CompSci 516
Database Systems

Lecture 1
Introduction
and
SQL

Instructor: Sudeepa Roy

Course Website

- http://www.cs.duke.edu/courses/fall19/compsci516/

- Please check frequently for updates!

Instructor

- Sudeepa Roy
  - sudeepa@cs.duke.edu
  - https://users.cs.duke.edu/~sudeepa/
  - office hour: Tuesdays 2:45 pm – 3:45 pm, LSRC D325, and by appointments
  - No office hour today, instead on Friday 8/30 2-3 pm

- About myself
  - Assistant Professor in CS
  - PhD: UPenn, Postdoc: Univ. of Washington
  - Joined Duke CS in Fall 2015
  - Research interests:
    - Data Analysis, causality, query optimization, data science, database theory, applications of data, uncertain data,…

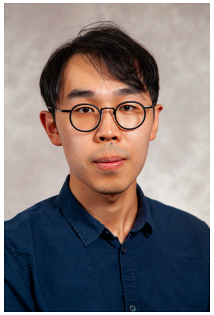
* Offering you full help!

Three (half*-)TAs

- Yuchao Tao
  - yuchao.tao@duke.edu

- Yanlin Yu
  - yanlin.yu@duke.edu

- Tianrui Zhang
  - tanrui.zhang@duke.edu



- All CompSci 516 veterans!
  - office hours: TBD

Logistics

- Discussion forum: Piazza
  - All enrolled students (by yesterday) are already there
  - Send me an email if you have not received a welcome email from Piazza
- To reach course staff:
  - compsci516-staff@cs.duke.edu
  - Please use piazza as much as possible
- Lecture slides will be uploaded before the class as incomplete notes
  - but will be updated after the class

Grading

- Three Homework: 30%
- Project: 10%
- Midterm: 20%
- Final: 30%
- Class participation: 10%
  - In-class quizzes: 5%
  - In-class labs: 5%

Grading Strategy

- Relative grading
  - The actual grade distribution at the end will depend on the performance of the entire class on all the components.
  - Topper of the class gets A+ irrespective of the number, and all and only “above expectation” performances get A+.
  - No fixed lowest grade or grade distribution.
  - Everyone can get good grade by working hard!

Homework

- Due in about 2 weeks after they are posted/previous hw is due
  - ALWAYS start early!
  - Part of the homework may be due in 1 week

- Two *late days* with penalty
  - For the take-home part (not the in-class lab part) of each homework
  - 25% penalty on the entire assignment if you submit within the next 24 hours after the deadline
  - 50% penalty on the entire assignment if you submit within the next 24 hours after the deadline
  - No credit after 48 hours
  - No credit after solutions are posted (even if within the first 48 hours)
  - Start early and do not count on late days!

- contact the instructor if you have a *valid* reason to be late
  - Another exam, project, hw is NOT a valid reason – we will always be fair to all

- To be done strictly individually

- PLEASE READ WHAT IS ALLOWED/NOT ALLOWED (will be repeated in class next week)
- https://www2.cs.duke.edu/courses/fall19/compsci516/Lectures/CompSci516-HonorCode.pdf

Homework Overview

- You will learn how to use traditional and new database systems in the homework
  - Have to learn them mostly on your own following tutorials available online and with some help from the TA
- HW1: Traditional DBMS
  - SQL and Postgres (and some XML too!)
- HW2: Distributed data processing
  - Spark and AWS
- HW3: NOSQL
  - MongoDB

Exams

- Midterm – Oct 15 (Tues)
- Final – Dec 14 (Sat)

- In class
- Closed book, closed notes, no electronic devices
- Total weight: 20 + 30 % = 50 %
- Exams will test your understanding of the material
- Both exams are comprehensive
  - would include every lecture up to the exams

Projects

- 10% weight
- In groups of 3-4
  - Groups of smaller and larger sizes need instructor's permission
  - Each group member should do approx. equal work
- Very flexible in terms of topic!
- Show your creativity and researcher-side!
- Work done should be at least equivalent to
  - one hw * no. of group members

- All group members will get the same grade
- More information and ideas for projects will be posted later

Project Deliverables

1. Project proposal
   – problem selection is part of the project
2. Midterm progress report
3. Final project report
4. A final 5-10 mins project presentation and/or demonstration

- Due dates will be posted (about 1 month time for all three reports)

