Predicting Physician Burnout Using EHR Activity Logs

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Background



Physician Burnout

Burnout

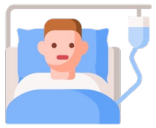
-- “mental exhaustion caused by one’s professional life”

Consequence



Substance Abuse

Suicidal Ideation



Medical error

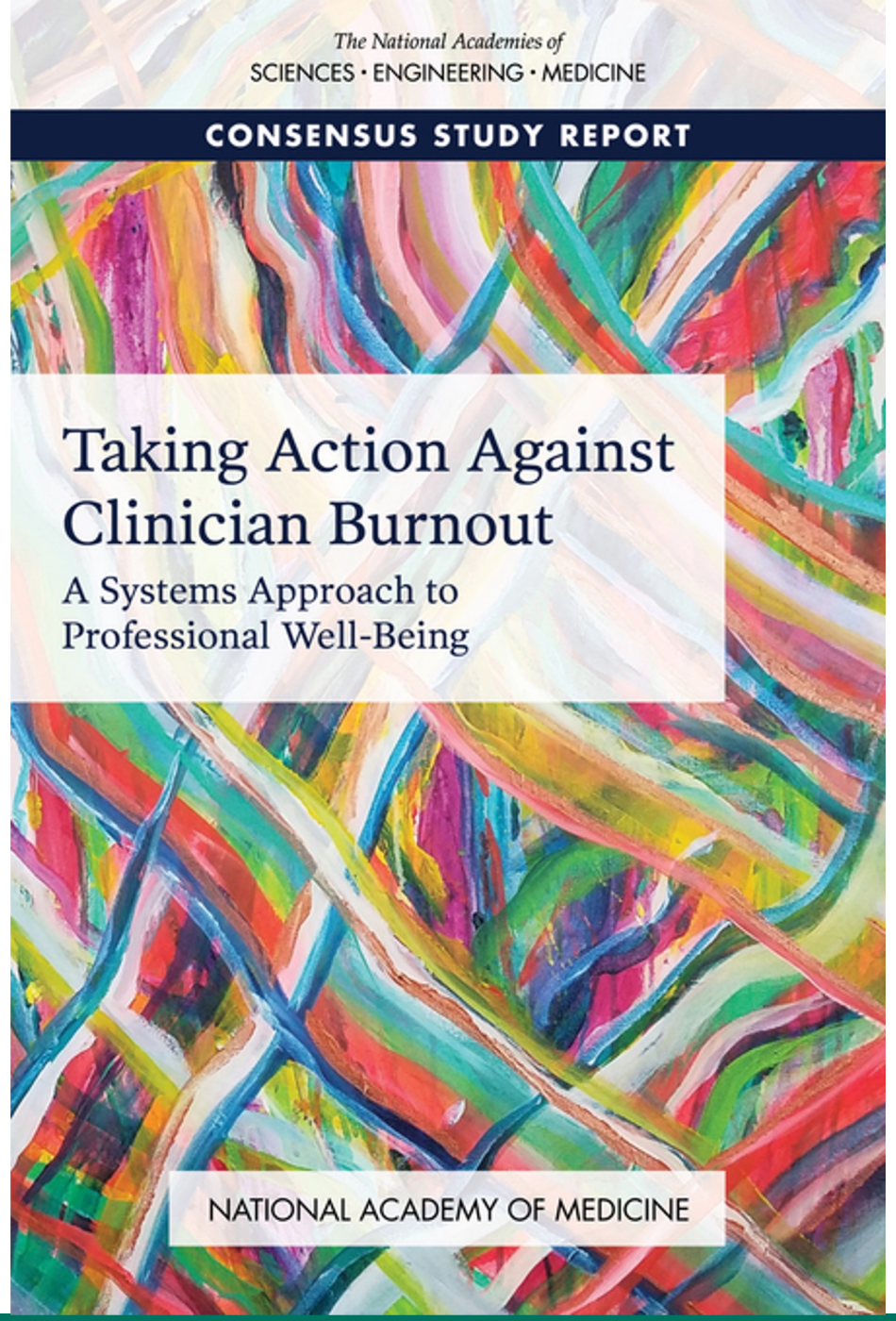
Poor care quality



Increased turnover

Decreased work hours

> $4 billion /year



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50% of physicians

70% of trainee physicians (residents, fellows)

COVID-19 pandemic further fueled the negative impact

Measurement and Intervention

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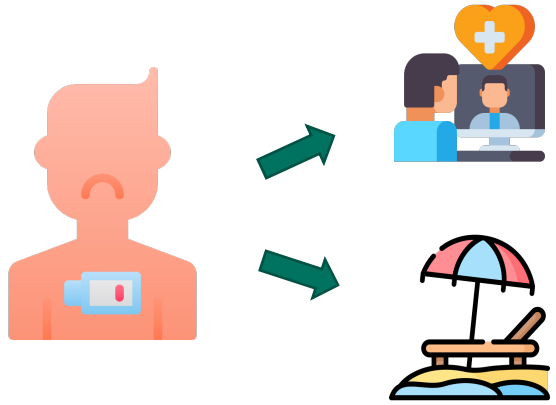
Traditional Burnout Assessment



Obtrusive, Slow and **Expensive**

Personalized Intervention



Requires monitoring & prediction system

No such system yet!

Approach I:
Feature Engineering + Standard ML



What are EHR Activity Logs?

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Time	USER_ID	PAT_ID	Clinical Action
12/21/19 7:21	M58530		Inpatient Patient Lists list loaded
12/21/19 7:21	M58530		Inpatient system list accessed
12/21/19 7:21	M58530	A	Storyboard viewed
12/21/19 7:21	M58530	A	SmartSets activity selected
12/21/19 7:21	M58530	A	Visit Navigator template loaded
12/21/19 7:21	M58530	A	Problem List accessed
12/21/19 7:21	M58530	A	Chart Review Encounters tab selected
12/21/19 7:21	M58530	A	Chart Review Notes tab selected
12/21/19 7:21	M58530	A	Chart Review Note report viewed
12/21/19 7:22	M58530	A	Report with patient data viewed



Tracks **who** performed **what** at **what time**.

Machine Learning for Burnout Prediction

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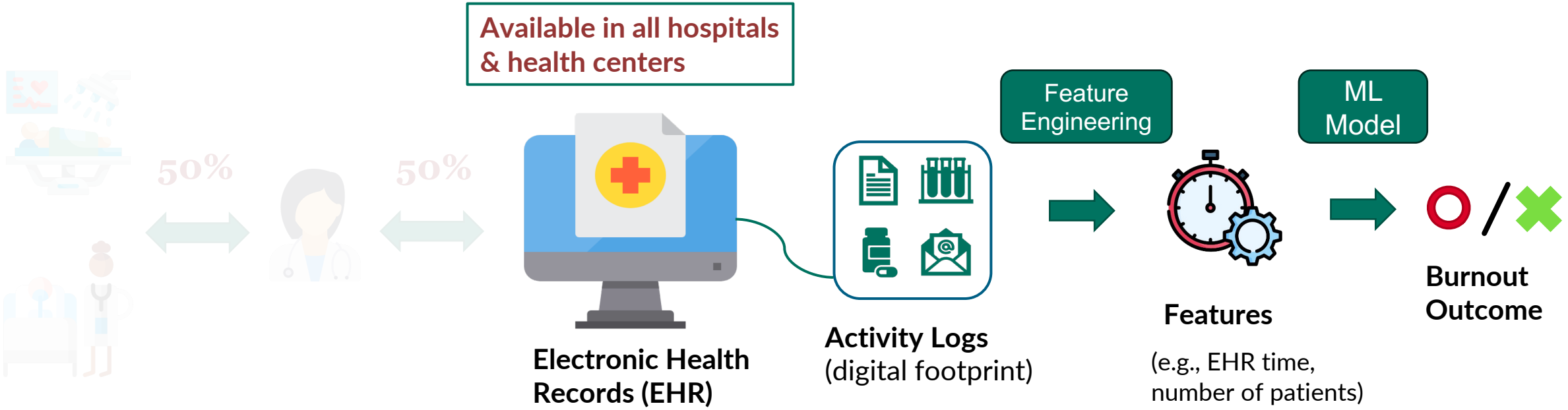
Goal: A system that can assess the risk of burnout



Digital Phenotyping for Burnout

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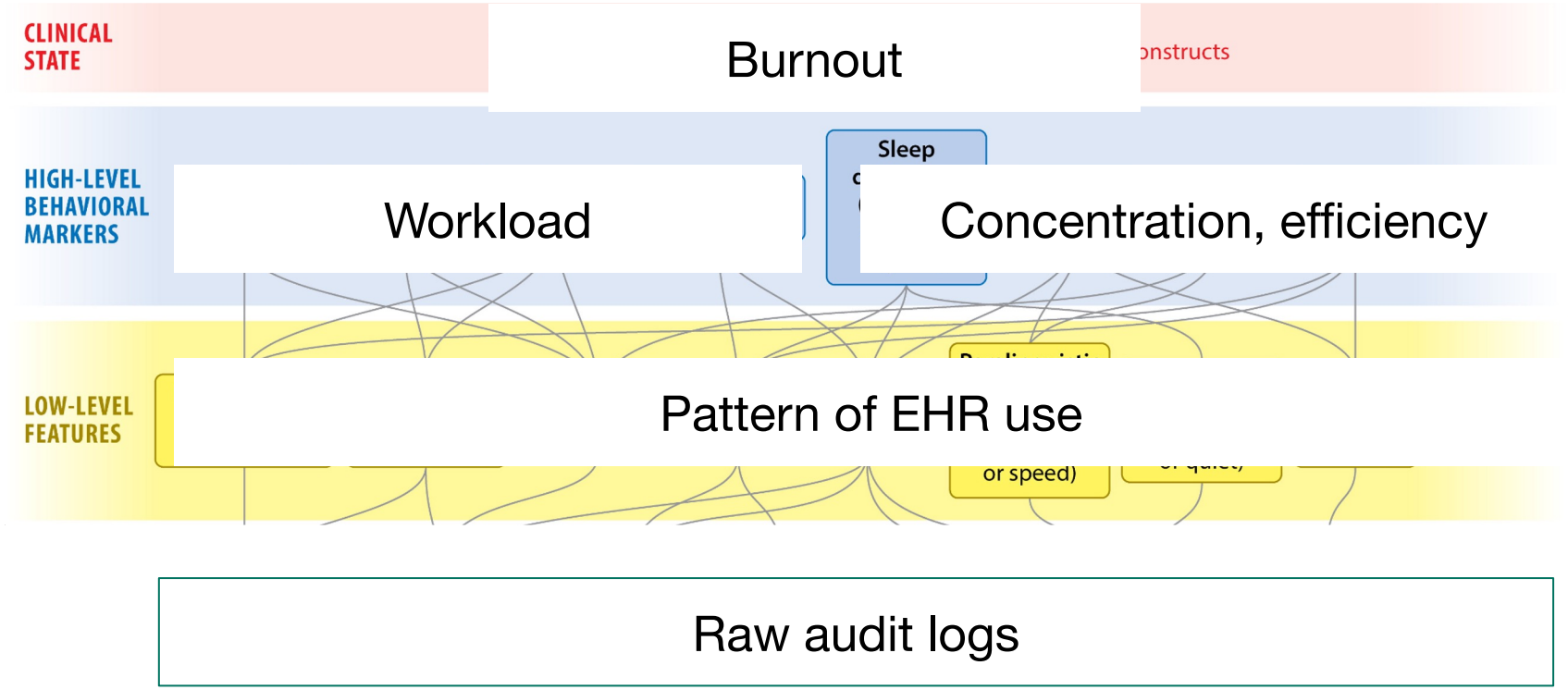

