Toward a Two-Tier Clinical Warning System for Hospitalized Patients

Gregory Hackmann¹, Minmin Chen¹, Octav Chipara¹*, Chenyang Lu¹, Yixin Chen¹, Marin Kollef², Thomas C. Bailey²

¹ Department of Computer Science and Engineering, Washington University
² Department of Medicine, Washington University School of Medicine
* Now with Department of Computer Science, University of Iowa
Vision: Two-Tiered Clinical Early Warning

- Tier 1: identify at-risk patients from existing medical record data

- Tier 2: issue real-time warnings from existing medical records and real-time vital sign monitoring
Early Warning System

- Electronic medical record systems aggregate a wealth of data about a patient’s condition
- Challenge: how to determine the importance of these data?

- Feasibility study using approach based on logistic regression
Algorithm Overview

- Logistic regression assigns a weight to each kind of input in predicting an outcome.
- Standard logistic regression does not:
  - Operate on time-series data
  - Handle missing data
Algorithm Overview

- Logistic regression assigns a weight to each kind of input in predicting an outcome
- Standard logistic regression does not:
  - Operate on time-series data
  - Handle missing data
- Split window of data into $n$ equally-sized “buckets”
- Calculate min/mean/max of each bucket
- Find separate weights for all $3n$ values
Algorithm Overview

- Logistic regression assigns a weight to each kind of input in predicting an outcome.
- Standard logistic regression does not:
  - Operate on time-series data
  - Handle missing data
- Try to fill in empty buckets by “carrying over” most recent value.
- If patient had no data for a variable, use mean over entire historical dataset as a fallback.
Evaluation: Retrospective Analysis

- Dataset of 28,927 hospital visits from 19,116 patients
- 36 categories of data + outcome (ICU transfer)

- Snapshot of 24 hours’ data for each patient, divided into 6 buckets
- Use first half of dataset to train logistic model
- Use second half of dataset to test model against known outcome
Retrospective Analysis

Predicative Performance

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area under curve</td>
<td>0.8834</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.9500</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.4877</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>0.3138</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>0.9753</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.9292</td>
</tr>
</tbody>
</table>
Evaluation: Real-Time Simulation

- Retrospective study looks at one 24-hour window per patient
- Real-time detection system would produce a series of scores over entire hospital stay
Real-Time Simulation

Predictive Performance

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area under curve</td>
<td>0.7293</td>
</tr>
<tr>
<td>Specificity</td>
<td>0.9492</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>0.4127</td>
</tr>
<tr>
<td>Positive predictive value</td>
<td>0.2955</td>
</tr>
<tr>
<td>Negative predictive value</td>
<td>0.9691</td>
</tr>
<tr>
<td>Accuracy</td>
<td>0.9229</td>
</tr>
</tbody>
</table>
Conclusion

- Tier 1: early warning feasibility study
- Sensitivity of 41.3% at a manageable alarm rate

- Tier 2: real-time vital sign monitoring
- Under clinical trial in four units at Barnes-Jewish Hospital

- Ongoing work: enhancements to Tier 1 performance, development of Tier 2 real-time detection algorithm