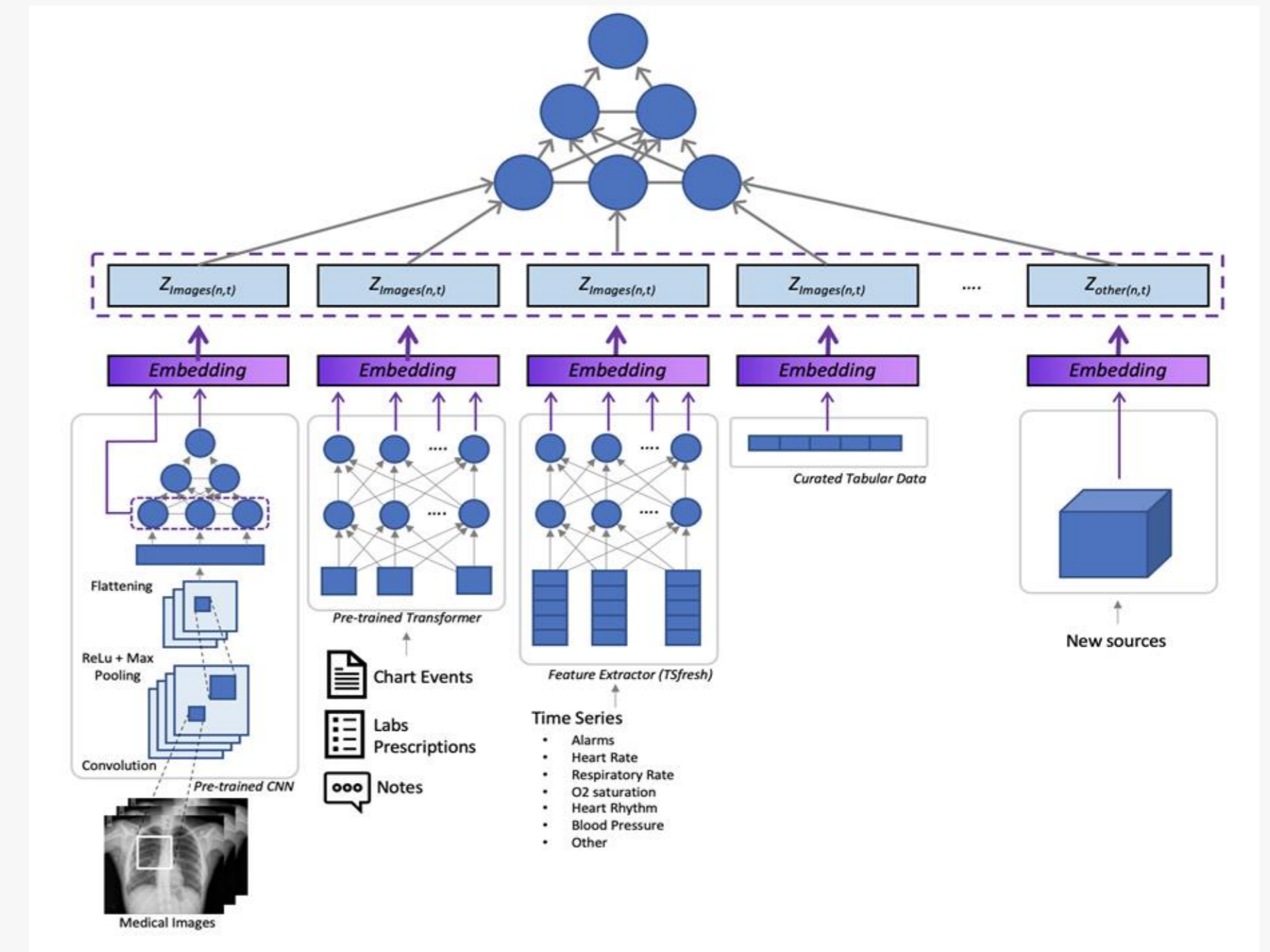


HAIM: Holistic AI for Medicine

An application of Multimodal AI



- Motivation
- Holistic AI for Medicine (HAIM)
- HAIM in action at Hartford Health care System
- Other areas

- Let us think how medical **doctors make decisions**
- They utilize:
 - scans** (MRIs, CTs, Xrays, etc.)
 - language** (radiology reports, doctors and nurses notes)
 - tabular data** (electronic medical records)
 - time series, genomic information**
- Can machines use **multimodal data** to make medical diagnoses and decisions?

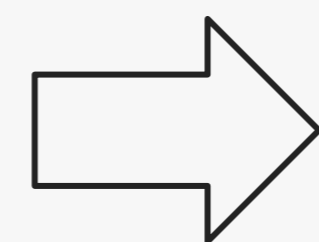
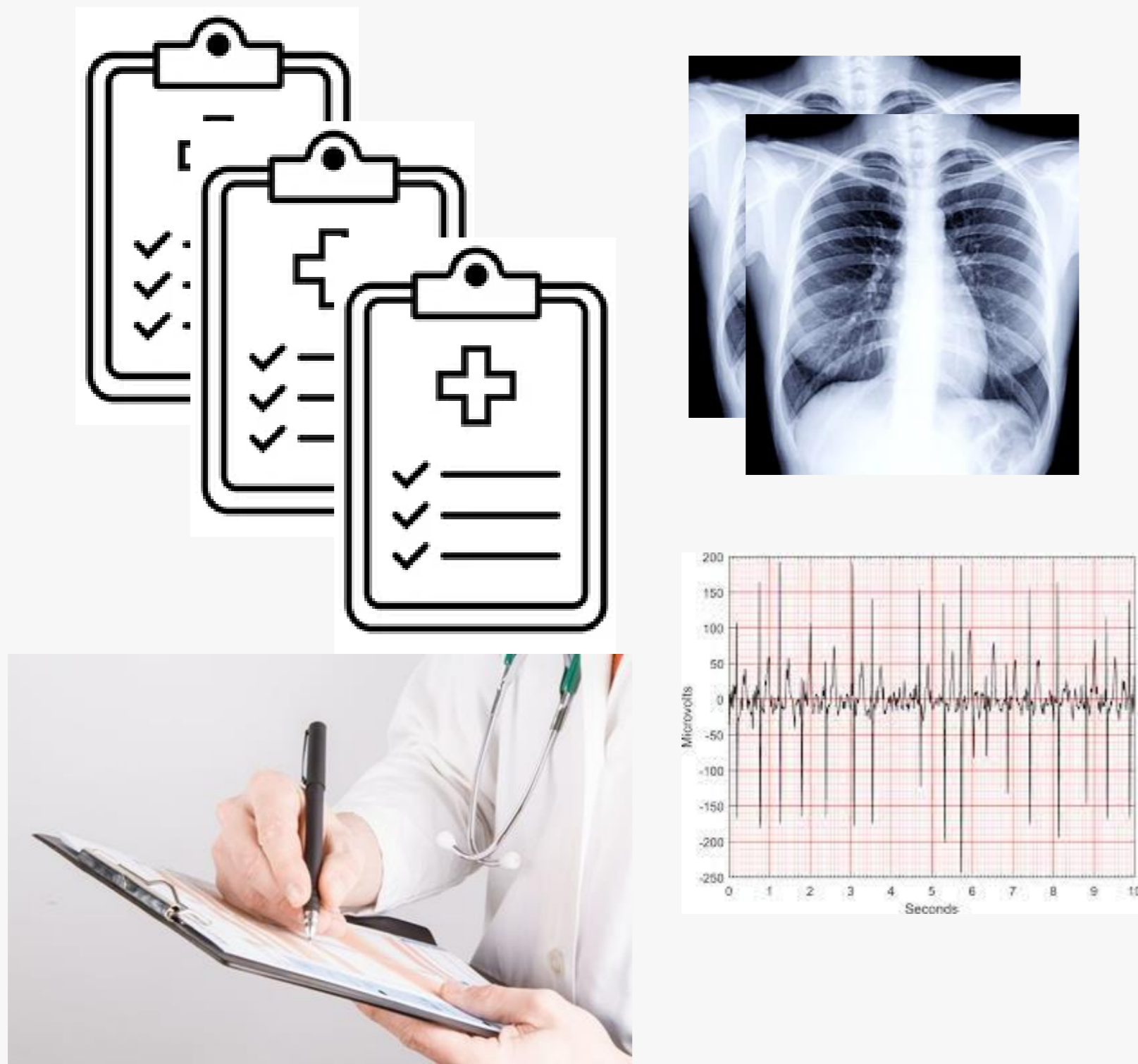
- The five basic human **senses**:
touch, sight, hearing, smell and taste
- **Multi-modality** is a fundamental characteristic of **human Life**
- **Why** not for Machines?