Mohr et al (2017) *Ann. Rev. Clin. Psych.*

Digital Phenotyping for Burnout

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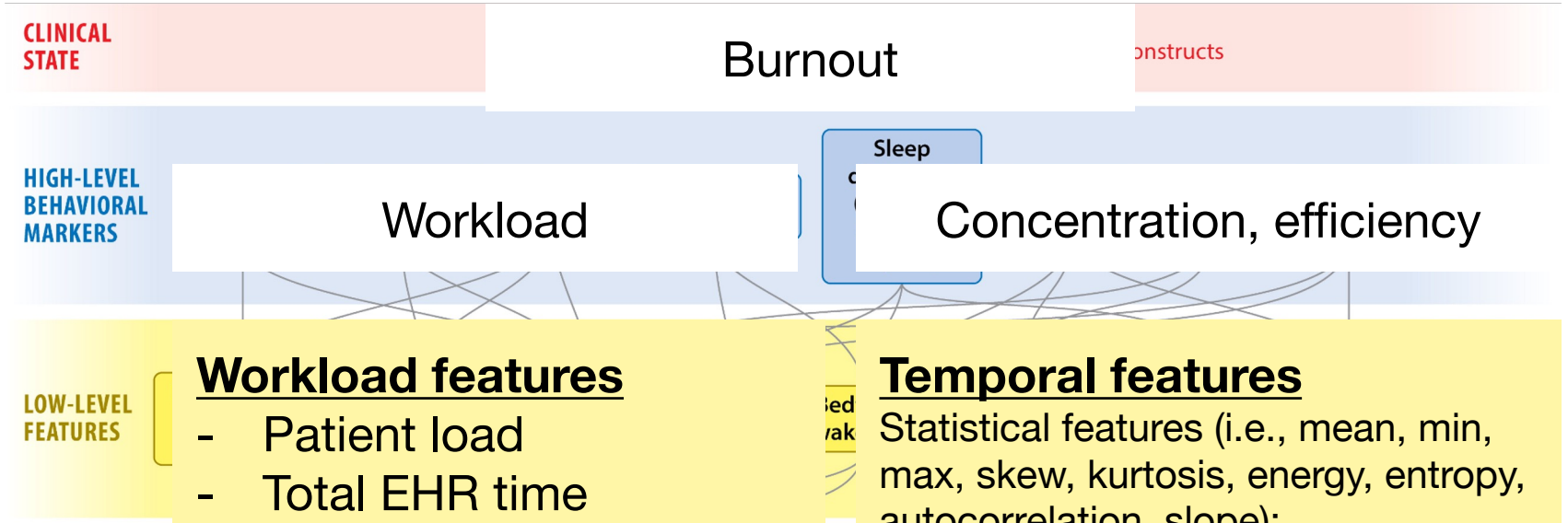


Workload features

- Patient load
- Total EHR time
- After-hours time
- Inbox time
- Chart review time
- Note time
- Order volume

Temporal features

Statistical features (i.e., mean, min, max, skew, kurtosis, energy, entropy, autocorrelation, slope):

- Temporal pattern of EHR click activities
- Temporal pattern of attention switching

Burnout Score

0.0 — 4.0

Low — High

EHR: Electronic Health Records

Association with Burnout

Statistical analysis shows:

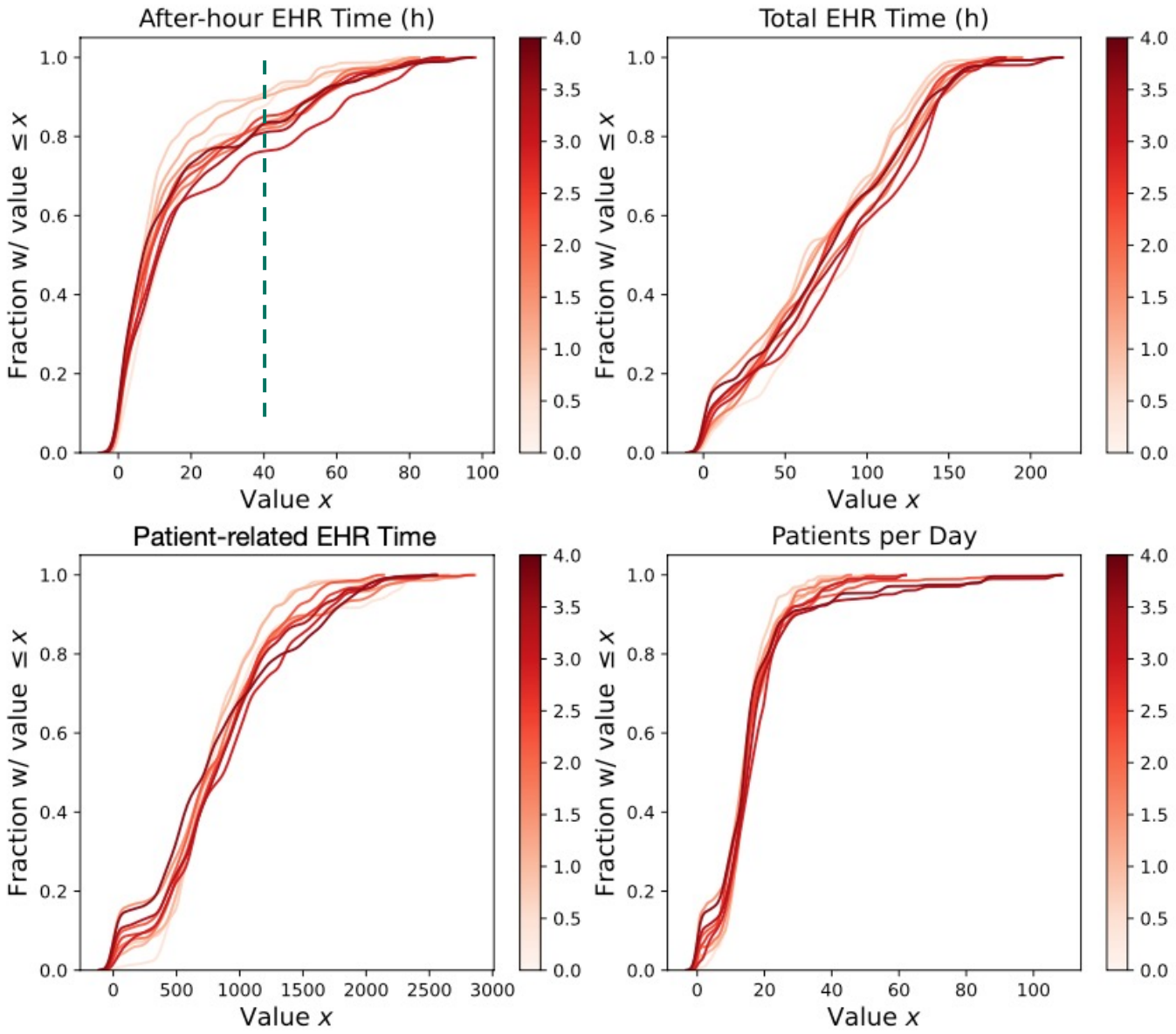
Higher workload links to higher risk of burnout.

e.g., 25% burned-out **VS** 10% healthy physicians have spent > 40H/month on "after-hour" working

There exists predictive information in EHR activity logs

Workload & Burnout

Cumulative Distribution Functions (CDF)



Study Design and Data Collection

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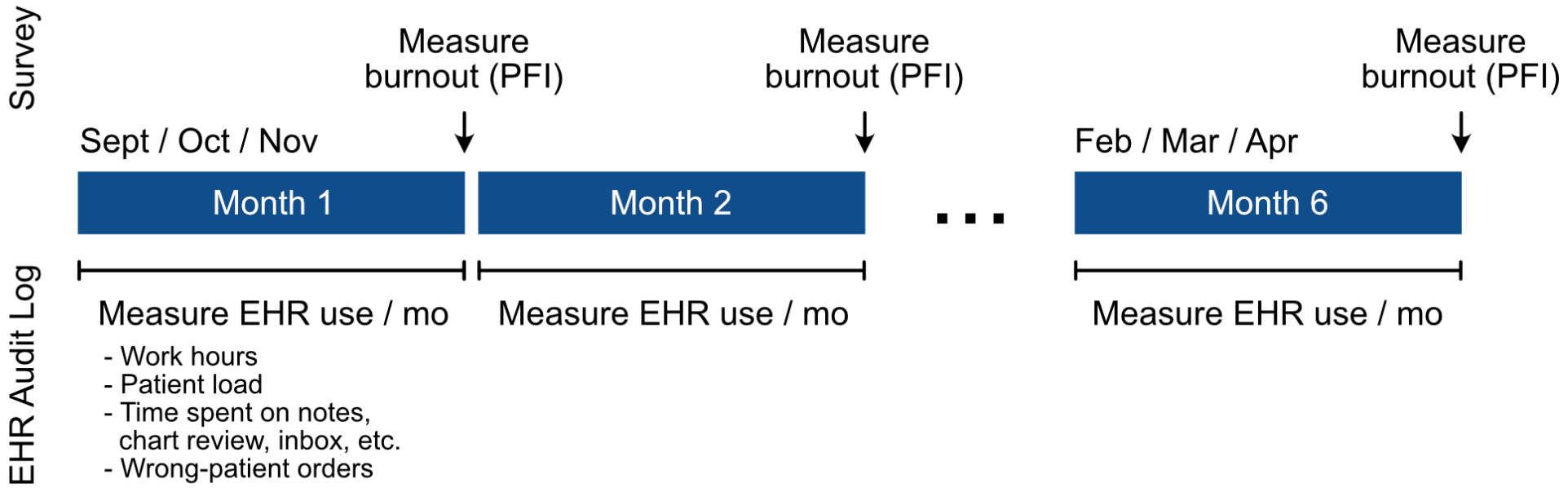

