Domain Knowledge Augmented Contrastive Learning on Dynamic Hypergraphs for Improved Health Risk Prediction

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University of Iowa

Overview

- Motivation
- Problem Formulation
- Our Approach
- Experiments
- Conclusion

Patient Risks in Hospitals

- In 2022, there were 6,120 hospitals in the US with 33,679,935 admissions[1]
- Patients admitted to hospitals have several risks:
  - Risk of getting Healthcare Associated Infections (HAIs)
  - Risk of Medication/ diagnosis errors
  - Risk of worsening physical health leading to admission in critical care units
- This risks sometimes even lead to death!

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[1] https://www.aha.org/statistics/fast-facts-us-hospitals

How big are the costs?

- Patient risks are costly:
  - About 4% of patients in the US are diagnosed with an infection during their hospitalization[1]
  - ICU costs per day in 2010 were estimated to be $4300, a 61% increase since the 2000 cost per day of $2669[2]
- In the 2021 annual report published by CDC[3], acute care hospitals in USA have:
  - **14%** increase in MRSA cases
  - **12%** increase in ventilator-associated events
  - **11%** increase in surgical site infections following abdominal hysterectomy
- Forecasting these risks before they take place is crucial to prevent them

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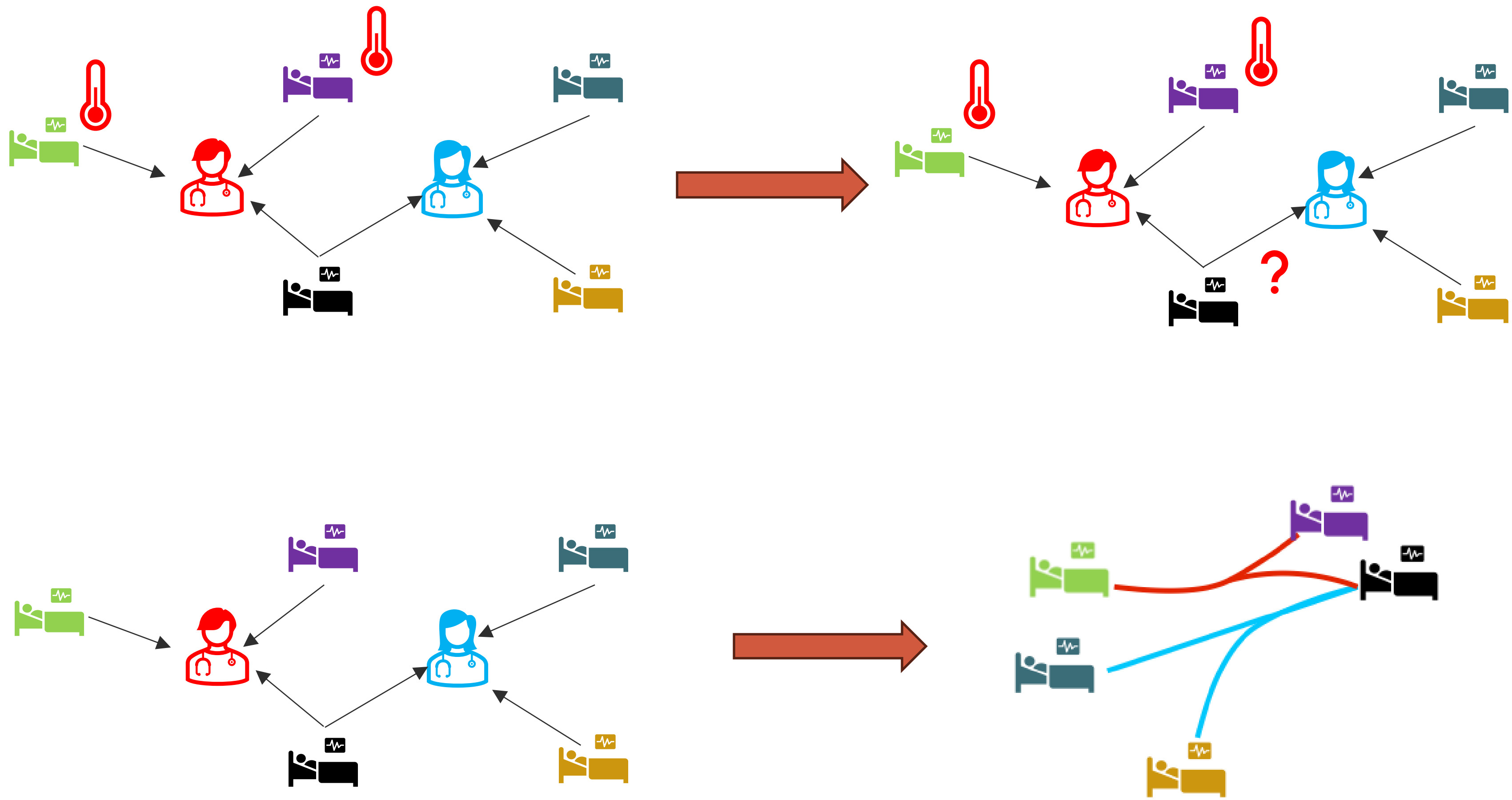
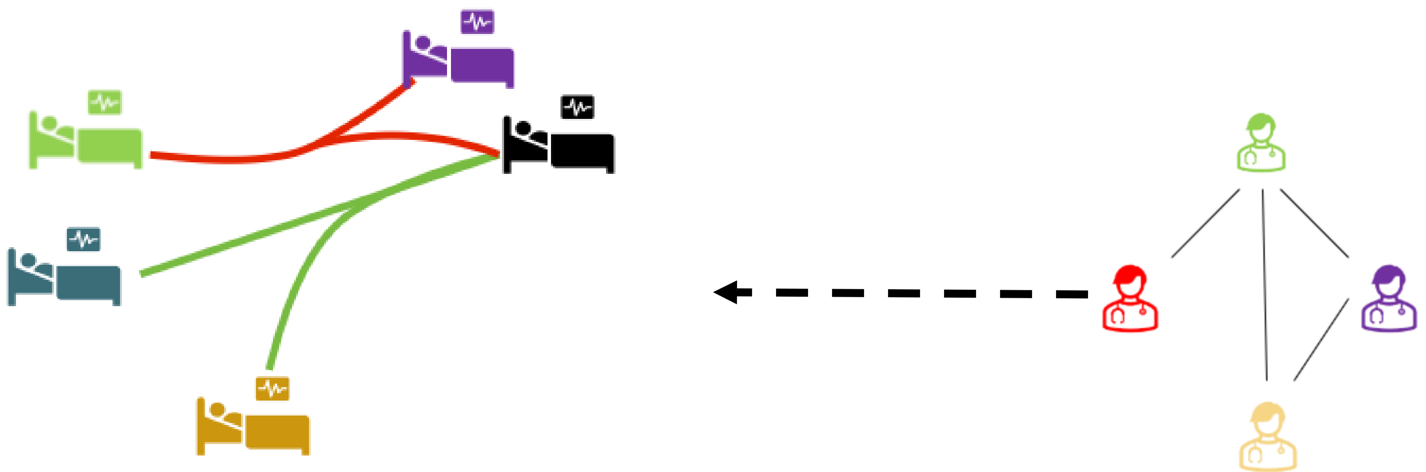
[1] Magill, Shelley S., et al. "Multistate point-prevalence survey of health care–associated infections." New England Journal of Medicine 370.13 (2014): 1198-1208.
[2] https://sccm.org/communications/critical-care-statistics
[3] https://www.aha.org/news/headline/2022-11-11-cdc-reports-increase-certain-health-care-associated-infections-2021

