Early Prediction of Sepsis: How to Tackle a Lethal Threat
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Ashish Sharma, PhD
Shamim Nemati, PhD
Department of Biomedical Informatics
Emory University

@_AshishSharma
Leading cause of death in hospitals  
~30M affected (1M in USA)  
15-30% die from sepsis  
$24B/yr US Hospitals (#1)  

Lifesaving if caught early  
Every hour equals 4 - 8% improvement in survival  

Sources:  WHO, NIH/NIGMS, Sepsis Alliance, AHRQ  
Seymour et. al. NEJM 2017  
Kumar et. al. Crit Care Med. 2006
Sepsis-3 as a Clinical Construct: ΔSOFA>2 + Clinical Suspicion
Deep AI Sepsis Expert (Deep-AISE)

- Trained and validated on 30,000 and 50,000 patient cohorts, 1,000 miles apart.
- Predicting Sepsis (following Sepsis-III definition) 4-8 hours in advance with an AUC of 0.85.
- Reveals top causes per each prediction.
Deep-AISE Performance

- Deep-AISE (GRU + Cox Regression) now achieves an AUC of 0.89 for 4 hours ahead prediction of sepsis.

- We just extracted a new cohort of 100,000 patients from four Emory Hospitals (EUH, EUHM, ESJH, EJCH).

- NSF grant to enable Multi-Institutional training of deep learning Algorithms.
Next Step: How does one take an ML Algorithm to Bedside
aka. Production Deployment

Model Development and Training
- TensorFlow, Keras, pyTorch, MATLAB,...

Deployment (going to bedside)
- Data Wrangling (w/o Human in the loop)
- on-demand deployment of Algorithms
- Scalability
- Performance and Latency
- Monitoring, Testing and Reliability
- User Interfaces
The process starts at the patient bedsides. Data from the patient monitors is fed into a predictive engine called DeepAISE. This engine produces an at-a-glance sepsis risk score that represents a composite of numerous types of data. Emory chose to deploy it through Google Cloud Platform for scalability and flexibility using the Google Healthcare API, Pub/Sub, Dataflow, ML Engine, Tensorflow, Kubernetes, and the Google Container Engine.
Solution: Forecast the Onset of Sepsis Within Actionable Windows

4, 6, or 12 hour forecasts (AUC: 0.89) with real-time Clinical Interpretability
Command Center

The result is a dashboard that allows the care providers to see a summary of the patients and their sepsis risk score.

The dashboard also shows care providers historical data if she selects an individual patient that allows her to make more informed decisions about the patients care.
<table>
<thead>
<tr>
<th>Room</th>
<th>AISE</th>
<th>DRS</th>
</tr>
</thead>
<tbody>
<tr>
<td>G509</td>
<td>0.88</td>
<td>97.96</td>
</tr>
<tr>
<td>G515</td>
<td>0.75</td>
<td>2.9</td>
</tr>
<tr>
<td>G14</td>
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<td>4.05</td>
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<tr>
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<td>0.46</td>
<td>3.67</td>
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<td>G505</td>
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<td>0.15</td>
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<tr>
<td>IC10</td>
<td>0.45</td>
<td>0.04</td>
</tr>
<tr>
<td>C10</td>
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<td>0.38</td>
</tr>
<tr>
<td>C206</td>
<td>0.40</td>
<td>0.38</td>
</tr>
<tr>
<td>C201</td>
<td>0.68</td>
<td>31.25</td>
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<tr>
<td>C222</td>
<td>0.74</td>
<td>2.31</td>
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<tr>
<td>C245</td>
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<td>C253</td>
<td>0.41</td>
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<tr>
<td>C121</td>
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<tr>
<td>C126</td>
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<td>0.15</td>
</tr>
<tr>
<td>C133</td>
<td>0.40</td>
<td>0.14</td>
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Notified Provider:

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<th>AISE</th>
<th>Date</th>
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<tbody>
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<tr>
<td>E511</td>
<td>0.44</td>
<td>10/19/2018</td>
</tr>
<tr>
<td>E512</td>
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</tr>
<tr>
<td>E513</td>
<td>0.29</td>
<td>10/19/2018</td>
</tr>
</tbody>
</table>

Treatment Initiated:

<table>
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<th>Room</th>
<th>Date</th>
</tr>
</thead>
<tbody>
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</tr>
<tr>
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</tr>
<tr>
<td>L205</td>
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</table>
The top of each card shows the patient's name and/or room number. The bottom of the card shows the patient's risk (AISE Score). The closer the score is to 1, the more likely the patient is to develop sepsis. The arrow represents trends over the past 4 hours.
Clinical Interpretation

Dashboard and Details
Why Cloud First

What about On-Prem infrastructure? Hybrid Infrastructure?

Scalable and Affordable Computing
- On Demand Computing (lower capital expenditures)

Managed services that enable new design patterns for computing
- Big Query/RedShift etc.
- Serverless Computing
- Data wrangling Services, e.g. DataFlow

Lower/Different barriers to adoption
- Work with APIs, not Servers
- Local IT has to become cloud aware
Leverage Vendor Services for Scalability and Redundancy

- Deployed Deep AISE on ML Engine, GKE and other cloud functions
- Deployment Time < 1 day
- Improves model development by allowing one to test, during development, with real-world scale and constraints
Cloudy Pipelines can Work (e.g. Google Genomics, DNANexus, NCI Cloud Resources, Globus Genomics…)

- Frameworks like Kubeflow bring Data Engineering to ML/AI Dev
  - Rely on orchestrators capable of running pipelines on local/cloud/hybrid

- Think multi-stage pipelines not standalone monoliths
  - Stages → containerized or API endpoints or FaaS

Processing at Scale

Hint: Docker is not the silver bullet
$1M project — DRIVe Solving Sepsis Program

Emory led consortia to validate and integrate DeepAISE across multiple sites

Leverages the efficiencies of Cloud

Integrates with local IT for real-time forecasts

Seek regulatory approval
Acknowledgements

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- Members of the BMI Department
- Doctors and Nurses at the Emory Critical Care Center