Machine Learning Evaluation Pipeline

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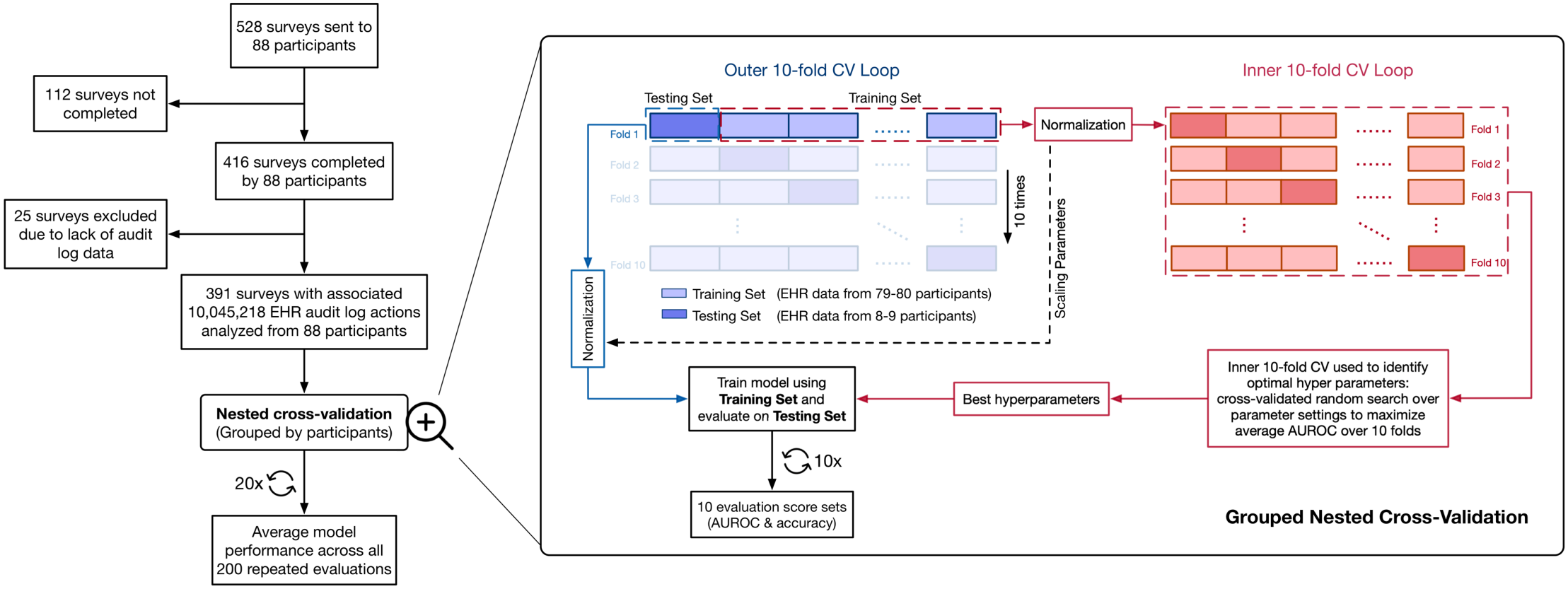

Lou et al. (2022) *Journal of Biomedical Informatics*.

Workload and temporal features weakly predict burnout

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Feature Set	Best Model	Mean Absolute Error	AUROC	Accuracy
Workload	Random Forest	0.602 (0.412, 0.826)	0.595 (0.355, 0.808)	0.567 (0.393, 0.742)
Temporal	Support Vector Machine	0.596 (0.391, 0.826)	0.581 (0.343, 0.790)	0.556 (0.318, 0.756)
Workload + Temporal	Gradient Boosting Machine	0.619 (0.438, 0.844)	0.583 (0.270, 0.831)	0.559 (0.386, 0.780)

Median PFI burnout score: 1.2 (IQR 0.7-1.7)

PFI score > 1.33 used to indicate burnout

Lou et al. (2022) *Journal of Biomedical Informatics*.

Baseline burnout is highly predictive of future burnout

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Workload + Temporal	Gradient Boosting Machine	0.619 (0.438, 0.844)	0.583 (0.270, 0.831)	0.559 (0.386, 0.780)
First Survey Score + Workload	Neural Network	0.423 (0.293, 0.567)	0.829 (0.607, 0.996)	0.781 (0.587, 0.936)
First Survey Score	Neural Network	0.432 (0.304, 0.570)	0.819 (0.551, 0.999)	0.765 (0.547, 0.952)

Lou et al. (2022) *Journal of Biomedical Informatics*.

Limitations

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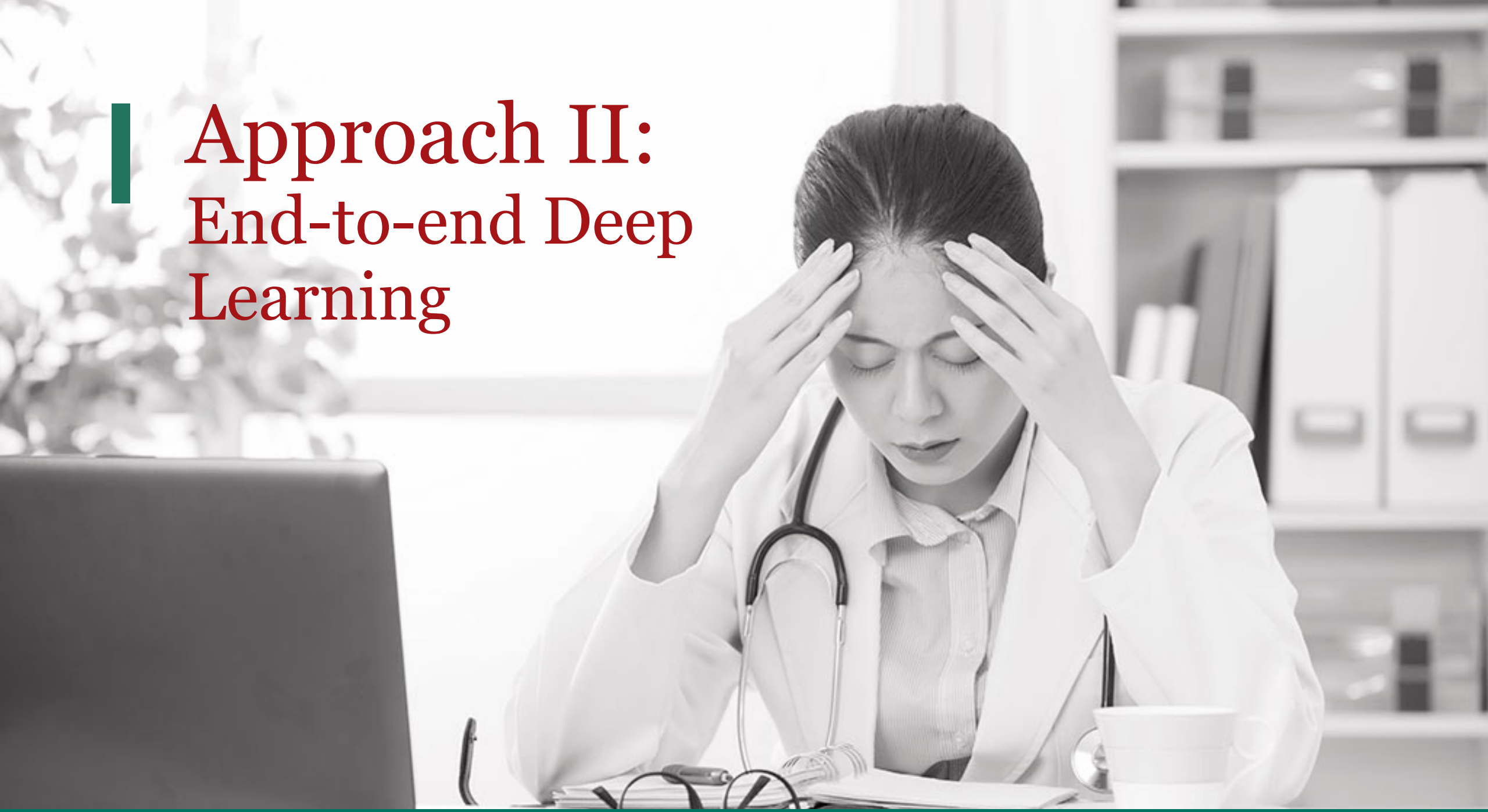
Study Design

- Small participant set (88 physicians x 6 months)
- Can't capture the <50% "off-the-grid" non-EHR work
- Resident physicians may not be the right population to develop a stable model – not "steady state"
- Inter-individual variability in response to workload & workflow

Modeling

- Heavily require domain knowledge for feature engineering
- Inability to capture other factors that might also contribute to burnout

Approach II:
End-to-end Deep Learning



Directly Using Raw Logs

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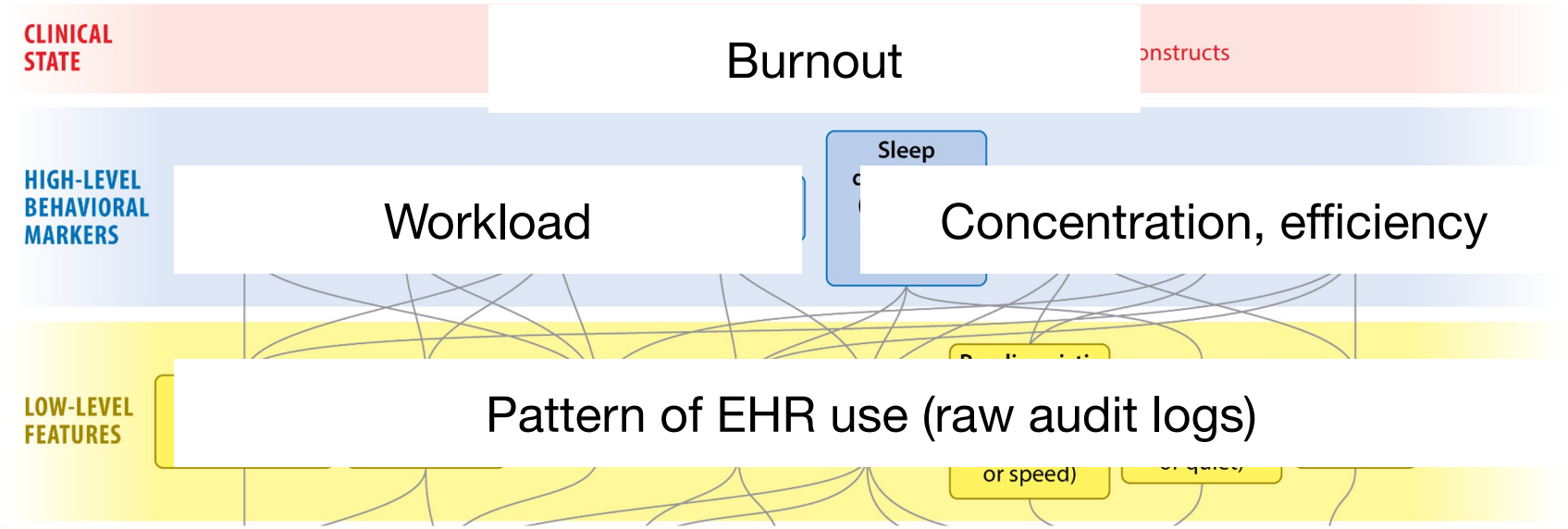

