COMP 543: Tools & Models for Data Science

Introduction to Relational Databases

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What is a Database?

- A collection of data
- Plus, a set of programs for managing that data

Back in the Day...

- The dominant data model was the network or navigational model (60's and 70's)
- Data were a set of records with pointers between them
- Much DB code was written in COBOL
- Big problem was lack of physical data independence
  - Code was written for specific storage model
  - Want to change storage? Modify your code
  - Want to index your data? Modify your code
  - Led to very little flexibility
    - Your code locked you into a physical database design!

Some People Realized This Was a Problem

- By 1970, EF Codd (IBM) was looking at the so-called relational model
  - Landmark 1970 paper, “A relational model of data for large shared data banks”
  - Led to the 1981 Turing Award
    - Highest honor a computer scientist receives
    - Analogous to a Nobel Prize
- Idea: data stored in “relations”
  - A relation is a table of tuples or records
  - Attributes of a tuple have no sub-structure (are atomic)
- No pointers!

Querying in the Relational Model

- Querying is done via a “relational calculus”
- Declarative
  - You give a mathematical description of the tuples you want
  - System figures out how to get those for you

? Why is this good?

Querying in the Relational Model

- Querying is done via a “relational calculus”
- Declarative
  - You give a mathematical description of the tuples you want
  - System figures out how to get those for you
- ? Why is this good?
  - Data independence!
  - Your code has no data access specifications
  - You can change the physical organization with no code re-writes

Relational Schema

- All data are stored in tables, or relations
- A relation schema consists of:
  - A relation name (e.g., LIKES)
  - A set of (attribute_name, attribute_type) pairs
    - Each pair is referred to as an "attribute"
    - Or sometimes as a "column"
  - Usually denoted using
    LIKES (DRINKER string, COFFEE string)
  - Or simply LIKES (DRINKER, COFFEE)

A Relation

- A relation schema defines a set of sets
  - Specifically, if $T_1, T_2, ..., T_n$ are the n attribute types
  - Where each T_i is a set of possible values
    - Ex: string is all finite-length character strings
    - Ex: integer is all numbers from -2^{31} to $2^{31} - 1$
  - Then a realization of the schema (aka a “relation”) is a subset of
    - $T_1 \times T_2 \times ... \times T_n$
    - where $\times$ is the Cartesian product operator

A Relation (continued)

- So for the relation schema
  LIKES (DRINKER string, COFFEE string)
- A corresponding relation might be

$$\{(\text{'Chris', 'Espresso'}), (\text{'Risa', 'Cold Brew'})\}$$

- This is also referred to as a “table”
- The entries in the relation are referred to as
  - “rows”
  - “tuples”
  - “records”

Relational Terminology

Attribute = Column:
Name of each column

Relation = Table

LIKES

Drinker	Coffee
Chris	Espresso
Risa	Cold Brew

Tuple = Row = record:
A single entry in the table

Keys

- In the relational model, given $R(A_1, A_2, ..., A_n)$
- A set of attributes $K = \{K_1, ..., K_m\}$ is a KEY of R if:
  - For any valid realization R' of R...
  - For all t_1, t_2 in R'...
  - If $t_1[K_1] = t_2[K_1]$ and $t_1[K_2] = t_2[K_2]$ and ... $t_1[K_m] = t_2[K_m]$...
  - Then it must be the case that $t_1 = t_2$

? Note: every relation schema SHOULD have a key... why?

Keys: Exercise

? What is a key for
STUDENT (NETID, FNAME, LNAME, AGE, COLLEGE)?

Keys: Exercise

? What is a key for
LIKES (DRINKER, COFFEE)?

Keys: Exercise

- What is a key for
  LIKES (DRINKER, COFFEE)?
  What is the relation about?
  Is it about a drinker's favorite style of coffee?
  Or about the first person to drink a coffee?
  Or about what styles of coffee does each drinker like?
  Context matters!

Keys (continued)

- A relation schema can have many keys
- Those that are minimal are **CANDIDATE KEY**s
  - “Minimal” means no subset is a key
- One is typically designated as the **PRIMARY KEY**
- Denoted with an underline
  - STUDENT (<u>NETID</u>, FNAME, LNAME, AGE, COLLEGE)

Connecting Relations

The relational model does not have pointers that connect different relations

Why not?

