CompSci 516
Database Systems

Lecture 25

Recursive Query Evaluation
and
Data Mining

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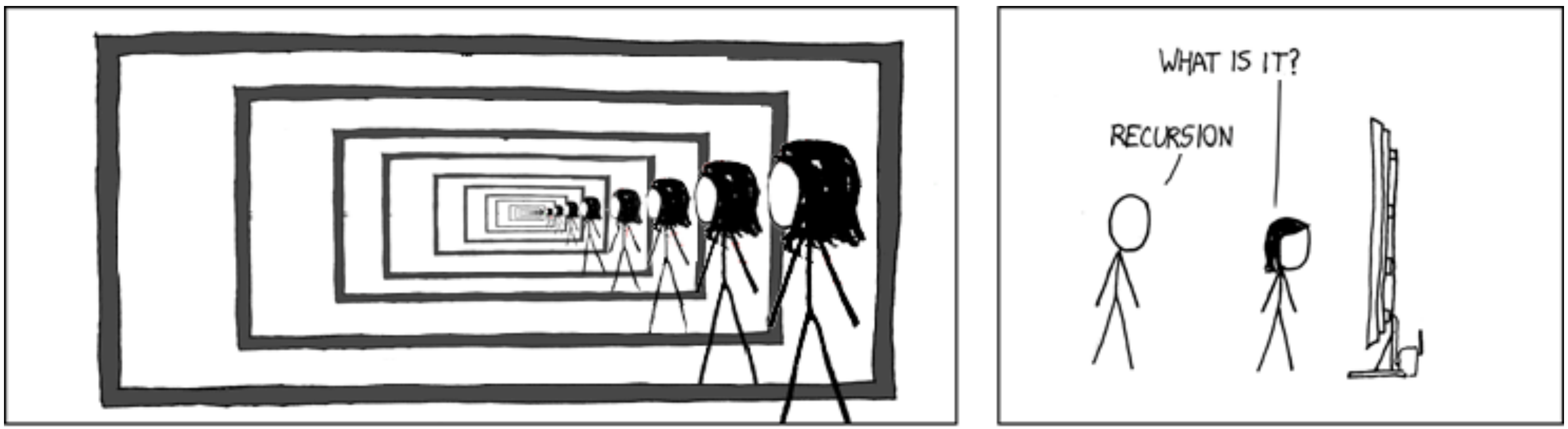
Recursive Query in Databases

Recursion!

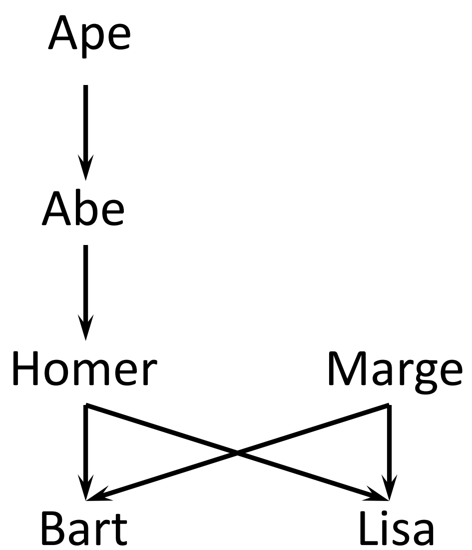


http://xkcdsw.com/1105

A motivating example

Parent (*parent*, *child*)

parent	*child*
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Ape	Abe



- Example: find Bart's ancestors
- "Ancestor" has a recursive definition
  - X is Y's ancestor if
    - X is Y's parent, or
    - X is Z's ancestor and Z is Y's ancestor

Recursion in Databases

- Consider a graph G(V, E). Can you find out all "ancestor" vertices that can reach "x" using Relational Algebra/Calculus?

- NO! – ANCESTOR cannot be defined using a constant-size union of select-project-join queries (conjunctive queries)

- No RA/RC expressions can express ANCESTOR or REACHABILITY (TRANSITIVE CLOSURE) (Aho-Ullman, 1979)

- A limitation of RA/RC in expressing recursive queries
- Solution: Use "Datalog" language and include recursion in SQL
  - A long discussion in the DB community on whether recursion should be supported

Recursion in SQL

- SQL2 had no recursion
  - You can find Bart's parents, grandparents, great grandparents, etc.

```
SELECT p1.parent AS grandparent
FROM Parent p1, Parent p2
WHERE p1.child = p2.parent
AND p2.child = 'Bart';
```

  - But you cannot find all his ancestors with a single query

- SQL3 introduces recursion
  - WITH clause
  - Implemented in PostgreSQL (common table expressions)
  - SQL:1999 (SQL3) and later versions support "linear Datalog"

