CS 2550 / Spring 2006
Principles of Database Systems

03 – SQL

Alexandros Labrinidis
University of Pittsburgh

SQL

- SQL = **S**tructured **Q**uery **L**anguage
  - since early 1970s
- Combination of relational algebra and relational calculus constructs
- More acronyms:
  - DML: **D**ata **M**anipulation **L**anguage
  - DDL: **D**ata **D**efinition **L**anguage
    - Includes view definition, integrity constraints, authorization control

Relation Schema Example

- Account (account_number, branch_name, balance)
- Branch (branch_name, branch_city, assets)
- Customer (customer_name, customer_street, customer_city)
  - For simplicity assume *customer_name* unique
- Depositor (customer_name, account_number)
- Loan (loan_number, branch_name, amount)
- Borrower (customer_name, loan_number)

Basic Structure

- A typical SQL query has the form:
  - **select** $A_1, A_2, \ldots, A_n$ → RA projection
  - **from** $r_1, r_2, \ldots, r_m$ → RA cartesian product
  - **where** P → RA selection
  - A_i represent attributes
  - r_i represent relations
  - P is a predicate
- Query is equivalent to the relational algebra expression:

$$\prod_{A1, A2, \ldots, An}(\sigma_P(r_1 \times r_2 \times \ldots \times r_m))$$

NOTE: SQL results may contain duplicates

- The result of an SQL query is a relation.

SQL – select

- **select** clause lists attributes desired in the result
  - corresponds to the projection operation of the relational algebra
- E.g. find the names of all branches in the *loan* relation

  select *branch_name*
  from *loan*
- Same query, in the "pure" relational algebra syntax:

  $\Pi_{\text{branch\_name}}(loan)$
- NOTE: SQL does not permit the '-' character in names,
- NOTE: SQL names are case insensitive, i.e. you can use capital or small letters

SQL – select – II

- SQL allows duplicates in relations and in query results
- To force elimination of duplicates, insert keyword **distinct** after **select**
- E.g. find the names of all branches in the *loan* relations, and remove duplicates

  select distinct *branch_name*
  from *loan*
- Keyword **all** specifies that duplicates not be removed

  select all *branch_name*
  from *loan*

SQL – select – III

- An asterisk in the select clause denotes "all attributes"

  select *
  from *loan*
- select can contain arithmetic expressions
  - Similar to generalized projection from Relational Algebra
  - Can involve the operation, +, –, *, and /,
  - Can operate on constants or attributes of tuples
- Example:

  select *loan_number, branch_name, amount* * 100
  from *loan*

SQL – where

- **where** clause specifies conditions the result must satisfy
  - corresponds to the selection predicate of the relational algebra
- Example:
  - find all loan number for loans made at the Perryridge branch with loan amounts greater than $1200

    select *loan_number*
    from *loan*
    where *branch_name* = '*Perryridge*' **and** *amount* > 1200
- Comparison results can be combined using **and, or, not**
- Comparisons can be applied to results of arithmetic expressions

SQL – where – II

- SQL includes a **between** comparison operator
- Example:
  - Find the loan number of those loans with loan amounts between \$90,000 and \$100,000 (that is, ≥\$90,000 and ≤\$100,000)

    select *loan_number*
    from *loan*
    where *amount* **between** 90000 **and** 100000

  is equivalent to:

    select *loan_number*
    from *loan*
    where *amount* >=90000 **and** amount <= 100000

SQL – from

- **from** clause lists the relations involved in the query
  - corresponds to the Cartesian product operation of the relational algebra
- Examples:
  - Find the Cartesian product *borrower x loan*

    select *
    from *borrower, loan*
  - Find the name, loan number and loan amount of all customers having a loan at the Perryridge branch.

    select *customer_name, borrower.loan_number, amount*
    from *borrower, loan*
    where *borrower.loan_number = loan.loan_number* **and** *branch_name* = 'Perryridge'

SQL – rename

- SQL allows renaming relations and attributes using the **as** clause:

  old_name **as** *new_name*
- Example:
  - Find the name, loan number and loan amount of all customers; rename the column name *loan_number* as *loan_id*

select *customer_name, borrower.loan_number* **as** *loan_id, amount*
from *borrower, loan*
where *borrower.loan_number = loan.loan_number*

SQL – tuple variables

- Tuple variables are defined in the **from** clause via the use of the **as** clause
- Examples:
  - Find the customer names and their loan numbers for all customers having a loan at some branch.

    select *customer_name, T.loan_number, S.amount*
    from *borrower* **as** *T, loan* **as** *S*
    where *T.loan_number = S.loan_number*
  - Find the names of all branches that have greater assets than some branch located in Brooklyn

    select distinct *T.branch_name*
    from *branch* **as** *T, branch* **as** *S*
    where *T.assets > S.assets* **and** *S.branch_city = `Brooklyn'*

SQL – like

- Like
  - string-matching operator for comparisons on character strings
- Patterns are described using two special characters:
  - percent (%) matches any substring
  - underscore (_) matches any single character
- Examples:
  - Find the names of all customers whose street includes "Main"

    select *customer_name*
    from *customer*
    where *customer_street* **like** '%Main%'
  - Starts-in, Ends-in?
- Match the name "twenty%"

  like 'twenty\%' **escape** '\'

SQL – order

- **Order-by** clause causes the tuples in the result to appear in sorted order
- Example:
  - List in alphabetic order the names of all customers having a loan in the Perryridge branch

    select **distinct** *customer_name*
    from *borrower, loan*
    where *borrower loan_number = loan.loan_number* **and**
    branch_name = 'Perryridge'
    order by *customer_name*
- specify **desc** for descending order
- specify **asc** for ascending order (default)
  - E.g. **order by** *customer_name* **desc**

SQL – order – II

- It is possible to define two or more attributes to order by
- Example:
  - List entire loan relation in descendingorder of amount
  - If several loans have same amount, order by loan_number

    select *
    from *loan*
    order by *amount* ***desc****, loan_number* ***asc***

SQL Set Operations

- The set operations **union, intersect,** and **except** operate on relations
- correspond to the relational algebra operations $\cup$, $\cap$, –
- Each of the above operations automatically eliminates duplicates
- to retain all duplicates use the corresponding multiset versions **union all, intersect all** and **except all.**