- **Integrated multimodal** artificial intelligence framework for healthcare applications

Luis R. Soenksen, Yu Ma, Cynthia Zeng, Leonard D.J. Boussioux, Kimberly Villalobos Carballo, Liangyuan Na, Holly M. Wiberg, Michael L. Li, Ignacio Fuentes, Dimitris Bertsimas

- **Nature Digital Medicine**, September 2022.

- The Story of **IBM Watson**
- Can we use a **holistic perspective** of AI (computer vision, NLP, ML) to improve the ability of models to make predictions and prescriptions in Medicine?



HAIM

Unified Patient
Information
Representation

Notes

e Events

Procedur

Lab,

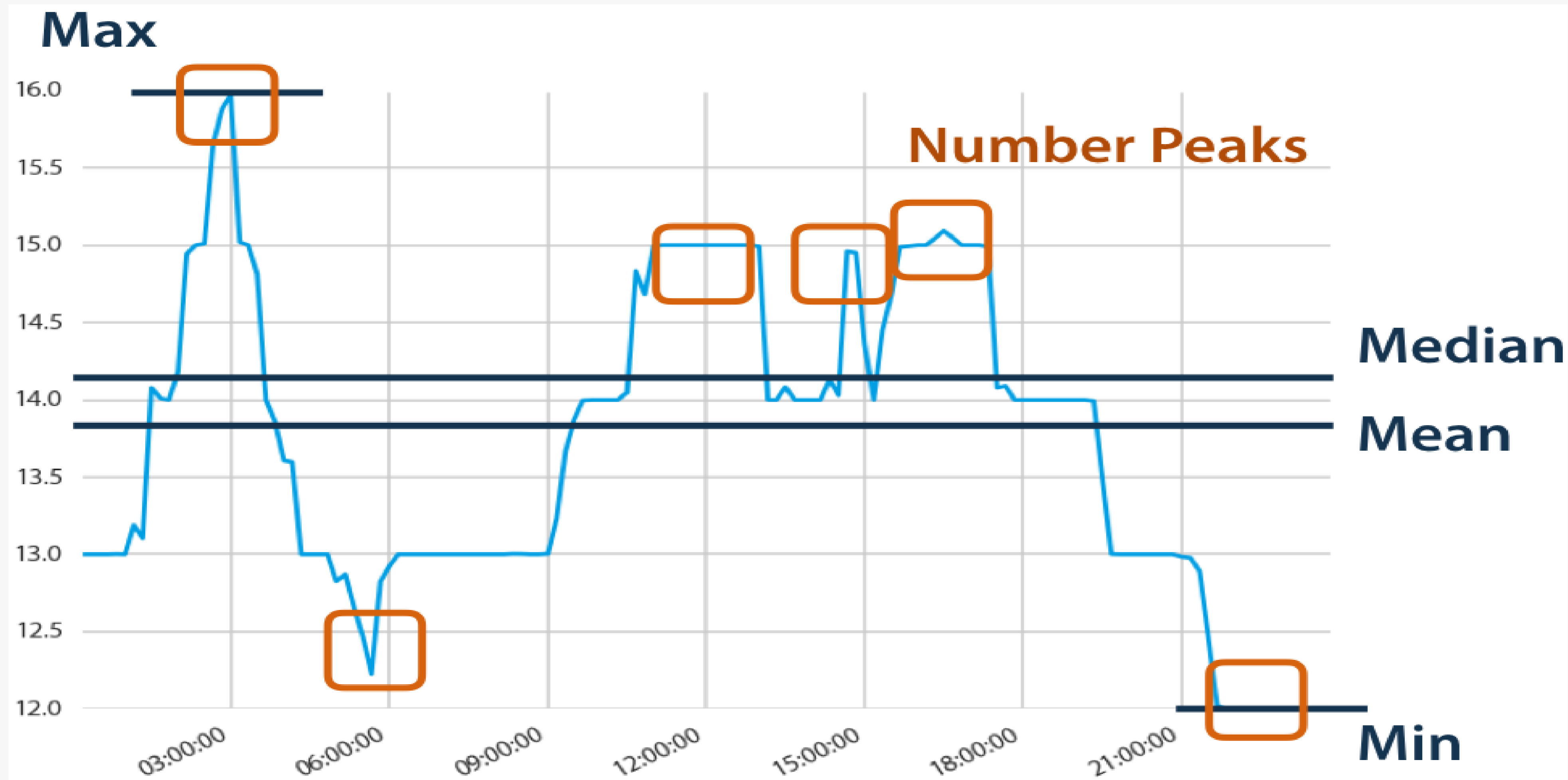
Chart,

XRays

CG

Structured (Tabular) EHR Data

charttime	storetime	itemid	value	valuenum	valueuom	warning	label	abbreviation	linksto	category	unitname	param_type
2167-11-07 20:00:00	2167-11-07 20:35:00	220045.0	57	57.0	bpm	0.0	Heart Rate	HR	chartevents	Routine Vital Signs	bpm	Numeric
2167-11-07 20:00:00	2167-11-07 20:29:00	220046.0 ↓	120	120.0	bpm	0.0	Heart rate Alarm - High	HR Alarm - High	chartevents	Alarms	bpm	Numeric
2167-11-07 20:00:00	2167-11-07 20:29:00	220047.0	50	50.0	bpm	0.0	Heart Rate Alarm - Low	HR Alarm - Low	chartevents	Alarms	bpm	Numeric
2167-11-07 20:00:00	2167-11-07 20:35:00	220210.0	19	19.0	insp/min	0.0	Respiratory Rate	RR	chartevents	Respiratory	insp/min	Numeric
2167-11-07 20:00:00	2167-11-07 20:35:00	220277.0	98	98.0	%	0.0	O2 saturation pulseoxymetry	SpO2	chartevents	Respiratory	%	Numeric
...



