CAUSALITY IN DATABASES

By Meliou et al.
Database Causality – Preliminaries

- $D$ – all tuples of a database
- $D^n$ – endogenous tuples
  - Possible causes
- $D^x$ – exogenous tuples
  - Deemed not to be possible causes
  - $D^x = D - D^n$

- Partition determined by the system or by the user
Database Causality – Definition

• \( q \) – a query
• \( r \) – a possible answer to \( q \)
• \( t \in D^n \) – an endogenous tuple

• \( t \) is called a COUNTERFACTUAL CAUSE for \( r \) in \( D \) if \( D \models q(r) \) and \( D - \{t\} \not\models q(r) \).

• \( t \in D \) is called an actual cause for \( r \) if there exists a set \( \Gamma \subseteq D^n \) such that \( t \) is a counterfactual cause for \( r \) in \( D - \Gamma \)
  • \( \Gamma \) is called a contingency for \( t \).
Database Causality – Intuition

- $t$ is called a COUNTERFACTUAL CAUSE for $r$ in $D$ if $D \models q(r)$ and $D - \{t\} \not\models q(r)$.
  - Removal of $t$ from $D$ removes $r$ from result of evaluating $q$ on $D$

- $t \in D$ is called an actual cause for $r$ if there exists a set $\Gamma \subseteq D^n$ such that $t$ is a counterfactual cause for $r$ in $D - \Gamma$
  - After removing $\Gamma$ from the $D$, $D$ is at the state where removing/inserting $t$ causes $r$ to switch between an answer and a non-answer
Degree of Responsibility

- Definition: responsibility of a cause $t$ for an answer $r$ to a query $q$ is $\rho_t = \left(1 + \min_{\Gamma} |\Gamma|\right)^{-1}$

- A function of the minimal number of tuples need to be removed from $D$ such that $t$ becomes counterfactual (the switch).

- Between candidates $A$ and $B$,
  - In a 6-5 vote, each vote for $A$ is critical
    - Responsibility = 1
  - In a 11-0 vote, 5 votes have to be changed before one becomes critical
    - Responsibility = 1/6
Applications

• Explaining unexpected answers
• Diagnosing network failures
• Handling aggregate queries
• View-conditioned causality
• Preemption
• Why-not causality for non-answers
Explaining Unexpected Answers

- Looking for genres of films directed by Tim Burton
- Known for directing fantasy movies involving dark, Gothic themes
- E.g. “Edward Scissorhands”, “Beetlejuice”, “Alice in Wonderland”
Explaining Unexpected Answers

- Use responsibility to identify most “interesting” explanations
Diagnosing Network Failure

- Connected(x,y) :- Link(x,y), Active(x), Active(y)
  - x and y are connected, if they are physically linked and both of them are active

- Connected(x,y) :- Connected(x,z), Link(z,y), Active(y)
  - If x and z are connected (indicating z is active), and z and y are connected, then x and y are connected

- Connected(x,y) :- Connected(y,x)
  - Connectivity graph is undirected
Diagnosing Network Failure

- Suppose physical links do not break down
  - Tuples in Link deemed exogenous

- Only servers break down
  - Tuples in Active deemed endogenous

- Query: Connected(A,B)
  - Observed to be false, but reported by the database to be true
  - Each server on a simple path from A to B is an actual cause
  - Minimal contingency for a server C is a set of servers $\Gamma$ such that $\Gamma \cup \{C\}$ is a minimal cut disconnecting A from B.
Handling Aggregate Queries

• **Query**: select `sum(A)` from `R`
  • Only tuples with `R.A ≠ 0` is counterfactual.

• **Query**: select ‘true’ from `R` having `sum(A) > 500`
  • Assuming an instance of `R.A`: `{450, 150, 75, 25}`.
  • \( \rho_{450} = 1, \rho_{150} = \rho_{75} = \frac{1}{2}, \rho_{25} = 0 \)
View-Conditioned Causality

- Additional information: queries $v_1, v_2, \ldots, v_k$, and their answers $b_1, b_2, \ldots, b_k$

- What are the most probable causes of unexpected answer $r$ to query $q$,
- while answers $b_1, b_2, \ldots, b_k$ to queries $v_1, v_2, \ldots, v_k$ are normal expected.
Preemption

• If Alice and Bob both throw a rock at a bottle, and Alice throws first, then her throw would be cause of the bottle breaking, not Bob’s.
• But CAUSALITY treats “Alice’s throw” and “Bob’s throw” symmetrically.

• Not really captured by this CAUSALITY definition…

• But handled by the full HP definition
Why-not Causality for non-answers

• $t$ is called a COUNTERFACTUAL CAUSE for the non-answer $r$ in $D^x$ if $D^x \not\models q(r)$ and $D^x \cup \{t\} \models q(r)$.

• $t \in D$ is called an actual cause for the non-answer $r$ if there exists a set $\Gamma \subseteq D^n$ such that $t$ is a counterfactual cause for the non-answer $r$ in $D^x \cup \Gamma$. 
Discussion

• Limitation of CAUSALITY
  • Only works for monotone queries
  • For non-monotone queries, such as ranked based queries (top-k), should refer to the full HP definition

• Applicability to class projects