CS 232A: Database System Principles

Introduction: Prerequisites checklist & Course Overview

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Introduction

- (Prereq) Applications' View of a Relational Database Management System (RDBMS)
- The Big Picture of UCSD's DB program
- (Prereq) Relational Model Quick Overview
- (Prereq) SQL Quick Overview

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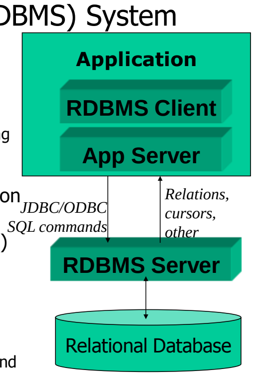
Applications' View of a Relational Database Management (RDBMS) System

- Applications: ……….
- Persistent data structure
  - Large volume of data
  - "Independent" from processes using the data
- SQL high-level programming interface for access & modification
  - Automatically optimized
- Transaction management (ACID)
  - Atomicity: all or none happens, despite failures & errors
  - Concurrency
  - Isolation: appearance of "one at a time"
  - Durability: recovery from failures and other errors



CSE232A and the rest of UCSD's database course program

- CSE132A: Basics of relational database systems
  - Application view orientation
  - Basics on algebra, query processing
- CSE132B: Application-oriented project course
  - How to design and use in applications complex databases
  - Active database aspects and materialized views
  - JDBC issues
- CSE135: Online Analytics Applications
  - Data cubes
  - Live analytics dashboards
  - Application server aspects pertaining to JDBC

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CSE232A and the rest of UCSD's database course program

- **CSE232 is about how databases work internally**
  - rather than how to make databases for applications
  - yet, knowing internals makes you a master database programmer
- CSE233: Database Theory
  - Theory of query languages
  - Deductive and Object-Oriented databases
- CSE232B: Advanced Database Systems
  - o Non-conventional database systems, such as
    - o mediators & distributed query processing
    - o object-oriented and XML databases
    - o Deductive databases and recursive query processing

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Data Structure: Relational Model

- Relational databases: *Schema* + *Data*
- *Schema* (also called *scheme*):
  - collection of *tables* (also called *relations*)
  - each table has a set of *attributes*
  - no repeating relation names, no repeating attributes in one table
- *Data* (also called *instance*):
  - set of *tuples*
  - tuples have one *value* for each attribute of the table they belong

Movie

Title	Director	Actor
Wild	Lynch	Winger
Sky	Berto	Winger
Reds	Beatty	Beatty
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Schedule

Theater	Title
Odeon	Wild
Forum	Reds
Forum	Sky

Review Slide from Victor Vianu's 132A

Relational Model: Primary and Foreign Keys

- "**`Theater`** is *primary key* of **`Schedule`**" means its value is unique in **`Schedule.Theater`**
- "**`Title`** of **`Schedule`** references **`Movie.Title`**" means every **`Title`** value of **`Schedule`** also appears as **`Movie.Title`**
- If attribute R.A references primary key S.B then we say that "R.A is a *foreign key* that references S.B"
  - Most common reference case
  - See NorthWind

Movie

Title	Director	Actor
Wild	Lynch	Winger
Sky	Berto	Winger
Reds	Beatty	Beatty
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Schedule

Theater	Title
Odeon	Wild
Forum	Reds
Forum	Sky

Lack of conventional primary, foreign keys and violation of normalization rules makes this a practically unlikely schema

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Programming Interface: JDBC/ODBC

- How client opens connection with server
- How access & modification commands are issued
- …

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Access (Query) & Modification Language: SQL

- SQL
  - used by the database application
  - *declarative*: we only describe ***what*** we want to retrieve
  - based on *tuple relational calculus*
    - Important in logic-based optimizations
- The result of a query is always a table
- Internal Equivalent of SQL: Relational Algebra
  - used internally by the database system
  - *procedural*: we describe ***how*** we retrieve
    - Important in query processing and optimization
  - often useful in explaining the semantics of SQL in an indirect way
  - *Confusing point:* Set (in theory) vs Bag (in practice) semantics