Time	Sample Event Strings
Day 1	'Education Readiness/Motivation: High'
Day 1	'Troponin T: 0.13 ng/mL, Warning: outside normal'
Day 2	'Respiratory Rate: 23 insp/min'
Day 3	'Platelet Count: 217 K/luL'

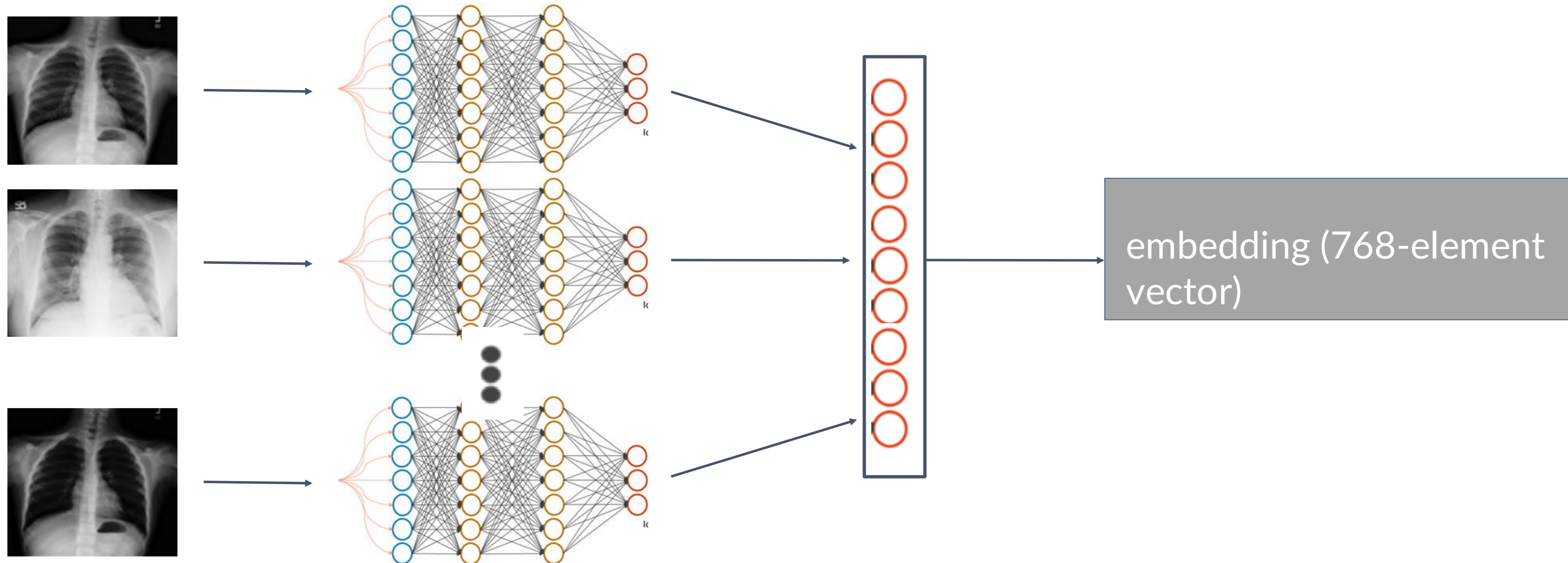
Patient Summary:
Education Readiness/Motivation: High.
Troponin T: 0.13 ng/mL, Warning: outside normal. Respiratory Rate: 23 insp/min.
Platelet Count: 217 K/luL.

BioBERT embedding
(768-element vector)

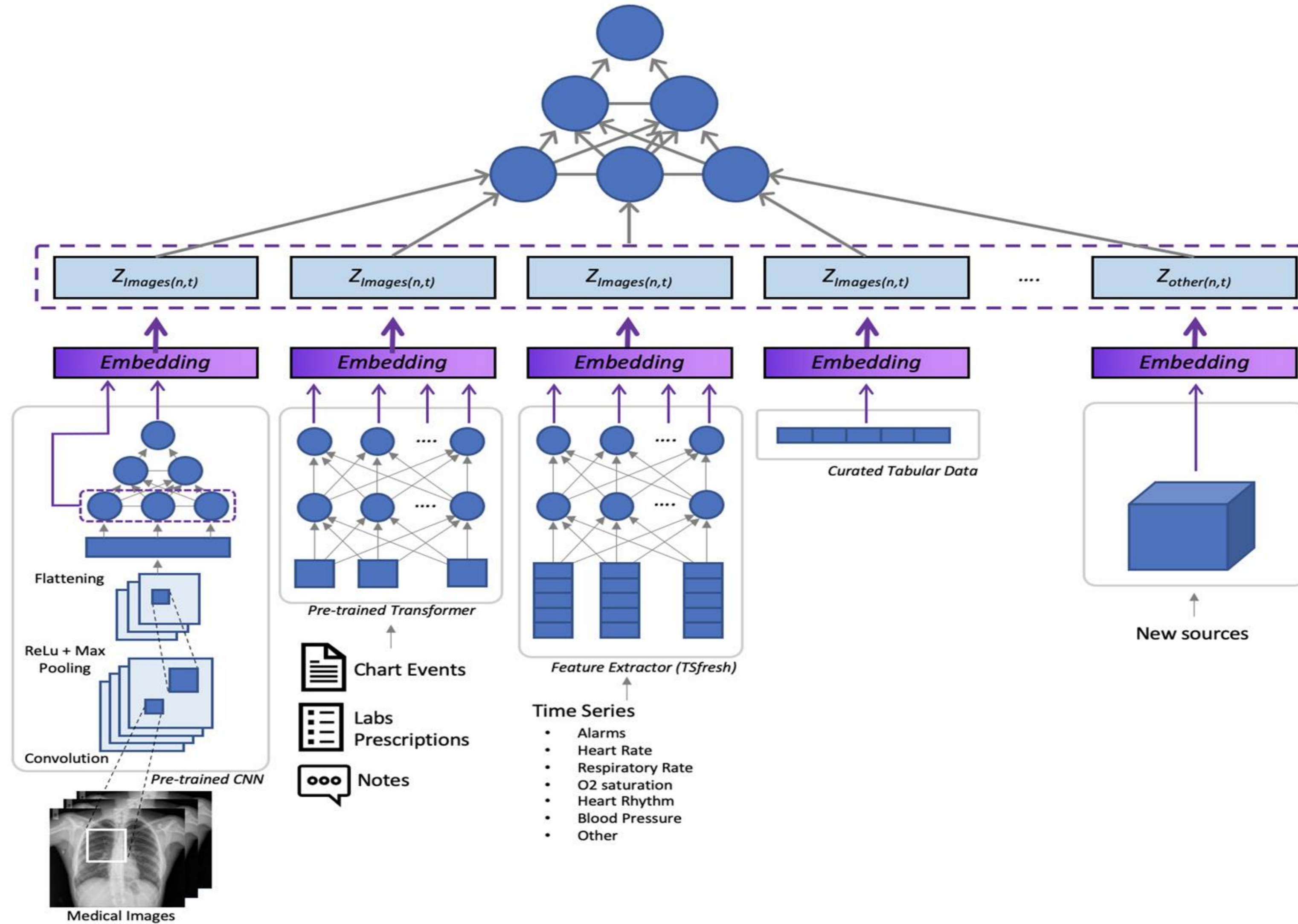
Clinical indication for ECG: I51.9 - Ill-defined symptoms of heart disease. Regular supraventricular tachycardia, most likely sinus tachycardia. Non-specific intraventricular conduction delay. Diffuse non-specific ST-T wave abnormalities. Compared to tracing #1 sinus tachycardia has replaced sinus rhythm with frequent premature atrial contractions and premature ventricular contractions.

