



CS589 Principles of DB Systems
Winter 2011
Lecture 1-3: Introduction to Datalog

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Goals for this lecture

- Introduce you to Datalog queries
- Briefly introduce the various versions of Datalog
- Explain how Datalog queries are interpreted
We will consider *efficient* interpretation later

Datalog – a query language based on definite Horn logic clauses

- Datalog is a query language
 - Related to domain calculus
- A Datalog program consists of one or more clauses (also called rules)
- Datalog syntax is the same as Prolog but without functions and without the extralogical features such as Cut and Fail.
- The order of clauses does not matter in Datalog; the order of literals in the body of a rule does not matter.

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Example Datalog Query

Student(s-id, s-name, major, f-id, age)
 Faculty(f-id, f-name, rank, dept)

Query 1:
 Result (x, y) :- Student(s,x,m,f,a), Faculty(f,y,r,d).

head (under x, y) *body* (under Student and Faculty)

if (under :-)

join (under comma)


Choosing variables for answer (project) → (x, y)

Literals separated by commas are "ANDed" together → (f, y, r, d)

An equivalent query in domain calculus:
 $\{x, y \mid \exists s(\exists m(\exists f(\exists a(\exists r(\exists d($
 $\text{Student}(s,x,m,f,a) \wedge \text{Faculty}(f,y,r,d))))))\}$

An equivalent query in relational algebra:
 $\pi_{s\text{-name},f\text{-name}}(\text{Student} \bowtie \text{Faculty})$

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Example Datalog Query 2

Student(s-id, s-name, major, f-id, age)
Faculty(f-id, f-name, rank, dept)

Choosing variables for answer (project)


Query 2:
Result (x,y) :- Student(x,y,"CS",f,a).

Constant of "CS" selects students with major = "CS"

An equivalent query in domain calculus:
 $\{x, y \mid \exists f(\exists a(\text{Student}(x,y,"CS",f,a)))\}$

An equivalent query in relational algebra:
 $\pi_{s\text{-id}, s\text{-name}}(\sigma_{\text{major}="CS"}(\text{Student}))$

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Exercise


Student(s-id, s-name, major, f-id, age)
Faculty(f-id, f-name, rank, dept)

Query 3:
Answer(x) :- Student(a,x,b,c,21),Faculty(c,d,e,"CS").

Write an equivalent query in domain or tuple calculus:

Write an equivalent query in relational algebra:

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Comparing domain calculus & Datalog

Student(s-id, s-name, major, f-id, age)

$\{ a, b, c \mid \exists x(\exists y(\text{Student}(a,b,c,x,y))) \}$

This expression defines a set (query answer). The tuple $\langle a,b,c \rangle$ is in this set provided there exists an x and a y where the tuple $\langle a,b,c,x,y \rangle$ is in relation **student** (with relation schema **Student**).


Result(a,b,c) :- Student(a,b,c,x,y).

This is a definite Horn clause that says
 "Result(a,b,c) is true if Student(a,b,c,x,y) is true."
 In a Horn clause, every variable is universally quantified.

This clause is the same as:
 $(\forall a)(\forall b)(\forall c)(\forall x)(\forall y)(\text{Student}(a,b,c,x,y) \rightarrow \text{Result}(a,b,c))$

So ... are these expressions defining the same query?

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Implication (quick reminder)

Any logical connector can be defined using a truth table.
 Here we show the truth table for \wedge (and) and for \rightarrow (implication).

p	q	$p \wedge q$
true	true	true
true	false	false
false	true	false
false	false	false

p	q	$p \rightarrow q$
true	true	true
true	false	false
false	true	true
false	false	true


$(\forall a)(\forall b)(\forall c)(\forall x)(\forall y)(\text{Student}(a,b,c,x,y) \rightarrow \text{Result}(a,b,c))$

If ever the left part is true, then the right part must be true.

Result (a,b,c) :- Student(a,b,c,x,y).

If the body (the right hand side) is true, then the head (left hand side) must be true.
 Evaluation of Datalog actively looks for tuples that satisfy the body.

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Datalog Example – for Union

Student(s-id, name, major, f-id, age)
 Faculty(f-id, name, rank, dept)

Result(x,y) :- Student(x,y,a,b,c).

Result(x,y) :- Faculty(x,y,d,e).

This is a Datalog program consisting of two rules. They both produce **Result** tuples.

