Introduction to SQL

Select-From-Where Statements
Subqueries
Grouping and Aggregation

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Why SQL?

- SQL is a very-high-level language.
  - Say "what to do" rather than "how to do it."
  - Avoid a lot of data-manipulation details needed in procedural languages like C++ or Java.
- Database management system figures out "best" way to execute query.
  - Called "query optimization."

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Select-From-Where Statements

SELECT desired attributes
FROM one or more tables
WHERE condition about tuples of
the tables

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Our Running Example

- All our SQL queries will be based on the following database schema.
  - Underline indicates key attributes.

Beers(<u>name</u>, manf)
Bars(<u>name</u>, addr, city, phone, license)
Drinkers(<u>name</u>, addr, city, phone)
Likes(<u>drinker</u>, <u>beer</u>)
Sells(<u>bar</u>, <u>beer</u>, price)
Frequents(<u>drinker</u>, <u>bar</u>)

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Example

- Using Beers(name, manf), what beers are made by Anheuser-Busch?

```
SELECT name
FROM Beers
WHERE manf = 'Anheuser-Busch';
```

Notice SQL uses single-quotes for strings.
SQL is *case-insensitive*, except inside strings.

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Result of Query

name
Bud
Bud Lite
Michelob
. . .

The answer is a relation with a single attribute, name, and tuples with the name of each beer by Anheuser-Busch, such as Bud.

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Meaning of Single-Relation Query

- Begin with the relation in the FROM clause.
- Apply the selection indicated by the WHERE clause.
- Apply the extended projection indicated by the SELECT clause.

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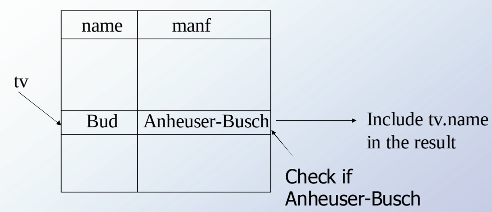
Operational Semantics



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Operational Semantics

- To implement this algorithm think of a *tuple variable* ranging over each tuple of the relation mentioned in FROM.
- Check if the "current" tuple satisfies the WHERE clause.
- If so, compute the attributes or expressions of the SELECT clause using the components of this tuple.

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* In SELECT clauses

- When there is one relation in the FROM clause, * in the SELECT clause stands for "all attributes of this relation."
- Example using Beers(name, manf):

```
SELECT *
FROM Beers
WHERE manf = 'Anheuser-Busch';
```

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Result of Query:

name	**manf**
Bud	Anheuser-Busch
Bud Lite	Anheuser-Busch
Michelob	Anheuser-Busch
. . .	. . .

Now, the result has each of the attributes of Beers.

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Renaming Attributes

- If you want the result to have different attribute names, use "AS <new name>" to rename an attribute.
- Example based on Beers(name, manf):

```
SELECT name AS beer, manf
FROM Beers
WHERE manf = 'Anheuser-Busch'
```

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Result of Query:

beer	manf
Bud	Anheuser-Busch
Bud Lite	Anheuser-Busch
Michelob	Anheuser-Busch
. . .	. . .

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Expressions in SELECT Clauses

- Any expression that makes sense can appear as an element of a SELECT clause.
- Example: from Sells(bar, beer, price):

```
SELECT bar, beer,
       price * 114 AS priceInYen
FROM Sells;
```

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Result of Query

bar	beer	priceInYen
Joe's	Bud	285
Sue's	Miller	342
…	…	…

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Another Example: Constant Expressions

- From Likes(drinker, beer) :

```
SELECT drinker,
       'likes Bud' AS whoLikesBud
FROM Likes
WHERE beer = 'Bud';
```

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Result of Query

drinker	whoLikesBud
Sally	likes Bud
Fred	likes Bud
…	…

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Complex Conditions in WHERE Clause

- From Sells(bar, beer, price), find the price Joe's Bar charges for Bud:

```
SELECT price
FROM Sells
WHERE bar = 'Joe''s Bar' AND
    beer = 'Bud';
```

Notice how we get a single-quote in strings.

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Patterns

- WHERE clauses can have conditions in which a string is compared with a pattern, to see if it matches.
- General form:
  <Attribute> LIKE <pattern> or
  <Attribute> NOT LIKE <pattern>
- Pattern is a quoted string with % = "any string"; _ = "any character."

