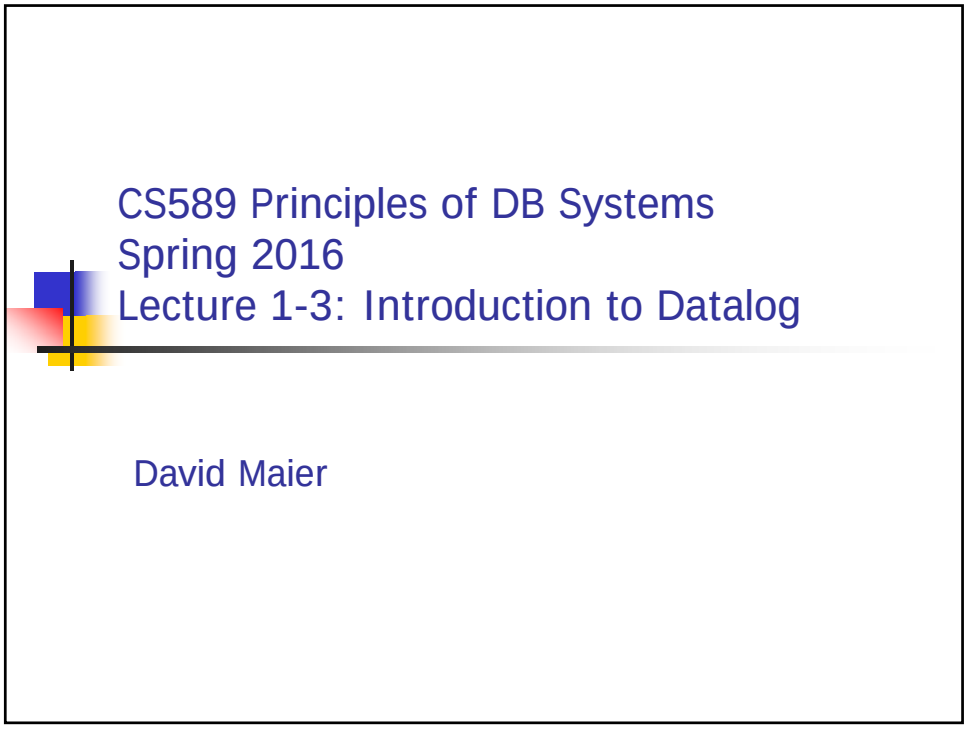
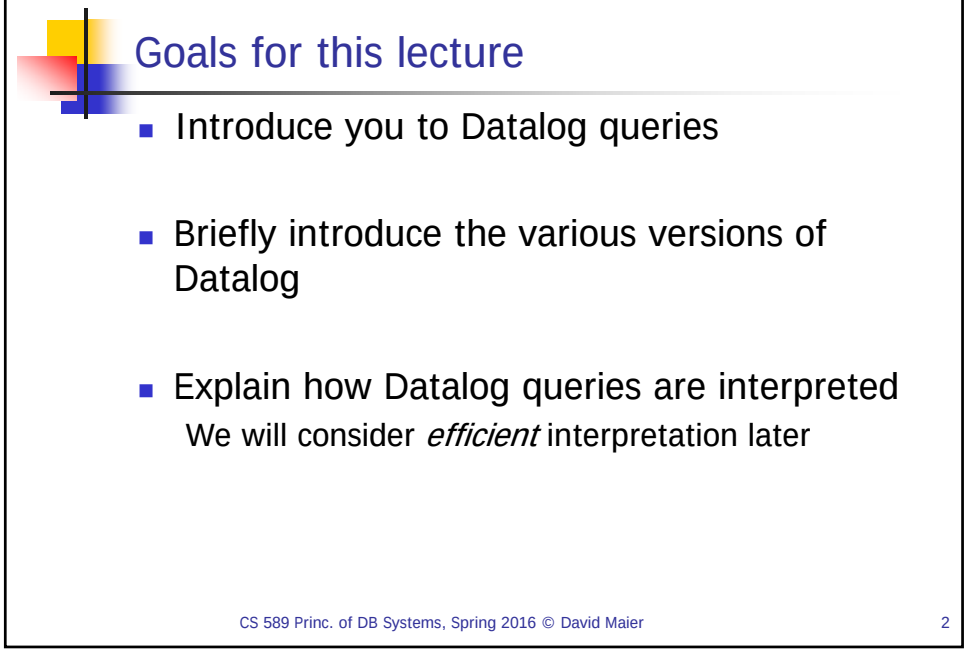


CS589 Principles of DB Systems
Spring 2016
Lecture 1-3: Introduction to Datalog

David Maier



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.

