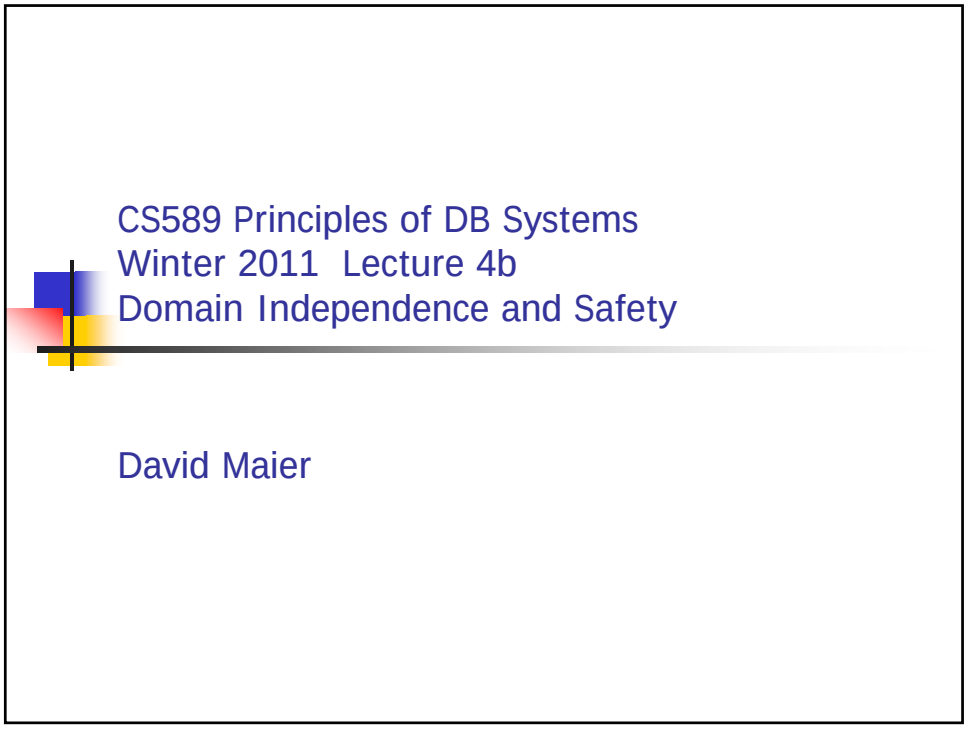

CS589 Principles of DB Systems
Winter 2011 Lecture 4b
Domain Independence and Safety

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Goals for this lecture

- Introduce the problems that can occur in calculus queries and Datalog .
- Define syntactic restrictions to avoid the problems
  - Domain independence (for calculus)
  - Safety (for Datalog)
- The restricted languages are equivalent to relational algebra
  - We could extend relational algebra instead, but would require infinite relations

What's the problem with calculus?

Student(name, age)
Teacher(name, age)

{n:name, a:age | ¬Student(n, a) }

{n:name, a:age | $\exists n_1(\exists a_1(\text{Student}(n,a_1) \vee \text{Teacher}(n_1,a)))$}

Are these valid well-formed formulas?
Do we want to consider these to be queries?
What would the query answer be?
Similar problems with tuple calculus

What's the query answer?

Student(name, age)
Teacher(name, age)
{n:name, a:age | ¬Student(n, a) }
char(20) 12-120
char(15) 16-90
Query answer depends on the domain for n and a.

DOM(name) is the set of possible names
DOM(age) is the set of possible ages

If domains are infinite, query answer is not a relation because relations must be finite.

If domains are finite, then changing the domain changes the query answer: char(20) → char(28)

What's the query answer?

{n:name, a:age | $\exists n_1(\exists a_1(Student(n,a_1) \vee Teacher(n_1,a)))$}

What's wrong here?

If Student(n, a_1) is true and Teacher(n_1,a) is false, the formula is true. But what is the value for a?

And similarly, if Teacher (n_1,a) is true and Student(n, a_1) is false, what is the value for n?

In both cases, values will depend on the domains.

Domain Independence

(informal definition) A query is domain independent if for each database instance, the answer to the query does not change if the domain changes.

The two main problems that cause domain dependence:

- $\neg$F
  - where some variable in F is not restricted elsewhere in the query
- F1 $\vee$ F2
  - such that they have different free variables

Determining whether a query is domain independent is *undecidable*.

