Introduction to Data Management CSE 344

Lecture 14: Datalog

Announcements

- WQ 4 and HW 4 are out
  - Both due next week
- Midterm on 11/7 in class
  - Previous exams on course webpage
- Midterm review next Fri (11/4) in class

Big Picture

- Relational data model
  - Instance
  - Schema
  - Query language
    - SQL
    - Relational algebra
    - Relational calculus
    - Datalog
- Query processing
  - Logical & physical plans
  - Indexes
  - Cost estimation
  - Query optimization

Review

Query Q:

$Q(x1, \ldots, xk) = P$

Relational predicate P is a formula given by this grammar:

$P ::= atom \mid P \wedge P \mid P \vee P \mid P \Rightarrow P \mid not(P) \mid \forall x.P \mid \exists x.P$

Atomic predicate is either a relational or interpreted predicate:

$atom ::= R(x1, \ldots, xk) \mid x = y \mid x > k \mid \ldots$

R(x,y) means (x,y) is in R

Likes(drinker, beer)
Frequents(drinker, bar)
Serves(bar, beer)

Review

Find all bars that serve all beers that Fred likes

$$A(x) = \forall y.\ Likes("Fred", y) \Rightarrow Serves(x,y)$$

- We want to find x's such that the formula on the RHS is true
- For a given bar x, we need to check whether the implication holds **for all values of y**
  - Not enough to just check one value of y!

$$A(x) = \forall y.\ not(Likes("Fred", y)) \vee Serves(x,y)$$

$= not(L("F", y_1)) \vee S(x, y_1) \wedge$
$not(L("F", y_2)) \vee S(x, y_2) \wedge$
$\vdots$

for all values of y

- Likewise, given a bar x, we need to iterate over **all values of y** and check whether Serves(x,y) is true!

Domain of variables

- The **active domain** of a RC formula P includes all constants that occur in P:
  - y > 3, then AD(P) = 3
  - R(x,y) then AD(P) = none (R is a predicate)
  - $\forall$y. R(x,2,y) $\Rightarrow$ S(x,y), then AD(P) = 2 (R, S are predicates)

- Active domain of a database instance includes all values that occurs in it

Domain independence

- A RC formula P is **domain independent** if for every database instance I and every domain D such that $AD(P) \cup AD(I) \subseteq D$, then $P_D(I) = P_{AD(P) \cup AD(I)}(I)$

- In other words, evaluating P on a larger domain than $AD(P) \cup AD(I)$ does not affect the query results
  – This is a desirable property!

Likes(drinker, beer)
Frequents(drinker, bar)
Serves(bar, beer)
IsBeer(beer)
IsBar(bar)

Domain independence

- $Q(x) = \forall y.\ Likes(x,y)$ is domain dependent
  - Suppose Likes = { (d1,b1), (d1,b2) }
  - What if we evaluate y over { b1, b2 }?
  - What about { b1, b2, b3 }?

- $Q(x) = \exists y.\ Likes(x,y)$ is domain independent
  - What if we evaluate y over { b1, b2 }?
  - What about { b1, b2, b3 }?

- $Q(x) = IsBar(x) \wedge \forall y.\ Serves(x,y) \Rightarrow IsBeer(y)$ is domain independent
  - Let IsBeer = { b1, b2 }, IsBar = { bar1 }, and Serves = { (bar1, b1), (bar1, b2) }
  - What if we evaluate y over { b1, b2 }? { b1, b2, b3 }?

Likes(drinker, beer)
Frequents(drinker, bar)
Serves(bar, beer)

Domain Independence

$A1(x) = \text{not } Likes(\text{"Fred"}, x)$

Make sure x is a beer

$A1(x) = \exists y\ Serves(y,x) \wedge \text{not } Likes(\text{"Fred"}, x)$

$A2(x,y) = Likes(\text{"Fred"}, x) \vee Serves(\text{"Bar"}, y)$

Same here

$A2(x,y) = \exists u\ Serves(u,x) \wedge \exists w\ Serves(w,y) \wedge [Likes(\text{"Fred"}, x) \vee Serves(\text{"Bar"}, y)]$

$A3(x) = \forall y.\ Serves(x,y)$

Likewise

$A3(x) = \exists u.Serves(x,u) \wedge \forall y. \exists z.Serves(z,y) \rightarrow Serves(x,y)$

Lesson: make sure your RC queries are domain independent

Datalog

- Book: 5.3, 5.4
- Query Language primer on website

What is Datalog?