Interactions are helpful for Risk Estimation



Incorporating Domain Knowledge



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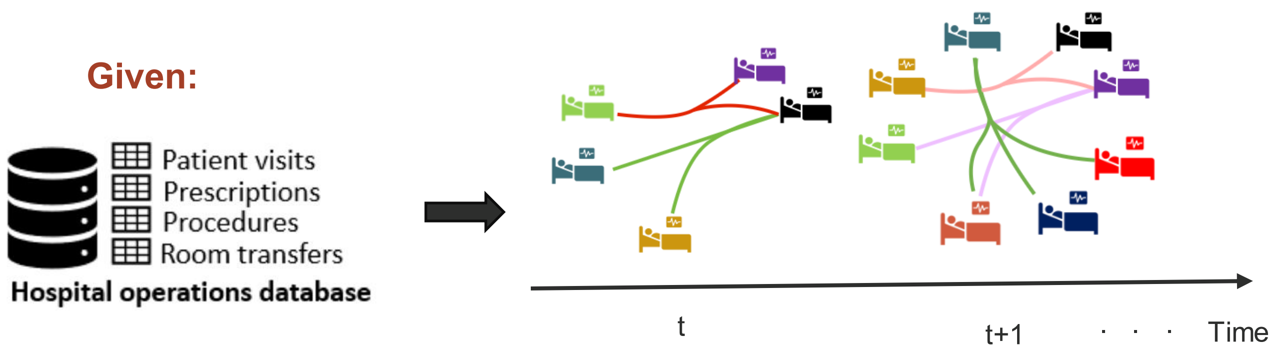
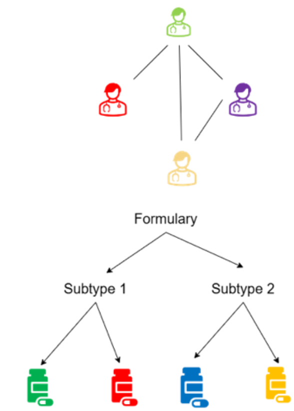
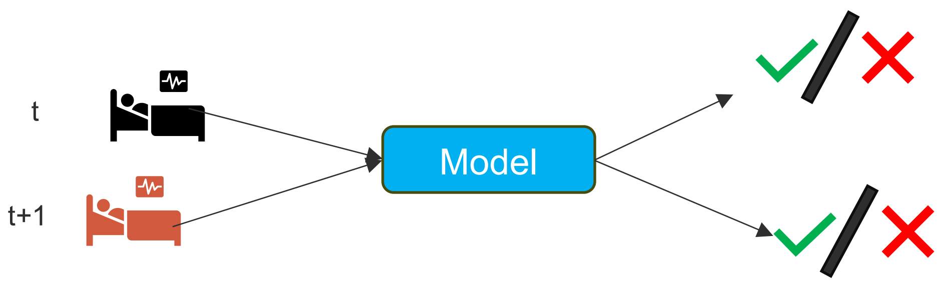
Problem Formulation

Given:





Learn:



Such That:

A loss function is minimized:

- Across all labeled patients
- Across training timestamps

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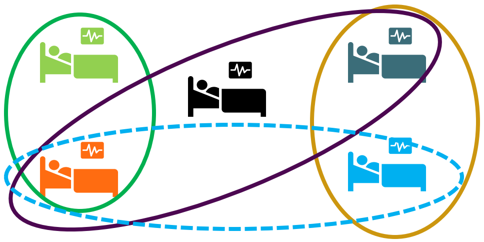
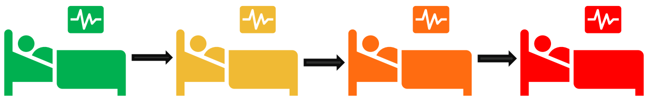
Challenges

- Missing Data
  - Interaction data is granular
  - Need for robust method



- Alignment to domain knowledge

- Temporal dependencies
  - Patient risk evolves over time
  - The effects of certain interactions are visible later



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Existing Works

- Clinical Literature:
  - Do not account for high-order interactions[1]
  - Do not use contact-based interactions [2,3]

- ML Methods:[4]
  - Randomly deletes interaction patterns for contrastive augmentations
  - Introduces harmful noise

[1] Oh, Jeeheh, et al. "A generalizable, data-driven approach to predict daily risk of Clostridium difficile infection at two large academic health centers." *infection control & hospital epidemiology* 39.4 (2018): 425-433.
[2] Xu, Ran, et al. "Hypergraph transformers for ehr-based clinical predictions." *AMIA Summits on Translational Science Proceedings* 2023 (2023): 582.
[3] Xu, Ran, et al. "Counterfactual and factual reasoning over hypergraphs for interpretable clinical predictions on ehr." *Machine Learning for Health*. PMLR, 2022.
[4] Ma, Tianyi, et al. "Hypergraph contrastive learning for drug trafficking community detection." *2023 IEEE International Conference on Data Mining (ICDM)*. IEEE, 2023.