BioBERT embedding (768-element vector)

Images

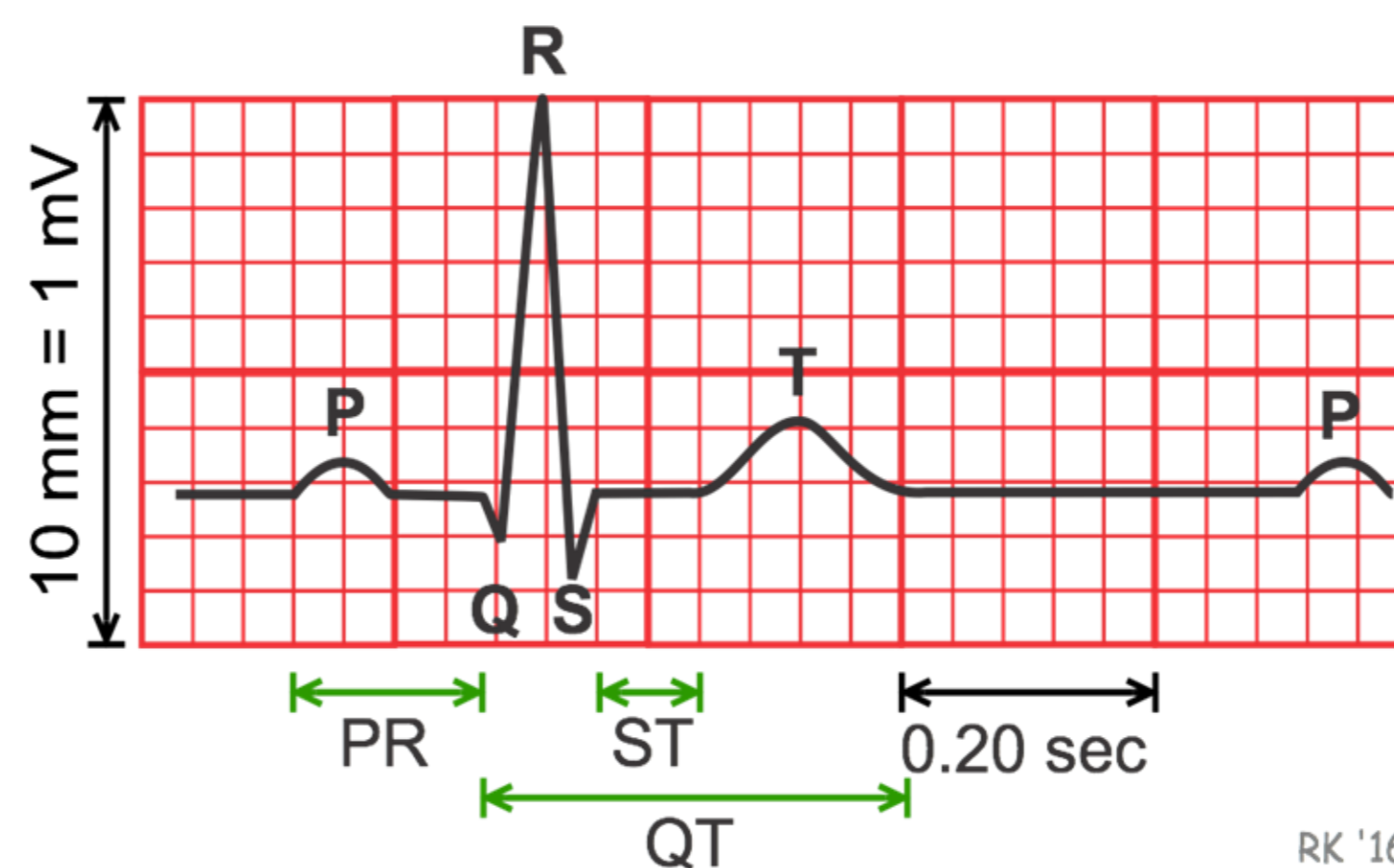
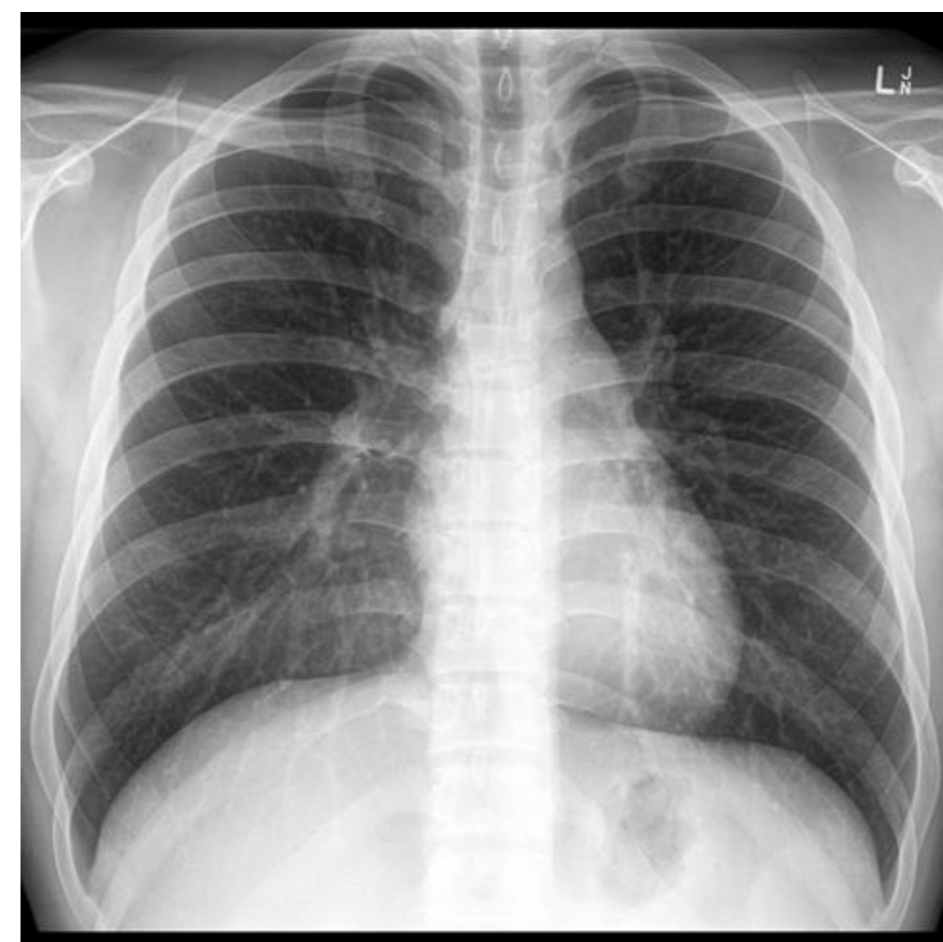