Raw audit logs

Mohr et al (2017) *Ann. Rev. Clin. Psych.*

Proposal: End-to-end Burnout Prediction

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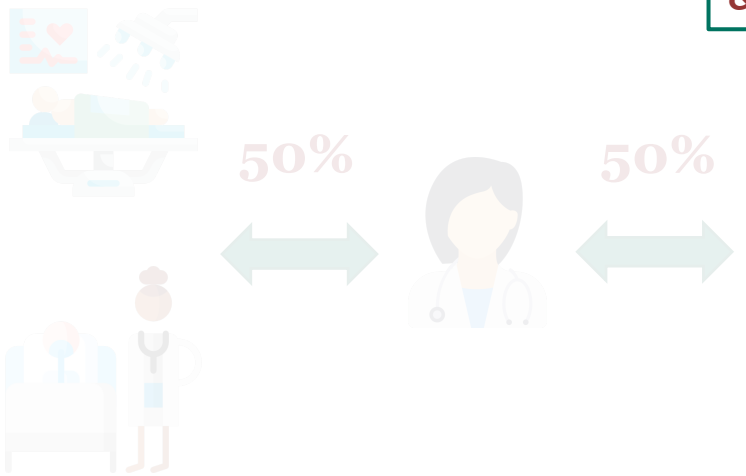
Goal: A system that can unobtrusively monitor and assess the risk of burnout in real time

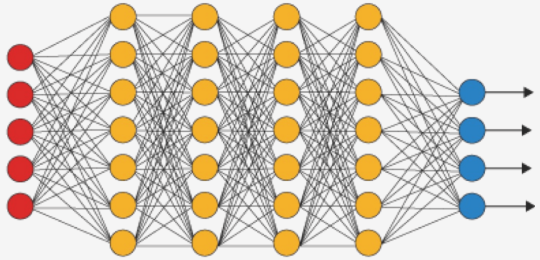
Available in all hospitals & health centers





Electronic Health Records (EHR)

Deep Neural Networks





Activity Logs
(digital footprint)

Workload
(e.g., EHR time, number of patients)



Burnout Outcome

Running in Background (Unobtrusive)

Data Collection

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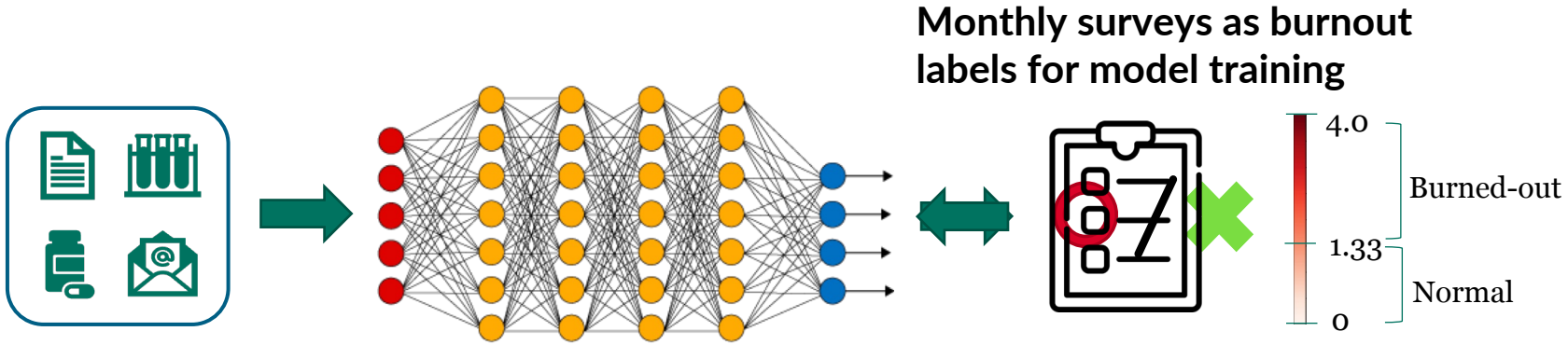
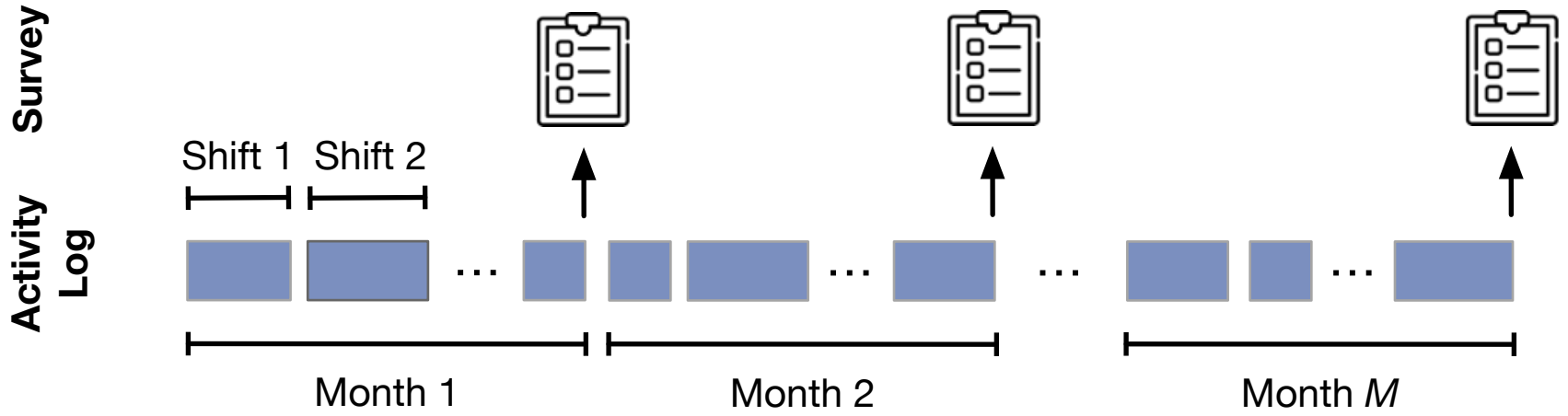
Model Training



Data Collection



(till now, 88 intern physicians across 6 months)

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Challenges & Proposed Model

Challenges to End-to-end Modeling

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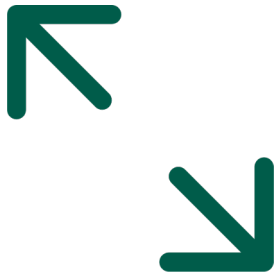
Challenge I

Content Understanding (Activity2Vec)



Challenge II

Large-scale Model Input



Challenge III

Limited Labels

I –Understanding Raw Activity Logs

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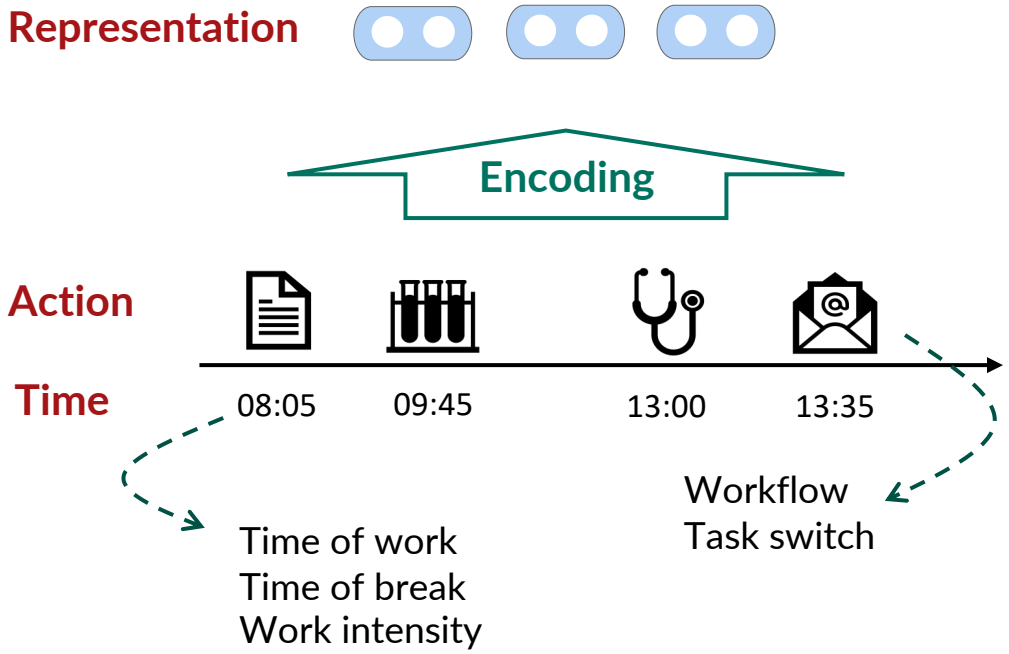
Challenge I

Raw Content Understanding

Extract useful (data-driven) knowledge from raw activity logs.

- Over 1,900 unique kinds of actions
- Irregular intervals
- Need capture dynamics/temporality

No standard data encoding method for clinical activity logs.