SQL Set Operations – II

- Depositor (customer_name, account_number)
- Borrower (customer_name, loan_number)
- Assume set of customers who have an account:
  select *customer_name* **from** *depositor*
- Assume set of customers who have a loan:
  select *customer_name* **from** *borrower*

SQL / Sets: Union

- Find all customers having an account, a loan, or both:
  (**select** *customer_name* **from** *depositor*)
  union
  (**select** *customer_name* **from** *borrower*)
- To retain all duplicates:
  (**select** *customer_name* **from** *depositor*)
  union all
  (**select** *customer_name* **from** *borrower*)
- If "Jones" has 3 accounts and 2 loans ➔ appears 5 times
  (sum of a, b)

SQL / Sets: Intersect

- Find all customers having both an account and a loan:
  (**select** *customer_name* **from** *depositor*)
  intersect
  (**select** *customer_name* **from** *borrower*)
- To retain all duplicates:
  (**select** *customer_name* **from** *depositor*)
  intersect all
  (**select** *customer_name* **from** *borrower*)
- If "Jones" has 3 accounts and 2 loans ➔ appears 2 times
  (min of a, b)

SQL / Sets: Except

- Find all customers having an account, but no a loan:
  (**select** *customer_name* **from** *depositor*)
  except
  (**select** *customer_name* **from** *borrower*)
- To retain all duplicates:
  (**select** *customer_name* **from** *depositor*)
  except all
  (**select** *customer_name* **from** *borrower*)
- If "Jones" has 3 accounts and 1 loans ➔ appears 2 times
  (a – b, if a>b, or 0 otherwise)

Roadmap

- SQL Intro
  - Select, From, Where
  - Rename
  - Order-by
  - Union, Intersect, Except
- Aggregate Functions
- Null Values
- Nested Subqueries
- Views

SQL / Aggregate Functions

- These functions operate on a collection of values and return a single value
- SQL offers five aggregate functions:

  avg(): average value
  min(): minimum value
  max(): maximum value
  sum(): sum of values
  count(): number of values

SQL / Aggregate Functions (Cont.)

- Find the average account balance at the Perryridge branch.

  select avg *(balance)*
  from *account*
  where *branch_name* = 'Perryridge'

- Find the number of tuples in the *customer* relation.

  select count (*)
  from *customer*

- Find the number of depositors in the bank.

  select count (distinct *customer_name)*
  from *depositor*

SQL Aggregation – Group By

- Find the number of depositors **for each branch.**

select *branch_name,* **count (distinct** *customer_name)*
from *depositor, account*
where *depositor.account_number = account.account_number*
group by *branch_name*

Note: Attributes in **select** clause outside of aggregate functions must appear in **group by** list

Note: Similar to aggregation with grouping from Relational Algebra

SQL Aggregation – Having Clause

- Example:
  - Find the names of all branches where the average account balance is more than $1,200.

select *branch_name*, **avg** *(balance)*
from *account*
group by *branch_name*
having avg *(balance)* > 1200

Note: predicates in the **having** clause are applied after the formation of groups, whereas predicates in the **where** clause are applied before forming groups

SQL – NULL Values

- Tuples can have **NULL** value for some of their attributes
  - For an unknown value
  - For a value that does not exist
- Predicate **is null** can be used to check for null values.
  - Find all loan numbers which appear in the *loan* relation with NULL values for *amount*

select *loan_number*
from *loan*
where *amount* **is null**

- Any arithmetic expression involving NULL returns NULL
  - E.g. 5 + NULL returns NULL

SQL – Logic with NULL Values

- Any comparison with *null* returns *unknown*
  - *E.g. 5 < null or null <> null or null = null*
- Three-valued logic using the truth value *unknown*:

AND	T	F	U
T	T	F	U
F	F	F	F
U	U	F	U

OR	T	F	U
T	T	T	T
F	T	F	U
U	T	U	U

	NOT
T	F
F	T
U	U

  - **"P is unknown"** → true if predicate P evaluates to *unknown*
- Result of **where** clause predicate is treated as *false* if it evaluates to *unknown*

SQL – NULL Values in Aggregations

- Example:
  - Find total of all loan amounts
    select sum *(amount)*
    from *loan*
  - sum() operator ignores null amounts
- In general:
  - sum(), avg(), min(), max() ignore null values
  - count(*) considers null values
- Aggregation on an empty set:
  - sum(), avg(), min(), max() return null
  - count(*) returns 0

Roadmap

- SQL Intro
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  - Rename
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  - Union, Intersect, Except
- Aggregate Functions
- Null Values
- Nested Subqueries
- Views

SQL – Nested Subqueries

- SQL provides a mechanism for nesting subqueries.
- A subquery is a **select-from-where** expression that is included within another query.
- A common use of subqueries is to perform tests for
  - set membership
  - set comparisons
  - set cardinality

Nested Subqueries – Examples /1

- Find all customers who have both an account and a loan at the bank:

```
( select customer_name from depositor )
intersect
( select customer_name from borrower )
```

- Find all customers who have both an account and a loan at the bank (version 2):

```
select distinct customer_name
from   borrower
where customer_name in (select customer_name
                        from   depositor)
```


Nested Subqueries – Examples /2

- Find all customers who have a loan at the bank but do not have an account at the bank:

```
( select customer_name from borrower )
except
( select customer_name from depositor )
```

- Find all customers who have a loan at the bank but do not have an account at the bank (version 2):

```
select distinct customer_name
from   borrower
where customer_name not in (select customer_name
                            from   depositor)
```

Nested Subqueries – Examples /3

- Find all customers who have both an account and a loan at the Perryridge branch

select distinct *customer_name*
from *borrower, loan*
where *borrower.loan_number = loan.loan_number* **and**
branch_name = "Perryridge" **and**
(branch_name, customer_name) **in**
(select *branch_name, customer_name*
from *depositor, account*
where *depositor.account_number = account.account_number)*

- Note: Above query can be written in a much simpler manner. The formulation above is simply to illustrate SQL features.