Class Participation

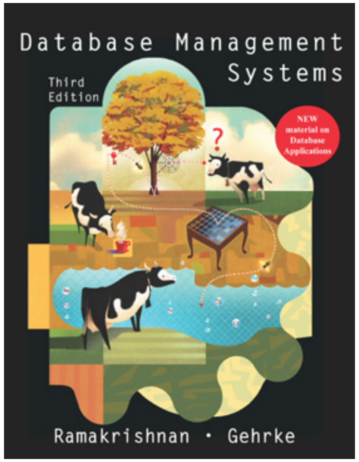
- 5% for quizzes, 5% for in-class labs
- Please bring laptops every day!
- Pop-up quiz
  - Participation (50%) + correct answering (50%)
  - lowest score will be dropped
- In-class labs
  - Attending the lab and submitting some solutions (50%)
  - Submitting correct solutions : within 24 hours after class ends (50%)
  - "Extra credit" 10% for submitting *all* correct solutions in class!

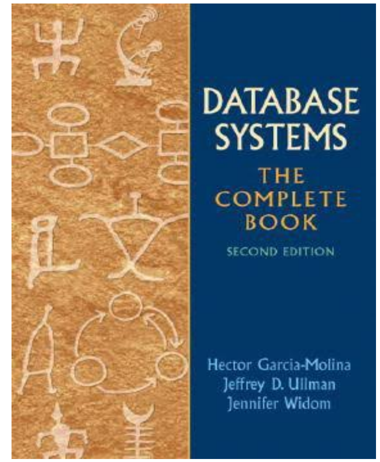
Please ask questions in class!

- In general, actively participate in the class!
  - Ask questions in class and on piazza
  - Stop me as many times as you need to understand the lectures
  - Answer each other's questions on piazza

- Also send (anonymous or not) feedback, suggestions, or concerns on Piazza or by email

Reading Material





- Will mostly follow the ”cowbook” by Ramakrishnan-Gehrke
  - The chapter numbers will be posted
- You do not have to buy the books, but it will be good to consult them from time to time
- You should be prepared to do quite a bit of reading from various books and papers

A Quick Survey

- Have you taken an undergrad database course earlier
  – CS 316/equivalent?
- Are you familiar with
  – SQL?
  – RA? (σ, Π, $\times$, $\bowtie$, ρ, $\cup$, $\cap$, -)
  – Keys, foreign keys?
  – Index in databases?
  – Logic: $\wedge$, $\vee$, $\forall$, $\exists$, $\neg$, $\in$, $\Rightarrow$
  – Transactions?
  – Map-reduce/Spark?
  – NOSQL?
- Have you ever worked with a dataset?
  – relational database, text, csv, XML
- Have you ever used a database system?
  – PostGres, MySQL, SQL Server, SQL Azure

What is this course about?

- This is a graduate-level database course in CS
  - We will cover principles, internals, and applications of database systems in depth
- Database concepts
  - Data Models, SQL, Views, Constraints, RA, Normalization
- Principles and internals of database management systems (DBMS)
  - Indexing, Query Execution-Algorithms-Optimization, Transactions, Parallel and Distributed Query Processing, Map Reduce
- Advanced and research topics in databases
  - e.g. Datalog, NOSQL, Data mining, …

What this course is NOT about

- Spark, AWS, cluster computing…
  - Partially covered in a HW and a lecture
- Machine learning based analytics
- Statistical methods for data analytics
- Python, R, …

Why should we care about databases?

- We are in a data-driven world

- Data = Currency, Data = Power, Data = Fun
- “Big Data” is supposed to change the mode of operation for almost every single field
  - Science, Technology, Healthcare, Business, Manufacturing, Journalism, Government, Education, …
- We must know how to collect, store, process, and analyze such data
- Storing data in flat files and writing python or C code would fail at some point!
- And hundreds of jobs on data science, data analysis, data engineer, …!

This week's plan

- Today
  - Relational Data Model and SQL
- Lecture-2:
  - First In-class lab on SQL (conducted by Yanlin and Tianrui)
  - You will install postgres, work on MovieLens data on movie reviews, and then write some queries
  - Will be graded
    - You will submit solutions on Gradescope (auto-graded instantaneously!)
  - Do not forget your laptop!
    - Any platform should be fine
  - Feel free to attend even if you are on the waitlist and would like to enroll in this class

- Next week:
  - Data model and data independence, more SQL

Relational Data Model

- Proposed by Edward (Ted) Codd in 1970
  - won Turing award for it!