Example Datalog Query

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

Literals separated by commas are "ANDed" together

predicate

Choosing variables for answer (project)

Query 1:

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

"if"

join

An equivalent query in domain calculus:

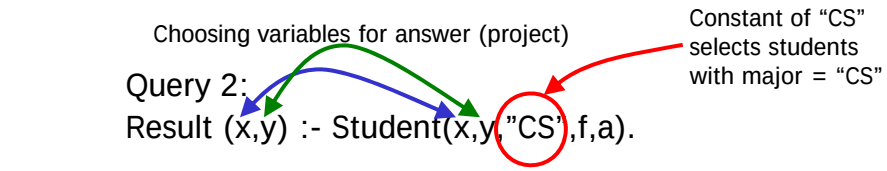
$\{x, y \mid \exists s(\exists m(\exists f(\exists a(\exists r(\exists d($
$\text{Student}(s,x,m,f,a) \wedge \text{Faculty}(f,y,r,d)))))))\}$

An equivalent query in relational algebra:

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

Example Datalog Query 2

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



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

An equivalent query in domain calculus:
{x, y | ∃f(∃a(Student(x,y,"CS",f,a))) }

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

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:

Comparing domain calculus & Datalog

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

{ a, b, c | ∃x(∃y(Student(a,b,c,x,y))) }

This expression defines a set (query answer). The tuple <a,b,c> is in this set provided there exists an x and a y where the tuple <a,b,c,x,y> 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:

(∀a)(∀b)(∀c)(∀x)(∀y)(Student(a,b,c,x,y) → Result(a,b,c))

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

Implication (quick reminder)

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

p	q	p^q
true	true	true
true	false	false
false	true	false
false	false	false

p	q	p→ q
true	true	true
true	false	false
false	true	true
false	false	true

(∀a)(∀b)(∀c)(∀x)(∀y)(Student(a,b,c,x,y) → 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.

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:

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

Exercise

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

Write a Datalog query that is equivalent to:
(Grad-course) ∩ (Undergrad-course)

Result(C, T, R) :- Grad-course(C, T, R),
Undergrad_course(C, T, R)

$r_1(A,B,C)$ $r_2(A,B,C)$ $r_1 \cap r_2 = r_1 \bowtie r_2$

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),¬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?

Exercise

Write each of these queries in Datalog.

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

1. $(\pi_{name}(\sigma_{age=21}Student)) \cup \pi_{name}Faculty)$
2. $Student \bowtie Faculty$
3. $(\pi_{name}(\sigma_{age=21}Student)) - (\pi_{name}(\sigma_{major=\text{“CS”}}Student))$

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)

