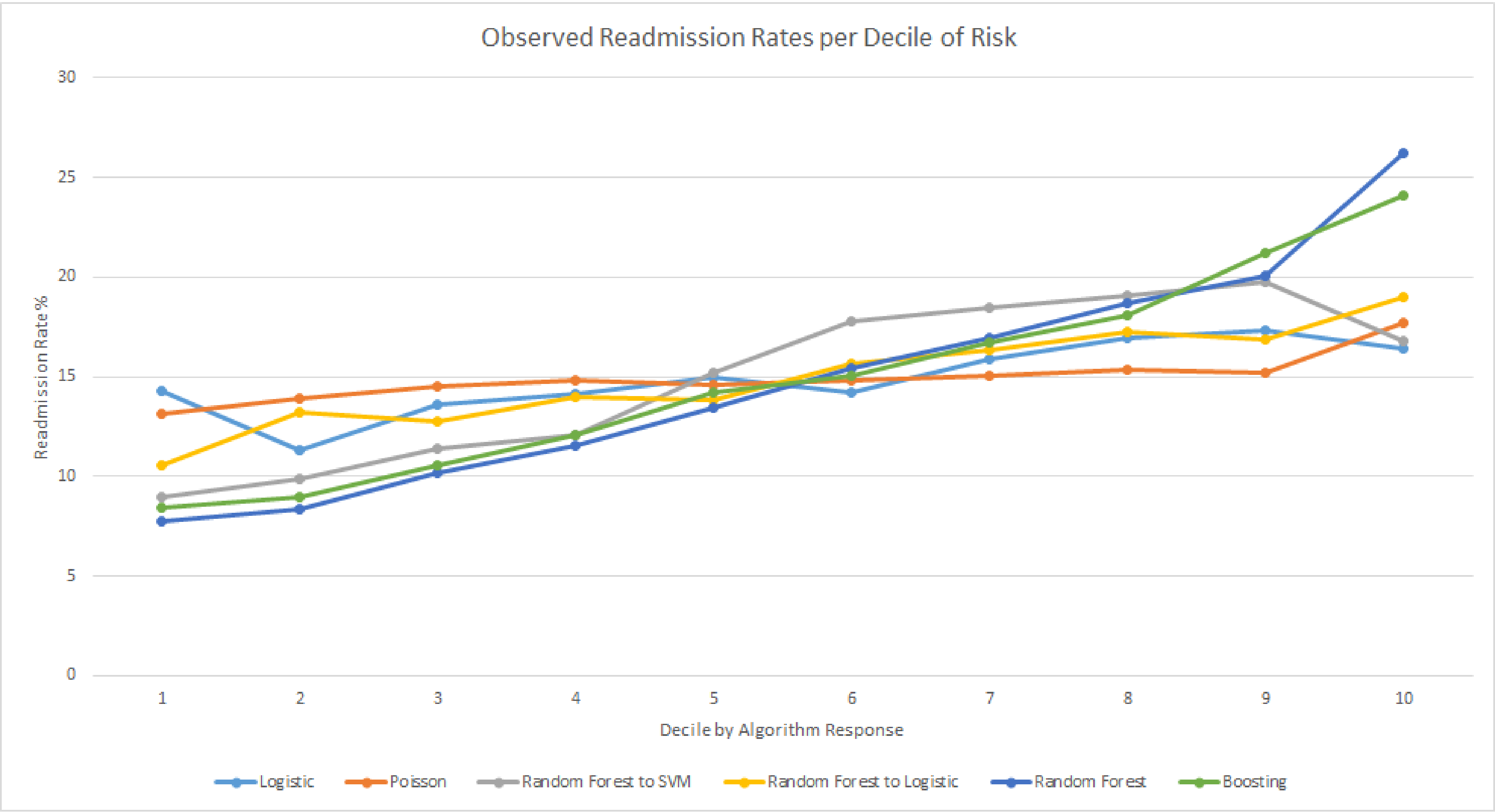
Acute Myocardial Infarction and Heart Failure



(Dharmajan et al. 2015) [1]

- Dharmajan et al. 2015 showed the relative risk for readmission and mortality for a year after hospitalization [1]
- Still, trials that aim to reduce Heart Failure readmissions have been relatively unsuccessful (Tele-HF, Beat-HF) [2][3]
- Big Data/Machine Learning models have modest accuracy in predicting readmissions [4]