- Motivation:
  - Simplicity
  - Easy query optimizations
  - Separation of abstraction and operations
    - More next week

Relational Data Model

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith1@math	19	3.8
53831	Madayan	madayan@music	11	1.8
53832	Guldu	guldu@music	12	2.0

- The data description construct is a Relation
  - Represented as a “table”
  - Basically a “set” of records (set semantic)
  - order does not matter
  - and all records are distinct
- however, it is true for the relational model, not for standard DBM
  - allow duplicate rows (bag semantic)
  - unless restricted by key constraints. Why?

Bag: {1, 1, 2, 2, 3, 2, 1, 5, 6, 1}
Set: {1, 2, 3, 5, 6}

Bag vs. Set

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith1@math	19	3.8
53831	Madayan	madayan@music	11	1.8
53832	Guldu	guldu@music	12	2.0

- Why “bag semantic” and not “set semantic” in standard DBMSs?
  - Primarily performance reasons
  - Duplicate elimination is expensive (requires sorting)
  - Some operations like “projection”s are much more efficient on bags than sets

Relational Data Model

Students

Attribute/
Column/
Field

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith1@math	19	3.8
53831	Madayan	madayan@music	11	1.8
53832	Guldu	guldu@music	12	2.0

Tuple/
Row/
Record

Value

What is a poorly chosen attribute in this relation?

- Relational database = a set of relations
- A Relation : made up of two parts
  1. Schema
  2. Instance

Schema and Instance

- One schema can have multiple instances
- Schema:
  - A template for describing an entity/relationship (e.g. students)
  - specifies name of relation + name and type of each column

  e.g. Students(sid: string, name: string, login: string, age: integer, gpa: real).
- Instance:
  - When we fill in actual data values in a schema
  - a table, has rows and columns
  - each row/tuple follows the schema and domain constraints
  - #Rows = cardinality, #fields = degree or arity
  - example below

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith1@math	19	3.8

Cardinality = 3, degree = 5

SQL
(Structured Query Language)

Relational Query Languages

- A major strength of the relational model: supports simple, powerful querying of data.

- Queries can be written intuitively, and the DBMS is responsible for an efficient evaluation
  - The key: precise semantics for relational queries
  - Based on a sound theory!
  - Allows the optimizer to extensively re-order operations, and still ensure that the answer does not change.

The SQL Query Language

- Developed by IBM (systemR) in the 1970s based on Ted Codd's relational model
  - First called "SEQUEL" (Structured English Query Language)
- First commercialized by Oracle (then Relational Software)in 1979
- Standards by ANSI and ISO since it is used by many vendors
  - SQL-86, -89 (minor revision), -92 (major revision), -96, -99 (major extensions), -03, -06, -08, -11, -16

Purposes of SQL

- Data Manipulation Language (DML)
  - Querying: SELECT-FROM-WHERE
  - Modifying: INSERT/DELETE/UPDATE (next week)
- Data Definition Language (DDL)
  - CREATE/ALTER/DROP (next week)

The SQL Query Language

- To find all 18 year old students, we can write:

all attributes

```
SELECT *
FROM Students S
WHERE S.age=18
```

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2

- To find just names and logins, replace the first line:

```
SELECT S.name, S.login
```

Querying Multiple Relations

- What does the following query compute?

```
SELECT  S.name, E.cid
FROM  Students S, Enrolled E
WHERE  S.sid=E.sid AND E.grade="A"
```

Enrolled

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

Given the following instances of Enrolled and Students:

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

we get: ??

Querying Multiple Relations

- What does the following query compute?

```
SELECT  S.name, E.cid
FROM  Students S, Enrolled E
WHERE  S.sid=E.sid AND E.grade="A"
```

Enrolled

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

Given the following instances of Enrolled and Students:

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

we get:

S.name	E.cid
Smith	Topology112

Read yourself, after reading the next few slides first

Basic SQL Query

```
SELECT      [DISTINCT] <target-list>
FROM        <relation-list>
WHERE       <qualification>
```

- relation-list A list of relation names
  - possibly with a "range variable" after each name
- target-list A list of attributes of relations in relation-list
- qualification Comparisons
  - (Attr op const) or (Attr1 op Attr2)
  - where op is one of = , <, >, <=, >= combined using AND, OR and NOT
- DISTINCT is an optional keyword indicating that the answer should not contain duplicates
  - Default is that duplicates are not eliminated!