Ancestor query in SQL3

Define a relation recursively

```
WITH RECURSIVE
Ancestor(anc, desc) AS
(
 (SELECT parent, child FROM Parent)
 UNION

 (SELECT a1.anc, a2.desc
     FROM Ancestor a1, Ancestor a2
     WHERE a1.desc = a2.anc)
)
SELECT anc
FROM Ancestor
WHERE desc = 'Bart';
```

base case

recursion step

Query using the relation defined in WITH clause

Finding ancestors

```
WITH RECURSIVE
Ancestor(anc, desc) AS
((SELECT parent, child FROM Parent)
 UNION
 (SELECT a1.anc, a2.desc
  FROM Ancestor a1, Ancestor a2
  WHERE a1.desc = a2.anc))
```

Q. Why should it stop after finite number of steps?

parent	*child*
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Ape	Abe

Continue until no more new tuples are generated – reaches a "fixpoint"

anc	*desc*

anc	*desc*
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Ape	Abe

anc	*desc*
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Ape	Abe
Abe	Bart
Abe	Lisa
Ape	Homer

anc	*desc*
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Ape	Abe
Abe	Bart
Abe	Lisa
Ape	Homer
Ape	Bart
Ape	Lisa

Fixed point of a query

- Fixed point of a function: value of x such that f(x) = x
  - E.g. x = 0, 2 for $f(x) = x^2 - x$
- A query q is just a function that maps an input table to an output table, so a fixed point of q is a table T such that $q(T) = T$

To compute fixed point of q

- Start with an empty table: $T \leftarrow \emptyset$
  - Initiate all tables to ∅ for multiple recursive relations
- Evaluate q over T
  - In the i-th iteration, use *all* recursive tables from the previous i-1-th iteration
  - If the result is identical to T, stop; T is a fixed point
  - Otherwise, let T be the new result; repeat
- Starting from ∅ produces the unique minimal fixed point (assuming q is monotone)
  - In the previous slide, think of the definition as Ancestor = q(Ancestor)

Optional slide

Linear recursion

- With linear recursion, a recursive definition can make only one reference to itself
- Non-linear
  - ```
    WITH RECURSIVE Ancestor(anc, desc) AS
    ((SELECT parent, child FROM Parent)
     UNION
     (SELECT a1.anc, a2.desc
      FROM Ancestor a1, Ancestor a2
      WHERE a1.desc = a2.anc))
    ```
- Linear
  - ```
    WITH RECURSIVE Ancestor(anc, desc) AS
    ((SELECT parent, child FROM Parent)
     UNION
     (SELECT anc, child
      FROM Ancestor, Parent
      WHERE desc = parent))
    ```

Optional slide

More on recursion

- Negation+recursion is tricky!
  - Need “stratification”

- Alternative Datalog format

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

Union: Two rules with the same “head”

Comma “,” = Join on the same variables

(A glimpse of)
Data Mining

Optional Reading Material

1. [RG]: Chapter 26

2. "Fast Algorithms for Mining Association Rules"
Agrawal and Srikant, VLDB 1994

25,426 citations on Google Scholar in November 2019!

- 23,863 in November 2018
- 23,038 in November 2017
- 20,610 in November 2016
- 19,496 in April 2016

One of the most cited papers in CS!

- Acknowledgement:

The following slides have been prepared adapting the slides provided by the authors of [RG] and using several presentations from the internet

Four Main Steps in KD and DM (KDD)

- Data Selection
  - Identify target subset of data and attributes of interest
- Data Cleaning
  - Remove noise and outliers, unify units, create new fields, use denormalization if needed
- Data Mining
  - extract interesting patterns
- Evaluation
  - present the patterns to the end users in a suitable form, e.g. through visualization

Several DM/KD (Research) Problems

- Discovery of causal rules
- Learning of logical definitions
- Fitting of functions to data
- Clustering
- Classification
- Inferring functional dependencies from data
- Finding “usefulness” or “interestingness” of a rule

Mining Association Rules

- Retailers collect and store massive amounts of sales data
  - transaction date and list of items
- Association rules:
  - e.g. 98% customers who purchase “tires” and “auto accessories” also get “automotive services” done
  - Customers who buy mustard and ketchup also buy burgers
  - Goal: find these rules from just transactional data (transaction id + list of items)

Applications

- Can be used for
  - marketing program and strategies
  - cross-marketing (mass e-mail, webpages)
  - catalog design
  - add-on sales
  - store layout
  - customer segmentation

Notations

- Items $I = \{i_1, i_2, \ldots, i_m\}$
- D : a set of transactions
- Each transaction $T \subseteq I$
  - has an identifier TID
- Association Rule
  - $X \rightarrow Y$ (not Functional Dependency!)
  - $X, Y \subset I$
  - $X \cap Y = \emptyset$

Confidence and Support

- Association rule $X \rightarrow Y$

- Confidence c = |Tr. with X and Y|/|Tr. with |X|
  - c% of transactions in D that contain X also contain Y

- Support s = |Tr. with X and Y| / |all Tr.|
  - s% of transactions in D contain X and Y.