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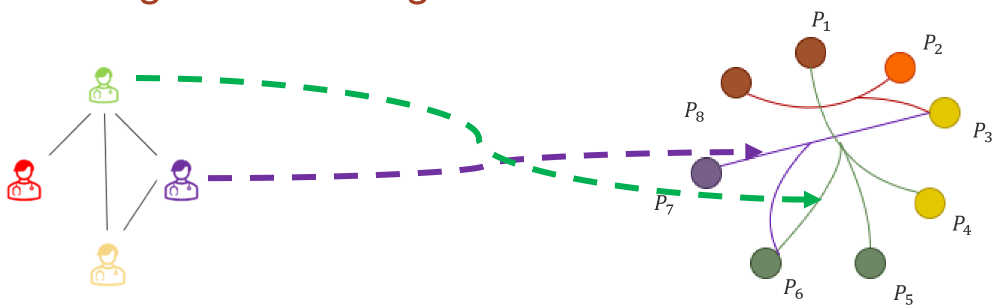
Our Ideas

- Domain-Knowledge Infused Augmentations



- Temporal Aggregation of Risk

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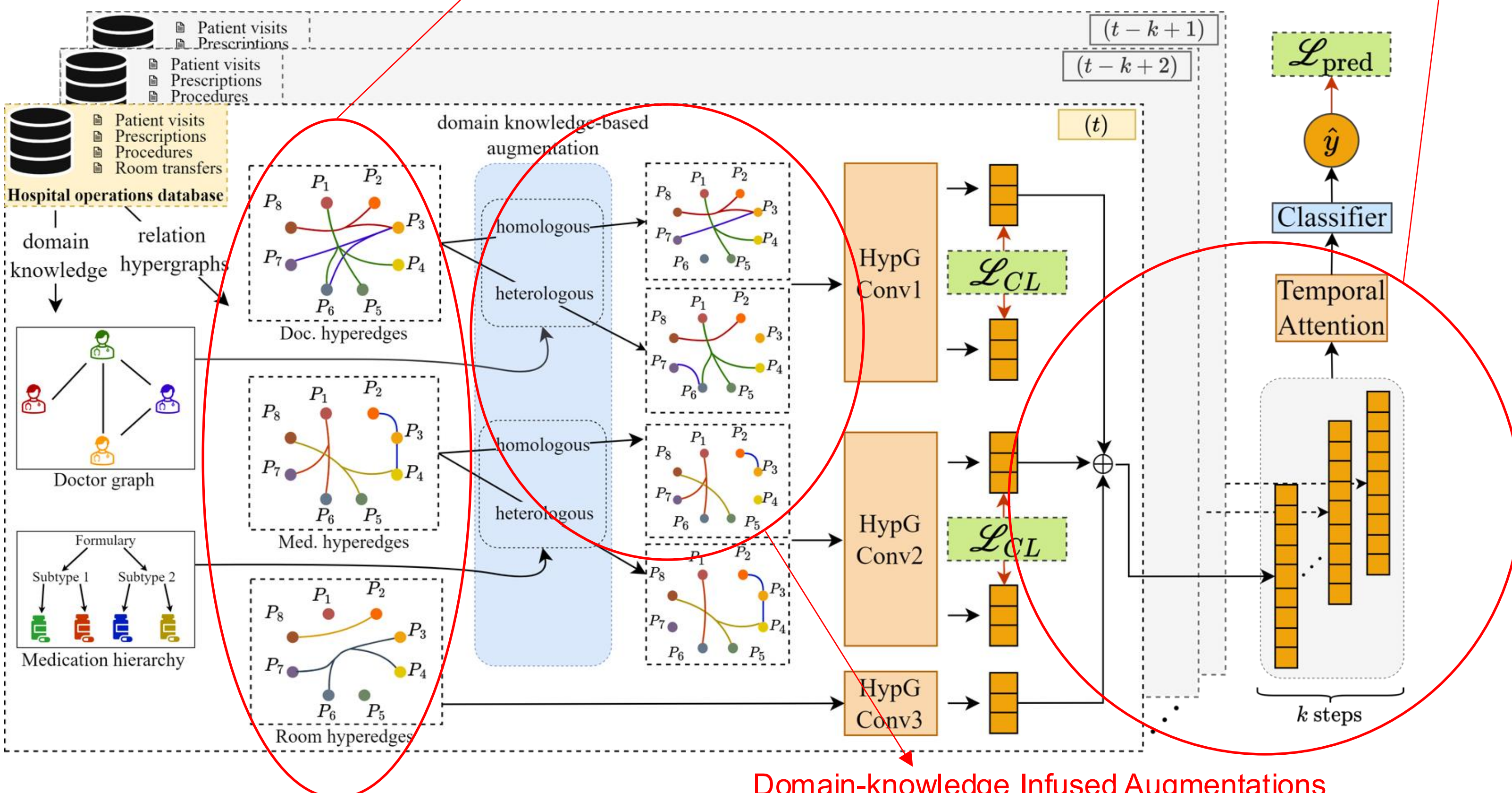
Our Approach: Overview