Read yourself, after reading the next few slides first

Conceptual Evaluation Strategy

```
SELECT      [DISTINCT]  <target-list>
FROM        <relation-list>
WHERE       <qualification>
```

- Semantics of an SQL query defined in terms of the following conceptual evaluation strategy:
  - Compute the cross-product of *<relation-list>*
  - Discard resulting tuples if they fail *<qualifications>*
  - Delete attributes that are not in *<target-list>*
  - If DISTINCT is specified, eliminate duplicate rows

- This strategy is probably the least efficient way to compute a query!
  - An optimizer will find more efficient strategies to compute the same answers

Example of Conceptual Evaluation

```
SELECT  S.sname
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid AND R.bid=103
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

What does this query return?

Example of Conceptual Evaluation

```
SELECT  S.sname
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid AND R.bid=103
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Step 1: Form "**cross product**" of Sailor and Reserves

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

sid	sname	rating	age	sid	bid	day
22	dustin	7	45	22	101	10/10/96
22	dustin	7	45	58	103	11/12/96
31	lubber	8	55	22	101	10/10/96
31	lubber	8	55	58	103	11/12/96
58	rusty	10	35	22	101	10/10/96
58	rusty	10	35	58	103	11/12/96

Example of Conceptual Evaluation

```
SELECT  S.sname
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid AND R.bid=103
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Step 2: Discard tuples that do not satisfy <qualification>

sid	sname	rating	age	sid	bid	day
~~22~~	~~dustin~~	~~7~~	~~45~~	~~22~~	~~101~~	~~10/10/96~~
~~22~~	~~dustin~~	~~7~~	~~45~~	~~58~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~22~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~58~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~22~~	~~101~~	~~10/10/96~~
58	rusty	10	35	58	103	11/12/96

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Example of Conceptual Evaluation

SELECT S.sname
FROM Sailors S, Reserves R
WHERE S.sid=R.sid AND R.bid=103

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Step 3: Select the specified attribute(s)

sid	sname	rating	age	sid	bid	day
~~22~~	~~dustin~~	~~7~~	~~45~~	~~22~~	~~101~~	~~10/10/96~~
~~22~~	~~dustin~~	~~7~~	~~45~~	~~58~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~22~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~58~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~22~~	~~101~~	~~10/10/96~~
58	rusty	10	35	58	103	11/12/96

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Recap

```
3  SELECT  S.sname
1  FROM    Sailors S, Reserves R
2  WHERE   S.sid=R.sid AND R.bid=103
```

Always start from “FROM” -- form cross product
Apply “WHERE” -- filter out some tuples (rows)
Apply “SELECT” -- filter out some attributes (columns)

Ques. Does this get evaluated this way in practice in a Database Management System (DBMS)?

No! This is conceptual evaluation for finding what is correct!
We will learn about join and other operator algorithms later

A Note on "Range Variables"

- Sometimes used as a short-name
- The previous query can also be written as:

```
SELECT  S.sname
FROM    Sailors S, Reserves R
WHERE   S.sid=R.sid AND bid=103
```

OR

```
SELECT  sname
FROM    Sailors, Reserves
WHERE   Sailors.sid=Reserves.sid
        AND bid=103
```

It is good style, however, to use range variables always!

A Note on "Range Variables"

- Really needed only if the same relation appears twice in the FROM clause (called self-joins)

- Find pairs of Sailors of same age

```
SELECT  S1.sname, S2. name
FROM    Sailors S1, Sailors S2
WHERE   S1.age = S2.age AND S1.sid < S2.sid
```

Why do we need the 2[nd] condition?

Find sailor ids who've reserved at least one boat

```
SELECT  ????
FROM  Sailors S, Reserves R
WHERE  S.sid=R.sid
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Find sailor ids who've reserved at least one boat

```
SELECT  S.sid
FROM  Sailors S, Reserves R
WHERE  S.sid=R.sid
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

- Would adding DISTINCT to this query make a difference?

Find sailors who've reserved at least one boat