Nested Subqueries – Set Comparison

- Find all branches that have greater assets than some branch located in Brooklyn.

select distinct *T.branch_name*
from *branch* **as** *T, branch* **as** *S*
where *T.assets > S.assets* **and** *S.branch_city* = 'Brooklyn'

- Same query using > **some** clause

select *branch_name*
from *branch*
where *assets* > **some** **(select** *assets*
from *branch*
where *branch_city* = 'Brooklyn')

Definition of SOME Clause

(5< **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline 6 \\ \hline\end{array}$) = true (read: 5 < some tuple in the relation)

(5< **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline\end{array}$) = false

(5 = **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline\end{array}$) = true

(5 ≠ **some** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline\end{array}$) = true (since 0 ≠ 5)

Note: (= **some**) same as **in**
(≠ **some**) not the same as **not in**

Definition of ALL Clause

(5< **all** $\begin{array}{|c|}\hline 0 \\ \hline 5 \\ \hline 6 \\ \hline\end{array}$) = false

(5< **all** $\begin{array}{|c|}\hline 6 \\ \hline 10 \\ \hline\end{array}$) = true

(5 = **all** $\begin{array}{|c|}\hline 4 \\ \hline 5 \\ \hline\end{array}$) = false

(5 ≠ **all** $\begin{array}{|c|}\hline 4 \\ \hline 6 \\ \hline\end{array}$) = true (since 5 ≠ 4 and 5 ≠ 6)

Note: (≠ **all**) same as **not in**

Nested Subqueries – Examples /4

- Find the names of all branches that have greater assets than all branches located in Brooklyn.

```
select  branch_name
from    branch
where  assets > all   (select assets
                       from branch
                       where branch_city = 'Brooklyn')
```


Test for Empty Relations

- The **exists** construct returns the value **true** if the argument subquery is nonempty.
- **exists** r equivalent to $r \neq \varnothing$
- **not exists** r equivalent to $r = \varnothing$

Nested Subqueries – Examples /5

- relation A contains relation B is equivalent to exists (B except A)

Find all customers who have an account at all branches in Brooklyn:

```
select distinct S.customer_name
from     depositor as S
where   not exists (     (select branch_name
                          from branch
                          where branch_city = 'Brooklyn')
                          except
                          (select R.branch_name
                          from depositor as T, account as R
                          where   T.account_number = R.account_number and
                                  S.customer_name = T.customer_name) )
```


Relation Schema Example

- Account (account_number, branch_name, balance)
- Branch (branch_name, branch_city, assets)
- Customer (customer_name, customer_street, customer_city)
  - For simplicity assume *customer_name* unique
- Depositor (customer_name, account_number)
- Loan (loan_number, branch_name, amount)
- Borrower (customer_name, loan_number)

SQL Pattern Matching

- LIKE: percent (%) matches any substring
  underscore (_) matches any single character
- Examples:
  - Must end in 'base' → like
  - Must have at least two chars → like
  - Must have at least two 'a's → like
  - Must include 'taba' → like
  - Must end in se end start in da → like
  - Must have exactly 8 chars → like
  - Must start in 'data' → like

SQL Pattern Matching SOLUTIONS

- LIKE: percent (%) matches any substring
  underscore (_) matches any single character
- Examples:
  - Must end in 'base' → like '%base'
  - Must have at least two chars → like '__%'
  - Must have at least two 'a's → like '%a%a%'
  - Must include 'taba' → like '%taba%'
  - Must end in se end start in da → like 'da%se'
  - Must have exactly 8 chars → like '________'
  - Must start in 'data' → like 'data%'

So Far

- Select, From, Where
- Rename
- Like
- Order-by
- Union, Intersect, Except
- Aggregation
  - avg(), min(), max(), sum(), count()
  - Group-by, Having
- Null Values
- Nested Subqueries
  - A subquery is a select-from-where expression that is included within another query

Nested Subqueries

- New operators:
  - in, not in
  - >some, =>some, <some, <=some, =some, <>some
  - >all, =>all, <all, <=all, =all, <>all
  - exists, not exists
- Example:
  - Find all customers who have a loan at the bank but do not have an account at the bank

select distinct *customer_name*
from *borrower*
where *customer_name* **not in (select** *customer_name*
from depositor)

Test for Empty Relations

- The **exists** construct returns the value **true** if the argument subquery is nonempty.
  - **exists** *r* equivalent to $r \neq \emptyset$
  - **not exists** *r* equivalent to $r = \emptyset$
- The following are equivalent:
  - relation A **contains** relation B
  - $(B - A) = \emptyset$
  - **not exists** (B except A)

Test for Empty Relations – Example

- Find all customers who have an account at all branches in Brooklyn:

```
select distinct S.customer_name
from    depositor as S
where   not exists (   (select branch_name
                        from branch
                        where branch_city = 'Brooklyn')

                        except

                       (select R.branch_name
                        from depositor as T, account as R
                        where   T.account_number = R.account_number and
                                S.customer_name = T.customer_name) )
```


Test for Absence of Duplicate Tuples

- The **unique** construct tests whether a subquery has any duplicate tuples in its result (opposite: **not unique**)
- Find all customers who have ~~at most one~~ account at the Perryridge branch

at least two

```
select T.customer_name
from depositor as T
where not unique (
      select R.customer_name
      from account, depositor as R
      where  T.customer_name = R.customer_name and
             R.account_number = account.account_number and
             account.branch_name = 'Perryridge')
```


Views

create view **v** as *<query expression>*
drop view **v**

- Examples
  - create view **Oakland_accounts** as
    select * from accounts
    where branch_name = 'Oakland'
  - Find all accounts in Oakland whose balance is over $200
    select * from Oakland_accounts
    where balance > 200
  - create view **loan_info** as
    select * from borrower, loan
    where borrower.loan_number = loan.loan_number

View Examples

- A view consisting of branches and their customers

```
create view all_customer as
  (select branch_name, customer_name
   from   depositor, account
   where depositor.account_number = account.account_number)
union
  (select branch_name, customer_name
   from   borrower, loan
   where borrower.loan_number = loan.loan_number)
```