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Example

- From Drinkers(name, addr, phone) find the drinkers with exchange 555:

```
SELECT name
FROM Drinkers
WHERE phone LIKE '%555-_ _ _ _';
```

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NULL Values

- Tuples in SQL relations can have NULL as a value for one or more components.
- Meaning depends on context. Two common cases:
  - *Missing value* : e.g., we know Joe's Bar has some address, but we don't know what it is.
  - *Inapplicable* : e.g., the value of attribute *spouse* for an unmarried person.

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Comparing NULL's to Values

- The logic of conditions in SQL is really 3-valued logic: TRUE, FALSE, UNKNOWN.
- When any value is compared with NULL, the truth value is UNKNOWN.
- But a query only produces a tuple in the answer if its truth value for the WHERE clause is TRUE (not FALSE or UNKNOWN).

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Three-Valued Logic

- To understand how AND, OR, and NOT work in 3-valued logic, think of TRUE = 1, FALSE = 0, and UNKNOWN = ½.
- AND = MIN; OR = MAX, NOT(x) = 1-x.
- Example:

TRUE AND (FALSE OR NOT(UNKNOWN))
= MIN(1, MAX(0, (1 - ½))) =
MIN(1, MAX(0, ½) = MIN(1, ½) = ½.

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Surprising Example

- From the following Sells relation:

bar	beer	price
Joe's Bar	Bud	NULL

SELECT bar
FROM Sells
WHERE price < 2.00 OR price >= 2.00;

UNKNOWN UNKNOWN

UNKNOWN

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Reason: 2-Valued Laws != 3-Valued Laws

- Some common laws, like commutativity of AND, hold in 3-valued logic.
- But not others, e.g., the "law of the excluded middle": *p* OR NOT *p* = TRUE.
  - When *p* = UNKNOWN, the left side is MAX(½, (1 – ½)) = ½ != 1.

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Multirelation Queries

- Interesting queries often combine data from more than one relation.
- We can address several relations in one query by listing them all in the FROM clause.
- Distinguish attributes of the same name by "<relation>.<attribute>"

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Example

- Using relations Likes(drinker, beer) and Frequents(drinker, bar), find the beers liked by at least one person who frequents Joe's Bar.

```
SELECT beer
FROM Likes, Frequents
WHERE bar = 'Joe''s Bar' AND
   Frequents.drinker =
        Likes.drinker;
```

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Formal Semantics

- Almost the same as for single-relation queries:
  1. Start with the product of all the relations in the FROM clause.
  2. Apply the selection condition from the WHERE clause.
  3. Project onto the list of attributes and expressions in the SELECT clause.

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Operational Semantics

- Imagine one tuple-variable for each relation in the FROM clause.
  - These tuple-variables visit each combination of tuples, one from each relation.
- If the tuple-variables are pointing to tuples that satisfy the WHERE clause, send these tuples to the SELECT clause.

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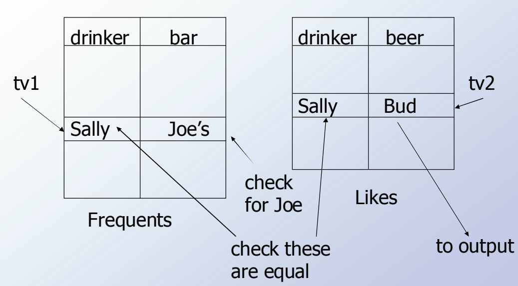
Example



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Explicit Tuple-Variables

- Sometimes, a query needs to use two copies of the same relation.
- Distinguish copies by following the relation name by the name of a tuple-variable, in the FROM clause.
- It's always an option to rename relations this way, even when not essential.

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Example

- From Beers(name, manf), find all pairs of beers by the same manufacturer.
  - Do not produce pairs like (Bud, Bud).
  - Produce pairs in alphabetic order, e.g. (Bud, Miller), not (Miller, Bud).

```
SELECT b1.name, b2.name
FROM Beers b1, Beers b2
WHERE b1.manf = b2.manf AND
   b1.name < b2.name;
```

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Subqueries

- A parenthesized SELECT-FROM-WHERE statement (*subquery*) can be used as a value in a number of places, including FROM and WHERE clauses.
- Example: in place of a relation in the FROM clause, we can place another query, and then query its result.
  - Better use a tuple-variable to name tuples of the result.

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Subqueries That Return One Tuple

- If a subquery is guaranteed to produce one tuple, then the subquery can be used as a value.
  - Usually, the tuple has one component.
  - A run-time error occurs if there is no tuple or more than one tuple.