So...we first define "positive" and "negative" occurrences of a variable

Positive occurrences of a variable (iff only one of these hold)	Negative occurrences of a variable (iff only one of these hold)
$R(y_1, y_2, \ldots, x, \ldots, y_k)$	x does not appear in formula F at all
$x=v$ where v is a constant	$x=y$ where y is a variable (or $y = x$)
$\neg F$ if x occurs negatively in F	$\neg F$ if x occurs positively in F
$F_1 \wedge F_2$ if x occurs positively in F_1 or positively in F_2	$F_1 \wedge F_2$ if x occurs negatively in F_1 and negatively in F_2
$F_1 \vee F_2$ if x occurs positively in F_1 and positively in F_2	$F_1 \vee F_2$ if x occurs negatively in F_1 or negatively in F_2
$F_1 \rightarrow F_2$ if x occurs negatively in F_1 and positively in F_2	$F_1 \rightarrow F_2$ if x is positive in F_1 and negative in F_2
$\exists y:A$ (F) if x is not = y and x occurs positively in F	$\forall y:A$ (F) if x is not = y and x occurs negatively in F

What are Positive and Negative Variables?

Student(name, age)

Teacher(name, age)

1 $\exists n_1(\exists a_1(\text{Student}(n,a_1) \wedge \text{Teacher}(n_1,a)))$

2 $\exists n_1(\exists a_1(\text{Student}(n,a_1) \vee \text{Teacher}(n_1,a)))$

3 $\forall a(\neg\text{Student}(n, a) \vee \exists n_1(\text{Teacher}(n_1,a)))$

4 $\neg\text{Student}(n, a)$

5 $\exists y(\text{Student}(n, a) \wedge a = y\ \}$

Syntatic restriction: "Allowed" domain calculus queries

- A domain calculus query is allowed if its formula is allowed.
- A domain calculus formula F is allowed if all of these conditions hold:
  - Every free variable in F occurs positively in F (What are the free variables?)
  - For every subformula $\exists x{:}A\ (G)$ of F, x is positive in G
  - For every subformula $\forall x{:}A\ (G)$ of F, x is negative in G

Which are Allowed Queries?

Student(name, age)
Teacher(name, age)

OK {n:name, a:age | $\exists n_1(\exists a_1(\text{Student}(n,a_1) \wedge \text{Teacher}(n_1,a)))$}

Ambiguous in many ways

{n:name, a:age | $\exists n_1(\exists a_1(\text{Student}(n,a_1) \vee \text{Teacher}(n_1,a)))$}

Free variable is negative, quantifiers are OK

{n:name | $\forall a(\neg\text{Student}(n, a) \vee \exists n_1(\text{Teacher}(n_1,a)))$}

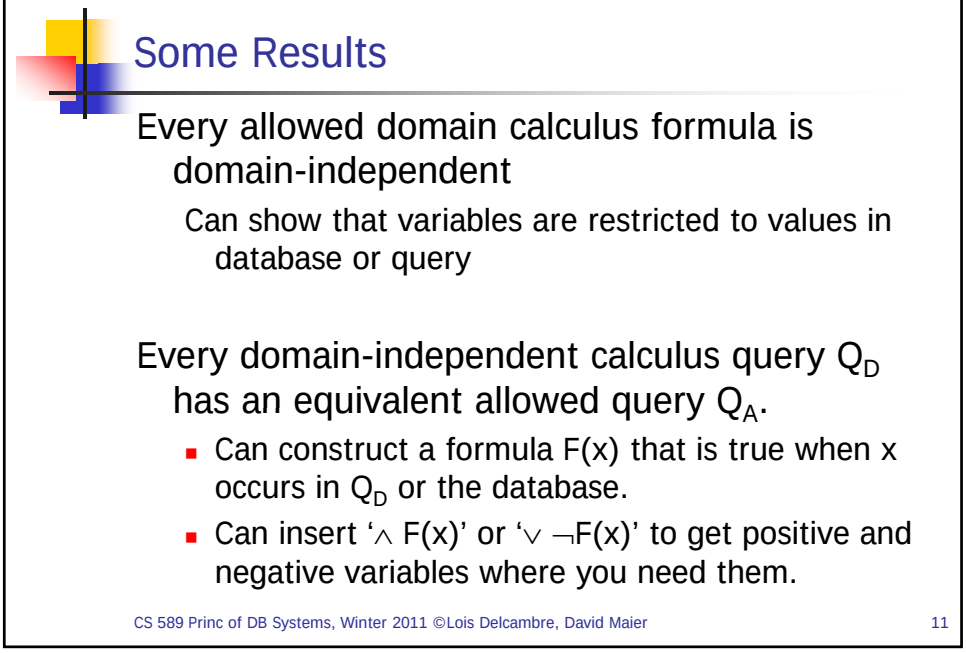
Not OK

{n:name, a:age | $\neg$Student(n, a) }

Not OK (It is domain independent)