- Another query language for relational model
  - Simple and elegant
  - Initially designed for *recursive* queries
- Today:
  - Some companies use datalog for data analytics, e.g., LogicBlox
  - Increased interest due to recursive analytics
- We discuss only *recursion-free* or *non-recursive* datalog and add negation

Why Do We Learn Datalog?

- A query language that is closest to mathematical logic
  - Good language to reason about query properties
- Datalog can be translated to SQL (practice at home!)
  - Helps to express complex SQL as we will see next lecture
  - Can also translate back and forth between datalog and RA

- Fact: relational algebra, non-recursive datalog with negation, and relational calculus all have the same expressive power!

```sql
USE AdventureWorks2008R2;
GO
WITH DirectReports (ManagerID, EmployeeID, Title, DeptID, Level)
AS
(
-- Anchor member definition
    SELECT e.ManagerID, e.EmployeeID, e.Title, edh.DepartmentID,
        0 AS Level
    FROM dbo.MyEmployees AS e
    INNER JOIN HumanResources.EmployeeDepartmentHistory AS edh
        ON e.EmployeeID = edh.BusinessEntityID AND edh.EndDate IS NULL
    WHERE ManagerID IS NULL
    UNION ALL
-- Recursive member definition
    SELECT e.ManagerID, e.EmployeeID, e.Title, edh.DepartmentID,
        Level + 1
    FROM dbo.MyEmployees AS e
    INNER JOIN HumanResources.EmployeeDepartmentHistory AS edh
        ON e.EmployeeID = edh.BusinessEntityID AND edh.EndDate IS NULL
    INNER JOIN DirectReports AS d
        ON e.ManagerID = d.EmployeeID
)
-- Statement that executes the CTE
SELECT ManagerID, EmployeeID, Title, DeptID, Level
FROM DirectReports
INNER JOIN HumanResources.Department AS dp
    ON DirectReports.DeptID = dp.DepartmentID
WHERE dp.GroupName = N'Sales and Marketing' OR Level = 0;
GO
```

```
DirectReports(eid, 0) :-
            Employee(eid),
            not Manages(_, eid)
DirectReports(eid, level+1) :-
            DirectReports(mid, level),
            Manages(mid, eid)
```

SQL Query vs Datalog
(which would you rather write?)

Datalog

We do not run datalog in 344; to try out on you own:

- Download DLV (http://www.dbai.tuwien.ac.at/proj/dlv/)
- Run DLV on this file
- Can also try IRIS

  (http://www.iris-reasoner.org/demo)

```
parent(william, john).
parent(john, james).
parent(james, bill).
parent(sue, bill).
parent(james, carol).
parent(sue, carol).

male(john).
male(james).
female(sue).
male(bill).
female(carol).

grandparent(X, Y) :- parent(X, Z), parent(Z, Y).
father(X, Y) :- parent(X, Y), male(X).
mother(X, Y) :- parent(X, Y), female(X).
brother(X, Y) :- parent(P, X), parent(P, Y), male(X), X != Y.
sister(X, Y)  :- parent(P, X), parent(P, Y), female(X), X != Y.
```

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog: Facts and Rules

Facts = tuples in the database

```
Actor(344759,'Douglas', 'Fowley').
Casts(344759, 29851).
Casts(355713, 29000).
Movie(7909, 'A Night in Armour', 1910).
Movie(29000, 'Arizona', 1940).
Movie(29445, 'Ave Maria', 1940).
```

Rules = queries

No need for ∃x ∃z

```
Q1(y) :-  Movie(x,y,z), z='1940'.
```

```
Q2(f, l) :-  Actor(z,f,l), Casts(z,x),
             Movie(x,y,'1940').
```

```
Q3(f,l) :- Actor(z,f,l), Casts(z,x1), Movie(x1,y1,1910),
                         Casts(z,x2), Movie(x2,y2,1940)
```

Extensional Database Predicates = EDB = Actor, Casts, Movie

Intensional Database Predicates = IDB = Q1, Q2, Q3

Datalog: Terminology

head　　　　　　body

atom　　atom　　atom (aka subgoal)

```
Q2(f, l) :- Actor(z,f,l), Casts(z,x), Movie(x,y,'1940').
```

f, l = head variables

x,y,z = existential variables

More Datalog Terminology

Q(args) :- R1(args), R2(args), ...