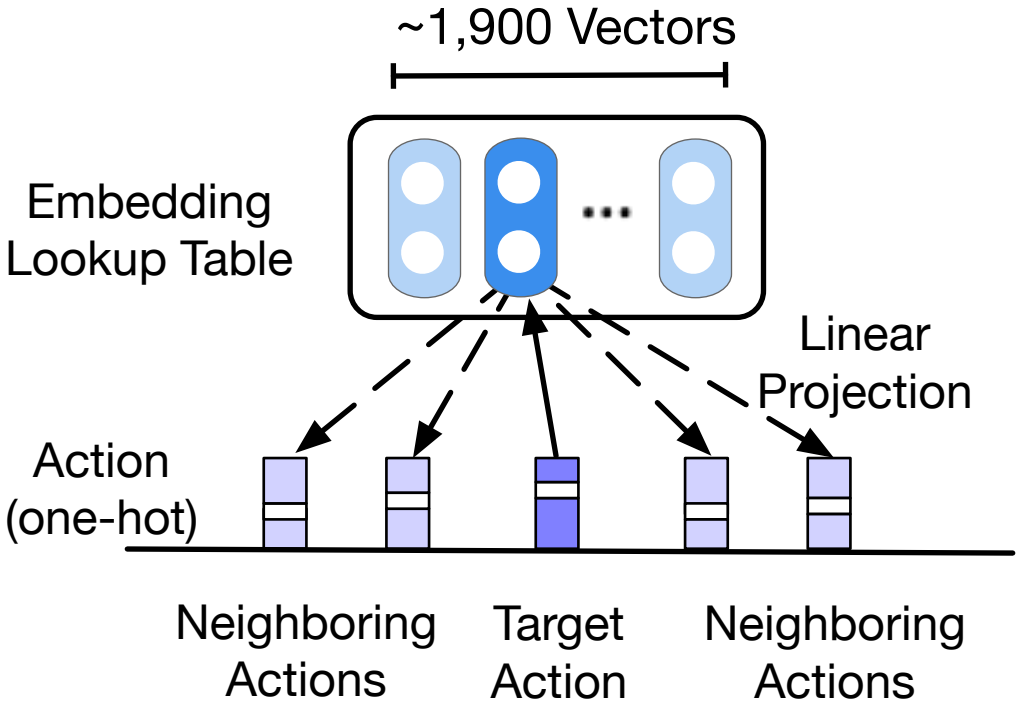
Learning Activity Context



A: Note Review
B: Report Review

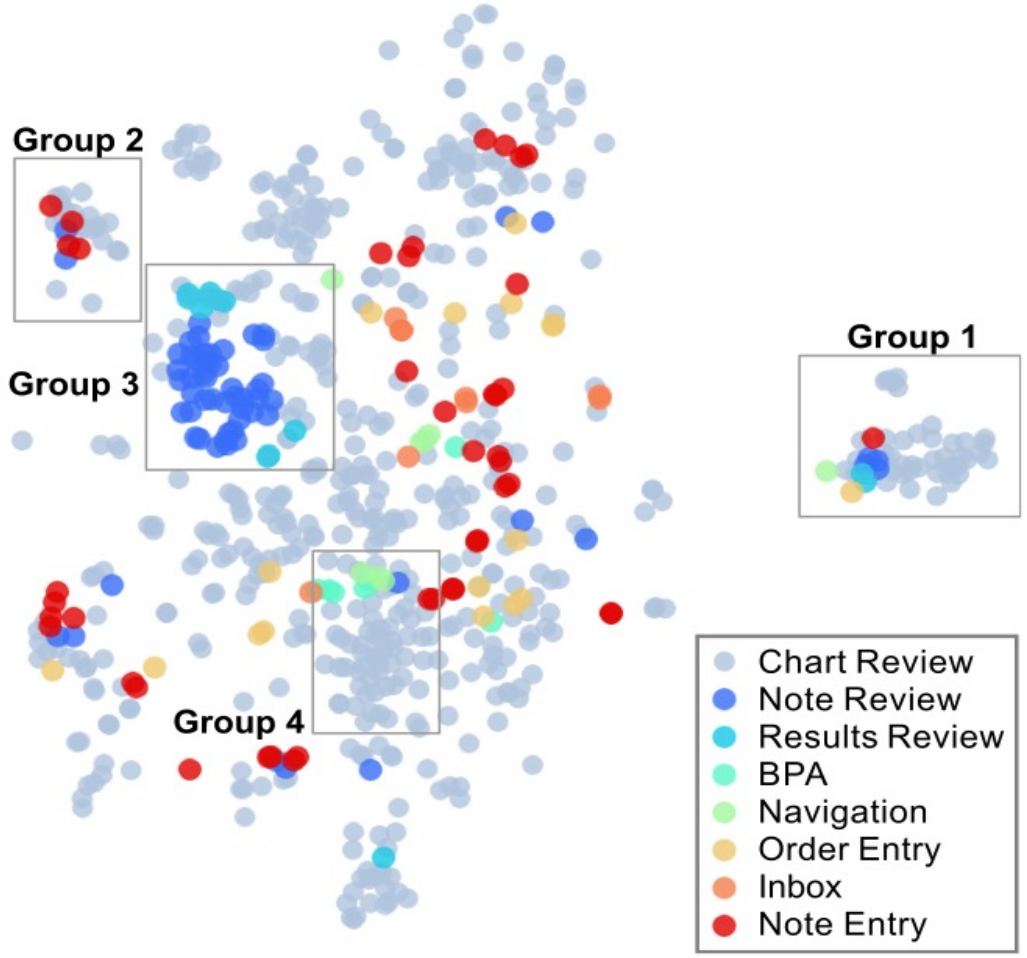
Semantically similar

Similar embedding (representation)



"Skip-Gram Algorithm"

Learned Action Embedding



Identified Workflow Groups

Group 1:
Mobile EHR client

Group 2:
Preoperative assessment module

Group 3:
Inpatient pre-rounding

Group 4:
Outpatient setting

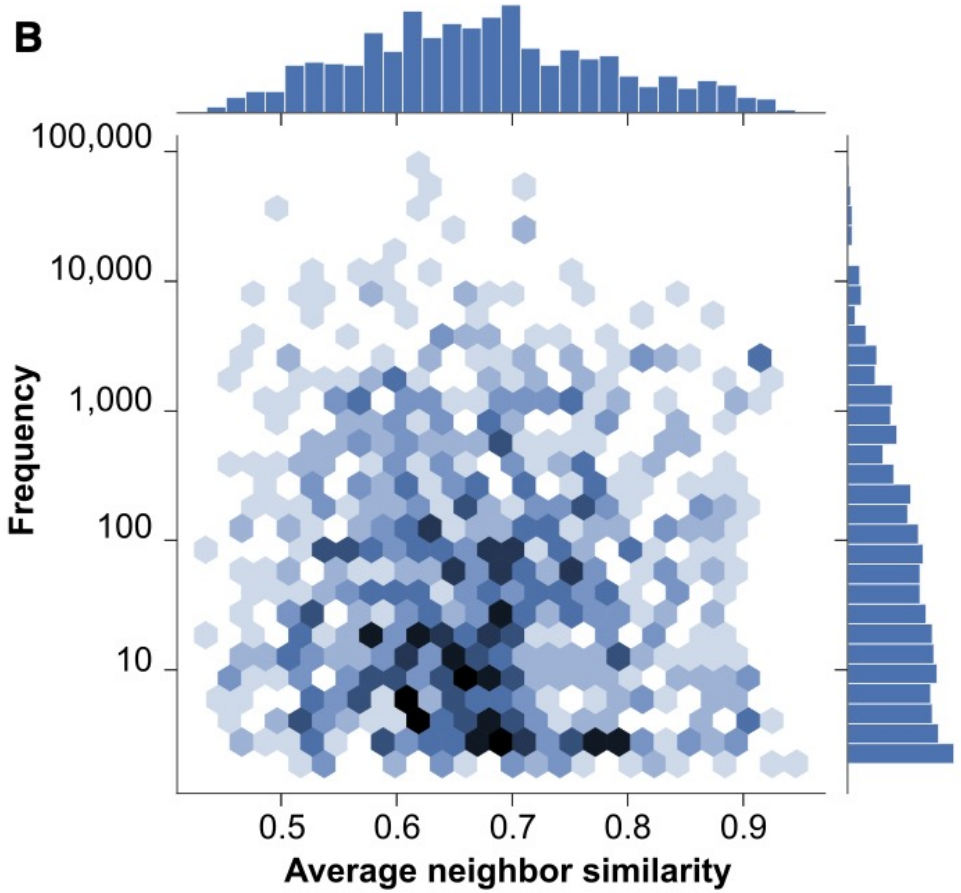
Learned Action Embedding

A

Most similar actions to 'Results Review accessed'

Action	Similarity
Results Review exited	0.779
Report viewed - Radiology Results	0.634
Report viewed - Result Detail	0.626
Report viewed - Lab Result Template	0.606
Report viewed - IP Vitals	0.582
Chart Review Encounters tab selected	0.557
Report viewed - CV Echo	0.551
Order list changed	0.550
Report viewed for an order	0.537
Report viewed - IP Flowsheet	0.529

B



Action-time Joint Embedding

Contextual **Action** Embedding

$f_A(\boldsymbol{e}_j)$

Time **Interval** Embedding

$f_I(t_{i+1} - t_i)$

Time **Periodicity** Embedding

$f_P(\sin(t_i))$

⇨

Action-time **Joint** Embedding

$\boldsymbol{g}_i = f(\boldsymbol{e}_j, t_i)$

$\boldsymbol{e}_j$: one-hot encoding of the j-th unique action

$\boldsymbol{f}$: Function implemented by a neural network

Action-time Joint Embedding

Action Embedding

$$\mathbf{a}_i^{(k)} = \mathbf{W}_a \mathbf{e}_i^{(k)}$$

Time **Interval** Embedding

$$\mathbf{b}_i^{(k)} = \tanh\left(\mathbf{W}_b \cdot \log\left(t_i^{(k)} - t_{i-1}^{(k)}\right) + \mathbf{d}_b\right)$$

Time **Periodicity** Embedding

$$\mathbf{c}_i^{(k)}[j] = \begin{cases} \omega_j t_i^{(k)} + \varphi_j, & \text{if } j = 1 \\ \sin(\omega_j t_i^{(k)} + \varphi_j), & \text{if } 1 < j \leq d \end{cases}$$

$$\mathbf{g}_i^{(k)} = \text{Concat}([\mathbf{a}_i^{(k)}; \mathbf{b}_i^{(k)}; \mathbf{c}_i^{(k)}])$$

Action-time **Joint** Embedding

II – Modeling on Long Dependencies

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Challenge II

Large-scale Model Input

- 20,000 ~ 90,000 actions per month*person
- 1,000 ~ 8,000 actions per shift*person
- Need Long dependencies

Table: Statistics of Dataset

Statistics	Number
# total data points (actions)	15,767,634
# types of actions	1,961
# participants	88
# total months of audit logs	754
# months with eligible surveys (labels)	391

e.g., single-level RNNs

- "no-brainer" for sequential data
- Recurrent structure → slow to train
- Gradient issue → worse for long data sequence

Model	**Training Time** (per epoch)
RNNs	> 5 h

RNN: Recurrent Neural Networks

Hierarchical Sequence Modeling

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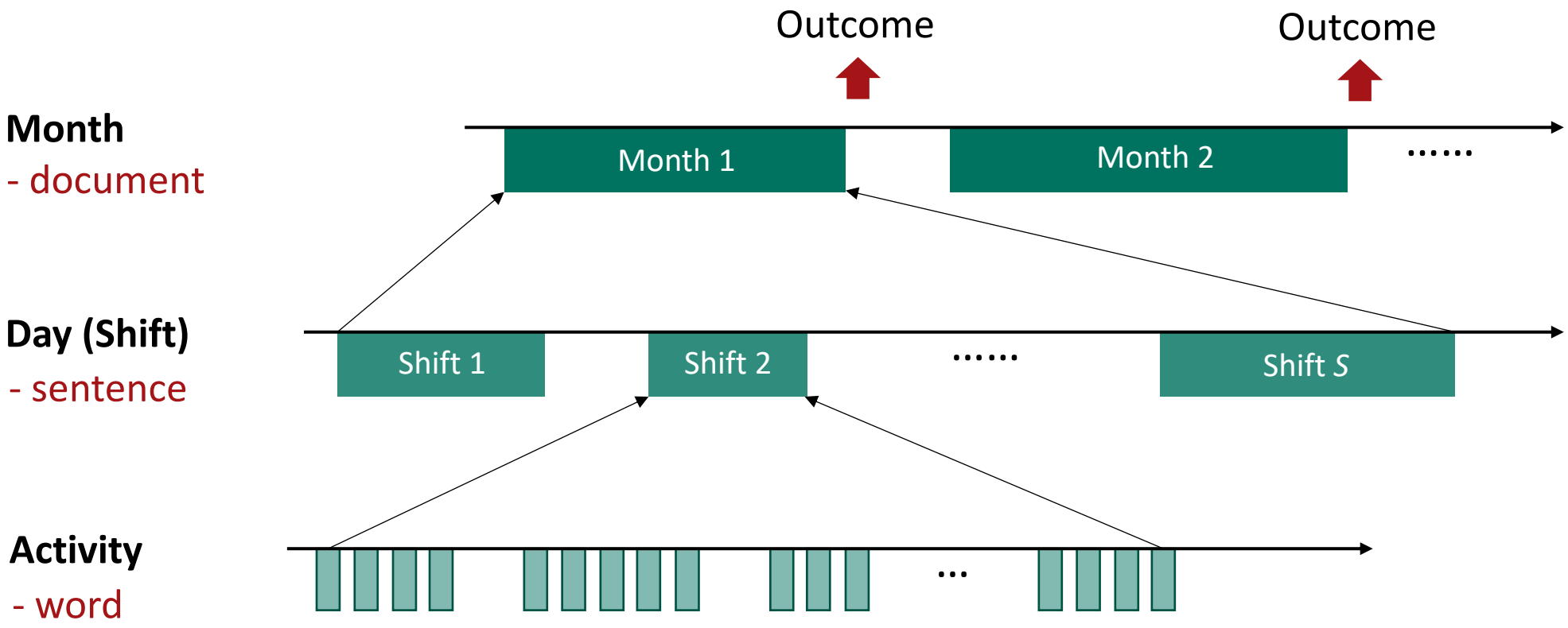


Temporal clustering of activities may contain useful information associated with burnout.