Support Example

TID	Cereal	Beer	Bread	Bananas	Milk
1	X		X		X
2	X		X	X	X
3		X			X
4	X			X	
5			X		X
6	X				X
7		X		X	
8			X		

- Support(Cereal)
  - 4/8 = .5
- Support(Cereal → Milk)
  - 3/8 = .375

Confidence Example

TID	Cereal	Beer	Bread	Bananas	Milk
1	X		X		X
2	X		X	X	X
3		X			X
4	X			X	
5			X		X
6	X				X
7		X		X	
8			X		

- Confidence(Cereal → Milk)
  - 3/4 = .75
- Confidence(Bananas → Bread)
  - 1/3 = .33333…

Check yourself

$X \rightarrow Y$ is not a Functional Dependency

For functional dependencies

- F.D. = two tuples with the same value of of X must have the same value of Y
  - $X \rightarrow Y$ => $XZ \rightarrow Y$ (concatenation)
  - $X \rightarrow Y$, $Y \rightarrow Z$ => $X \rightarrow Z$ (transitivity)

For association rules

- $X \rightarrow A$ does not mean $XY \rightarrow A$
  - May not have the minimum support
  - Assume one transaction {AX}
- $X \rightarrow A$ and $A \rightarrow Z$ do not mean $X \rightarrow Z$
  - May not have the minimum confidence
  - Assume two transactions {XA}, {AZ}

Problem Definition

- Input
  - a set of transactions D
    - Can be in any form – a file, relational table, etc.
  - min support (minsup)
  - min confidence (minconf)

- Goal: generate all association rules that have
  - support >= minsup and
  - confidence >= minconf

Decomposition into two subproblems

- 1. Apriori
  - for finding “large” itemsets with support >= minsup
  - all other itemsets are “small”

- 2. Then use another algorithm to find rules X → Y such that
  - Both itemsets X ∪ Y and X are large
  - X → Y has confidence >= minconf

- Paper focuses on subproblem 1
  - if support is low, confidence may not say much
  - subproblem 2 in full version of the paper

Basic Ideas - 1

- Q. Which itemset can possibly have larger support: ABCD or AB
  – i.e. when one is a subset of the other?

- Ans: AB
  – any subset of a large itemset must be large
  – So if AB is small, no need to investigate ABC, ABCD etc.

Basic Ideas - 2

- Start with individual (singleton) items {A}, {B}, …
- In subsequent passes, extend the "large itemsets" of the previous pass as "seed"
- Generate new potentially large itemsets (candidate itemsets)
  - E.g., if {AB} {AC} are two large itemsets of size 2, a candidate itemset for size 3 is {ABC} (different last item in the otherwise same sequence)
- Then count their actual support from the data
- At the end of the pass, determine which of the candidate itemsets are actually large
  - becomes seed for the next pass
- Continue until no new large itemsets are found

Announcements

Annoucements (11/26, Tues)

- Final: 12/14 (Sat), 2-5 pm, in class
  - Closed book/notes
  - *Comprehensive*, but likely to have more emphasis on material after midterm
- Please fill out course evaluations!
  - Currently only 1/52 ☺ (thanks to you who filled it out!)
  - A very important step toward improving the class for the future – the course is for you, so all feedback and suggestions much appreciated for future offerings!
  - Will take a few minutes on Dukehub but a huge favor to us – we need your help!
  - A small token of appreciation:
    - 90% (>= 46) filled by the deadline, +4 bonus points in midterm to the entire class
    - 75% (>= 39) filled by the deadline, +2 bonus points in midterm to the entire class

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Announcements (11/26, Tues)

- Project slides (3 only) and report due on 12/11 (Wed)
  - Google slide deck will be posted
  - Everyone knows what every other group worked on and their results!
  - Project grading will be relative
  - Feel free to add voiceover in notes/ audio (encouraged!)

- Offline 3-slide per project
  - Tentative: Motivation/Problem (1), Your contributions (2)
  - You present the current status of the project
    - problem, example, your approach, future work
  - Best to show plots/ screenshots/ results/ demo!
  - Try to show the most interesting observation/findings in 3 slides

Summary!

Take-Aways

- DBMS Basics
- DBMS Internals
- Overview of Research Areas
- Hands-on Experience in DB systems

DB Systems

- Traditional DBMS
  - PostGres, SQL
- Large-scale Data Processing Systems
  - Spark/Scala, AWS
- New DBMS/NOSQL
  - MongoDB
- In addition
  - XML, JSON, JDBC, Python/Java

DB Basics

- SQL
- RA/Logical Plans
- RC
- Recursion in SQL / Datalog
  - Why we needed each of these languages

- Normal Forms

DB Internals and Algorithms

- Storage
- Indexing
- Operator Algorithms
  – External Sort
  – Join Algorithms
- Cost-based Query Optimization
- Transactions
  – Concurrency Control
  – Recovery

Large-scale Processing and New Approaches

- Parallel DBMS
- Distributed DBMS
- Map Reduce
- NOSQL

- Hope some of you will further explore Database Systems/Data Management/Data Analysis/Big Data as a researcher or practitioner!