High-order interactions

Temporal Risk Aggregation



Domain-knowledge Infused Augmentations

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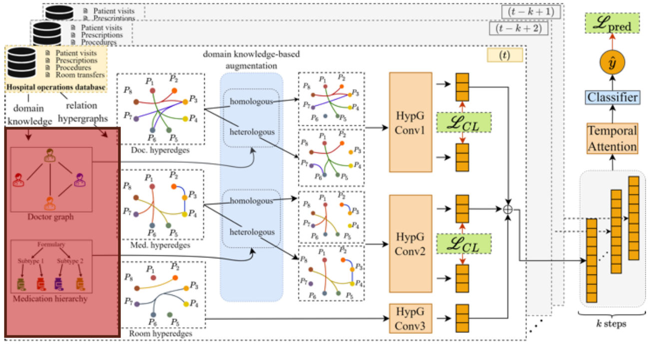
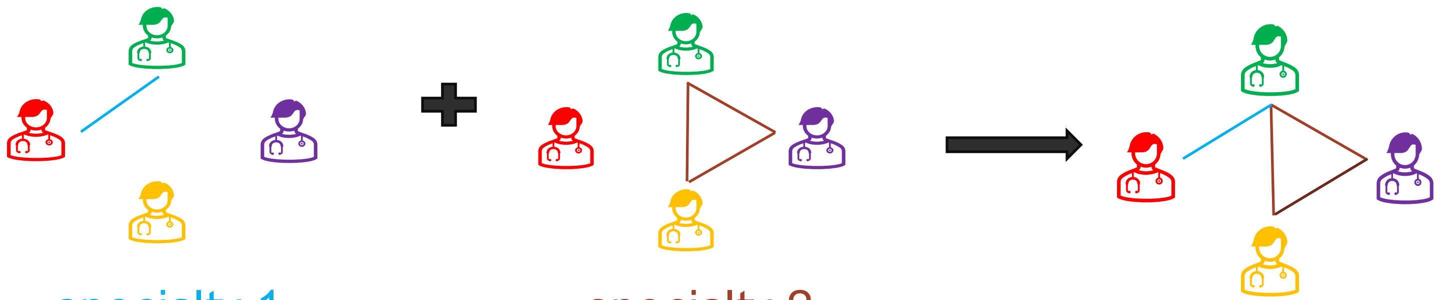


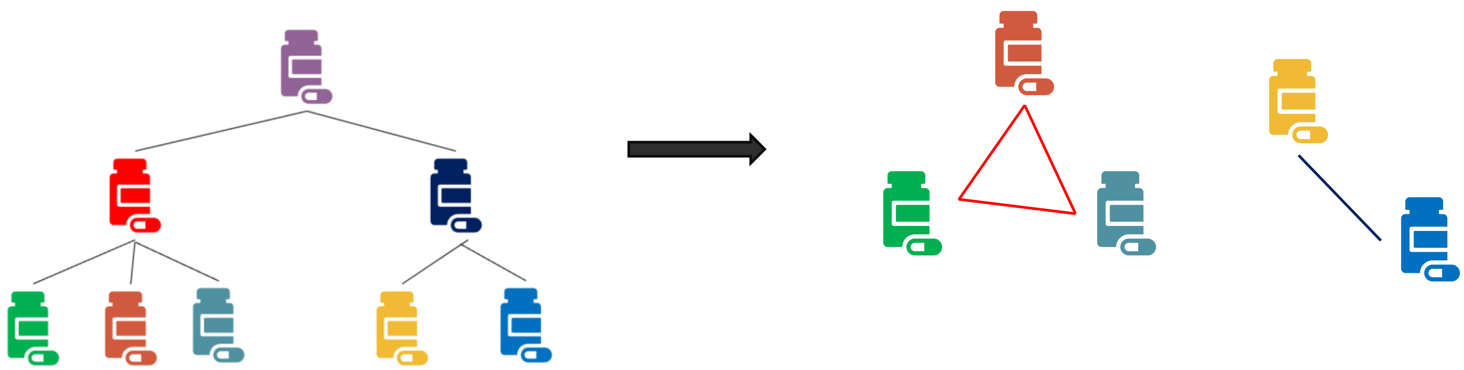
Domain Graph Construction

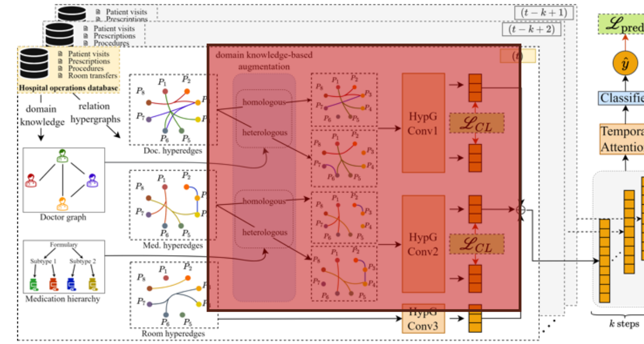
- Doctor Graph:



specialty 1 specialty 2

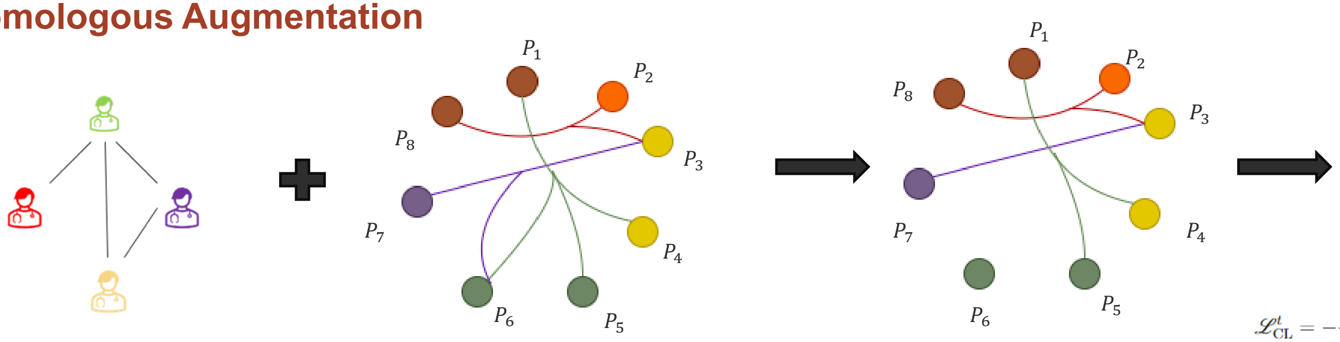
- Medication Graph:

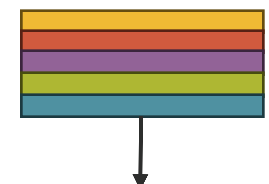




Contrastive Augmentations

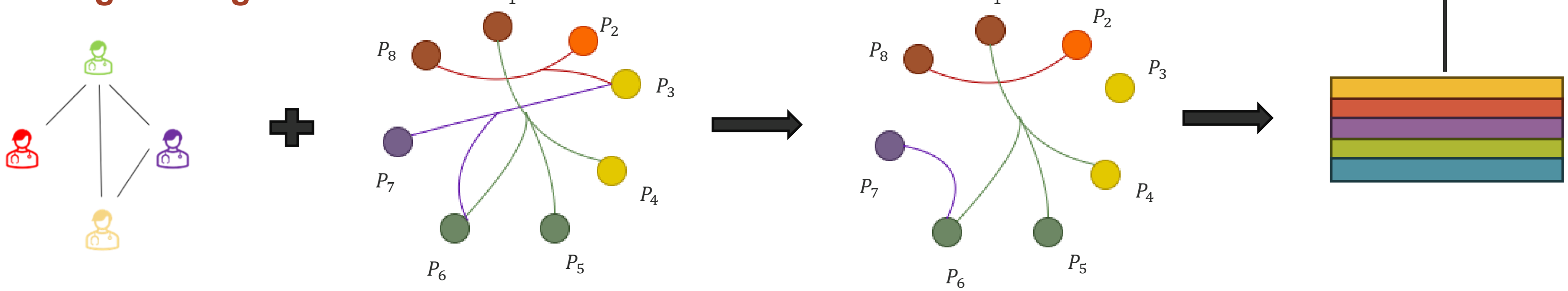
Homologous Augmentation





$$\mathscr{L}^t_{\mathrm{CL}} = -\frac{1}{|\mathscr{P}|}\sum_{i=1}^{|\mathscr{P}|}\log\frac{\exp\left(\frac{\delta_{i,i}}{\rho}\right)}{\sum_{j\neq i}\exp\left(\frac{\delta_{i,j}}{\rho}\right)+\exp\left(\frac{\delta_{i,i}}{\rho}\right)}$$

Heterologous Augmentation



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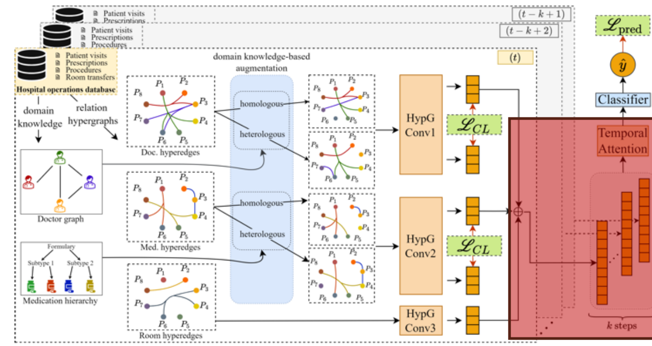
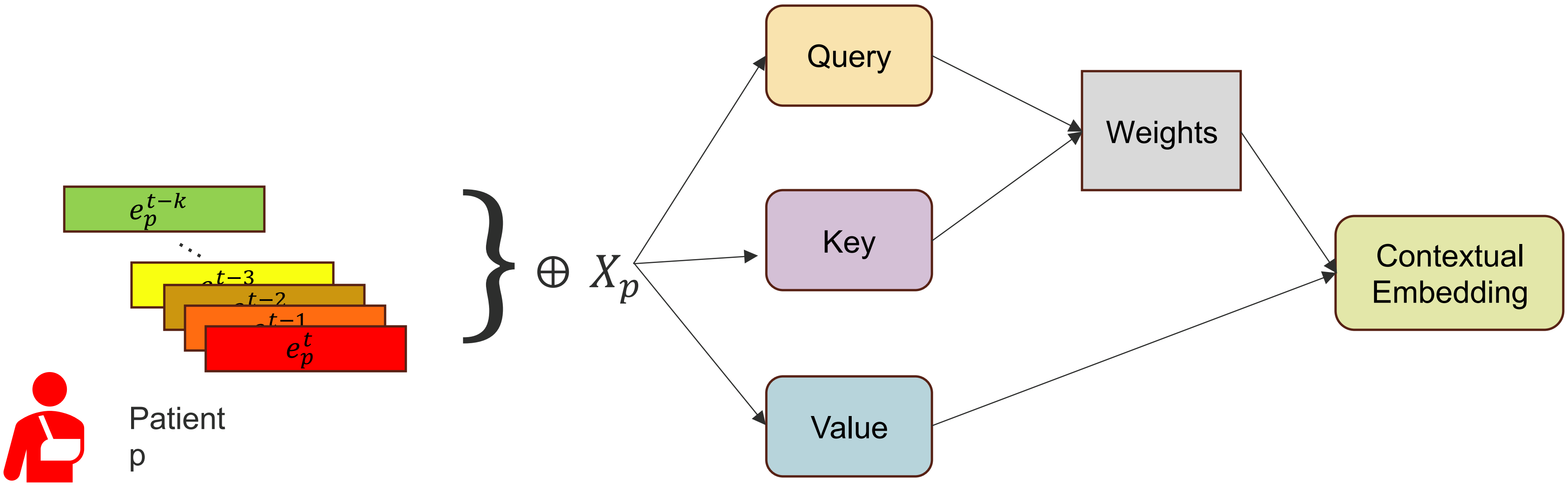
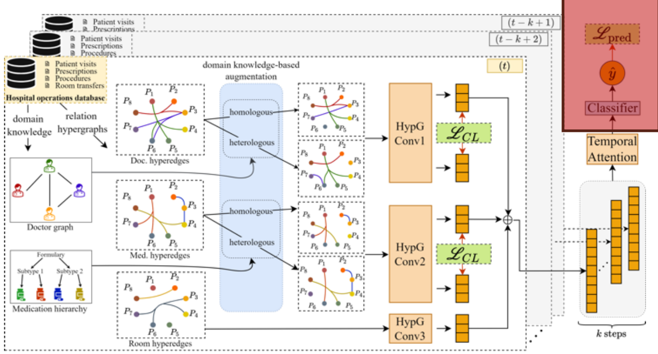
Temporal Aggregation





Training



- After obtaining temporal embedding for each patient, predicted label $\hat{y}$ is obtained by passing it through a Feed-Forward Layer
- For each binary prediction label, the loss is:

$$\mathcal{L}_{\text{pred}}^{t} = -[y_p^t \log(\hat{y}_p^t) + (1 - y_p^t)\log(1 - \hat{y}_p^t)]$$