Basic Relational Algebra Operators (Set)

- *Selection* (σ)
  - $\sigma_c R$ selects tuples of the argument relation *R* that satisfy the condition *c.*
  - The condition *c* consists of atomic predicates of the form
    - *attr = value* (*attr* is attribute of *R*)
    - *attr1 = attr2*
    - other operators possible (e.g., >, <, !=, LIKE)
  - Bigger conditions constructed by conjunctions (*AND*) and disjunctions (*OR*) of atomic predicates

Find tuples where director="Berto"

$\sigma_{Director=\text{“Berto”}}$Movie

Title	Director	Actor
Sky	Berto	Winger
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Find tuples where director=actor

$\sigma_{Director=Actor}$Movie

Title	Director	Actor
Reds	Beatty	Beatty

$\sigma_{Director=\text{“Berto”}\ OR\ Director=Actor}$Movie

Title	Director	Actor
Sky	Berto	Winger
Reds	Beatty	Beatty
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	Snyder

Basic Relational Algebra Operators (SET)

- *Projection* (π)
  - $\pi_{attr1,\ \ldots,\ attrN} R$ returns a table that has only the attributes *attr1, …, attrN* of *R*
  - *Set version:* ***no*** duplicate tuples in the result (notice the example has only one (Tango,Berto) tuple
  - *Bag version: allows duplicates*
- *Cartesian Product* (x)
  - the schema of the result has all attributes of both *R* and *S*
  - for every pair of tuples *r* from *R* and *s* from *S* there is a result tuple that consists of *r* and *s*
  - if both *R* and *S* have an attribute *A* then rename to *R.A* and S.A

$\pi_{Title,Director}$ Movie

Title	Director
Wild	Lynch
Sky	Berto
Reds	Beatty
Tango	Berto

Project the title and director of Movie

R

A	B
0	1
2	4

S

A	C
a	b
c	d

R x S

R.A	B	S.A	C
0	1	a	b
0	1	c	d
2	4	a	b
2	4	c	d

SQL Queries: The Basic From

- Basic form

SELECT DISTINCT *a1*, …, *aN*
FROM *R1*, …, *RM*
WHERE *condition*

- Equivalent relational algebra expression

$\pi_{a1,\ \ldots,\ aN}\sigma_{condition}(R1 \text{ x } \ldots \text{ x} RM)$

- WHERE clause is optional
- When more than one relations of the FROM have an attribute named *A* we refer to a specific *A* attribute as *<RelationName>.A*

Find titles of currently playing movies

```
SELECT Title
FROM Schedule
```

Find the titles of all movies by "Berto"

```
SELECT Title
FROM Schedule
WHERE Director="Berto"
```

Find the titles and the directors of all currently playing movies

```
SELECT Movie.Title, Director
FROM Movie, Schedule
WHERE Movie.Title=Schedule.Title
```

Duplicates and Nulls

- *Duplicate elimination* must be explicitly requested
  - SELECT DISTINCT … FROM … WHERE …
- *Null values*
  - all comparisons involving NULL are ½ by definition
  - Simplification: ½ -> false
  - all aggregation operations, except *count*, ignore NULL values

SELECT Title
FROM Movie

Title
Tango
Tango
Tango

SELECT DISTINCT Title
FROM Movie

Title
Tango

Title	Director	Actor
Wild	Lynch	Winger
Sky	Berto	Winger
Reds	NULL	Beatty
Tango	Berto	Brando
Tango	Berto	Winger
Tango	Berto	NULL

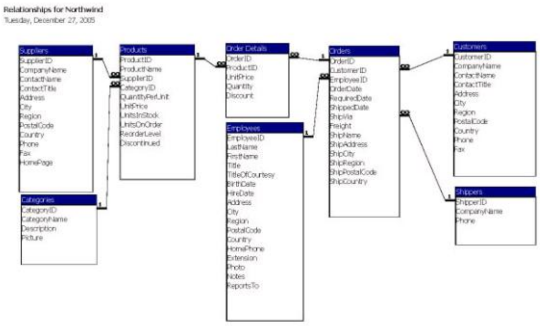
SQL Queries: Aliases

- Use the same relation more than once in the FROM clause
- By introducing tuple variables
- Example: find actors who are also directors

```
SELECT t.Actor
FROM Movie t, Movie s
WHERE t.Actor=s.Director
```