Readmission Modeling



(Mortazavi et al 2016) [4]

Heart Failure and Readmissions

- High Readmission rates impose a tremendous burden on patients and healthcare systems. [5]
- Modeling of recovery has been challenging. [6]
- Cardiac rehabilitation programs have shown promise but low adherence
  - Limited program availability, cost of attending, cost of transportation all impact performance [7][8]
  - Home-based program too hard to follow, or approximate too much and lose individual feedback and engagement [9][10]

End-to-end systems

- Start with fit patient trending to unfit
- Unfit patient trending to heart attack
- Heart attack causing damage to the heart muscle
- Heart attack needing operation
- Post-operation recovery

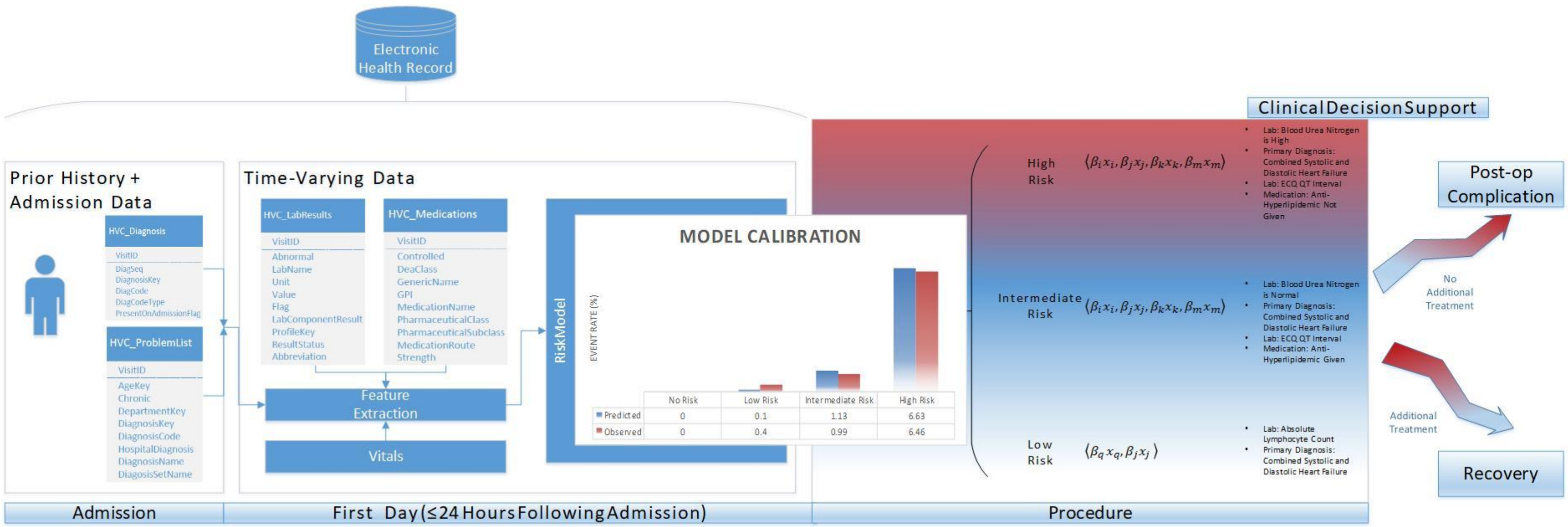
End-to-end systems

- Start with fit patient trending to unfit
- Unfit patient trending to heart attack
- Heart attack causing damage to the heart muscle
- Heart attack needing operation
- Post-operation recovery

STMI

TEXAS A&M UNIVERSITY

Time-Line



(Mortazavi et al, 2017) [11]

STMI

TEXAS A&M UNIVERSITY

Results

TABLE V
BEST MEAN AUC (95% CONFIDENCE INTERVAL (CI), MODEL) FOR PREDICTING RESPIRATORY FAILURE IN PCI PATIENTS

Test Configuration	Mean AUC (95% CI - Model)	Mean F-score	Mean Top 20 Precision
eRI	0.62 (0.53–0.71, GLM)	0.12 (0.01–0.22)	0.04
windowed eRI	0.63 (0.45–0.81, XGB)	0.15 (0.05–0.24)	0.07
lastRI	0.66 (0.59–0.73, GLM)	0.19 (0.10–0.28)	0.11
windowed lastRI	0.67 (0.48–0.85, XGB)	0.17 (0.07–0.27)	0.08
EHR-RI	0.80 (0.70–0.90, RF)	0.24 (0.11–0.37)	0.00
EHR	0.81 (0.70–0.92, RF)	0.25 (0.12–0.37)	0.00