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Example

- From Sells(bar, beer, price), find the bars that serve Miller for the same price Joe charges for Bud.
- Two queries would surely work:
  1. Find the price Joe charges for Bud.
  2. Find the bars that serve Miller at that price.

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Query + Subquery Solution

```
SELECT bar
FROM Sells
WHERE beer = 'Miller' AND
   price = (SELECT price
            FROM Sells
            WHERE bar = 'Joe''s Bar'
              AND beer = 'Bud');
```

The price at which Joe sells Bud

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The IN Operator

- <tuple> IN <relation> is true if and only if the tuple is a member of the relation.
  - <tuple> NOT IN <relation> means the opposite.
- IN-expressions can appear in WHERE clauses.
- The <relation> is often a subquery.

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Example

- From Beers(name, manf) and Likes(drinker, beer), find the name and manufacturer of each beer that Fred likes.

```
SELECT *
FROM Beers
WHERE name IN (SELECT beer
               FROM Likes
               WHERE drinker = 'Fred');
```

The set of beers Fred likes

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The Exists Operator

- EXISTS(<relation>) is true if and only if the <relation> is not empty.
- Example: From Beers(name, manf) , find those beers that are the unique beer by their manufacturer.

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Example Query with EXISTS

```
SELECT name
FROM Beers b1
WHERE NOT EXISTS(
    SELECT *
    FROM Beers
    WHERE manf = b1.manf AND
          name <> b1.name);
```

Notice scope rule: manf refers to closest nested FROM with a relation having that attribute.

Set of beers with the same manf as b1, but not the same beer

Notice the SQL "not equals" operator

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The Operator ANY

- x = ANY(<relation>) is a boolean condition true if x equals at least one tuple in the relation.
- Similarly, = can be replaced by any of the comparison operators.
- Example: x > ANY(<relation>) means x is not the smallest tuple in the relation.
  - Note tuples must have one component only.

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The Operator ALL

- Similarly, x <> ALL(<relation>) is true if and only if for every tuple t in the relation, x is not equal to t.
  - That is, x is not a member of the relation.
- The <> can be replaced by any comparison operator.
- Example: x >= ALL(<relation>) means there is no tuple larger than x in the relation.

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Example

- From Sells(bar, beer, price), find the beer(s) sold for the highest price.

```
SELECT beer
FROM Sells
WHERE price >= ALL(
    SELECT price
    FROM Sells);
```

price from the outer Sells must not be less than any price.

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Union, Intersection, and Difference

- Union, intersection, and difference of relations are expressed by the following forms, each involving subqueries:
  - (subquery) UNION (subquery)
  - (subquery) INTERSECT (subquery)
  - (subquery) EXCEPT (subquery)

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Example

- From relations Likes(drinker, beer), Sells(bar, beer, price), and Frequents(drinker, bar), find the drinkers and beers such that:
  1. The drinker likes the beer, and
  2. The drinker frequents at least one bar that sells the beer.

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Solution

```
(SELECT * FROM Likes)
  INTERSECT
(SELECT drinker, beer
 FROM Sells, Frequents
 WHERE Frequents.bar = Sells.bar
);
```

The drinker frequents a bar that sells the beer.

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Bag Semantics

- Although the SELECT-FROM-WHERE statement uses bag semantics, the default for union, intersection, and difference is set semantics.
  - That is, duplicates are eliminated as the operation is applied.

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Motivation: Efficiency

- When doing projection, it is easier to avoid eliminating duplicates.
  - Just work tuple-at-a-time.
- For intersection or difference, it is most efficient to sort the relations first.
  - At that point you may as well eliminate the duplicates anyway.

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Controlling Duplicate Elimination

- Force the result to be a set by SELECT DISTINCT . . .
- Force the result to be a bag (i.e., don't eliminate duplicates) by ALL, as in . . . UNION ALL . . .

Example: DISTINCT

- From Sells(bar, beer, price), find all the different prices charged for beers:

```
SELECT DISTINCT price
FROM Sells;
```

- Notice that without DISTINCT, each price would be listed as many times as there were bar/beer pairs at that price.

Example: ALL

- Using relations Frequents(drinker, bar) and Likes(drinker, beer):

```
(SELECT drinker FROM Frequents)
    EXCEPT ALL
(SELECT drinker FROM Likes);
```

- Lists drinkers who frequent more bars than they like beers, and does so as many times as the difference of those counts.