1. Not nice mathematically
   - Mathematical elegance key goal in model design
2. Difficult implementation
   - Move an object? All pointers are invalid!
   - Solution: Use a centralized look-up table
     - Expensive
     - Complicated
     - Problem still exists

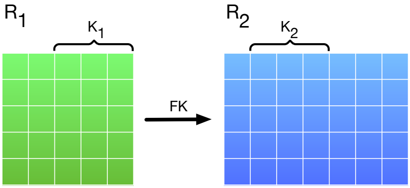
Solution: Foreign Keys

- But we still need some notion of between-tuple references
  - LIKES (DRINKER, COFFEE)
  - DRINKER (DRINKER, FNAME, LNAME)
  - Clearly, LIKES.DRINKER refers to DRINKER.DRINKER
- Accomplished via the idea of a FOREIGN KEY

Foreign Keys (continued)

- Given a relation schema: R_1, R_2
  - We say a set of attributes K_1 from R_1 is a foreign key to a set of attributes K_2 from R_2 if...
  - (1) K_2 is a candidate key for R_2, and...
  - (2) For any valid realizations R'_1, R'_2 of R_1, R_2...
  - For each tuple $t_1 \in R'_1$, it MUST be the case that there exists $t_2 \in R'_2$ s.t...
  - $t_1[K_{1,1}] = t_2[K_{2,1}]$ and $t_1[K_{1,2}] = t_2[K_{2,2}]$ and ... $t_1[K_{1,m}] = t_2[K_{2,m}]$

? Intuitively, what does this mean?



Foreign Key Interpretation

Intuitively, what does this mean?

- The foreign key must be an attribute or set of attributes that uniquely identify a record in another table
- AND that combination of attribute values must be present in the other table
- The foreign key may consist of
  - More than one attribute
  - Attributes with different names in each table

? Which way is the foreign key?

PERSON

NETID	FIRSTNAME	LASTNAME
cmj4	Chris	Jermaine
rbm2	Risa	Myers

LIKES

DRINKER	COFFEE
cmj4	Espresso
rbm2	Cold Brew
cmj4	Chai Latte

Foreign Key Interpretation

- In other words
  - The target must be a candidate key
  - There are no dangling pointers
- Why is this a requirement?
  - To prevent inconsistencies
  - To match to a single target
- The database enforces these requirements via
  - Cascading deletes
  - To match to a single target
  - Failed inserts

Queries/Computations in the Relational Model

- The original query language was the RELATIONAL CALCULUS
  - Fully declarative programming language
  - Mostly theoretical/math – not actually implemented
  - Helps you understand how to write SQL
- next was the RELATIONAL ALGEBRA
  - Imperative
  - Define a set of operations over relations
  - An RA program is then a sequence of those operations
  - This is the “abstract machine” of RDBs
  - Helps you understand query performance

Queries/Computations in the Relational Model

- Today we use SQL
  - Heavily influenced by RC
  - Has aspects of RA
  - More complex than either of them!

Overview of Relational Calculus

- RC is a variant on first order logic
- You say: "Give me all tuples t where $P(t)$ holds"
- $P(t)$ is a predicate in first order logic

Predicates

- First order logic allows predicates
  - Predicate: A function that evals to true/false
  - “It’s raining on day X” or $Raining(X)$
  - “It’s cloudy on day X” or $Cloudy(X)$
- Build more complicated predicates using logical operations over them
  - and ($\wedge$) (both)
  - or ($\vee$) (either or both)
  - not ($\neg$) (flip truth value)
  - implies ($\rightarrow$)
  - if and only if ($\leftrightarrow$)

Predicates: And

$Raining(X) \wedge Cloudy(X)$ Evaluates to TRUE if both:

- It is raining on day X and
- It is cloudy on day X

AND Truth Table

p	**q**	**p ∧ q**
T	T	T
T	F	F
F	T	F
F	F	F

Predicates: Or

$Raining(X) \wedge Cloudy(X)$ Evaluates to TRUE if either:

- It is raining on day X
  or
- It is cloudy on day X

OR Truth Table

p	**q**	**p** $\vee$ **q**
T	T	T
T	F	T
F	T	T
F	F	F

Predicates: Implies

$Raining(X) \rightarrow Cloudy(X)$
Evaluates to TRUE if either:

- It is not raining on day X
  or
- It is raining and cloudy on day X
- $\rightarrow$ is like a logical "if-then"
- State is FALSE if it is raining and not cloudy
- If it's not raining, we don't care about whether or not it's cloudy

IMPLICATION
Truth Table

p	q	$p \rightarrow q$
T	T	T
T	F	F
F	T	T
F	F	T

Predicates: If and Only If

Raining(X) $\leftrightarrow$ Cloudy(X) Evaluates to TRUE if both:

- Raining(X) $\rightarrow$ Cloudy(X)
  AND
- Cloudy(X) $\rightarrow$ Raining(X)

IFF Truth Table

p	**q**	**p $\rightarrow$ q**	**q $\rightarrow$ p**	**p $\leftrightarrow$ q**
T	T	T	T	T
T	F	F	T	F
F	T	T	F	F
F	F	T	T	T

Predicates (continued)

- Example: $Raining(X) \rightarrow Cloudy(X)$
- Evaluates to true if either:
  - It is not raining on day X, or
  - It is raining and cloudy on day X
- Example: $Raining(X) \wedge Cloudy(X)$
- Evaluates to true if:
  - It is raining and cloudy on day X
- Note the difference between them!
  - $\rightarrow$ is like a logical “if-then”

First Order Logic

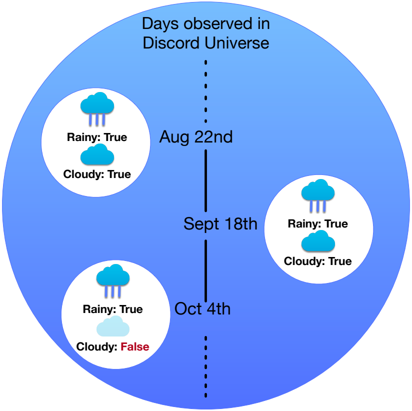
- Just predicates and logical ops?
  - You've got predicate logic
- But when you add quantification
  - $\forall$, $\exists$
  - You've got first order logic

Universal Quantification

- Asserts that a predicate is true all of the time
- Example:
  - $\forall(X)(Raining(X) \rightarrow Cloudy(X))$
  - Zero-argument predicate (takes no params)
  - Asserts that it only rains when it is cloudy
  - Note: idea of universe of discourse is key!
  - X is a variable. It ranges over the entire universe of discourse
  - Plug the value of that variable into the predicate. If it is always true, then the predicate is true

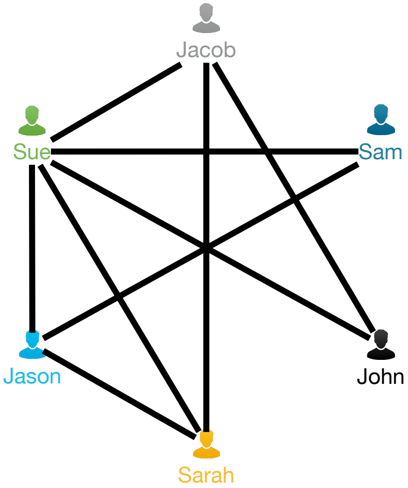
Universal Quantification Example 1

- $\forall(X)(Raining(X) \rightarrow Cloudy(X))$
- Given the following Universe of Discourse, is our predicate T or F?



Universal Quantification Example 2

- $\forall(X)(Friends(X, Y))$
- This is a predicate over Y
- Asserts that person Y is friends with everyone
- Can be T or F, depending on what's in the U of D



Existential Quantification

- Asserts that a predicate can be satisfied
- Example:
  - $\exists(X)(Raining(X) \wedge \neg Cloudy(X))$
  - Asserts that it is possible for it to rain when it is not cloudy
  - aka a “sun shower"

Existential Quantification

- Asserts that a predicate can be satisfied
- Example:
  - $\exists(X)(Raining(X) \wedge \neg Cloudy(X))$
  - Asserts that it is possible for it to rain when it is not cloudy

Important Equivalence

- $\forall(X)(P(X))$ is equivalent to...
- $\neg\exists(X)(\text{not } P(X))$
  - Ex: $\neg\exists(X,Y)(Friends(X,Y) \wedge Friends(X,Z) \wedge Friends(Y,Z))$
  - Can be changed to:
  - $\forall(X,Y)(\neg(Friends(X,Y) \wedge Friends(X,Z) \wedge Friends(Y,Z)))$
  - Or $\forall(X,Y)(\neg Friends(X,Y) \vee \neg Friends(X,Z) \vee \neg Friends(Y,Z))$
- Which is easier?
  - Often easier to reason about $\exists$ compared to $\forall$
  - Can be hard to conceptualize an assertion that something is true over every item in the entire universe!
  - In fact, SQL does not even have $\forall$

? What is the name of rule applied to distribute the negation?

Questions?