Unified HAIM framework



The MIMIC-IV Dataset

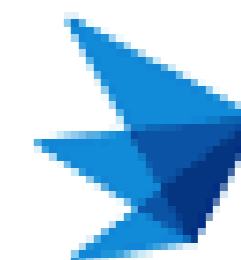
- Ample sample size: 34,537 patient records
- Patients of the emergency ICU rooms
- Records gathered from Beth Israel Deaconess Medical Center
- Data of multiple-modalities including:
 - Chest X-RAY
 - EHR
 - Radiology notes
 - ECG



Impression
Left lower lobe consolidation (comm
pneumonia)

Plan
1) Maintain O2 saturations between
2) Sputum culture
3) Blood culture
4) Commence antibiotic therapy:
• Amoxicillin 500mg PO TDS -
• Clarithromycin PO 500mg B1

RK '16



Targets



- **Mortality Prediction**
- Predict if patient is deceased/sent to hospice or alive at their hospital discharge



- **Diagnosis**
- Predict if patient has a certain disease
- Fracture, Lung Lesion, Enlarged CM, Consolidation, Pneumonia, Atelectasis, Lung Opacity, Pneumothorax, Edema, Cardiomegaly



- **Length of Stay**
- Predict if patient exits hospital in 48 hours

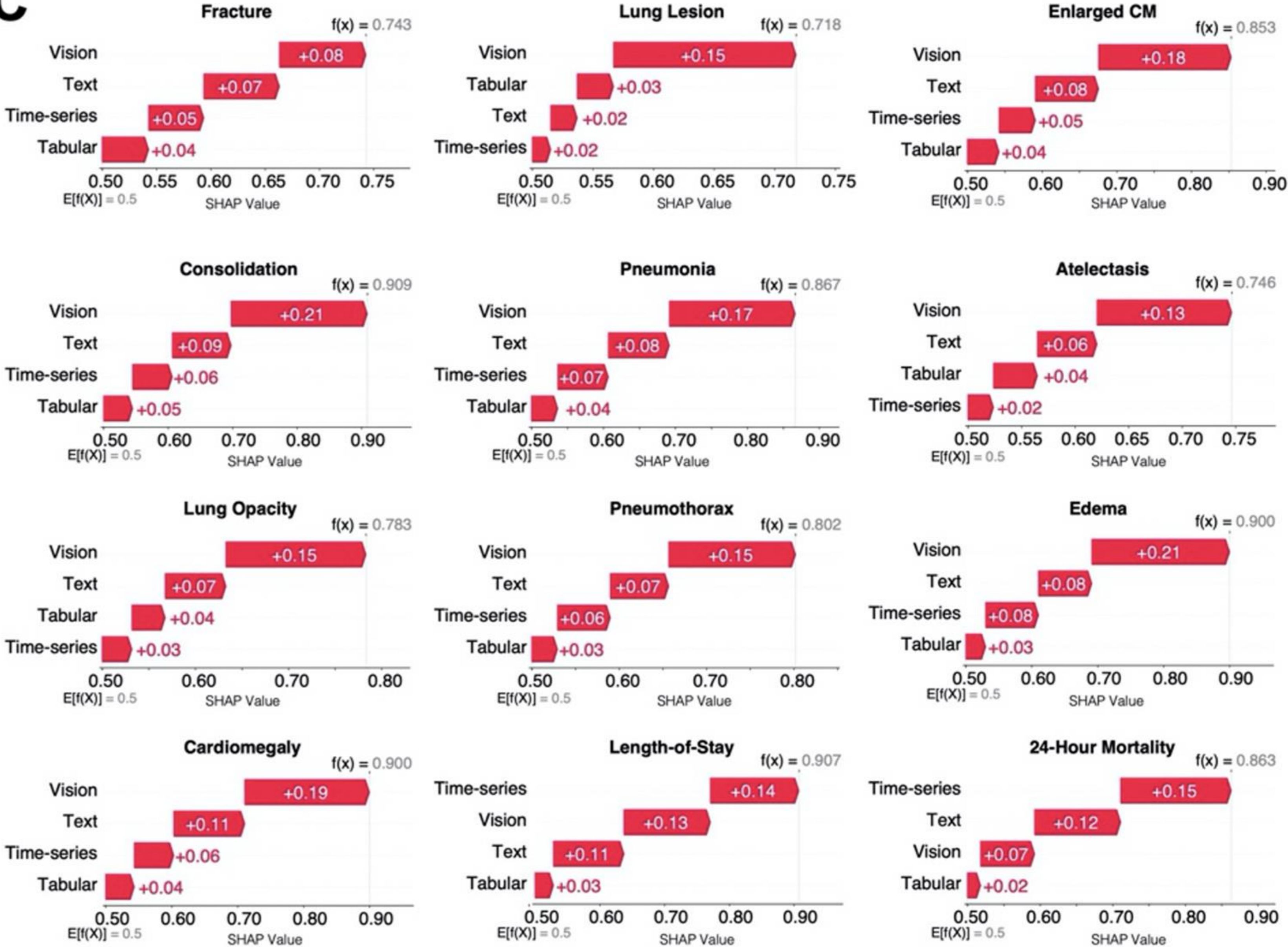
HAIM Significantly Outperforms Single Modality



Goal	HAIM
Mortality Prediction	11-33% Improvement
Disease Classification	6-22% Improvement
Length of Stay	8-20% Improvement

SHAP Analysis

C



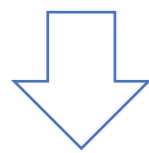
Application of HAIM at Hartford Healthcare System

- Largest hospital system in Connecticut
- Operating revenue of \$5 billion
- 7 diverse hospitals, ranging from academic to community, from large to small (total ~2500 beds)
- Representative of typical US hospital networks



Highlight on Practical Implementation

Deployment



Deployed an end-to-end software in production

Control Center Irre Iyna

Select Account

- HHC HH Hartford Hospital
- HHC HOCC The Hospital of Central Connecticut
- HHC BH Backus Hospital
- HHC CH Charlotte Hungerford Hospital
- HHC MMC Midstate Medical Center
- HHC SV St. Vincent's Medical Center
- HHC WH Windham Hospital

Hartford HealthCare

Application List

- Block Optimization
- Length of Stay
- ED Nurses
- Identity & Access Management

Impact

- Hundreds of users (physicians, nurses, etc.)
- Assists with operational decisions daily at 7 hospitals
- Projected annual revenue uplift in millions of dollars
- Scaling to other hospital systems in the world