- The overall objective function to be minimized over training timestamps τ is:

$$\mathcal{L} = \sum_{t \in \tau} (\gamma \mathcal{L}_{CL}^{t} + (1-\gamma)\mathcal{L}_{\text{pred}}^{t})$$

- We used Adaptive Moment Estimation Optimization (ADAM) algorithm for optimization

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Data

- Hospital Operations Data was obtained from:
  - The University of Iowa Hospitals and Clinics **(UIHC)**
  - Beth Israel Deaconess Medical Center **(MIMIC-IV)**
- The resultant patient-hospital interaction data statistics are:

Interaction Type	UIHC	MIMIC-IV
Patient-Doctor/HCW	23,085	8,046
Patient- Medication	349,345	34,857
Patient-Room/Unit	16,771	3,334

- Tasks:
  - CDI Incidence Prediction
  - MICU Transfer Prediction

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CDI Incidence Prediction

- **Clostridioides difficile infection (CDI)** is a common HAI, increasing the mortality risk of patients with weakened immune systems
- Binary Classification Problem:
  - Instance: Patient at time t and features at that time
  - Label: Binary indicator of getting infection in next 3 days[1]
- Evaluation Metric:
  - ROC-AUC Score
  - AUPRC Score
- Averaged across 3 independent runs

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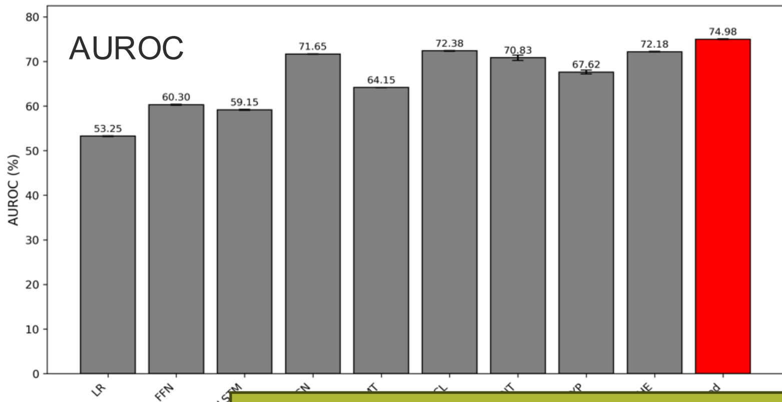
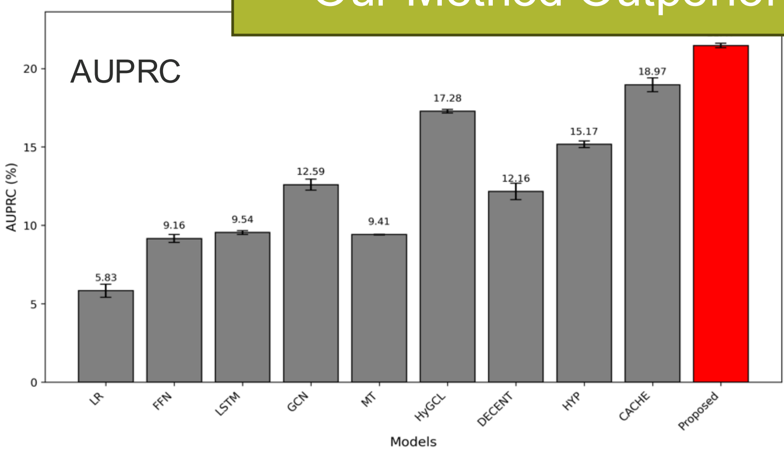
[1] M. Monsalve, S. Pemmaraju, S. Johnson, and P. M. Polgreen, “Improving risk prediction of clostridium difficile infection using temporal event-pairs,” in IEEE ICHI, 2015

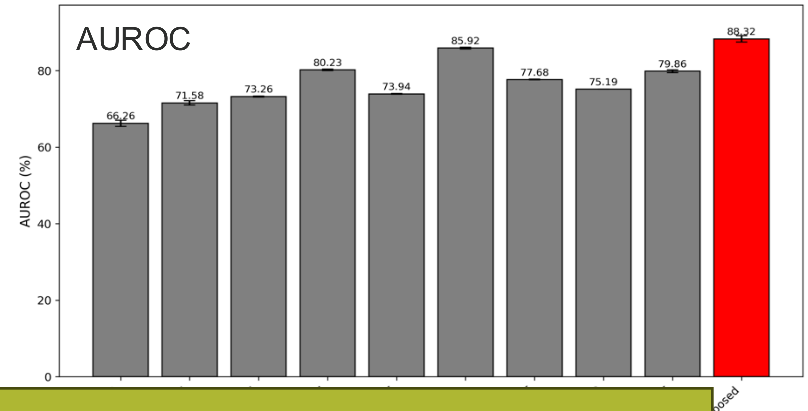
Results: CDI Incidence Prediction

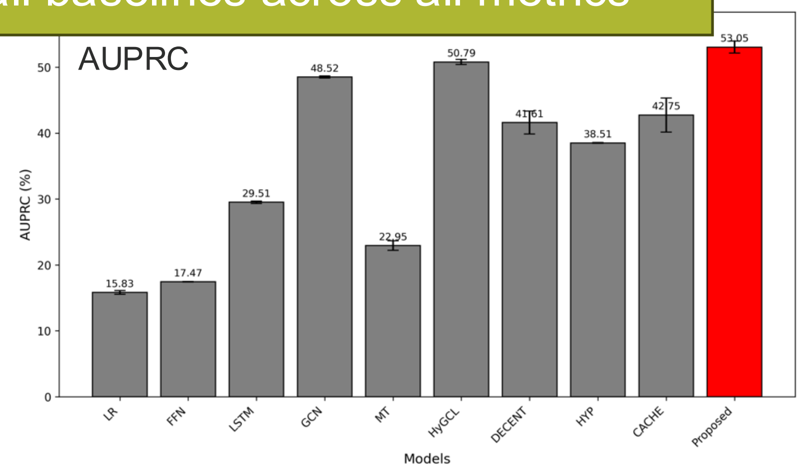
- UIHC:





- MIMIC-IV:





Our Method Outperforms all baselines across all metrics

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MICU Transfer Prediction

- Forecast whether a patient is at risk of transfer to a **Medical Intensive Care Unit (MICU)**
- Binary Classification Problem:
  - Instance: Patient at time t and features at that time
  - Label: Binary indicator of MICU transfer in the next k days
- Evaluation Metric:
  - ROC-AUC Score
  - AUPRC Score
- Averaged across 3 independent runs

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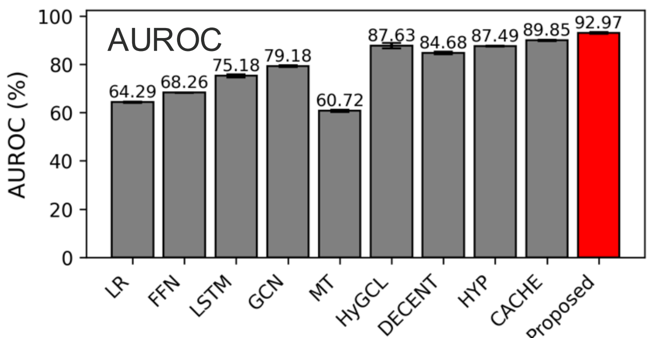
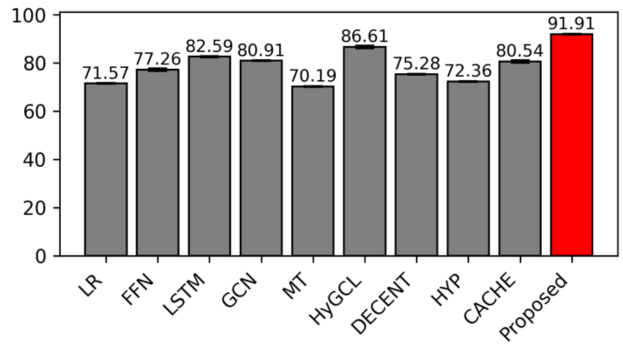
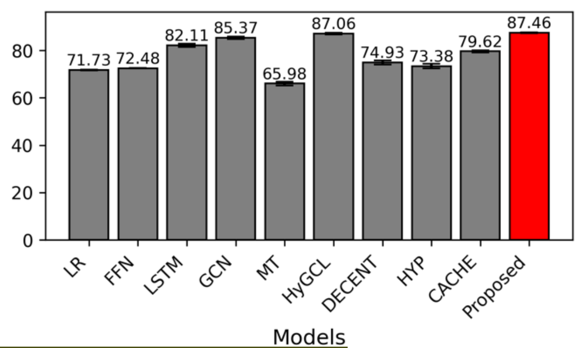
MICU Transfer: UIHC

- 1- day ahead
- 2- day ahead
- 3- day ahead







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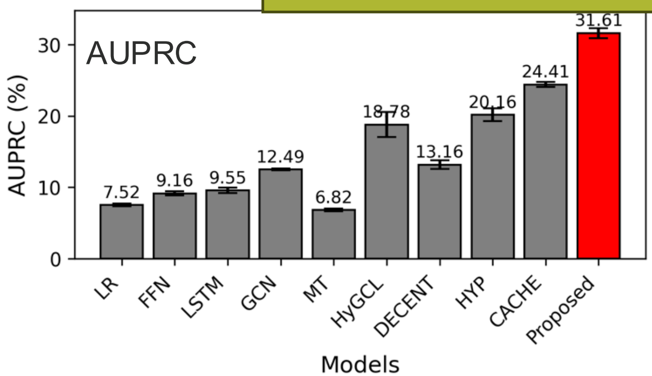
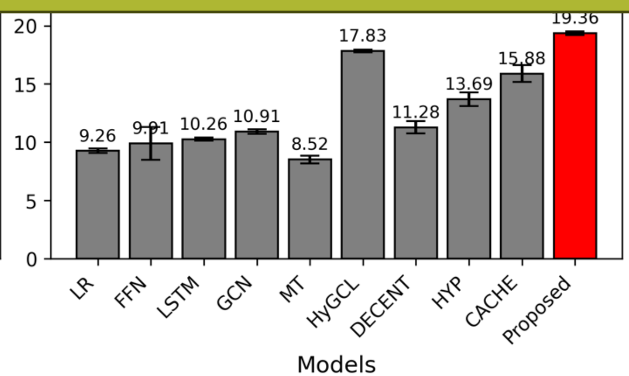
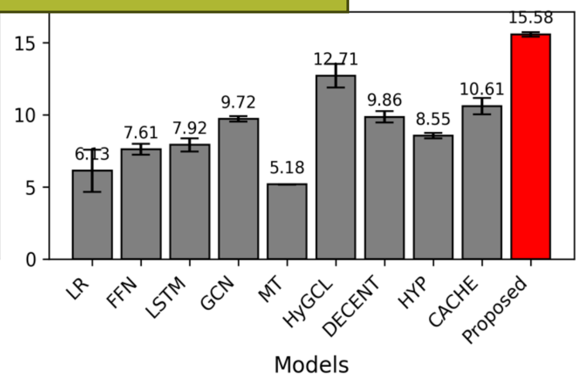
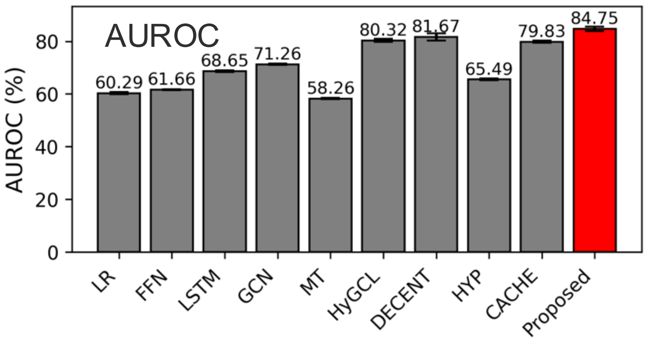