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).
```

Database Perspective

Can think of ground facts as stored database.

Extensional DB

Can think of rules as view over stored data (and other views)

Intensional DB

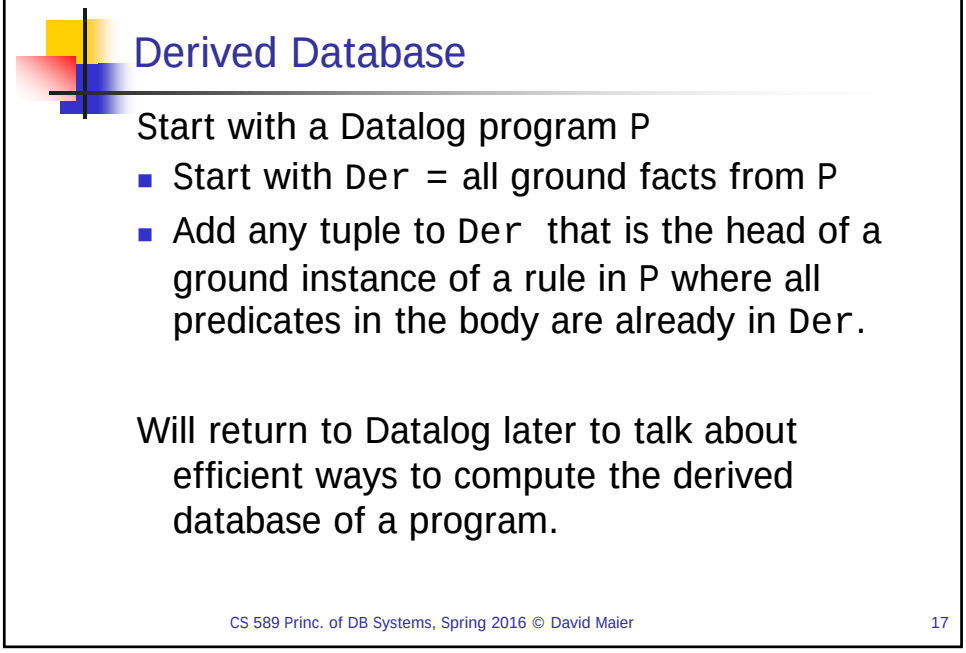
Interpreting a Datalog Program

Treat a rule as representing all its *ground instances*

substitute a value for each variable symbol

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

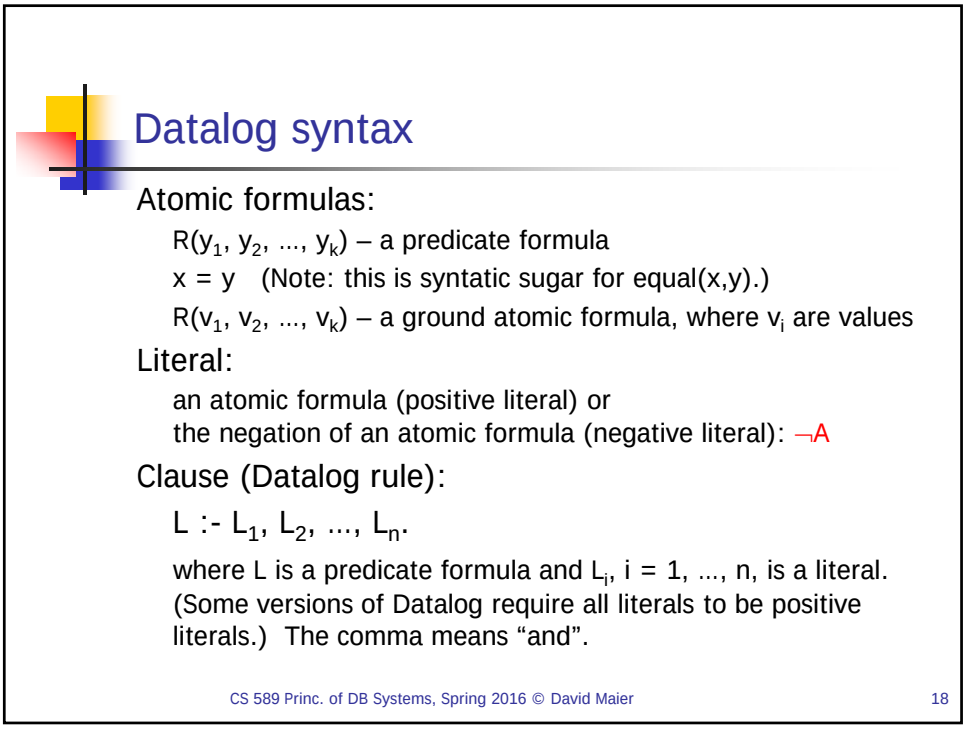


Derived Database

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.



Datalog syntax

Atomic formulas:

$R(y_1, y_2, ..., y_k)$ – a predicate formula

x = y (Note: this is syntatic sugar for equal(x,y).)

$R(v_1, v_2, ..., v_k)$ – a ground atomic formula, where v_i are values

Literal:

an atomic formula (positive literal) or
the negation of an atomic formula (negative literal): ¬A

Clause (Datalog rule):

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

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

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!