- Find all customers of the Perryridge branch

```
select  customer_name
from    all_customer
where  branch_name = 'Perryridge'
```


View Examples (cont)

- Explicitly define attribute names
  - Create view **branch_loan_totals** (branch_name, total_loan)

```
      as   select branch_name, sum(amount)
           from loan
           group-by branch_name
```

  - Schema:
    Loan (loan_number, branch_name, amount)
    Borrower (customer_name, loan_number)
  - create view **loan_info_short** as

```
           select customer_name, amount
           from borrower, loan
           where borrower.loan_number = loan.loan_number
```


Complex Queries

- Find the average account balance of those branches where the average account balance is > $1200

```
select      branch_name, avg (balance)
from        account
group by    branch_name
having      avg (balance) > 1200
```

- Find the average account balance of those branches where the average account balance is > $1200

```
select branch_name, avg_balance
from (select branch_name, avg (balance)
        from account
        group by branch_name)
        as result (branch_name, avg_balance)
where avg_balance > 1200
```


So Far

- Basic SQL
- Rename, Like, Order-by
- Union, Intersect, Except
- Aggregation
  - avg(), min(), max(), sum(), count()
  - Group-by, Having
- Null Values
- Nested Subqueries
- Views
- Complex Queries

Roadmap

- Database Modification
  - Deletions
  - Insertions
  - Updates
- Transactions
- Joined Relations

SQL – Deletion

- delete from R
  where P
  - R is relation name
  - P is predicate
- Delete all accounts in the Perryridge Branch
  - delete from account
    where branch_name = 'Perryridge'
- Delete all loans with amounts between $1300 and $1700
  - delete from loan
    where amount between 1300 and 1700

SQL – Deletion /2

- Delete all accounts at every branch located in Pittsburgh

delete from *account*
where *branch_name* **in** (**select** *branch_name*
from *branch*
where *branch_city* = 'Pittsburgh')

SQL – Deletion /3

- Delete all accounts with balances below the average

delete from *account*
where *balance* < (**select avg** *(balance)*
from *account)*

- Problem: as we delete tuples from *deposit,* the average balance changes
- Solution (used in SQL):

1. First, compute **avg** balance and find all tuples to delete
2. Next, delete all tuples found above (without recomputing **avg** or retesting the tuples)

SQL – Insertion

- Add a new tuple to *account*

  insert into *account*
  values ('A-9732', 'Perryridge', 1200)

  or equivalently:

  insert into *account (branch_name, balance, account_number)*
  values ('Perryridge', 1200, 'A-9732')

  or equivalently:

  insert into *account (balance, branch_name, account_number)*
  values (1200, 'Perryridge', 'A-9732')

- Add a new tuple to *account* with *balance* set to null

  insert into *account*
  values ('A-777', 'Perryridge', *null*)

SQL – Insertion /2

- Provide as a gift for all loan customers of the Perryridge branch, a $200 savings account
  - Let the loan number = account number for the savings account

- **insert into** *account*
  select *loan_number, branch_name,* 200
  from *loan*
  where *branch_name* = 'Perryridge'

- **insert into** *depositor*
  select *customer_name, loan_number*
  from *loan, borrower*
  where branch_name = 'Perryridge' **and**
  loan.loan_number = borrower.loan_number

SQL – Insertion /3

- The select-from-where statement is **fully evaluated** before any of its results are inserted into the relation

- Otherwise, queries like

  insert into *table*1
  select *
  from *table*1

  would cause problems (what?)

SQL – Updates

- Increase all account balances by 5%
  - update account
    set balance = balance * 1.05

- Increase all account balances by 6% if balance over 500
  - update account
    set balance = balance * 1.06
    where balance > 500

- Increase all account balances by 7% if balance over avg
  - update account
    set balance = balance * 1.07
    where balance > select avg (balance)
    from account

SQL – Updates /2

- Increase all accounts with balances over $10,000 by 6%, all other accounts receive 5%.
  - Write **two** update statements:

    update *account*
    set *balance* = *balance* ∗ 1.06
    where *balance* > 10000

    update *account*
    set *balance* = *balance* ∗ 1.05
    where *balance* ≤ 10000

- The order is important. Why?
- Can be done better using the **case** statement (next)

SQL – Updates / Case Statement

- Same query as before:
  Increase all accounts with balances over $10,000 by 6%, all other accounts receive 5%.

  update *account*
  set *balance* = **case**
  when *balance* <= 10000 **then** *balance* *1.05
  else *balance* * 1.06
  end

SQL Updates / Views

- Create a view of all loan data in *loan* relation, hiding the *amount:*

  create view *branch_loan* **as**
  select *branch_name, loan_number*
  from *loan*

- Add a new tuple to *branch_loan*

  insert into *branch_loan*
  values ('Perryridge', 'L-307')

  This insertion must be represented by the insertion of tuple
  ('L-307', 'Perryridge', *null*)
  into the *loan* relation

- Updates on more complex views are difficult or impossible to translate, and hence are disallowed.

Roadmap

- Database Modification
  - Deletions
  - Insertions
  - Updates
- Transactions
- Joined Relations

SQL – Transactions

- A transaction is a sequence of queries and update statements executed as a **single unit**
  - Started implicitly
  - Terminated by:
    - **Commit** – makes all updates permanent
    - **Rollback** – undoes all updates performed by transaction
- Motivating Example:
  - Transfer money from account A to account B
    - Deduct $x from A
    - Credit $x to B
  - If one of two steps fail ➔ database is in inconsistent state
  - Either both steps should succeed or none

SQL – Transactions (Cont.)