Your book uses:

Q(args) :- R1(args) AND R2(args) AND ....

- $R_i(args_i)$ is called an atom, or a relational predicate
- $R_i(args_i)$ evaluates to true when relation R_i contains the tuple described by $args_i$.
  - Example: Actor(344759,'Douglas', 'Fowley') is true

- In addition to relational predicates, we can also have arithmetic predicates
  - Example: z='1940'.

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Semantics

- Meaning of a datalog rule = a logical statement !

```
Q1(y) :- Movie(x,y,z), z='1940'.
```

- Means:
  - $\forall$x. $\forall$y. $\forall$z. [(Movie(x,y,z) and z='1940') $\Rightarrow$ Q1(y)]
  - and Q1 is the **smallest** relation that has this property

- Note: logically equivalent to:
  - $\forall$ y. [($\exists$x. $\exists$ z. Movie(x,y,z) and z='1940') $\Rightarrow$ Q1(y)]
  - That's why vars not in head are called "existential variables".

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog program

A datalog program is a collection of one or more rules

Each rule tells us how to infer the contents of relations from others

Example: Find all actors with Bacon number ≤ 2

```
B0(x) :- Actor(x,'Kevin', 'Bacon')
B1(x) :- Actor(x,f,l), Casts(x,z), Casts(y,z), B0(y)
B2(x) :- Actor(x,f,l), Casts(x,z), Casts(y,z), B1(y)
 Q4(x) :- B0(x)
 Q4(x) :- B2(x)
```

Note: Q4 means the *union* of B0 and B2

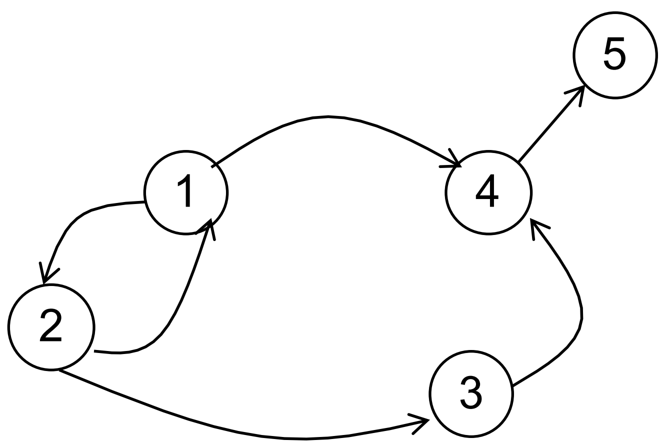
We actually don't need Q4(x) :- B0(x)

Recursive Datalog

- In datalog, rules can be recursive

```
Path(x, y) :- Edge(x, y).
Path(x, y) :- Path(x, z), Edge (z, y).
```

- We study only on non-recursive datalog



Edge encodes a graph
Path finds all paths

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Datalog with negation

Find all actors who do not have a Bacon number < 2

```
B0(x) :- Actor(x,'Kevin', 'Bacon')
B1(x) :- Actor(x,f,l), Casts(x,z), Casts(y,z), B0(y)
Q6(x) :- Actor(x,f,l), not B1(x), not B0(x)
```

Actor(id, fname, lname)
Casts(pid, mid)
Movie(id, name, year)

Safe Datalog Rules

Here are *unsafe* datalog rules. What's "unsafe" about them ?

```
U1(x,y) :- Movie(x,z,1994), y>1910
```

```
U2(x)   :- Movie(x,z,1994), not Casts(u,x)
```

A datalog rule is *safe* if every variable appears in some positive relational atom

Simpler than in relational calculus