```
SELECT S.sid
FROM Sailors S, Reserves R
WHERE S.sid=R.sid
```

Sailor

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Reserves

sid	bid	day
22	101	10/10/96
58	103	11/12/96

- Would adding DISTINCT to this query make a difference?
  - Note that if there are multiple bids for the same sid, you get multiple output tuples for the same sid
  - Without distinct, you get them multiple times
- What is the effect of replacing *S.sid* by *S.sname* in the SELECT clause?
  - Would adding DISTINCT to this variant of the query make a difference even if one sid reserves at most one bid?

Simple Aggregate Operators

COUNT (*)
COUNT ([DISTINCT] A)
SUM ([DISTINCT] A)
AVG ([DISTINCT] A)
MAX (A)
MIN (A)

single column

Check yourself:
What do these queries compute?

```
SELECT  COUNT (*)
FROM  Sailors S
```

```
SELECT  AVG (S.age)
FROM  Sailors S
WHERE  S.rating=10
```

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.rating= (SELECT  MAX(S2.rating)
                  FROM  Sailors S2)
```

```
SELECT  COUNT (DISTINCT S.rating)
FROM  Sailors S
WHERE S.sname='Bob'
```

```
SELECT  AVG ( DISTINCT S.age)
FROM  Sailors S
WHERE  S.rating=10
```

Next: different types of joins

- Theta-join
- Equi-join
- Natural join
- Outer Join

Condition/Theta Join

```
SELECT *
FROM Sailors S, Reserves R
WHERE S.sid=R.sid and age >= 40
```

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Form cross product, discard rows that do not satisfy the condition

sid	sname	rating	age	sid	bid	day
22	dustin	7	45	22	101	10/10/96
~~22~~	~~dustin~~	~~7~~	~~45~~	~~58~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~22~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~58~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~22~~	~~101~~	~~10/10/96~~
58	rusty	10	35	58	103	11/12/96

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Equi Join

```
SELECT  *
FROM  Sailors S, Reserves R
WHERE  S.sid=R.sid and age = 45
```

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

A special case of theta join
Join condition only has equality predicate =

sid	sname	rating	age	sid	bid	day
22	dustin	7	45	22	101	10/10/96
~~22~~	~~dustin~~	~~7~~	~~45~~	~~58~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~22~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~58~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~22~~	~~101~~	~~10/10/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~58~~	~~103~~	~~11/12/96~~

sid	bid	day
22	101	10/10/96
58	103	11/12/96

Natural Join

```
SELECT *
FROM Sailors S NATURAL JOIN Reserves R
```

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

A special case of equi join
Equality condition on ALL common predicates (sid)
Duplicate columns are eliminated

sid	bid	day
22	101	10/10/96
58	103	11/12/96

sid	sname	rating	age	bid	day
22	dustin	7	45	101	10/10/96
~~22~~	~~dustin~~	~~7~~	~~45~~	~~103~~	~~11/12/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~101~~	~~10/10/96~~
~~31~~	~~lubber~~	~~8~~	~~55~~	~~103~~	~~11/12/96~~
~~58~~	~~rusty~~	~~10~~	~~35~~	~~101~~	~~10/10/96~~
58	rusty	10	35	103	11/12/96

End of Lecture-1

Outer Join

```
SELECT S.sid, R. bid
FROM Sailors S LEFT OUTER JOIN Reserves R
ON S.sid=R.sid
```

sid	sname	rating	age
22	dustin	7	45
31	lubber	8	55
58	rusty	10	35

Preserves all tuples from the left table whether or not there is a match
if no match, fill attributes from right with null
Similarly RIGHT/FULL outer join

sid	bid	day
22	101	10/10/96
58	103	11/12/96

sid	bid
22	101
31	null
58	103

Expressions and Strings

```
SELECT  S.age,   age1=S.age-5,   2*S.age AS age2
FROM  Sailors S
WHERE  S.sname LIKE 'B_%B'
```

- Illustrates use of arithmetic expressions and string pattern matching
- *Find triples (of ages of sailors and two fields defined by expressions) for sailors*
  - *whose names begin and end with B and contain at least three characters*
- LIKE is used for string matching. `_' stands for any one character and `%' stands for 0 or more arbitrary characters
  - You will need these often