Problem & Motivation

Develop and implement machine learning models to predict patient operational characteristics

Discharge next 24 hr & 48 hr

Final destination

Mortality risk

ICU risk next 24 hr & 48 hr

for all patients hospitalized in Hartford HealthCare

Provide clinical and operational assistance

Identify and prioritize patients

Reduce length of stay and save costs

Prepare for treatment and disposition plans

Warn possible deteriorations

Allocate hospital resources

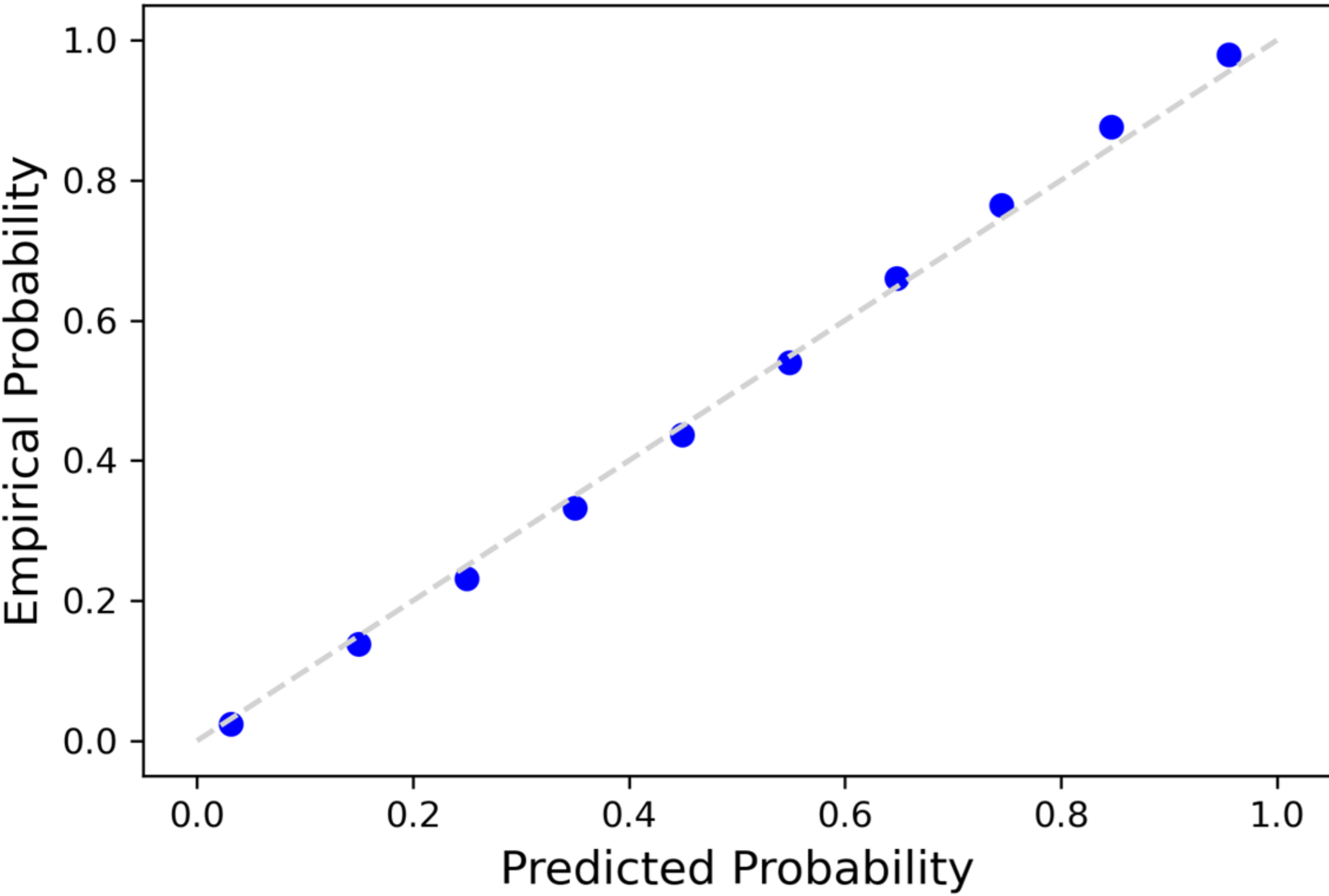
for physicians, nurses, case and bed managers

AUC Metrics for All 7 Hospitals

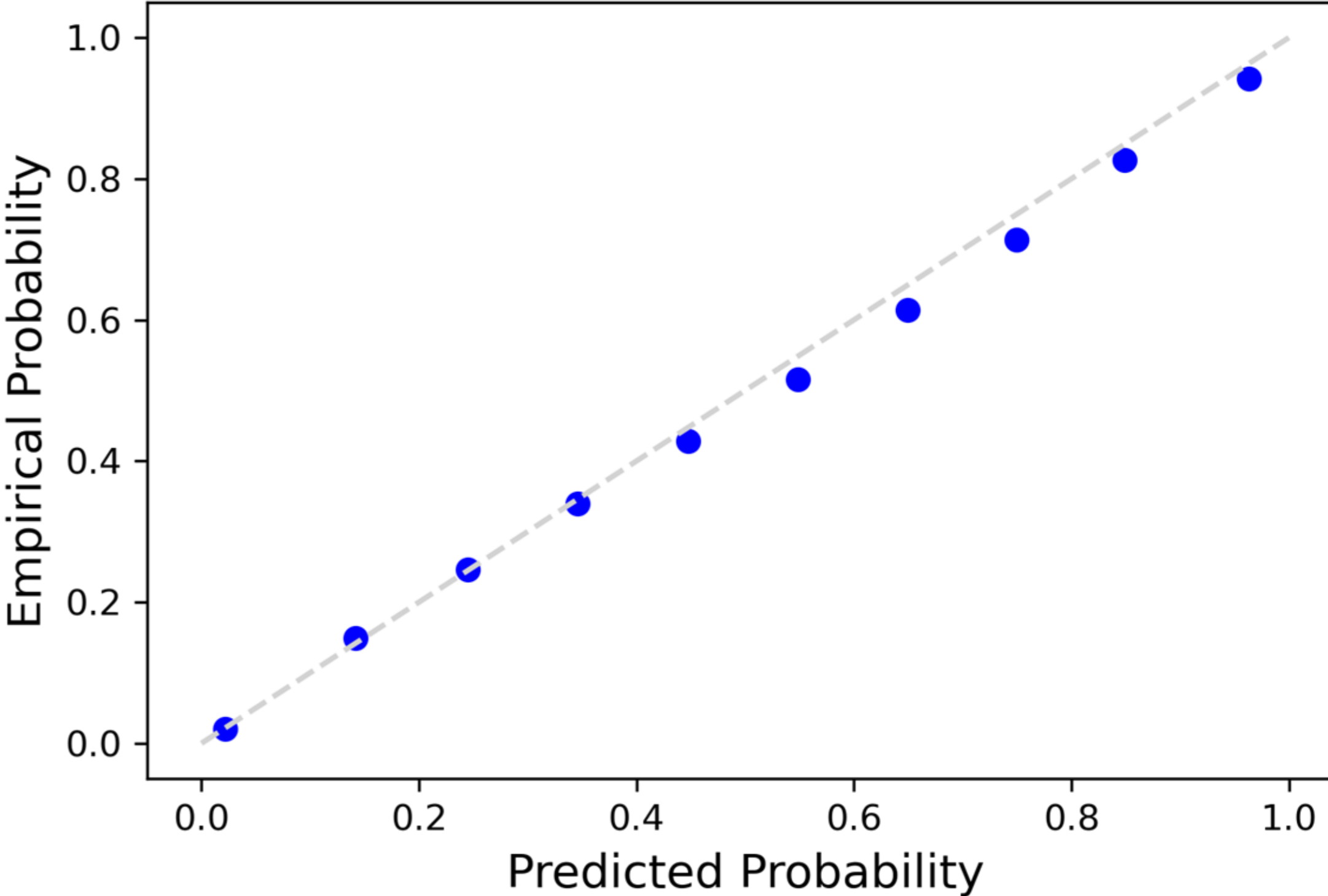
		HH	CH	BH	HOCC	MMC	SV	WH
Mortality		0.915	0.902	0.919	0.905	0.925	0.902	0.888
Destination		0.858	0.871	0.884	0.884	0.879	0.869	0.802
Discharge	In 1 day	0.832	0.812	0.857	0.844	0.837	0.848	0.768
	In 2 days	0.830	0.816	0.852	0.843	0.836	0.841	0.757
Enter ICU	In 1 day	0.867	0.853	0.868	0.868	0.872	0.850	No ICU unit
	In 2 days	0.834	0.813	0.818	0.811	0.847	0.812	
Leave ICU	In 1 day	0.896	0.830	0.871	0.883	0.887	0.820	
	In 2 days	0.896	0.848	0.865	0.880	0.876	0.833	