- In most database systems, each SQL statement that executes successfully is automatically committed.
  - Each transaction would then consist of only a single statement
  - Automatic commit can usually be turned off, allowing multi-statement transactions
- Another option in SQL:1999
  - enclose statements within

    begin atomic

    ...

    end

Roadmap

- Database Modification
  - Deletions
  - Insertions
  - Updates
- Transactions
- Joined Relations

Joined Relations

- Join operation
  - take two relations and return as a result another relation
  - typically used as subquery expressions in **from** clause
- Join condition
  - defines which/how tuples in the two relations match
  - defines what attributes are present in the result of the join
- Join type
  - defines how to treat tuples that **do not match**

Join Types
inner join **left outer join** **right outer join** **full outer join**

Join Conditions
natural **on** <predicate> **using** (A_1, A_2, ..., A_n)

Joined Relations – II

- **on** <predicate>
  - join condition = predicate
  - schema includes all attributes (left relation first, right second)
  - SQL does not require attribute names to be unique
- **natural join**
  - natural join (from Relational Algebra) on all common attributes
  - schema:
    - common attributes first (same order as in left relation)
    - remaining attributes from left relation
    - remaining attributes from right relation
- **using** (<attribute_list>)
  - Same as natural join, BUT focus only on attributes in attribute_list (must be common and appear once in result)

Example Datasets

- Loan

loan_number	*branch_name*	*amount*
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

- Borrower

customer_name	*loan_number*
Jones	L-170
Smith	L-230
Hayes	L-155

- Note: borrower information missing for L-260 and loan information missing for L-155

Joined Relations – Examples

- *loan* **inner join** *borrower* **on** *loan.loan_number = borrower.loan_number*

loan_number	*branch_name*	*amount*	*customer_name*	*loan_number*
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230

- *loan* **left outer join** *borrower* **on** *loan.loan_number = borrower.loan_number*

loan_number	*branch_name*	*amount*	*customer_name*	*loan_number*
L-170	Downtown	3000	Jones	L-170
L-230	Redwood	4000	Smith	L-230
L-260	Perryridge	1700	*null*	*null*

Joined Relations – Examples

- *loan* **natural inner join** *borrower*

loan_number	*branch_name*	*amount*	*customer_name*
L-170	Downtown	3000	Jones
L-230	Redwood	4000	Smith

- loan **natural right outer join** *borrower*

loan_number	*branch_name*	*amount*	*customer_name*
L-170	Downtown	3000	Jones
L-230	Redwood	4000	Smith
L-155	null	null	Hayes

Joined Relations – Examples

- *loan* **full outer join** *borrower* **using** *(loan_number)*

loan_number	*branch_name*	*amount*	*customer_name*
L-170	Downtown	3000	Jones
L-230	Redwood	4000	Smith
L-260	Perryridge	1700	*null*
L-155	null	null	Hayes

- Find all customers who have either an account or a loan (but not both) at the bank.

select *customer_name*
from (*depositor* **natural full outer join** *borrower*)
where *account_number* **is** *null* **or** *loan_number* **is** *null*

Roadmap

- Joined Relations
- **SQL – Data Definition Language**
  - **Domain Types and Definitions**
  - Domain Constraints
  - Referential Integrity
  - Schema Changes

Data Definition Language (DDL)

Allows the specification of a set of relations and also information about each relation, including:

- The schema for each relation.
- The domain of values associated with each attribute.
- Integrity constraints
- The set of indices to be maintained for each relations.
- Security and authorization information for each relation.
- The physical storage structure of each relation on disk

Domain Types in SQL

- **char(n):** fixed length character string, with user-specified length *n*
- **varchar(n):** Variable length character strings, with user-specified maximum length *n.*
- **int:** Integer (finite subset of the integers / machine-dependent).
- **smallint:** Small integer (a machine-dependent subset of the integer domain type).
- **numeric(p,n):** Fixed point number, with user-specified precision of *p* digits, with *n* digits to the right of decimal point.
- **real, double precision:** Floating point and double-precision floating point numbers, with machine-dependent precision.
- **float(n):** Floating point number, with user-specified precision of at least *n* digits

Domain Types in SQL – II

- Null values are allowed in all the domain types
  - Declaring an attribute to be **not null** prohibits null values for that attribute.
- **create domain** construct in SQL-92 creates user-defined domain types
- Examples:
  - **create domain** *person_name* **char**(25) **not null**
  - **create domain** customer_city **varchar**(50)

Date/Time Types in SQL

- **date.** Dates, containing a (4 digit) year, month and date
  - E.g. **date** '2001-7-27'
- **time.** Time of day, in hours, minutes and seconds.
  - E.g. **time** '09:00:30' **time** '09:00:30.75'
- **timestamp**: date plus time of day
  - E.g. **timestamp** '2001-7-27 09:00:30.75'
- **Interval**: period of time
  - E.g. Interval '1' day
  - Subtracting a date/time/timestamp value from another gives an interval value
  - Interval values can be added to date/time/timestamp values

Date/Time Types in SQL – II

- Operations on Date Types:
  - Datetime (**+** or **–**) Interval = Datetime
  - Datetime **–** Datetime = Interval
  - Interval (***** or **/**) Number = Interval
  - Interval (**+** or **–**) Interval = Interval
- Can compare data/time/timestamp values
- Can extract values of individual fields from date/time/timestamp
  - E.g. **extract** (**year from** r.start_time)
- Can cast string types to date/time/timestamp
  - E.g. **cast** <string-valued-expression> **as date**

Create Table Construct

- An SQL relation is defined using the **create table** command:

  create table r (A_1 D_1, A_2 D_2, ..., A_n D_n,
  (integrity-constraint$_1$),
  ...,
  (integrity-constraint$_k$))
  - r is the name of the relation
  - each A_i is an attribute name in the schema of relation r
  - D_i is the data type of values in the domain of attribute A_i
- Example:

  create table *branch*
  (*branch_name* char(15) **not null,**
  branch_city char(30),
  assets integer)

Roadmap

- Joined Relations
- **SQL – Data Definition Language**
  - Domain Types and Definitions
  - **Domain Constraints**
  - Referential Integrity
  - Schema Changes

Domain Constraints

- The most elementary form of integrity constraint.
- They test values inserted in the database, and test queries to ensure that the comparisons make sense.
- New domains can be created from existing data types
  - E.g. **create domain** *Dollars* **numeric**(12, 2)
    create domain *Pounds* **numeric**(12,2)
- We cannot assign or compare a value of type Dollars to a value of type Pounds.
  - However, we can convert type:
    (**cast** *r.A* **as** *Pounds*)
    (Should also multiply by the dollar-to-pound conversion-rate)

Domain Constraints – check clause

- **check** clause in SQL permits domains to be restricted:
- Example:
  - Use **check** clause to ensure that an hourly-wage domain allows only values greater than a specified value.
    create domain *hourly-wage* **numeric(5,2)**
    constraint *value-test* **check**(*value* > = 4.00)
  - The domain has a constraint that ensures that the hourly-wage is greater than 4.00
  - The clause **constraint** *value-test* is optional; useful to indicate which constraint an update violated.