TABLE VIII
BEST MEAN AUC (95% CONFIDENCE INTERVAL (CI), MODEL) FOR PREDICTING INFECTION IN PCI PATIENTS

Test Configuration	Mean AUC (95% CI - Model)	Mean F-score	Top 20 Precision
eRI	0.72 (0.54–0.89, XGB)	0.10 (0.00–0.20)	0.03
windowed eRI	0.71 (0.54–0.88, XGB)	0.11 (−0.05–0.27)	0.01
lastRI	0.64 (0.43–0.84, XGB)	0.10 (−0.01–0.27)	0.02
windowed lastRI	0.61 (0.54–0.88, XGB)	0.13 (−0.06–0.21)	0.02
EHR-RI	0.81 (0.66–0.95, XGB)	0.12 (0.04–0.21)	0.03
EHR	0.83 (0.72–0.93, XGB)	0.14 (0.04–0.23)	0.04

Cardiac Rehabilitation

- Heart Rate and V02
- Exercise
- Resting Heart Rate, Respiration Rate, and Blood Pressure
- First: Must understand variety of measurements, intensities, and context the data is gathered in

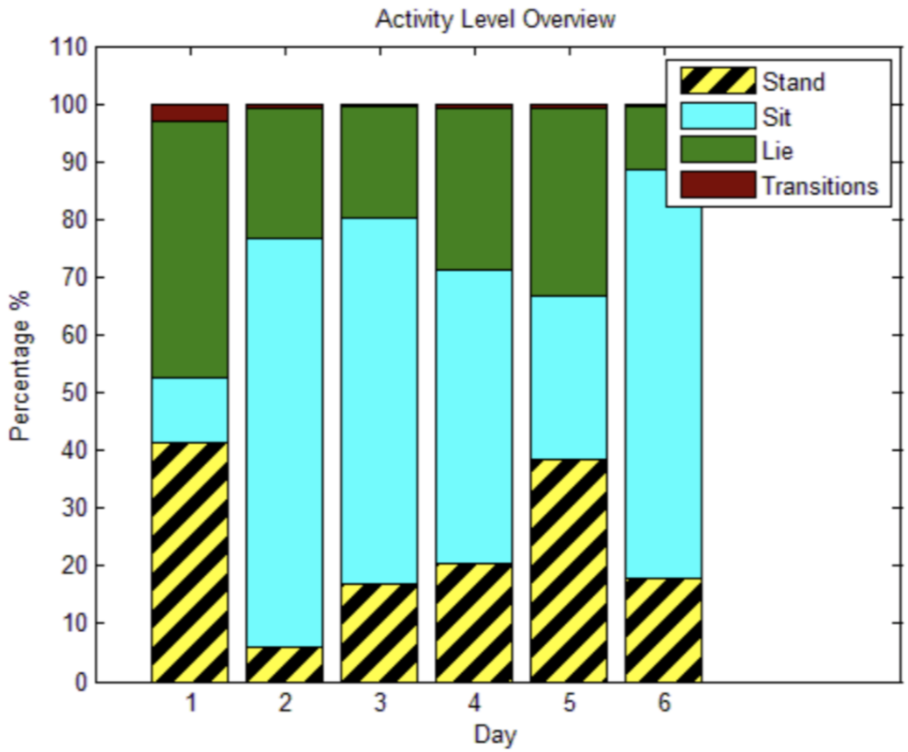
Smartwatch > Smartphones

Table 1. Movements Captured

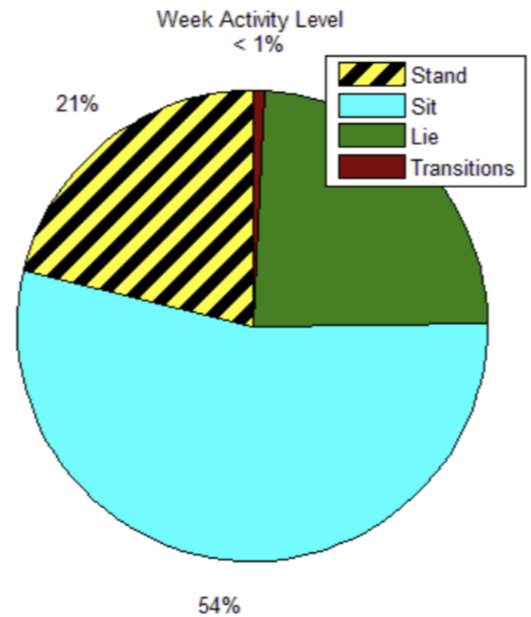
Phase	Movement State	Activity Description
Transitions	Sit - Stand Stand - Sit Sit - Lie Lie - Sit Stand - Lie Lie - Stand	Minimal Movement Transition
Activities of Daily Living	Standing	Using Phone (10 sec) Brushing Teeth (10 sec) Lifting Cup (10 times) Swinging Arms(10 times) Walk (10 sec) Open Door (10 times) Look at Watch (10 times) Clean with broom (10 sec)
	Sitting	Typing (10 sec) Reading Book (10 sec) Brushing Teeth (10 sec) Look at Watch (10 times) Bicep Curl (10 times) Use TV Remote (10 sec)
	Lying	Adjust Pillow (10 sec) Text with phone (10 sec) Adjust in Bed (10 sec) Reading Book (10 sec) Adjust blanket (10 sec)
Walk	Step Forward Step Backward	10 times 10 times

(Mortazavi et al 2015) [12]