{n:name, a:age | $\exists y(\text{Student}(n, a) \wedge a = y$ }

y—



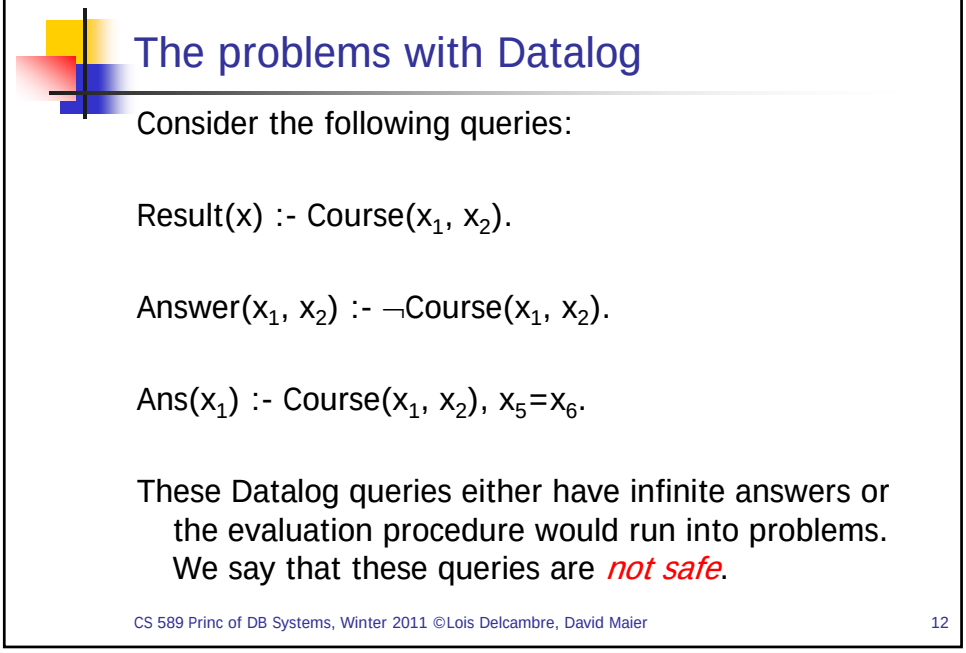
Some Results

Every allowed domain calculus formula is domain-independent

Can show that variables are restricted to values in database or query

Every domain-independent calculus query Q_D has an equivalent allowed query Q_A.

- Can construct a formula F(x) that is true when x occurs in Q_D or the database.
- Can insert '$\wedge$ F(x)' or '$\vee \neg$F(x)' to get positive and negative variables where you need them.



The problems with Datalog

Consider the following queries:

Result(x) :- Course(x_1, x_2).

Answer(x_1, x_2) :- $\neg$Course(x_1, x_2).

Ans(x_1) :- Course(x_1, x_2), x_5=x_6.

These Datalog queries either have infinite answers or the evaluation procedure would run into problems. We say that these queries are *not safe*.

So, we define positive and negative variables and safe Datalog rules

A Datalog rule is safe if all the variables appearing in the literals of C (both head and body) occur positively in C.

A Datalog program is safe if all the rules are safe.

A variable x occurs positively if x appears in:

- $R(y_1, y_2, \ldots, x, \ldots, y_k)$ where this is a positive literal in the body of the rule
- x=v where v is a constant (in the body of the rule)
- x=y or y=x where y is a variable that occurs positively in C (in the body of the rule)

Comments

- In a safe Datalog rule, all the variables in the head of the rule must occur in one or more literals in the body.
- All the variables that occur in a negative literal in the body of a safe Datalog rule, must occur positively in one or more atomic formulae in its body.
- Safe Datalog query → query answer is always finite.
- Allowable domain calculus query → query answer is always finite.