Domain Constraints – check clause 2

- Can have complex conditions in domain check
- Examples
  - Make sure account is either checking or savings
  - **create domain** *AccountType* **char**(10)
    constraint *account-type-test*
    check (**value in** ('Checking', 'Savings'))
  - Make sure branch-name is valid one
  - **check** (*branch-name* **in** (**select** *branch-name* **from** *branch*))

Roadmap

- Joined Relations
- **SQL – Data Definition Language**
  - Domain Types and Definitions
  - Domain Constraints
  - **Referential Integrity**
  - Schema Changes

Referential Integrity

- Ensures that a value that appears in one relation for a given set of attributes, also appears for a certain set of attributes in another relation.
- Examples:
  - If "Perryridge" is a branch name appearing in one of the tuples in the *account* relation, then there exists a tuple in the *branch* relation for branch "Perryridge".
  - If faculty_id "12345678" appears in one of the tuples in the teaches relation, then there exists a tuple in the faculty relation for faculty with id="12345678"

Referential Integrity – Definition

- Formal Definition
  - Let $r_1(R_1)$ and $r_2(R_2)$ be relations with primary keys K_1 and K_2 respectively.
  - The subset α of R_2 is a ***foreign key*** referencing K_1 in relation r_1, if for every t_2 in r_2 there must be a tuple t_1 in r_1 such that $t_1[K_1] = t_2[\alpha]$.
  - Referential integrity constraint also called subset dependency since its can be written as
    $\prod_\alpha (r_2) \subseteq \prod_{K1} (r_1)$

RI on Database Modifications

- α of R_2 is a ***foreign key*** referencing K_1 in relation r_1
- **Insert.** If a tuple t_2 is inserted into r_2, we must ensure that there is a tuple t_1 in r_1 such that $t_1[K] = t_2[\alpha]$.
  $t_2[\alpha] \in \prod_K (r_1)$
- **Delete.** If a tuple, t_1 is deleted from r_1, we must compute the set of tuples in r_2 that reference t_1:
  $\sigma_{\alpha = t1[K]} (r_2)$
  If this set is not empty
  - either the delete command is rejected as an error, or
  - the tuples that reference t_1 must themselves be deleted (cascading deletions are possible).

RI on Updates

- α of R_2 is a ***foreign key*** referencing K_1 in relation r_1
- If a tuple t_2 is updated in relation r_2 and the update modifies values for foreign key α, then a test similar to the insert case is made:
  - Let t_2' denote the new value of tuple t_2. We must ensure that $t_2'[\alpha] \in \prod_K(r_1)$

RI on Updates (2)

- α of R_2 is a ***foreign key*** referencing K_1 in relation r_1
- If a tuple t_1 is updated in r_1, and the update modifies values for the primary key (K), then a test similar to the delete case is made:
  - We must compute
    $\sigma_{\alpha = t1[K]}(r_2)$
    using the old value of t_1 (the value before the update is applied).
  - If this set is not empty
    1. the update may be rejected as an error, or
    2. the update may be cascaded to the tuples in the set, or
    3. the tuples in the set may be deleted.

Referential Integrity in SQL

- Primary, candidate and foreign keys can be specified as part of the SQL **create table** statement:
  - **primary key clause**:
    - list attributes that comprise the primary key.
  - **unique key clause**:
    - list attributes that comprise a candidate key.
  - **foreign key clause:**
    - list attributes that comprise the foreign key and specify name of the relation referenced by the foreign key
- By default, a foreign key references the primary key attributes of the referenced table
  foreign key (*account_number*) **references** *account*
- Short form for specifying a single column as foreign key
  account_number **char** (10) **references** *account*

RI – SQL Example

create table *customer*
(customer-name char(20)**,**
customer-street char(30),
customer-city char(30),
primary key (*customer-name))*

create table *branch*
(branch-name char(15)**,**
branch-city char(30),
assets integer,
primary key *(branch-name))*

RI – SQL Example (cont)

create table *account*
(account-number char(10)**,**
branch-name char(15),
balance integer,
primary key (*account-number),*
foreign key (*branch-name)* **references** *branch)*

create table *depositor*
(customer-name char(20)**,**
account-number char(10)**,**
primary key *(customer-name, account-number),*
foreign key *(account-number)* **references** *account,*
foreign key *(customer-name)* **references** *customer)*

Cascading Actions in SQL

create table *account*
. . .
foreign key(*branch-name)* **references** *branch*
on delete cascade
on update cascade
. . . **)**

- **on delete cascade**
  - ➔ if a delete of a tuple in *branch* results in referential-integrity constraint violation, the delete "cascades" to the *account* relation, deleting the tuple that refers to the branch that was deleted.
- Cascading updates are similar.

Referential Integrity in SQL (Cont.)

- Alternative to cascading:
  - **on delete set null**
  - **on delete set default**
- Null values in foreign key attributes complicate SQL referential integrity semantics, and are best prevented using **not null**
  - if any attribute of a foreign key is null, the tuple is defined to satisfy the foreign key constraint!