Example on Aliases and Long Primary/Foreign Key Join Chains

```
SELECT DISTINCT Customers.ContactName
FROM Customers, Customers AS Customers_1, Orders, Orders AS Orders_1,
[Order Details], [Order Details] AS [Order Details_1], Products
WHERE Customers.CustomerID=Orders.CustomerID
  AND Orders.OrderID=[Order Details].OrderID
  AND [Order Details].ProductID=Products.ProductID
  AND Products.ProductID=[Order Details_1].ProductID
  AND [Order Details_1].OrderID=Orders_1.OrderID
  AND Orders_1.CustomerID=Customers_1.CustomerID
  AND Customers_1.City="London";
```



SQL Queries: Nesting

- The WHERE clause can contain predicates of the form
  - *attr/value* IN *<SQL query>*
  - *attr/value* NOT IN *<SQL query>*
- The predicate is satisfied if the *attr* or *value* appears in the result of the nested *<SQL query>*
- Queries involving nesting but no negation can always be un-nested, unlike queries with nesting and negation

Another Form of the "Long Join" Query

```
SELECT DISTINCT Customers.ContactName
FROM Customers
WHERE Customers.CustomerID IN (
 SELECT Orders.CustomerID
 FROM Customers AS Customers_1, Orders, Orders AS Orders_1, [Order Details], [Order Details] AS [Order Details_1], Products
 WHERE Orders.OrderID=[Order Details].OrderID
   AND [Order Details].ProductID=Products.ProductID
   AND Products.ProductID=[Order Details_1].ProductID
   AND [Order Details_1].OrderID=Orders_1.OrderID
   AND Orders_1.CustomerID=Customers_1.CustomerID
   AND Customers_1.City="London"
);
```

Customers.CustomerID = Orders.CustomerID

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Query Expressing Negation with NOT IN

Find the contact names of customers who do not have orders of products also ordered by London customers

```
SELECT DISTINCT Customers.ContactName
FROM Customers
WHERE Customers.CustomerID NOT IN (
 SELECT Orders.CustomerID
 FROM Customers AS Customers_1, Orders, Orders AS Orders_1, [Order Details], [Order Details] AS [Order Details_1], Products
 WHERE Orders.OrderID=[Order Details].OrderID
   AND [Order Details].ProductID=Products.ProductID
   AND Products.ProductID=[Order Details_1].ProductID
   AND [Order Details_1].OrderID=Orders_1.OrderID
   AND Orders_1.CustomerID=Customers_1.CustomerID
   AND Customers_1.City="London"
);
```


SQL Queries: Aggregation and Grouping

- There is no relational algebra equivalent for aggregation and grouping
- Aggregate functions: AVG, COUNT, MIN, MAX, SUM, and recently user defined functions as well
- Group-by

Employee

Name	Dept	Salary
Joe	Toys	45
Nick	PCs	50
Jim	Toys	35
Jack	PCs	40

Find the average salary of all employees

SELECT Avg(Salary) AS AvgSal
FROM Employee

AvgSal
42.5

Find the average salary for each department

SELECT Dept, Avg(Salary) AS AvgSal
FROM Employee
GROUP-BY Dept

Dept	AvgSal
Toys	40
PCs	45

SQL Grouping: Conditions that Apply on Groups

- *HAVING* clause

Find the average salary of for each department that has more than 1 employee

SELECT Dept, Avg(Salary) AS AvgSal
FROM Employee
GROUP-BY Dept
HAVING COUNT(Name)>1