Hierarchical Sequence Modeling

High-level Encoder:
Daily measurement → Monthly measurement

Hi
Er

Lo
En

Low-level Encoder:
Activity embedding → Daily measurement

f_{High}:
RNNs
(e.g., LSTM)

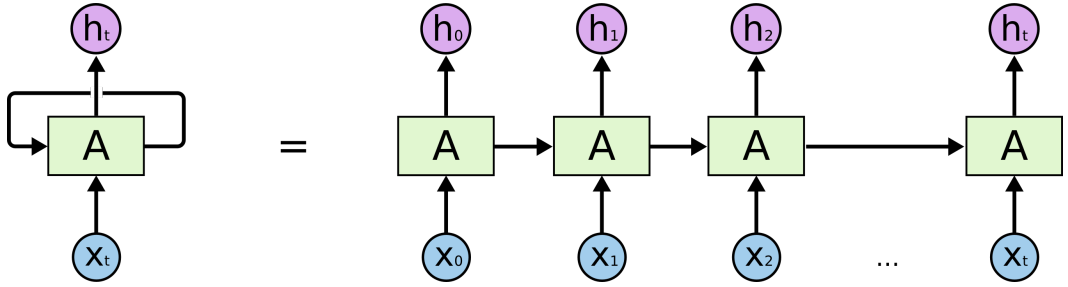
f_{Low} :
Convolutional
(e.g., TCN)

Raw data encoding:
Raw activity logs → Activity embedding (action & time)

Hierarchical burnout Prediction based on Activity Logs (HiPAL)

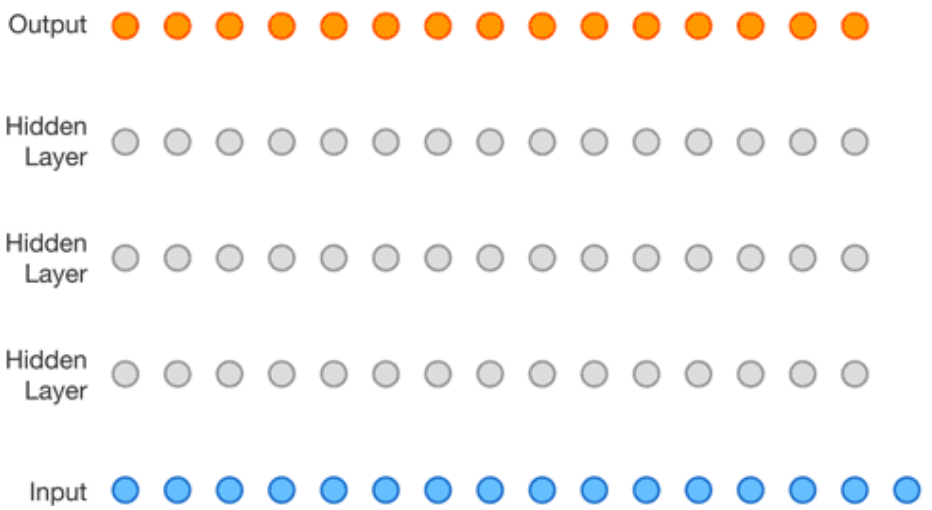
Design Choice: Sequence Models

Recurrent Neural Networks (RNN)
(e.g., LSTM, GRU)



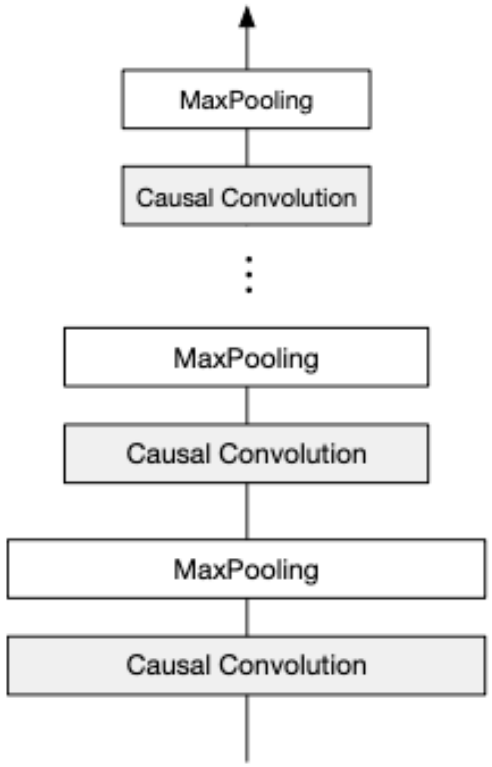
- Compute steps recurrently
- Time-consuming
- Gradient issue for long sequences

Temporal Convolutional Networks (TCN)

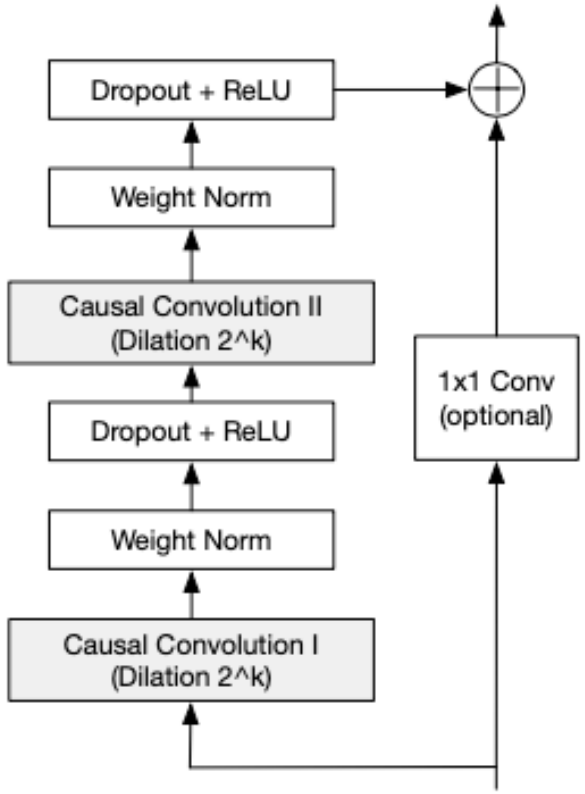


- Compute steps concurrently
- Efficient for long sequences
- Behave like RNN, compute like CNN

Variations of TCN



(A) CausalNet



(B) ResTCN

$$\mathbf{y} = \mathbf{W} * \mathbf{x} + \mathbf{d}$$
$$\mathbf{z} = \mathrm{BatchNorm}(\mathbf{y})$$
$$\mathbf{x}' = \mathrm{ReLU}(\mathbf{z})$$

(C) Fully Convolutional Networks (FCN)

III – Utilizing Unlabeled Data

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Challenge III
Limited Labels

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Experiment

Prediction Performance

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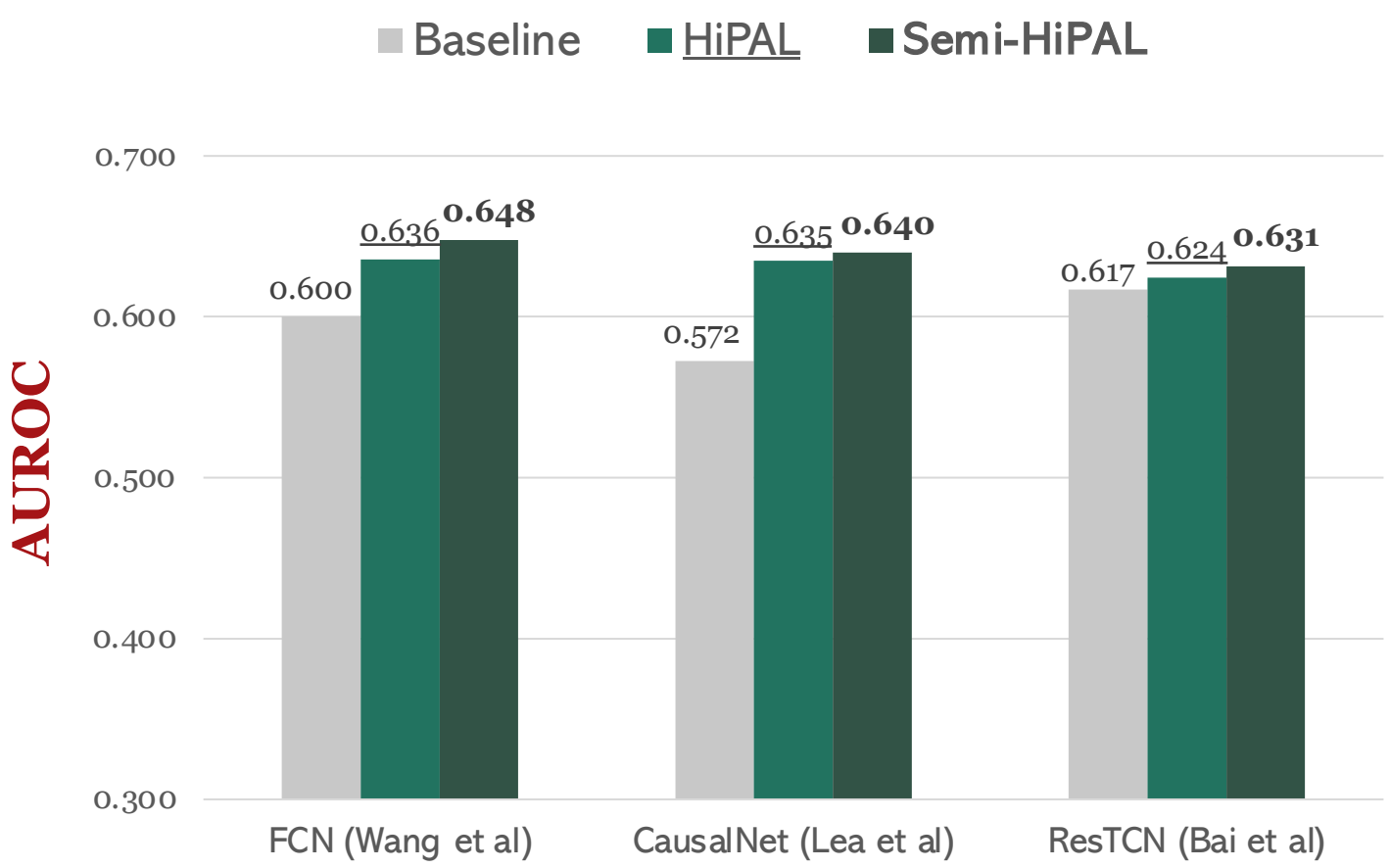

