Database Systems
CSE 414

Lecture 9-10: Datalog
(Ch 5.3–5.4)

Announcements

- HW2 is due today 11pm
- WQ2 is due tomorrow 11pm
- WQ3 is due Thursday 11pm
- HW4 is posted and due on Nov. 9, 11pm

What is Datalog?

- Another query language for relational model
  - Simple and elegant
  - Initially designed for *recursive* queries
  - 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

Datalog

- See book: 5.3 – 5.4
- See also: Query Language primer
  - article by Dan Suciu
  - covers relational calculus as well

Why Do We Learn Datalog?

- Datalog can be translated to SQL
  - Helps to express complex queries…


```
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 one would you rather write?)

Why Do We Learn Datalog?

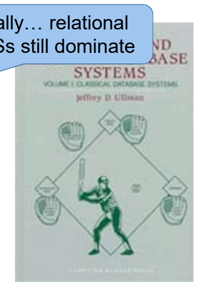
- Datalog can be translated to SQL
  - Helps to express complex queries
- Increase in Datalog interest due to recursive analytics
- A query language that is closest to mathematical logic
  - Good language to reason about query properties
  - Can show that:
  1. Non-recursive Datalog & RA have **equivalent power**
  2. Recursive Datalog is strictly more powerful than RA
  3. Extended RA & SQL92 is strictly more powerful than Datalog

Some History

Early database history:
- 60s: network data models
- 70s: relational DBMSs
- 80s: OO-DBMSs

Ullman (1988) predicts KBMSs will replace DBMSs as they replaced what came before
- KBMS: knowledge-base
- combines data & logic (inferences)

Actually… relational DBMSs still dominate



Datalog

We won't run Datalog in 414. Try out on you own:
- Download DLV (http://www.dlvsystem.com/dlv/)
- Run DLV on this file
- Can also try IRIS

```
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(pid, fname, lname)
Casts(pid, mid)
Movie(mid, 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

Q1(y) :- Movie(x, y, 1940).

Find Movies made in 1940

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

Datalog: Facts and Rules

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Movie(29445, 'Ave Maria', 1940).

Rules = queries

Q1(y) :- Movie(x, y, 1940).

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

Find Actors who acted in Movies made in 1940

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

Datalog: Facts and Rules

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Actor(344759, 'Douglas', 'Fowley').
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Rules = queries

Q1(y) :- Movie(x, y, 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)

Find Actors who acted in a Movie in 1940 and in one in 1910

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

Datalog: Facts and Rules

Facts = tuples in the database

Rules = queries

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).

Q1(y) :- Movie(x, y, 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 (a.k.a. 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), ...

Book writes:
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:
  - ∀x. ∀y. ∀z. [(Movie(x, y, z) and z=1940) ⇒ Q1(y)]
  - and Q1 is the smallest relation that has this property
- Note: logically equivalent to:
  - ∀ y. [(∃x. ∃z. Movie(x, y, z) and z=1940) ⇒ 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** expresses the idea that, from certain combinations of tuples in certain relations, we may **infer** that some other tuple must be in some other relation or in the query answer

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) :- B1(x)
Q4(x) :- B2(x)

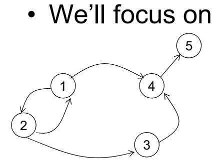
Note: Q4 means the *union* of B0, B1, & B2

