Why Am I Stuck?
Instance-Based (Token-Level) Causal Reasoning for AI

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Instance-Based Causality
What is it?

A specific causal hypothesis relating a particular sequence of events

Event1 > Causal Model(X) > Event2
Event3 > Inference > Event2
Event4

Event1 > Event2
Event3 > Event4
Instance vs. General Causation

Token vs. Type-Level Causation

Type-level model for lung cancer

Instance-based explanation for Bob’s lung cancer:

*Bob’s lung cancer was caused by that time when he snorted asbestos in the 80s.*
Why Should You Care About Instance-Based Causality?
Automated Scientific Discovery

Expected

Event1
Event2
Event3
Event4

time

Experimentation

Existing Theory

Explanation

Observation

Event1
Event2
Event3’
Event4’

time

Repeat

Prediction

Event1

Event2

Event3

Event4

Event3’ → Event4’
Dynamic Troubleshooting

Self-diagnosing Code

Autonomous Robotics

Video Understanding
“Causal Explication”

Past | Event1
---|---
Present | Event2
Future | Event3 → Event4

Unobserved
Observed
Desirable Properties of Causal Explication

1. **Multiple hypotheses**
2. **Simple hypotheses**
3. **Quantified hypotheses**
4. **Deals with unknowns**
5. **Fills in the gaps**

Bob Drinks a liquid  
Bob Falls Asleep
A car crashes
An ambulance comes

Bo drinks water
Bob Falls Asleep in his bed
A car crashes
An ambulance comes

Bob Drinks alcohol
Bob Falls Asleep
Bob is driving
Bob’s car crashes
An ambulance comes

Bob stayed up all night
Bob drinks coffee
Bob Falls Asleep
Bob is driving
Bob’s car crashes
An ambulance comes
How to represent instance-based causality?

Event1

Event2

Event3

Event4

E1=f1(U1)
E2=f2(E1,U2)
E3=f3(E2,U3)
E4=f4(E2,U4)

Directed Graph?

SEMs?
How to Perform Instance-Based Causal Reasoning?
Inference in a Causal Model:

Bob in room

Bob turns off light

Mary in room

Light off

Bob in room

Bob turns off light

Mary in room

Inference

P(X)

Bob in room

Bob turns off light

Light off
Inference in a Causal Model:

Bob in room
Mary in room
Light off

Bob turns off light
Light off

Bob in room
Mary in room

Bob turns off light
Light off

P(X)
Actual Causation & HP-Explanation (Halpern & Pearl 2001, 2005)

“Actual Causation”

“HP-Explanation”
Problem #1: Evidence-Dependent Structure
(Halpern & Pearl 2001, 2005)

Simultaneous Hits
- Mary Shoots → Mary Hits → Bottle Breaks
- Bob Shoots → Bob Hits → Bottle Breaks

Mary Hits First
- Mary Shoots → Mary Hits → Bottle Breaks
- Bob Shoots → Bob Hits → Bottle Breaks

Bob Hits First
- Mary Shoots → Mary Hits → Bottle Breaks
- Bob Shoots → Bob Hits → Bottle Breaks
Problem #2: Model Complexity

Example: HP’s rock throwing example with 1000s of people

1000! orderings
Problem #3: Infinite Structure

Stick hits Cue ball
Cue ball hits 5
5 hits 3 → 3 hits 11
5 hits 12 → 12 hits 9
9 hits 11 → 11 sinks in corner
Our Solution: Causal Logic Models
(Vennekens et al. 2009, Dash et al. 2013)

First-Order Knowledge Base
Modular
Evidence-Based

First-order Predicates  Temporality is Explicit  Causation not implication  More general than Horn clauses

\[ p_1 : A(\ldots, T_1) \land B(\ldots, T_1) \land \ldots C(\ldots, T_1) \rightarrow D(\ldots, T_2) \land E(\ldots, T_2) \land \ldots \land F(\ldots, T_2) \]

**Probabilistic Semantics**

| $p_1 : A \rightarrow C$ |
| $p_2 : B \rightarrow C$ |
Thanks!

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