Join Expressions

- SQL provides several versions of (bag) joins.
- These expressions can be stand-alone queries or used in place of relations in a FROM clause.

Products and Natural Joins

- Natural join:
  R NATURAL JOIN S;
- Product:
  R CROSS JOIN S;
- Example:
  `Likes NATURAL JOIN Serves;`
- Relations can be parenthesized subqueries, as well.

Theta Join

- R JOIN S ON <condition>
- Example: using Drinkers(name, addr) and Frequents(drinker, bar):

```
Drinkers JOIN Frequents ON
    name = drinker;
```

gives us all (*d, a, d, b*) quadruples such that drinker *d* lives at address *a* and frequents bar *b*.

Outerjoins

- R OUTER JOIN S is the core of an outerjoin expression. It is modified by:
  1. Optional NATURAL in front of OUTER.
  2. Optional ON <condition> after JOIN.
  3. Optional LEFT, RIGHT, or FULL before OUTER.
     - LEFT = pad dangling tuples of R only.
     - RIGHT = pad dangling tuples of S only.
     - FULL = pad both; this choice is the default.

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Aggregations

- SUM, AVG, COUNT, MIN, and MAX can be applied to a column in a SELECT clause to produce that aggregation on the column.
- Also, COUNT(*) counts the number of tuples.

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Example: Aggregation

- From Sells(bar, beer, price), find the average price of Bud:

```
SELECT AVG(price)
FROM Sells
WHERE beer = 'Bud';
```

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Eliminating Duplicates in an Aggregation

- Use DISTINCT inside an aggregation.
- Example: find the number of different prices charged for Bud:

```
SELECT COUNT(DISTINCT price)
FROM Sells
WHERE beer = 'Bud';
```

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NULL's Ignored in Aggregation

- NULL never contributes to a sum, average, or count, and can never be the minimum or maximum of a column.
- But if there are no non-NULL values in a column, then the result of the aggregation is NULL.

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Example: Effect of NULL's

```
SELECT count(*)
FROM Sells
WHERE beer = 'Bud';
```

The number of bars that sell Bud.

```
SELECT count(price)
FROM Sells
WHERE beer = 'Bud';
```

The number of bars that sell Bud at a known price.

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Grouping

- We may follow a SELECT-FROM-WHERE expression by GROUP BY and a list of attributes.
- The relation that results from the SELECT-FROM-WHERE is grouped according to the values of all those attributes, and any aggregation is applied only within each group.

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Example: Grouping

- From Sells(bar, beer, price), find the average price for each beer:

```
SELECT beer, AVG(price)
FROM Sells
GROUP BY beer;
```

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Example: Grouping

- From Sells(bar, beer, price) and Frequents(drinker, bar), find for each drinker the average price of Bud at the bars they frequent:

```
SELECT drinker, AVG(price)
FROM Frequents, Sells
WHERE beer = 'Bud' AND
    Frequents.bar = Sells.bar
GROUP BY drinker;
```

Compute drinker-bar-price for Bud tuples first, then group by drinker.

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Restriction on SELECT Lists With Aggregation

- If any aggregation is used, then each element of the SELECT list must be either:
  1. Aggregated, or
  2. An attribute on the GROUP BY list.

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Illegal Query Example

- You might think you could find the bar that sells Bud the cheapest by:

```
SELECT bar, MIN(price)
FROM Sells
WHERE beer = 'Bud';
```

- But this query is illegal in SQL.

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HAVING Clauses

- HAVING <condition> may follow a GROUP BY clause.
- If so, the condition applies to each group, and groups not satisfying the condition are eliminated.

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Example: HAVING

- From Sells(bar, beer, price) and Beers(name, manf), find the average price of those beers that are either served in at least three bars or are manufactured by Pete's.

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Solution

```
SELECT beer, AVG(price)
FROM Sells
GROUP BY beer
HAVING COUNT(bar) >= 3 OR
    beer IN (SELECT name
             FROM Beers
             WHERE manf = 'Pete''s');
```

Beer groups with at least 3 non-NULL bars and also beer groups where the manufacturer is Pete's.

Beers manu-factured by Pete's.

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Requirements on HAVING Conditions

- These conditions may refer to any relation or tuple-variable in the FROM clause.
- They may refer to attributes of those relations, as long as the attribute makes sense within a group; i.e., it is either:
  1. A grouping attribute, or
  2. Aggregated.

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