Probabilities Calibration

Calibration Curve - 48hr Discharge



Calibration Curve - Mortality



Predicted probabilities closely match empirical evidence.

Demo - Software in Production

Home Length of Stay

Alert: None Patient ENC CSN ID: Patient MRN ID Department Name: HH BLISS 7 EAST Service: Choose a date: 2/22/2022 Search

DAY OF EXTRACTION	ALERT	PAT MRN ID	TRANSITION PREDICTION RISK OF MORTALITY TODAY	CHANGE PROBABILITY MORTALITY FROM YESTERDAY	PROBABILITY DISCHARGE NEXT1DAYS XGB	PROBABILITY DISCHARGE NEXT2DAYS XGB	CHANGE PROBABILITY DISCHARGE FROM YESTERDAY	PREDICTION FINAL DESTINATION XGBOOST	PROBABILITY INICU NEXT1DAYS XGB	PROBABILITY INICU NEXT2DAYS XGB	EDD CHARTED DTTM	EXP DISCHARGE DATE
Feb 22, 2022	Red		0.376	0.035	0.039	↓ 0.269	-0.189	Home with service / Other facilities	0.043	0.06		2022-02-22
Feb 22, 2022			0.093	0.006	0.292	0.425	0.012	Home with service / Other facilities	0.004	0.011	2022-02-21	2022-02-23
Feb 22, 2022			0.074	0.024	0.003	↓ 0.08	-0.273	Home with service / Other facilities	0.023	0.047	2022-02-21	2022-02-22
Feb 22, 2022	Green		0.049	-0.006	0.713	0.81	0.034	Home with service / Other facilities	0.002	0.004	2022-02-21	2022-02-21
Feb 22, 2022	Yellow		0.022	-0.039	0.186	0.422	0.195	Home with service / Other facilities	0.012	0.014		2022-02-23
Feb 22, 2022	Red		0.46	-0.095	0.023	0.222	0.082	Home with service / Other facilities	0.014	0.026		2022-02-23
Feb 22, 2022			0.012	0.002	0.425	↓ 0.483	-0.148	Home with service / Other facilities	0.004	0.006		2022-02-22
Feb 22, 2022	Green		0.006	-0.001	0.74	0.844	0.168	Home without service	0.002	0.004	2022-02-21	2022-02-22