Recursive Datalog

- In Datalog, rules can be recursive

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

- We'll focus 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
```

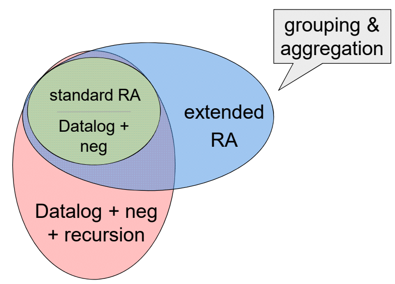
```
U2(x)   :- Movie(x, z, 1994), not Casts(u, x)
```

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

Datalog vs. Relational Algebra

- Every expression in standard relational algebra can be expressed as a Datalog query
- But operations in the extended relational algebra (grouping, aggregation, and sorting) have no corresponding features in the version of Datalog that we discussed today
- Similarly, Datalog can express recursion, which relational algebra cannot

Datalog vs. Relational Algebra



RA to Datalog by Examples

Schema for our examples:

R(A, B, C)
S(D, E, F)
T(G, H)

RA to Datalog by Examples

Union R(A, B, C) ∪ S(D, E, F)

U(x, y, z) :- R(x, y, z)
U(x, y, z) :- S(x, y, z)

RA to Datalog by Examples

Intersection R(A, B, C) ∩ S(D, E, F)

I(x, y, z) :- R(x, y, z), S(x, y, z)

RA to Datalog by Examples

Selection: $\sigma_{x>100 \text{ and } y=\text{'some string'}}$ (R)
L(x, y, z) :- R(x, y, z), x > 100, y='some string'

Selection: x>100 **or** y='some string'
L(x, y, z) :- R(x, y, z), x > 100
L(x, y, z) :- R(x, y, z), y='some string'

RA to Datalog by Examples

Equi-join: $R \bowtie_{R.A=S.D \text{ and } R.B=S.E} S$

J(x, y, z, u, v, w) :- R(x, y, z), S(u, v, w), x=u, y=v

J(x, y, z, w) :- R(x, y, z), S(x, y, w)

RA to Datalog by Examples

Projection π_x(R)

P(x) :- R(x, y, z)

RA to Datalog by Examples

To express set difference R – S,
we add negation

D(x, y, z) :- R(x, y, z), not S(x, y, z)

Examples

R(A, B, C)
S(D, E, F)
T(G, H)

Translate: $\Pi_A(\sigma_{B=3}$ (R))
B(a, b, c) :- R(a, b, c), b=3
A(a) :- B(a, b, c)

Examples

R(A, B, C)
S(D, E, F)
T(G, H)

Translate: $\Pi_A(\sigma_{B=3}(R))$
A(a) :- R(a, 3, _)
Underscore used to denote an "anonymous variable", a variable that appears only once.

Examples

R(A, B, C)
S(D, E, F)
T(G, H)

Translate: $\Pi_A(\sigma_{B=3}(R) \bowtie_{R.A=S.D} \sigma_{E=5}(S))$
A(a) :- R(a, 3, _), S(a, 5, _)

Friend(name1, name2)
Enemy(name1, name2)

More Examples

Find Joe's friends, and friends of Joe's friends.

```
A(x) :- Friend('Joe', x)
A(x) :- Friend('Joe', z), Friend(z, x)
```


Friend(name1, name2)
Enemy(name1, name2)

More Examples

Find all of Joe's friends who do not have any friends except for Joe:

- NonAns(x): all people (of Joe's friends) who have some friends who are not Joe

```
JoeFriends(x) :- Friend('Joe', x)
NonAns(x) :- Friend(y, x), y != 'Joe'
A(x) :- JoeFriends(x), not NonAns(x)
```


Friend(name1, name2)
Enemy(name1, name2)

More Examples

Find all people such that all their enemies' enemies are their friends

- NonAns(x): all people such that some of their enemies' enemies are not their friends

```
NonAns(x) :- Enemy(x, y), Enemy(y, z), not Friend(x, z)
A(x) :- Everyone(x), not NonAns(x)

Everyone(x) :- Friend(x, y)
Everyone(x) :- Friend(y, x)
Everyone(x) :- Enemy(x, y)
Everyone(x) :- Enemy(y, x)
```


Friend(name1, name2)
Enemy(name1, name2)

More Examples

Find all people x who have only friends all of whose enemies are x's enemies.

- NonAns(x): all people x who have some friends some of whose enemies are not x's enemies

what's wrong with this?

```
NonAns(x) :- Friend(x, y), Enemy(y, z), not Enemy(x, z)
A(x) :- not NonAns(x)
```

```
NonAns(x) :- Friend(x, y), Enemy(y, z), not Enemy(x, z)
A(x) :- Everyone(x), not NonAns(x)
```

Datalog Summary

- facts (extensional relations) and
  rules (intensional relations)
  – rules can use relations, arithmetic, union, intersect, …
- As with SQL, existential quantifiers are easier
  – use negation to handle universal
- Everything expressible in RA is expressible in non-recursive Datalog and vice versa
  – recursive Datalog can express more than (extended) RA
  – extended RA can express more than recursive Datalog