SQL as a Data Manipulation Language: Insertions

- inserting tuples
  - INSERT INTO *R* VALUES (*v1*,...,*vk*);
- some values may be left NULL
- use results of queries for insertion
  - INSERT INTO *R* SELECT ... FROM ... WHERE

```
INSERT INTO Movie
VALUES ("Brave", "Gibson", "Gibson");
```

```
INSERT INTO Movie(Title,Director)
VALUES ("Brave", "Gibson");
```

```
INSERT INTO EuroMovie
    SELECT * FROM Movie
    WHERE Director = "Berto"
```

SQL as a Data Manipulation Language: Updates and Deletions

- *Deletion* basic form: delete every tuple that satisfies *<cond>*
  - DELETE FROM *R* WHERE *<cond>*
- *Update* basic form: update every tuple that satisfies *<cond>* in the way specified by the SET clause
  - UPDATE *R* SET *A1=<exp1>*, ..., *Ak=<expk>* WHERE *<cond>*

Delete the movies that are not currently playing

```
DELETE FROM Movie
WHERE Title NOT IN SELECT Title
                   FROM Schedule
```

Change all "Berto" entries to "Bertoluci"

```
UPDATE Movie
SET Director="Bertoluci"
WHERE Director="Berto"
```

Increase all salaries in the Toys dept by 10%

```
UPDATE Employee
SET Salary = 1.1 * Salary
WHERE Dept = "Toys"
```

The "rich get richer" exercise:
Increase by 10% the salary of the employee with the highest salary

Transaction Management

- Transaction: Collection of actions that maintain the consistency of the database if ran to completion & isolated
- Goal: Guarantee integrity and consistency of data despite
  - Concurrency
  - Failures
- Concurrency Control
- Recovery

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Example Concurrency & Failure Problems

- Consider the "John & Mary" checking & savings account
  - C: checking account balance
  - S: savings' account balance
- Check-to-Savings transfer transaction moves $X from C to S
  - If it runs in the system alone and to completion the total sum of C and S stays the same

```
C2S(X=100)
Read(C);
C:=C-100
Write(C)
Read(S)
S:=S+100
Write(S)
```


Example Failure Problem & Recovery Module's Goal

```
C2S(X=100)
Read(C);
C:=C-100
Write(C)

CPU HALTS
Read(S)
S:=S+100
Write(S)
```

- Database is in inconsistent state after machine restarts
- It is not the developer's problem to account for crashes
- Recovery module guarantees that all or none of transaction happens and its effects become "durable"

Example Concurrency Problem & Concurrency Control Module's Goals

```
Serial Schedule
Read(C);
C:=C+100
Write(C)
Read(S)
S:=S-100
Write(S)
             Read(C)
             C:=C+50
             Write(C)
             Read(S)
             S:=S-50
             Write(S)
```

- If multiple transactions run in sequence the resulting database is consistent
- Serial schedules
  - De facto correct

Example Concurrency Problem & Concurrency Control Module's Goals

Good Schedule w/ Concurrency	
Read(C);	
C:=C+100	
Write(C)	
	Read(C)
	C:=C+50
	Write(C)
Read(S)	
S:=S-100	
Write(S)	
	Read(S)
	S:=S-50
	Write(S)

- Databases allow transactions to run in parallel

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Example Concurrency Problem & Concurrency Control Module's Goals

Bad Schedule w/ Concurrency	
Read(C);	
C:=C+100	
	Read(C)
Write(C)	
	C:=C+50
	Write(C)
	Read(S)
	S:=S-50
	Write(S)
Read(S)	
S:=S-100	
Write(S)	

- "Bad" interleaved schedules may leave database in inconsistent state
- Developer should not have to account for parallelism
- Concurrency control module guarantees *serializability*
  - only schedules equivalent to serial ones happen

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Course Topics

- Hardware aspects (very brief)
- Physical Organization Structure (very brief)
  Records in blocks, dictionary, buffer management,…
- Indexing
  B-Trees, hashing,…
- Query Processing
  rewriting, physical operators, cost-based optimization, semantic optimization…
- Crash Recovery

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Course Topics

- Concurrency Control
  - Correctness, locks, deadlocks…
- Materialized views
  - Incremental view maintenance, answering queries using views
- Federated databases
  - Distributed query optimization
- Parallel query processing
- Column databases

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Database System Architecture