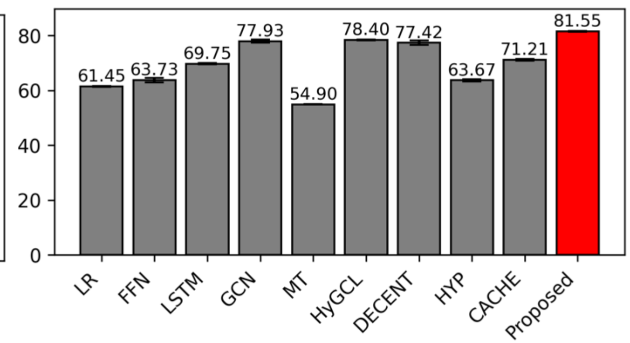


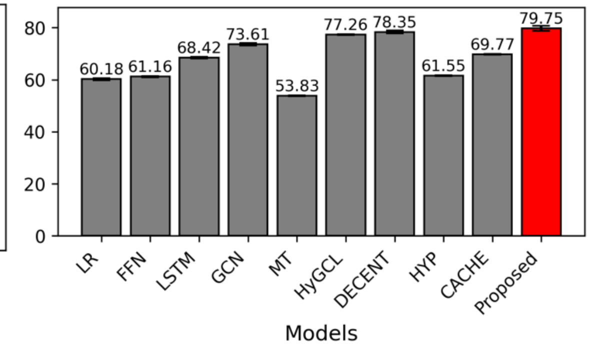


MICU Transfer: MIMIC-IV

- 1- day ahead
- 2- day ahead
- 3- day ahead







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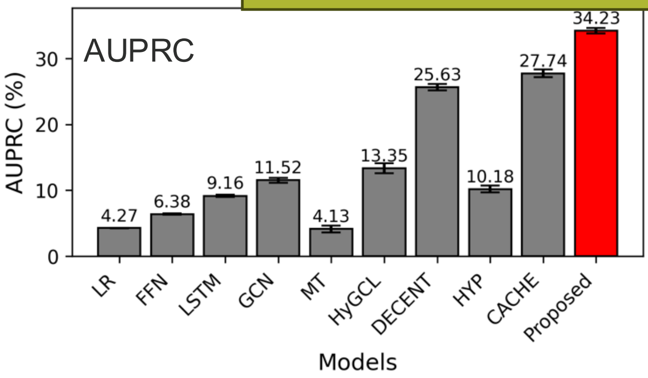

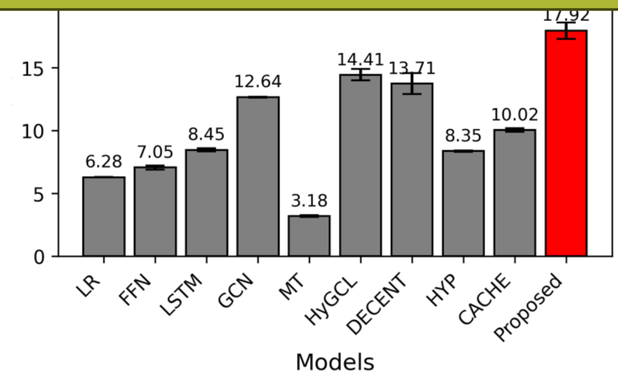

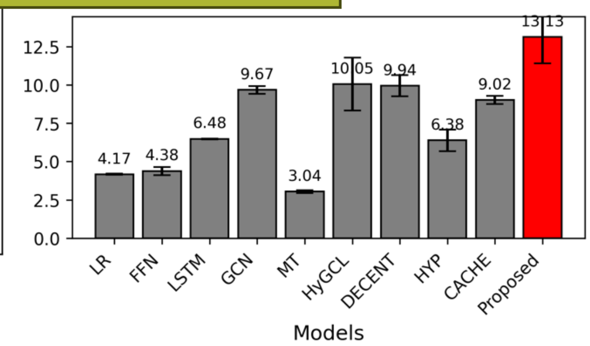

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Conclusion

- Leveraging high-order spatio-temporal mobility interactions is an effective way to estimate patient risk when prior visit information is unavailable. We use:
  - Patient-HCW/Doctor interaction
  - Patient-Medication interaction
  - Patient-Room interaction
- To exploit the domain information and account for missing interaction data, we propose a new hypergraph contrastive augmentation strategy that is aligned with domain information
- We evaluate the performance of the learned embeddings over the predictive tasks:
  - CDI Incidence Prediction
  - Short and Long Term MICU Transfer Prediction
- Our proposed model outperforms state-of-the-art baselines across both tasks

Thank You

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Hieu Vu

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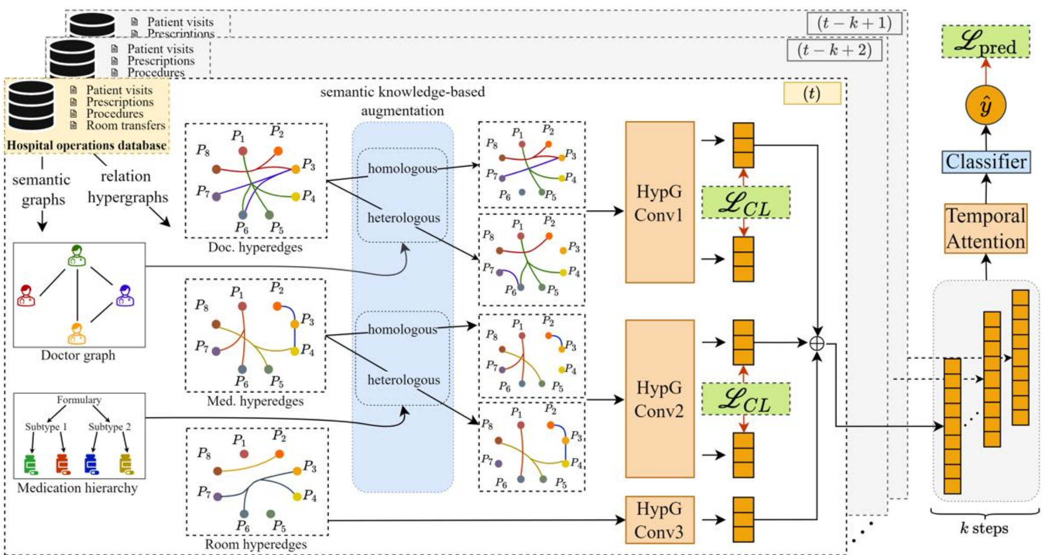

Code: https://github.com/Soothysay/HyperHAI

More Results in the Paper!

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