AUROC (higher → better):
Average true positive rate over all possible true negative rate

Training Efficiency

Method	Training Time (per epoch)
RNNs	> 5 h
HiPAL	< 1 min

Size of training set - 6 million activity logs
GPU - Nvidia RTX 3090

Practical Effectiveness

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AUROC = 0.6358

% True Positive Rate ⟷ (Trade off) % True Negative Rate

	Intervention	Cost	Model Preference	% True Positive	% True Negative
I	 EHR training Online therapy	Low	Sensitive	80%	41.5%
II	 Days off Vacations	High	Specific	47.8%	80%

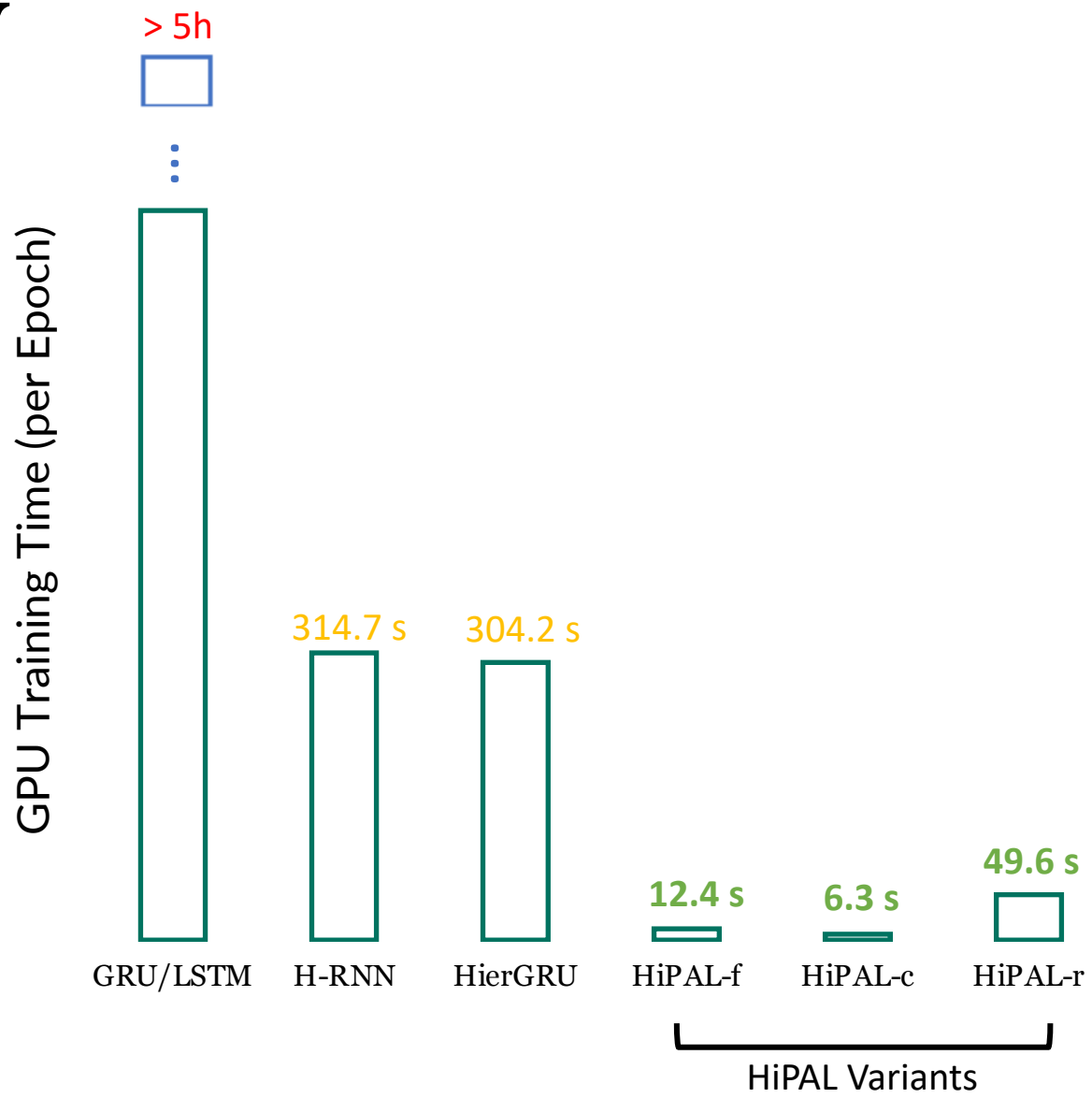
Training Efficiency

Single-level:
FCN, CausalNet and ResTCN

Hierarchical:
H-RNN: multi-level LSTM for video classification
HierGRU: replace f_{Low} as GRU

Ours:
HiPAL-f: f_{Low} = FCN
HiPAL-c: f_{Low} = CausalNet
HiPAL-r: f_{Low} = ResTCN
(f_{High} = LSTM)

RNN-based:
GRU and LSTM (recurrent, slow)



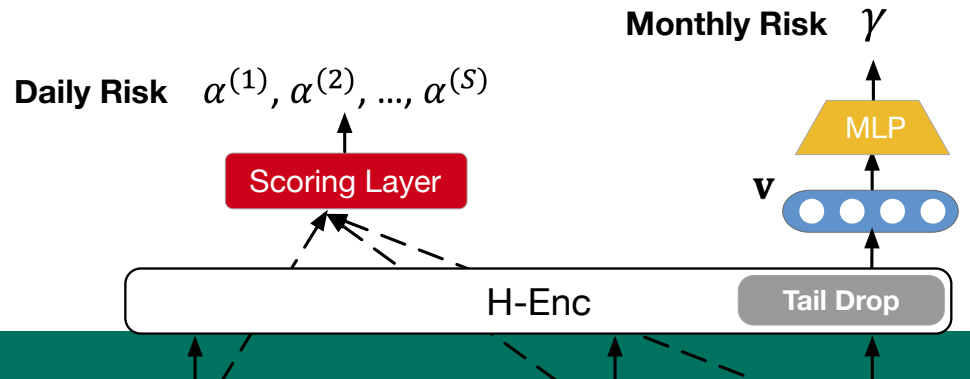
Temporal Consistency Regularization

Daily risk score: $\alpha^{(k)} = \text{Softmax}(\mathbf{W}_R \cdot \mathbf{r}^{(k)} + \mathbf{d}_R)$

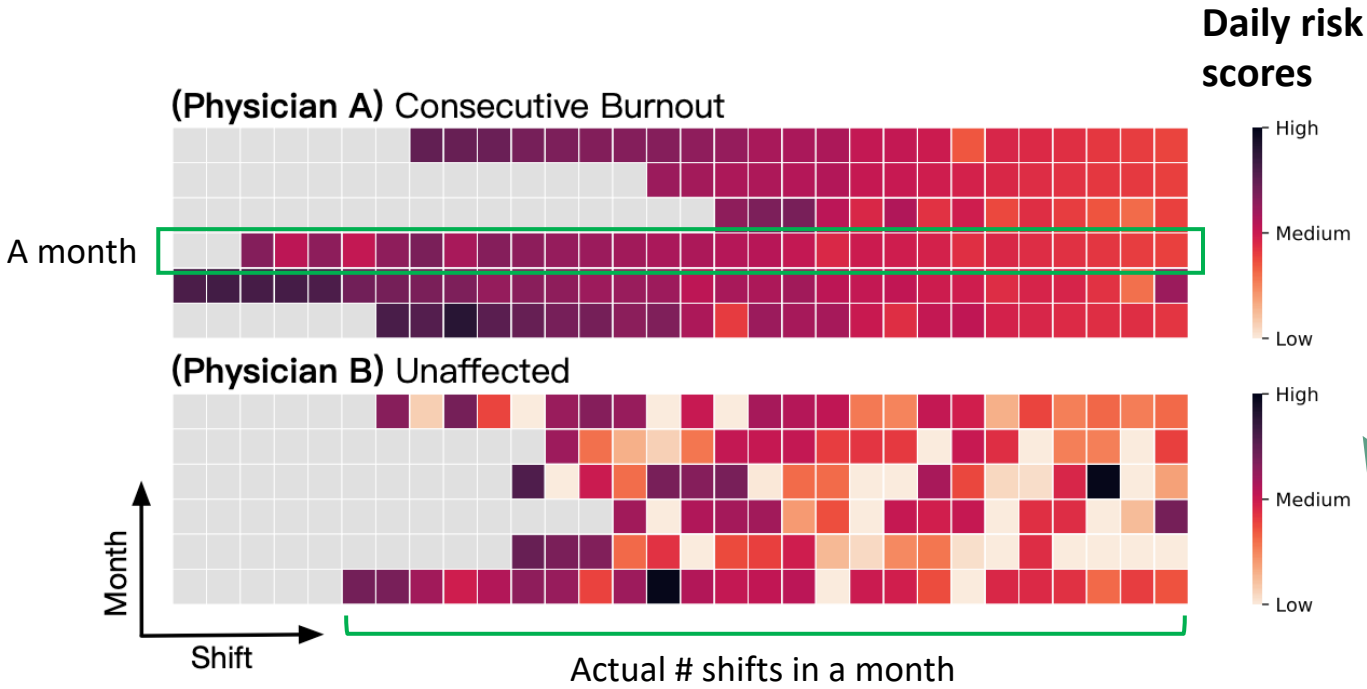
Daily loss: $\mathcal{L}_L = \frac{1}{T}\sum_{k=1}^{T} \text{CE}(\alpha^{(k)}, y)$