Summarization of Data



(**a**) Daily transition and state information of a user from the trial

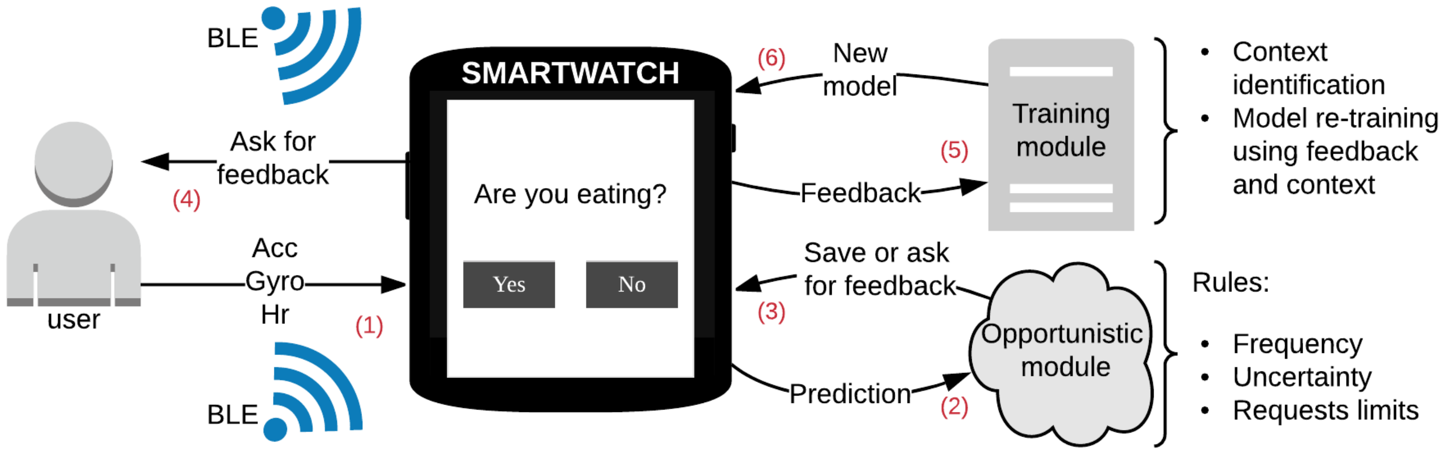


(**b**) Summary of Week

Important Features

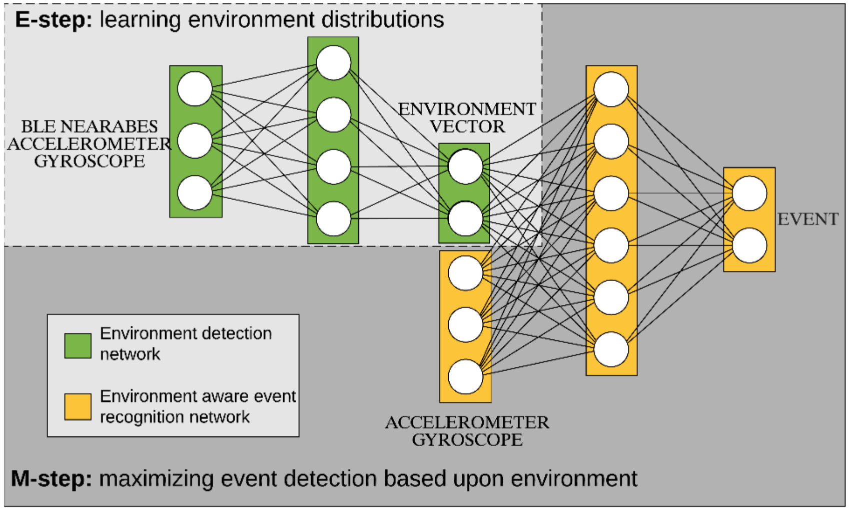
Features 1-10	**11-20**	**21-30**
Average Difference (a_x)	Mean (g_y)	Mean (a_x)
Average Difference (a_z)	Sum (g_y)	Sum (a_x)
Median of Intensity of Gyroscope ($\|\|g\|\|$)	Eigenvalues (a_x)	Dominant Frequency (g_x)
Mean (g_z)	Root Mean Square (a_x)	Energy (g_x)
Sum (g_z)	Energy (a_x)	Root Mean Square(g_x)
Dominant Frequency (g_z)	Root Sum of Squares (a_x)	Root Sum of Squares (g_x)
Energy (g_z)	Standard Deviation (g_z)	Peak Difference (g_y)
Root Sum of Squares (g_z)	Variance (g_z)	Peak Difference (g_x)
Root Mean Square (g_z)	Variance (g_x)	Dominant Frequency (g_y)
Peak Difference (g_z)	Standard Deviation (g_x)	First Peak (g_z)

Understanding the Context



(Solis et al, 2019, IoTDI) [13]