This query is equivalent to the following:

$\pi_{s-id, name}(\text{Student}) \cup \pi_{f-id, name}(\text{Faculty})$

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Exercise

Grad-course (c-num, title, credits)

Undergrad-course (c-num, title, credits)


Write a Datalog query that is equivalent to:

$(\text{Grad-course}) \cap (\text{Undergrad-course})$

*Result(x,y,z) :- Grad-course(x,y,z),
 Undergrad-course(x,y,z).*

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Datalog with negation


Student(s-id, name, major, f-id, age)
 Faculty(f-id, name, rank, dept)

No-advisees(x,y) :- Faculty(x,y,a,b), ^{$\exists c, \exists d, \exists e, \exists f$} \neg Student(c,d,e,x,f).
_^

Find the f-id and name for any faculty tuple for which there does not exist a Student tuple advised by this faculty member.

What is an equivalent relational algebra query?
 $\pi_{f-id, name}(Faculty \bar{\bowtie} \rho_{name \rightarrow sname}(Student))$

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Exercise

Write each of these queries in Datalog.

Student(s-id, s-name, major, f-id, age)
 Faculty(f-id, f-name, rank, dept)

- second 1. $(\pi_{name}(\sigma_{age=21} Student)) \cup \pi_{name} Faculty$
- third 2. $Student \bowtie Faculty$
- first 3. $(\pi_{name}(\sigma_{age=21} Student)) - (\pi_{name}(\sigma_{major='CS'} Student))$


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Datalog Facts

- An empty body is interpreted as true. So
`Student(126,"Hector Ng", "CS", 146, 23) :- .`
 means
`true → Student(126,"Hector Ng", "CS", 146, 23)`
 that is, Student is true for these values
- Abbreviated to
`Student(126,"Hector Ng", "CS", 146, 23).`
 Called a *fact* (or *ground fact*, if no variables)

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Datalog Program

- A Datalog program is a collection of rules (some could be facts)
- Will usually have a special relation name (e.g., Result, Answer) we are interested in


```

            Result(d) :- Course("CS",n,"Winter"),
                    Prereq(d,m,"CS",n),
                    Course(d,m,"Fall").
            Course("CS",311,"Winter").
            Course("CS",312,"Spring").
            Course("Math",119,"Fall").
            Prereq("Math",119,"CS",311).
            Prereq("CS",311,"CS",312).
```

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Database Perspective

Can think of ground facts as stored database.
Extensional DB

Can think of rules as view^s over stored data (and other views)
Intensional DB

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Interpreting a Datalog Program

Treat a rule as representing all its *ground instances*

substitute a value for each variable symbol


in → Result("Math") :- Course("CS",311,"Winter"),
Prereq("Math",119,"CS",311),
Course("Math",119,"Fall").

necessarily
not in → Result("CS") :- Course("CS",312,"Winter"),
Prereq("CS",311,"CS",312),
Course("CS",311,"Fall").

Not safe → Result("Acorn") :- Course("CS",96557,"Winter"),
Prereq("Acorn",2,"CS",96557),
Course("Acorn",2,"Fall").

Generally restrict to a *safe* substitution: Only values in program

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Derived Database

Start with a Datalog program P

- Start with Der = all ground facts from P
- Add any tuple to Der that is the head of a ground instance of a rule in P where all predicates in the body are already in Der .

Will return to Datalog later to talk about efficient ways to compute the derived database of a program.

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Datalog syntax

Atomic formulas:

- $R(y_1, y_2, \dots, y_k)$ – a predicate formula
- $x = y$ (Note: this is syntatic sugar for $equal(x,y)$.)
- $R(v_1, v_2, \dots, v_k)$ – a ground atomic formula, where v_i are values

Literal:

- an atomic formula (positive literal) or
- the negation of an atomic formula (negative literal): $\neg A$

Clause (Datalog rule):

$L :- L_1, L_2, \dots, L_n.$

where L is a predicate formula and $L_i, i = 1, \dots, n$, is a literal. (Some versions of Datalog require all literals to be positive literals.) The comma means "and".

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Datalog with recursion (more about this in a future lecture)

Parent-child(p-id, ch-id)

Ancestor(x,y) :- Parent-child(x, y).

Ancestor(x,z) :- Ancestor(x,y), Parent-child(y,z).

How does this Datalog program get evaluated?

Keep building the derived database until no new tuples get added to Ancestor.

The book describes the meaning of a program using the "immediate consequence" of a program.

Note each Datalog rule is independent. The variable names in separate rules have no connection.



Expressive power of Datalog languages (compared to relational algebra)

- Datalog – one rule, no negation, no recursion.
Conjunctive queries SPJ
- Datalog – multiple rules, no negation, no recursion. SPJU
- Datalog – multiple rules, no negation, with recursion. SPJU+ recursion but NOT relationally complete
- Datalog – multiple rules, with negation, no recursion. SPJU- relationally complete but no recursion
- Datalog – multiple rules, with negation, with recursion. Relationally complete plus recursion, but some queries are ambiguous!