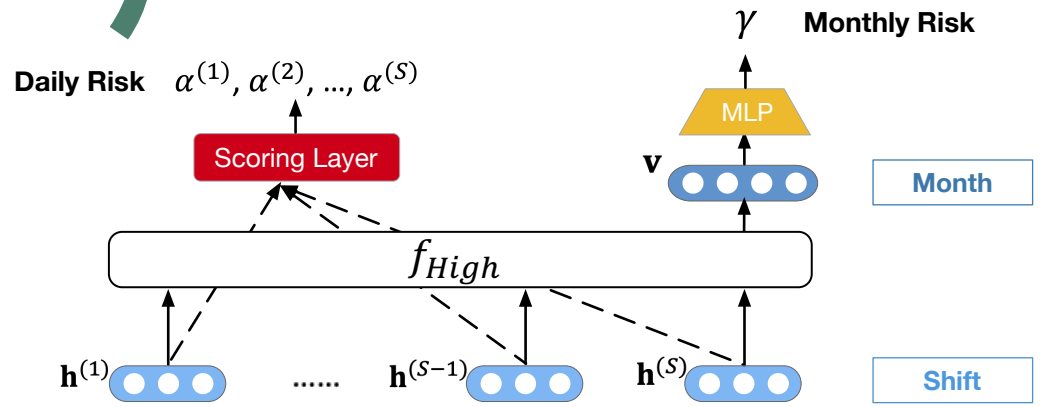
Monthly loss: $\mathcal{L}_H = \text{CE}(\gamma, y) = y \log \gamma + (1-y)\log(1-\gamma)$

Overall loss: $\mathcal{L} = \mathcal{L}_H + \lambda \mathcal{L}_L$

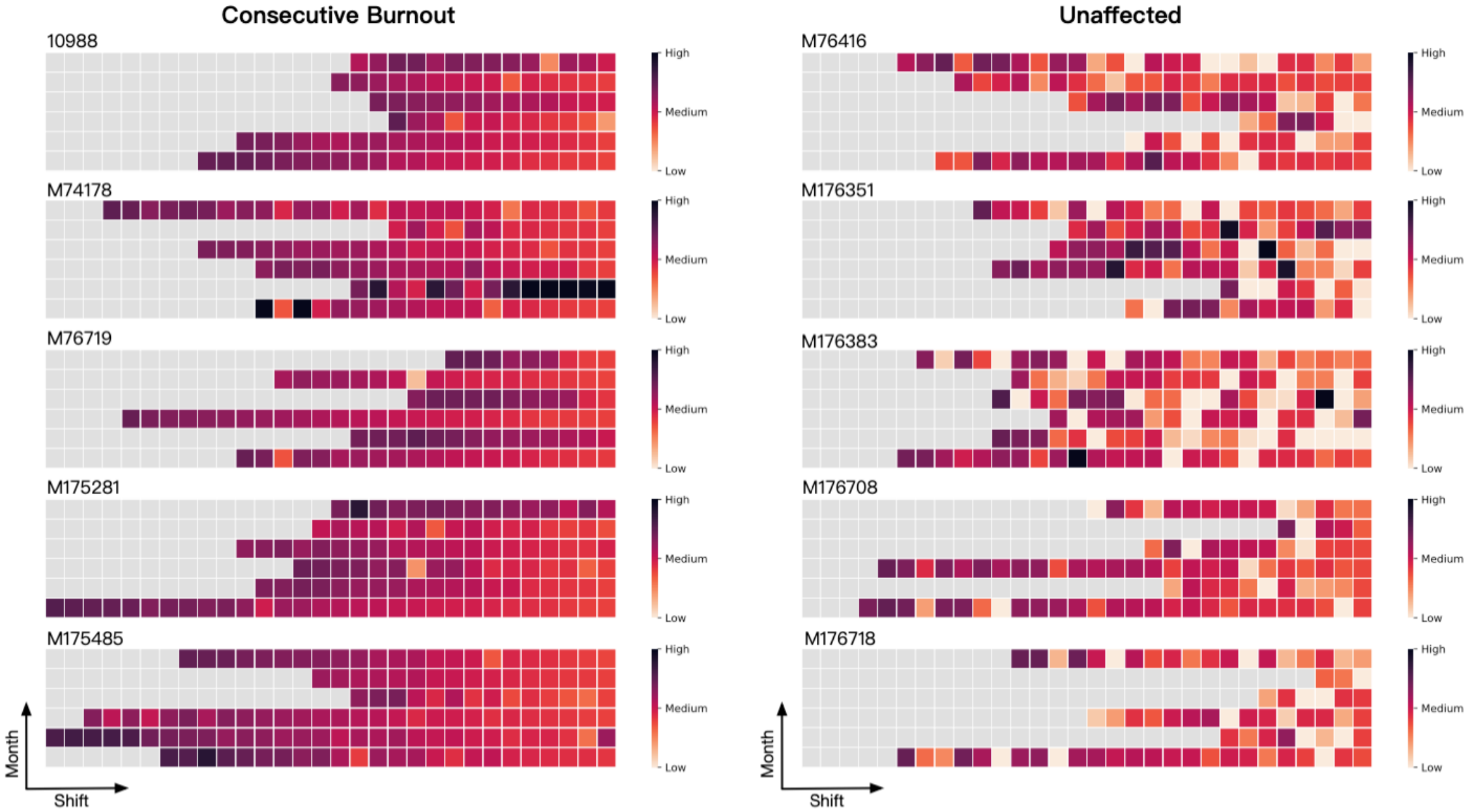


Interpretable Prediction





Can demonstrate how **daily risk** evolved over time and accumulated to final **monthly risk** of burnout.


Consecutive Burnout
10988
M74178
M76719
M175281
M175485
High
Medium
Low
Month
Shift
Unaffected
M76416
M176351
M176383
M176708
M176718
High
Medium
Low
Month
Shift

Ablation Study

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TC:
Temporal Consistency

Pretrain:
Action embedding pretraining (unsupervised)

Concat -- > Add:
Replace the embedding aggregation function from concatenation to numerical addition

Variant	AUROC	AUPRC	Accuracy
w/o Regularization			
w/ Different Embedding Settings			
w/ All	**.6347 (.0181)**	**.5502 (.0191)**	**.6400 (.0218)**

Ablation Study - Taildrop

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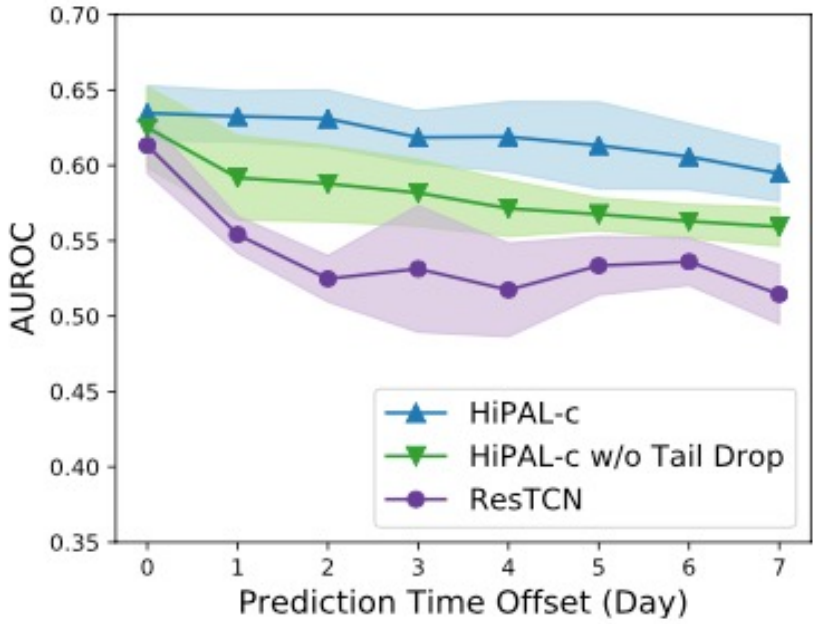

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Conclusion

Conclusion

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- End-to-end deep learning-based burnout prediction framework
- Learn contextual representations directly from raw activities
- Capture natural hierarchical structure of clinician activity logs
- Model long dependencies on large-scale activity logs with high efficiency
- Facilitate fast burnout phenotyping and individualized intervention

Limitations

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Study Design

- Small participant set (88 physicians x 6 months)
- Can't capture the <50% "off-the-grid" non-EHR work
- Resident physicians may not be the right population to develop a stable model – not "steady state"
- Inter-individual variability in response to workload & workflow

Modeling

- Did not consider dependencies across months
- Lack of lower-level explainability

Evaluating the Burnout Project

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1. Making the prediction actionable
   - Outcome: Burnout as defined by PFI survey
   - Clinical action: Interventions are unclear (scheduling, training, resources)
2. Potential biases in the outcome
   - Outcome is subjective, has reasonable validity but is imperfect
3. Training data quality
   - Small dataset (~80 people, ~300 surveys), maybe wrong population, not representative
   - Audit logs are reproducible and automatically generated
4. Practical predictors
   - Audit logs are required by law but are data intensive
5. Clinically meaningful measures of performance
   - AUROC because clinical action was unclear
   - Didn't measure calibration

Related Published Work

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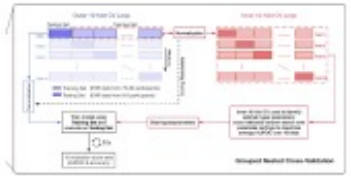
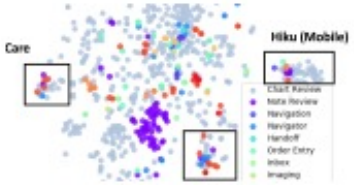


Predicting Physician Burnout using Clinical Activity Logs: Model Performance and Lessons Learned

Sunny S. Lou, **Hanyang Liu**, Benjamin Warner, Derek Harford, Chenyang Lu, Thomas Kannampallil

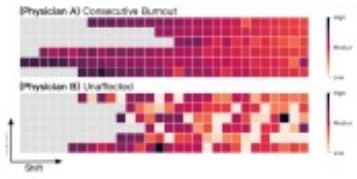
Journal of Biomedical Informatics, 2022. [pdf]



Characterizing the Microstructure of EHR Work Using Raw Audit Logs: An Unsupervised Action Embeddings Approach

Sunny S Lou, **Hanyang Liu**, Derek Harford, Chenyang Lu, Thomas Kannampallil

Journal of the American Medical Informatics Association (**JAMIA**), 2022. [pdf]



HiPAL: A Deep Framework for Physician Burnout Prediction Using Activity Logs in Electronic Health Records

Hanyang Liu, Sunny S. Lou, Ben Warner, Derek Harfort, Thomas Kannampallil, Chenyang Lu

ACM SIGKDD Conference on Knowledge Discovery and Data Mining (**KDD**), 2022. [pdf] [code][presentation]

Acknowledgement

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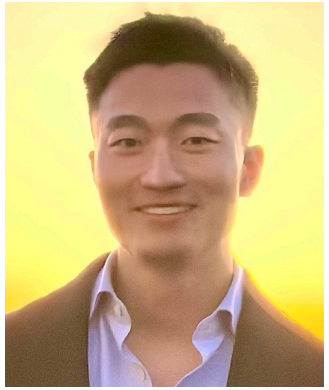

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