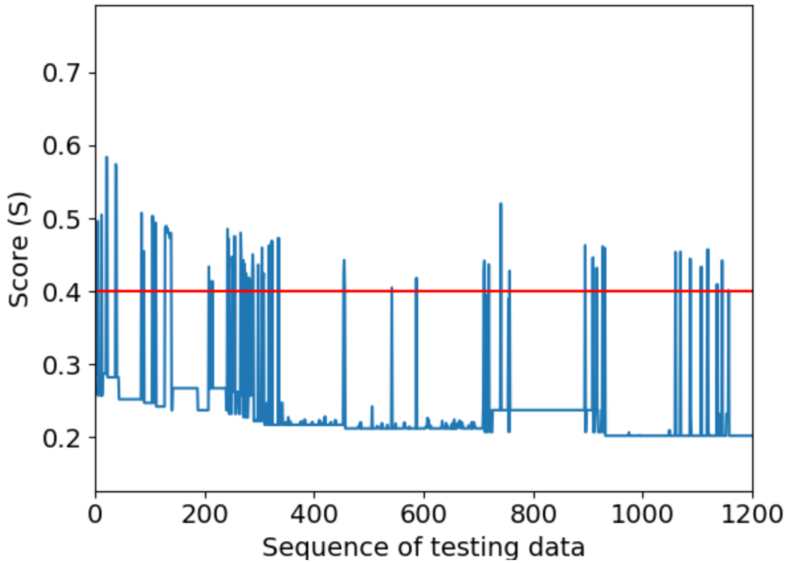
Deep Networks with EM



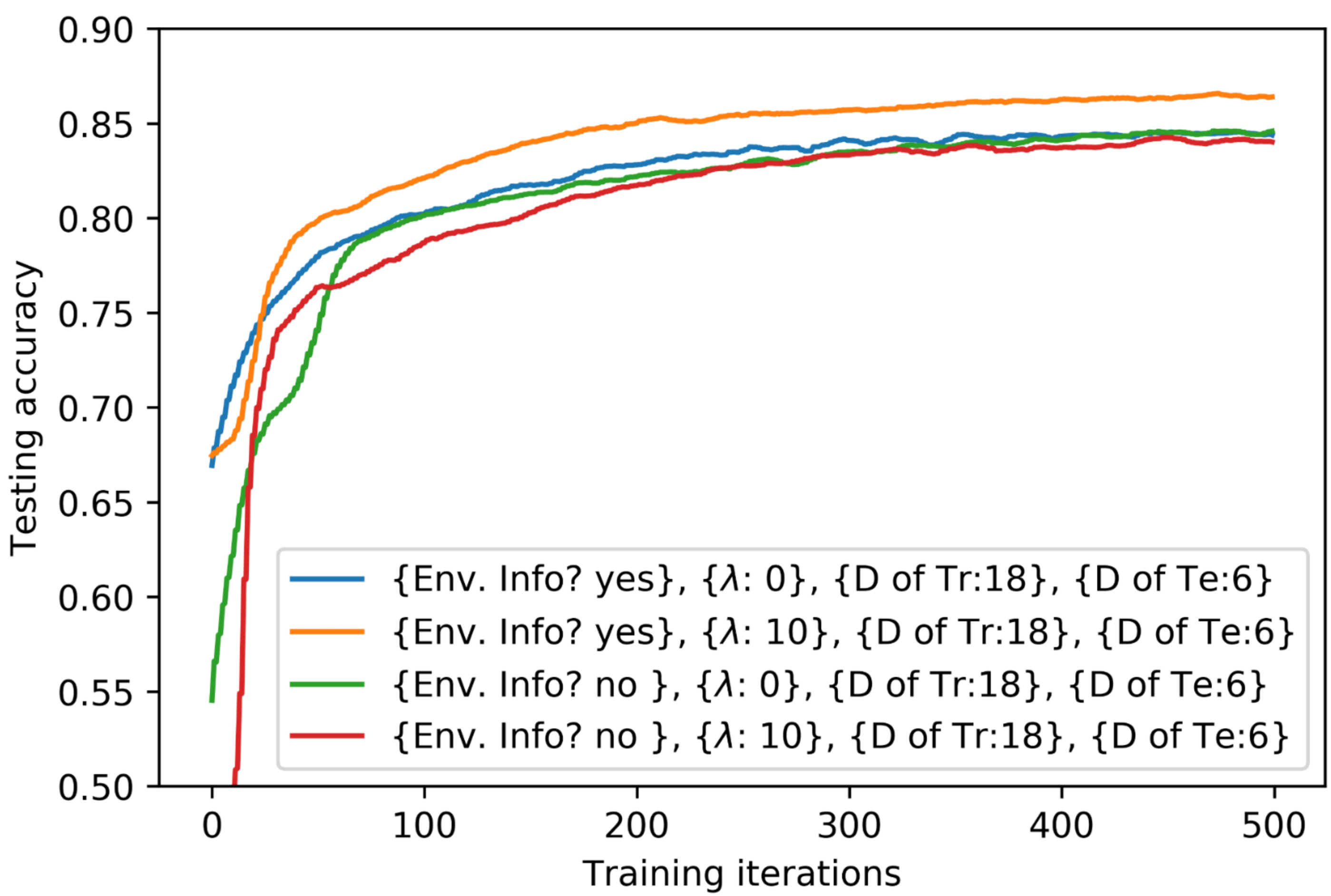
$$
\begin{aligned}
\log P(ACTIVITY|X,\theta) &= \\
\sum_{n=1}^{N} \log \sum_{c=1}^{N_c} P(activity_i, c_i = c|x_i,\theta) \\
\geq \sum_{n=1}^{N} \sum_{c=1}^{N_c} q(c_i = c) \log \frac{P(activity_i, c_i = c|x_i,\theta)}{q(c_i = c)} \\
= \sum_{n=1}^{N} \sum_{c=1}^{N_c} q(c_i = c) \log \frac{P(activity_i|c_i = c, x_i,\theta).P(c_i = c)}{q(c_i = c)} \\
&= \mathcal{L}(\theta, q)
\end{aligned}
$$

Reducing Labeling Burden

$$D(X) = \begin{cases} 0 \quad , \quad \text{if } ||X - \mu_c^X|| < m * \sigma_c^X \quad or \\ \qquad\qquad ||X - \mu_{neighbor}^X|| > n * \sigma_{neighbor}^X \\ \frac{||X - \mu_c^X||}{max(||X - \mu_j^X||)} \quad , \quad \text{otherwise} \end{cases}$$