Find sid's of sailors who've reserved a red or a green boat

Sailors (sid, sname, rating, age)
Reserves(sid, bid, day)
Boats(bid, bname, color)

```
SELECT  S.sid
FROM  Sailors S, Boats B, Reserves R
WHERE  S.sid=R.sid AND R.bid=B.bid
  AND (B.color='red' OR B.color='green')
```

- UNION: Can be used to compute the union of any two *union-compatible* sets of tuples
  - can themselves be the result of SQL queries
- If we replace OR by AND in the first version, what do we get?
- Also available: EXCEPT (What do we get if we replace UNION by EXCEPT?)

```
SELECT  S.sid
FROM  Sailors S, Boats B, Reserves R
WHERE  S.sid=R.sid AND R.bid=B.bid
            AND B.color='red'
UNION
SELECT  S.sid
FROM  Sailors S, Boats B, Reserves R
WHERE  S.sid=R.sid AND R.bid=B.bid
            AND B.color='green'
```

Find sid's of sailors who've reserved a red <u>and</u> a green boat

Sailors (sid, sname, rating, age)
Reserves(sid, bid, day)
Boats(bid, bname, color)

Find sid's of sailors who've reserved a red <u>and</u> a green boat

Sailors (sid, sname, rating, age)
Reserves(sid, bid, day)
Boats(bid, bname, color)

```
SELECT  S.sid
FROM  Sailors S, Boats B1, Reserves R1,
          Boats B2, Reserves R2
WHERE  S.sid=R1.sid AND R1.bid=B1.bid
  AND  S.sid=R2.sid AND R2.bid=B2.bid
  AND (B1.color='red' AND B2.color='green')
```

- INTERSECT: Can be used to compute the intersection of any two union-compatible sets of tuples.
  - Included in the SQL/92 standard, but some systems don't support it

```
SELECT  S.sid
FROM  Sailors S, Boats B, Reserves R
WHERE  S.sid=R.sid AND R.bid=B.bid
             AND B.color='red'
INTERSECT
SELECT  S.sid
FROM  Sailors S, Boats B, Reserves R
WHERE  S.sid=R.sid AND R.bid=B.bid
             AND B.color='green'
```

Nested Queries

Find names of sailors who've reserved boat #103:

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.sid IN  (SELECT  R.sid
                  FROM  Reserves R
                  WHERE  R.bid=103)
```

Sailors (sid, sname, rating, age)
Reserves(sid, bid, day)
Boats(bid, bname, color)

- A very powerful feature of SQL:
  - a WHERE/FROM/HAVING clause can itself contain an SQL query
- To find sailors who've not reserved #103, use NOT IN.
- To understand semantics of nested queries, think of a nested loops evaluation
  - For each Sailors tuple, check the qualification by computing the subquery

Nested Queries with Correlation

Find names of sailors who've reserved boat #103:

```
SELECT  S.sname
FROM  Sailors S
WHERE   EXISTS  (SELECT  *
                 FROM  Reserves R
                 WHERE  R.bid=103 AND S.sid=R.sid)
```

- EXISTS is another set comparison operator, like IN
- Illustrates why, in general, subquery must be re-computed for each Sailors tuple

Nested Queries with Correlation

Find names of sailors who've reserved boat #103 at most once:

```
SELECT  S.sname
FROM  Sailors S
WHERE   UNIQUE  (SELECT  R.bid
                 FROM  Reserves R
                 WHERE  R.bid=103 AND S.sid=R.sid)
```

- If UNIQUE is used, and * is replaced by *R.bid*, finds sailors with at most one reservation for boat #103
  - UNIQUE checks for duplicate tuples

More on Set-Comparison Operators

- We've already seen IN, EXISTS and UNIQUE
- Can also use NOT IN, NOT EXISTS and NOT UNIQUE.
- Also available: *op* ANY, *op* ALL, *op* IN
  - where op : >, <, =, <=, >=
- Find sailors whose rating is greater than that of some sailor called Horatio
  - similarly ALL

```
SELECT  *
FROM  Sailors S
WHERE  S.rating > ANY  (SELECT  S2.rating
                        FROM  Sailors S2
                        WHERE S2.sname='Horatio')
```

Summary

- Relational Data
- SQL
  - Semantic
  - Join
  - Simple Aggregates
  - Nested Queries

- You will learn these further and run yourself on PostGres on Thursday in the in-class lab on SQL!