Items per page: 20 1 - 16 of 16

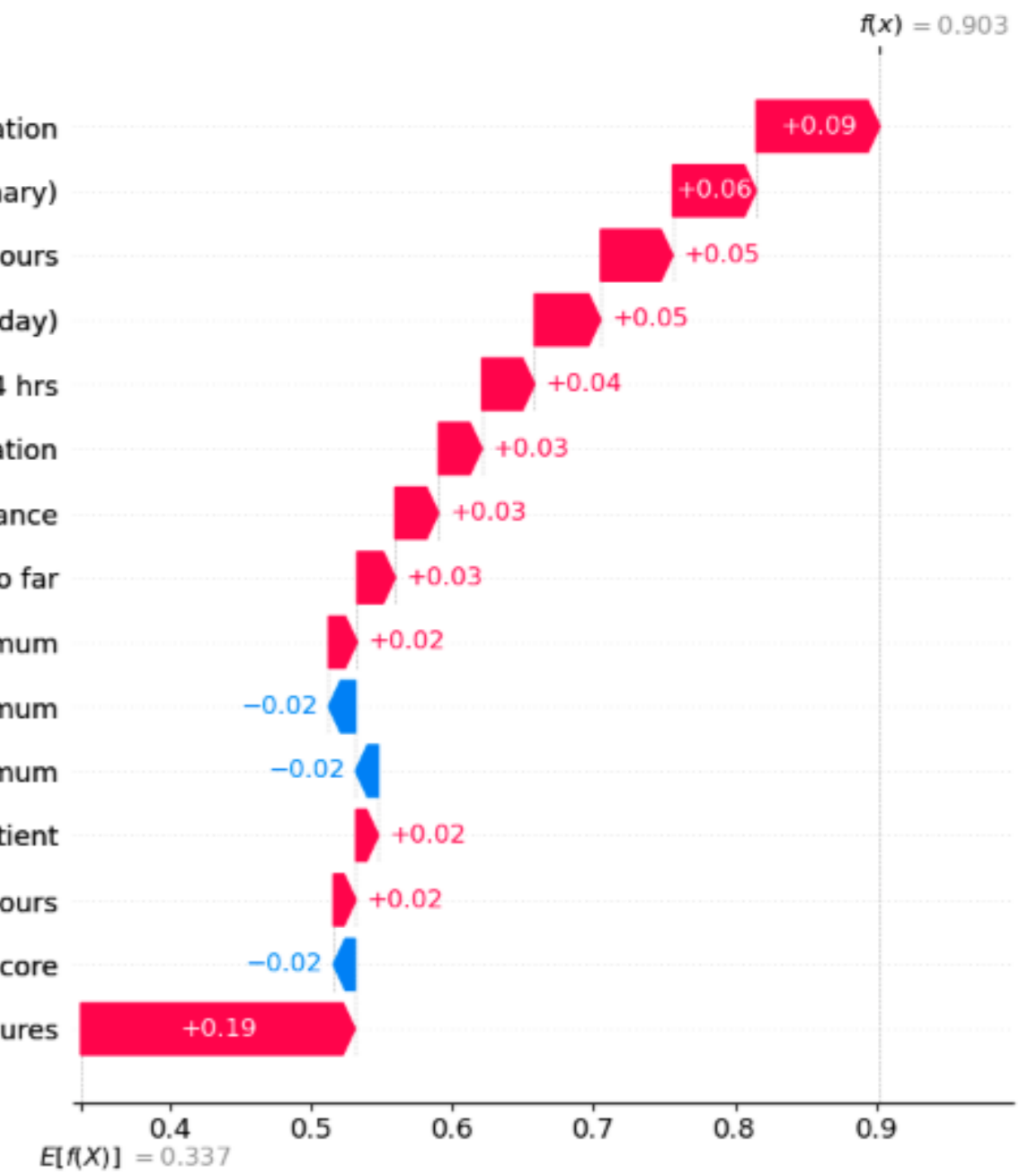
Example Patient - from Yellow to Green

Home Length of Stay

Patient MRN ID: None Patient ENC CSN ID: 100161601839

DAY OF EXTRACTION	ALERT	PAT MRN ID	HOSP DISCH TIME	DISCHARGE DISPOSITION	PROBAB DISCHA NEXT1D XGB
Apr 8, 2022		2001377606			0.0
Apr 9, 2022		2001377606			0.0
Apr 10, 2022		2001377606			0.0
Apr 11, 2022	Yellow	2001377606			0.1
Apr 12, 2022	Green	2001377606			0.2
Apr 13, 2022	Green	2001377606			0.7
Apr 14, 2022		2001377606	Apr 13, 2022 12:41:00 PM	Inpatient Rehab Facility	0.9

- 0 = attendings_count_standard_deviation
- 6 = Current department (category from dictionary)
- 3 = Number of attendings in daily Treatment team who have taken of the patient in the past 24 hours
- 2 = Day of the week (Today)
- 0 = Number of lab orders placed in the last 24 hrs
- 0 = albumin_slack_standard_deviation
- 0 = LYMPHS_ABS_slack_variance
- 1 = Number of ICD10 codes related to the admission so far
- 55 = general_all_maximum
- 1 = albumin_0Missing_1Normal_2Abnormal_maximum
- 3 = attendings_count_minimum
- 1 = Number of notes in the "Case Management" category written in the last 24h for the patient
- 2 = Number of different order types (e.g., radiology, general care, critical care, IV,,Aq) that have been placed for the patient in the past 24 hours
- 9 = Last fall risk score
- 1436 other features



Green alert if discharge probability in the next 24 hours or 48 hours is over 0.5.

Yellow alert if 48 hr discharge probability is between 0.35-0.5 and probability increases by over 0.1 from yesterday.

Comparison with Humans

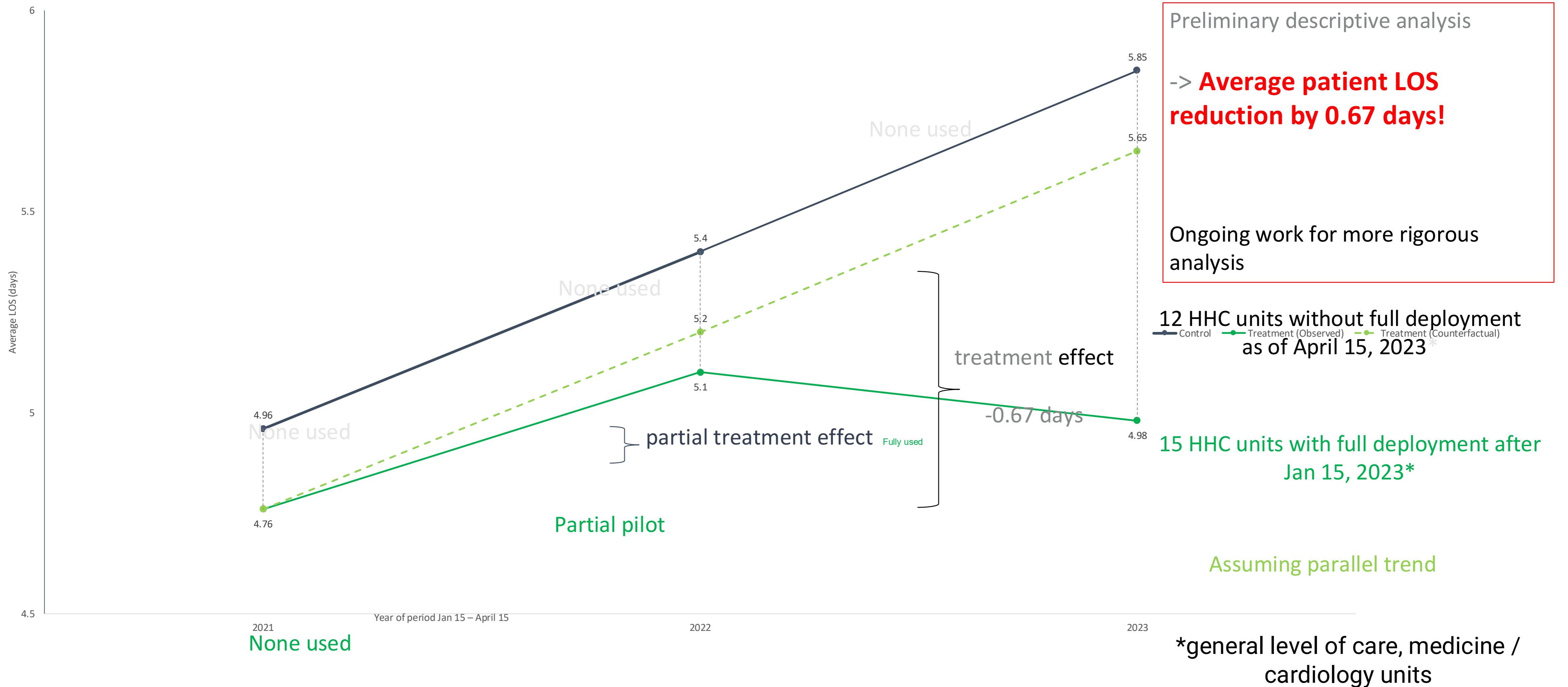
Metric	HH	CH	BH	HOCC
AUC	+0.186	+0.198	+0.180	+0.209
Proportion of discharges detected	+3%	+6%	+1%	+16%
Precision of predicted discharges	+10%	+11%	+12%	+12%

Compared with EDDs by doctors, the predictive models:

- **Have higher AUCs**
- **Identify more patients who can be discharged**
- **Make more accurate predictions**

* Results are validated on all inpatients from April to October in 2021

Empirical Length of Stay (LOS) Reduction



Current Work: applications of HAIM

- **Detecting Domestic Abuse** at the Brigham and Women Hospital
- **AI companion**
- **Automatic Detection** of data from notes, scans, labs at MGB
- **Unified diagnostics** from EKGs
- **Detection of Subdural Hematoma**