Activity and Context



References

- [1] Dharmarajan K, Hsieh AF, Kulkarni VT, Lin Z, Ross JS, Horwitz LI, Kim N, Suter LG, Lin H, Normand SL, Krumholz HM. Trajectories of risk after hospitalization for heart failure, acute myocardial infarction, or pneumonia: retrospective cohort study. bmj. 2015 Feb 6;350:h411.
- [2] Chaudhry SI, Mattera JA, Curtis JP, Spertus JA, Herrin J, Lin Z, Phillips CO, Hodshon BV, Cooper LS, Krumholz HM. Telemonitoring in patients with heart failure. New England Journal of Medicine. 2010 Dec 9;363(24):2301-9.
- [3] Ong MK, Romano PS, Edgington S, Aronow HU, Auerbach AD, Black JT, De Marco T, Escarce JJ, Evangelista LS, Hanna B, Ganiats TG. Effectiveness of remote patient monitoring after discharge of hospitalized patients with heart failure: the better effectiveness after transition–heart failure (BEAT-HF) randomized clinical trial. JAMA internal medicine. 2016 Mar 1;176(3):310-8.
- [4] Mortazavi BJ, Downing NS, Bucholz EM, Dharmarajan K, Manhapra A, Li SX, Negahban SN, Krumholz HM. Analysis of machine learning techniques for heart failure readmissions. Circulation: Cardiovascular Quality and Outcomes. 2016 Jan 1:CIRCOUTCOMES-116.
- [5] Kocher RP, Adashi EY. Hospital readmissions and the Affordable Care Act: paying for coordinated quality care. *JAMA*. 2011;306:1794–1795. doi: 10.1001/jama.2011.1561.
- [6] Dharmarajan K, Hsieh AF, Lin Z, Bueno H, Ross JS, Horwitz LI, Barreto-Filho JA, Kim N, Bernheim SM, Suter LG, Drye EE, Krumholz HM. Diagnoses and timing of 30-day readmissions after hospitaliza- tion for heart failure, acute myocardial infarction, or pneumonia. *JAMA*. 2013;309:355–363. doi: 10.1001/jama.2012.216476.
- [7] Jolly K, Taylor RS, Lip GY and Stevens AJIjoc. Home-based cardiac rehabilitation compared with centre-based rehabilitation and usual care: a systematic review and meta-analysis. 2006;111:343-351.
- [8] Dalal HM, Zawada A, Jolly K, Moxham T and Taylor RSJB. Home based versus centre based cardiac rehabilitation: Cochrane systematic review and meta-analysis. 2010;340:b5631.
- [9] Rawstorn JC, Gant N, Rolleston A, Whittaker R, Stewart R, Benatar J, Warren I, Meads A, Jiang Y, Maddison RJAopm and rehabilitation. End Users Want Alternative Intervention Delivery Models: Usability and Acceptability of the REMOTE-CR Exercise-Based Cardiac Telerehabilitation Program. 2018.
- [10] Rawstorn JC, Gant N, Meads A, Warren I and Maddison R. Remotely Delivered Exercise-Based Cardiac Rehabilitation: Design and Content Development of a Novel mHealth Platform. *JMIR mHealth and uHealth*. 2016;4:e57.
- [11] Mortazavi BJ, Desai N, Zhang J, Krumholz HM, inventors; Yale-New Haven Health Services Corp, assignee. Prediction of adverse events in patients undergoing major cardiovascular procedures. United States patent application US 15/894,040. 2018 Nov 1.
- [12] Mortazavi B, Nemati E, VanderWall K, Flores-Rodriguez HG, Cai JY, Lucier J, Naeim A, Sarrafzadeh M. Can smartwatches replace smartphones for posture tracking?. Sensors. 2015 Oct 22;15(10):26783-800.
- [13] Solis, R, Pakbin, A., Akbari, A., Mortazavi, B., Jafari, R. A Human-centered Wearable Sensing Platform with Intelligent Automated Data Annotation Capabilities. *ACM/IEE Conference on Internet of Things Design and Implementation*. April, 2019.

Questions?

- bobakm@tamu.edu