Roadmap

- Joined Relations
- **SQL – Data Definition Language**
  - Domain Types and Definitions
  - Domain Constraints
  - Referential Integrity
  - **Schema Changes**

Drop Table Construct

- The **drop table** command deletes all information about the dropped relation from the database.
  - E.g., drop table customer
  - delete all tuples and schema information
- Note difference from **delete**
  - E.g., delete from customer
  - all tuples are deleted, but schema information remains
- Note difference from **drop view**
  - E.g., drop view all-customer
  - no tuple is deleted, but view definition is deleted

Alter Table Construct

- The **alter table** command is used to add attributes to an existing relation.

  alter table *r* **add** *A D*

  where *A* is the name of the attribute to be added to relation *r* and *D* is the domain of *A.*
  - All tuples in the relation are assigned *null* as the value for the new attribute.
- The **alter table** command can also be used to drop attributes of a relation

  alter table *r* **drop** *A*

  where *A* is the name of an attribute of relation *r*
  - Dropping of attributes not supported by many databases

Integrity Constraints & Security

Integrity Constraints

- guard against accidental damage to the database
- we focus on constraints that can be tested with minimal overhead

Security

- prevent unauthorized access to data (read or write)

Roadmap

- **Triggers**
- Security
- Authorization
- Authorization in SQL

Triggers

- A **trigger** is a statement that is executed automatically by the system as a side effect of a modification to the database.
- To design a trigger mechanism, we must:
  - Specify the conditions under which the trigger is to be executed.
  - Specify the actions to be taken when the trigger executes.
- Event-Condition-Action model for triggers

Trigger Example

- Suppose that instead of allowing negative account balances, the bank deals with overdrafts by
  - setting the account balance to zero
  - creating a loan in the amount of the overdraft
  - giving this loan a loan number identical to the account number of the overdrawn account
- The condition for executing the trigger is an update to the *account* relation that results in a negative *balance* value.

Trigger Example in SQL

create trigger *overdraft-trigger* **after update on** *account* ← event
referencing new row as *nrow*
for each row
when *nrow.balance* < 0 ← condition
begin atomic
    insert into *borrower* ← actions
        (select *customer-name, account-number*
        from *depositor*
        where *nrow.account-number = depositor.account-number*);

    insert into *loan* **values**
        (n.*row.account-number, nrow.branch-name,* – *nrow.balance*);

    update *account* **set** *balance* = 0
    where *account.account-number = nrow.account-number*
end

Triggering Events and Actions in SQL

- Triggering event can be **insert**, **delete** or **update**
- Triggers on update can be restricted to specific attributes
  - **create trigger** *overdraft-trigger* **after update of** *balance* **on** *account*
- Values of attributes before and after an update can be referenced
  - **referencing old row as** : for deletes and updates
  - **referencing new row as** : for inserts and updates
- Triggers can be activated before an event, which can serve as extra constraints. E.g. convert blanks to null.

    create trigger *setnull-trigger* **before update on** *r*
    referencing new row as *nrow*
    for each row
        when *nrow.phone-number* = ' '
        set *nrow.phone-number* = **null**

Statement Level Triggers

- Instead of executing a separate action for each affected row, a single action can be executed for all rows affected by a transaction
  - Use **for each statement** instead of **for each row**
  - Use **referencing old table** or **referencing new table** to refer to temporary tables (called ***transition tables***) containing the affected rows
  - Can be more efficient when dealing with SQL statements that update a large number of rows

Triggers for External World Actions

- We sometimes require external world actions to be triggered on a database update
  - E.g. re-ordering an item whose quantity in a warehouse has become small, or turning on an alarm light,
- Triggers cannot be used to directly implement external-world actions, BUT
  - Triggers can be used to record actions-to-be-taken in a separate table
  - Have an external process that repeatedly scans the table, carries out external-world actions and deletes action from table

External World Actions (cont.)

- E.g. Suppose a warehouse has the following tables
  - *inventory(item, level):*
    How much of each item is in the warehouse
  - *minlevel(item, level) :*
    What is the minimum desired level of each item
  - *reorder(item, amount):*
    What quantity should we re-order at a time
  - *orders(item, amount) :*
    Orders to be placed (read by external process)

External World Actions (Cont.)

```
                                                  event
create trigger reorder-trigger after update of amount on inventory
referencing old row as orow, new row as nrow
for each row
    when nrow.level < = (select level                conditions
                           from minlevel
                           where minlevel.item = orow.item)
         and orow.level > (select level
                             from minlevel
                              where minlevel.item = orow.item)
 begin
     insert into orders
         (select item, amount                     actions
          from reorder
          where reorder.item = orow.item)
 end
```

When Not To Use Triggers

- Triggers were used earlier for tasks such as
  - maintaining summary data (e.g. total salary of each department)
  - Replicating databases by recording changes to special relations (called **change** or **delta** relations) and having a separate process that applies the changes over to a replica
- There are better ways of doing these now:
  - Databases today provide built in materialized view facilities to maintain summary data
  - Databases provide built-in support for replication
- Encapsulation facilities can be used instead of triggers in many cases
  - Define methods to update fields
  - Carry out actions as part of the update methods instead of through a trigger

Roadmap

- Triggers
- **Security**
- Authorization
- Authorization in SQL

Security

- **Security:** protection from malicious attempts to steal or modify data
- Database system level
- Operating system level
- Network level
- Physical level
- Human level

Security (cont.)

- Database system level
  - Authentication and authorization mechanisms to allow specific users access only to required data
  - We concentrate on authorization in the rest of this chapter
- Operating system level
  - Operating system super-users can do anything they want to the database! Good operating system level security is required.
- Network level: must use encryption to prevent
  - Eavesdropping (unauthorized reading of messages)
  - Masquerading (pretending to be an authorized user or sending messages supposedly from authorized users)

Security (cont.)

- Physical level
  - Physical access to computers allows destruction of data by intruders; traditional lock-and-key security is needed
  - Computers must also be protected from floods, fire, etc.
- Human level
  - Users must be screened to ensure that an authorized users do not give access to intruders
  - Users should be trained on password selection and secrecy

Roadmap

- Triggers
- Security
- **Authorization**
- Authorization in SQL

Authorization

Forms of authorization on parts of the database:

- **Read authorization** - allows reading, but not modification of data.
- **Insert authorization** - allows insertion of new data, but not modification of existing data.
- **Update authorization** - allows modification, but not deletion of data.
- **Delete authorization** - allows deletion of data

Authorization (cont.)

Forms of authorization to modify the database schema:

- **Index authorization** - allows creation and deletion of indices.
- **Resources authorization** - allows creation of new relations.
- **Alteration authorization** - allows addition or deletion of attributes in a relation.
- **Drop authorization** - allows deletion of relations.

