



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)

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

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

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

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What's the query answer?

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

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

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: $\text{char}(20) \rightarrow \text{char}(28)$

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What's the query answer?

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

What's wrong here?

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

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

In both cases, values will depend on the domains.

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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*.

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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)
$R(y_1, y_2, \dots, x_i, \dots, y_k)$	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

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What are Positive and Negative Variables?

Student(name, age)

Teacher(name, age)

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

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

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

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

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

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Syntactic 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)

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

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

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

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

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



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:

$\text{Result}(x) \text{ :- Course}(x_1, x_2).$

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

$\text{Ans}(x_1) \text{ :- Course}(x_1, x_2), x_5 = x_6.$

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:

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

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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 \rightarrow query answer is always finite.
- Allowable domain calculus query \rightarrow query answer is always finite.

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