Intervention-Aware Early Warning

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This work was performed at Amazon.
Early Warnings & Interventions

Adverse health events  Mechanical failures  Student drop-outs

Medicines  Repairs  Tutoring
Research Questions

• How to learn to early warn from data containing interventions?

• What is the correct way to handle interventions?
  • *Is it “just another” feature?*
Problem Statement

**GIVEN**

- a set of entities and for each entity,
  - measurements
  - interventions
  - labeled event occurrences

**LEARN**

- an online early warning scoring function
Common ML Approach

**INTERVENTION-AWARE EARLY WARNING**

**MOTIVATION**

Goal: Early warn $\Delta = 3$ hours ahead of time

**Solution:** Train ML to predict a function of observed future label

**Counter-intuitive Results**

**MOTIVATION**

"Asthma reduces the risk of pneumonia", Caruana et al KDD 2015

**Problem: Future labels are a function of intermediate interventions**

**Goal: Early warn $\Delta$ time steps ahead of time**
Intervention-Awareness

- Take into account **past** interventions
- Do not assume **future** interventions
Overview of SmokeAlarm

1. Model Learning

2. Early Warning Scoring
Model: Variables

- $\text{state}(t)$
- $\text{residue}(t)$
- $\text{residue}(t+1)$
- $\text{intervention}(t-1)$
- $\text{intervention}(t)$
- $\text{intervention}(t+1)$
- $\text{measurement}(t)$
- $\text{measurement}(t+1)$
- $\text{label}(t)$
- $\text{label}(t+1)$
Model: Parameters

- Duration of intervention
- Intervention-bound state evolution
- Intervention-free state evolution
Step 1: Model Learning

E-step
Update variables

M-step
Update parameters

Variables

Parameters
Early warning score = expected discounted number of events in the future
SmokeAlarm is Intervention-Aware

- Takes into account past interventions
- Does not assume future interventions
MOTIVATION

APPROACH

EXPERIMENTS
Real-World Task: Septic Shock

• Result of bacterial infection

• **Consequences:** organ failure, death

• **Early signs:** e.g., drop in pressure

• **Actionable:** antibiotics, vasopressor

• Early warnings are life-saving
Real-World ICU Data from Mimic-III

Mean arterial pressure (MAP)
Serum lactate (SL) & more

Vasopressor
(increases MAP)

Low MAP
High SL
Improved Precision, Recall

SmokeAlarm can distinguish between patients with and without septic shock.
Improved Lead Time

![Graph showing improved lead time with SmokeAlarm outperforming baselines.](image-url)
Summary

Problem

• Multiple types of interventions
• Streaming, semi-supervised settings
• Interpretability for high dimensional data

Model

Future Work

• Multiple types of interventions
• Streaming, semi-supervised settings
• Interpretability for high dimensional data

Accuracy

Thank you!
Questions: deswaran@cs.cmu.edu
Extra Slides
Interpretable Model

Vasopressor-free

Vasopressor-bound

Measurement 2: Serum Lactate
Measurement 1: Mean Arterial Pressure

early warning (escalating)

late warning (sick)

no warning (healthy)
Principle 1: Dominance

Earthquakes at L₁ and L₂ begin simultaneously. Earthquake at L₁ lasts longer than that at L₂.

Event expected more times $\Rightarrow$ higher early warning score.
Principle 2: Precedence

Event expected sooner \(\Rightarrow\) higher early warning score