Authorization and Views

- Users can be given authorization on views, without being given any authorization on the relations used in the view definition
- Ability of views to hide data serves both to
  - simplify usage of the system, and
  - enhance security by allowing users access only to data they need for their job
- A combination or relational-level security and view-level security can be used to limit a user's access to precisely the data that he/she needs.

View Example

- Suppose a bank clerk needs to know the names of the customers of each branch, but is not authorized to see specific loan information.
  - Approach: Deny direct access to the *loan* relation, but grant access to the view *cust-loan*, which consists only of the names of customers and the branches at which they have a loan.
  - The *cust-loan* view is defined in SQL as follows:

create view *cust-loan* **as**
  select *branchname*, *customer-name*
  from *borrower, loan*
  where *borrower.loan-number* = *loan.loan-number*

View Example (Cont.)

- The clerk is authorized to see the result of the query:

  select *
  from *cust-loan*

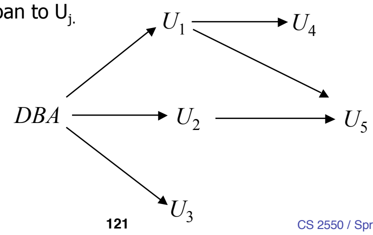
- When the query processor translates the result into a query on the actual relations in the database, we obtain a query on *borrower* and *loan*.
- Authorization must be checked on the clerk's query before query processing replaces a view by the definition of the view.

Authorization on Views

- Creation of view does not require **resources** authorization since no real relation is being created
- Creator of a view gets only those privileges that provide no additional authorization beyond that she already had.
- Example:
  - if creator of view *cust-loan* had only **read** authorization on *borrower* and *loan*, he gets only **read** authorization on *cust-loan*

Granting of Privileges

- The passage of authorization from one user to another may be represented by an authorization graph.
  - The nodes of this graph are the users.
  - The root of the graph is the database administrator.
- Consider graph for update authorization on loan.
  - An edge $U_i \rightarrow U_j$ indicates that user U_i has granted update authorization on loan to U_j.



Authorization Grant Graph

- **Requirement**: All edges in an authorization graph must be part of some path originating with the database administrator
- If DBA revokes grant from U_1:
  - Grant must be revoked from U_4 since U_1 no longer has authorization
  - Grant must not be revoked from U_5 since U_5 has another authorization path from DBA through U_2
- Must prevent cycles of grants with no path from the root:
  - DBA grants authorization to U_7
  - U7 grants authorization to U_8
  - U8 grants authorization to U_7
  - DBA revokes authorization from U_7
- Must revoke grant U_7 to U_8 and from U_8 to U_7 since there is no path from DBA to U_7 or to U_8 anymore.

Roadmap

- Triggers
- Security
- Authorization
- **Authorization in SQL**

Security Specification in SQL

- The grant statement is used to confer authorization
  - **grant** <privilege list>
  - **on** <relation name or view name> to <user list>
- <user list> is:
  - a user-id
  - *public*, which allows all valid users the privilege granted
  - A role (more on this later)
- Granting a privilege on a view does not imply granting any privileges on the underlying relations.
- The grantor of the privilege must already hold the privilege on the specified item (or be the database administrator).

Privileges in SQL

- **select:** allows read access to relation,or the ability to query using the view
  - Example: grant users U_1, U_2, and U_3 **select** authorization on the *branch* relation:

    grant select on *branch* **to** U_1, U_2, U_3
- **insert**: the ability to insert tuples
- **update**: the ability to update using the SQL update statement
- **delete**: the ability to delete tuples.
- **references**: ability to declare foreign keys when creating relations.
- **all privileges**: used as a short form for all the allowable privileges

Privilege To Grant Privileges

- **with grant option**: allows a user who is granted a privilege to pass the privilege on to other users.
- Example:

  grant select on *branch* **to** U_1 **with grant option**
  - gives U_1 the **select** privileges on branch and allows U_1 to grant this privilege to others

Roles

- Roles permit common privileges for a class of users can be specified just once by creating a corresponding "role"
- Privileges can be granted to or revoked from roles, just like user
- Roles can be assigned to users, and even to other roles

Roles Example

create role *teller*
create role *manager*

grant select on *branch* **to** *teller*
grant update (*balance***) on** *account* **to** *teller*
grant all privileges on *account* **to** *manager*

grant *teller* **to** *manager*

grant *teller* **to** *alice, bob*
grant *manager* **to** *avi*

Revoking Authorization in SQL

- The **revoke** statement is used to revoke authorization.
  revoke<privilege list>
  on <relation name or view name> **from** <user list> [**restrict**|**cascade**]
- Example:
  revoke select on *branch* **from** U_1, U_2, U_3 **cascade**
- Revocation of a privilege from a user may cause other users also to lose that privilege
  - referred to as cascading of the **revoke**.
- We can prevent cascading by specifying **restrict**:
  revoke select on *branch* **from** U_1, U_2, U_3 **restrict**
  With **restrict**, the **revoke** command fails if cascading revokes are required.

Revoking Authorization in SQL (cont)

- <privilege-list> may be **all to** revoke all privileges the revokee may hold.
- If <revokee-list> includes **public** all users lose the privilege except those granted it explicitly.
- If the same privilege was granted twice to the same user by different grantees, the user may retain the privilege after the revocation.
- All privileges that depend on the privilege being revoked are also revoked.

Limitations of SQL Authorization

- SQL does not support authorization at a tuple level
  - E.g. we cannot restrict students to see only (the tuples storing) their own grades
- With the growth in Web access to databases, database accesses come primarily from application servers.
  - End users don't have database user ids, they are all mapped to the same database user id
- All end-users of an application (such as a web application) may be mapped to a single database user
- The task of authorization in above cases falls on the application program, with no support from SQL
  - Benefit: fine grained authorizations, such as to individual tuples, can be implemented by the application.
  - Drawback: Authorization must be done in application code, and may be dispersed all over an application
  - Checking for absence of authorization loopholes becomes very difficult since it requires reading large amounts of application code

Audit Trails

- An audit trail is a log of all changes (inserts/deletes/updates) to the database along with information such as which user performed the change, and when the change was performed.
- Used to track erroneous/fraudulent updates.
- Can be implemented using triggers, but many database systems provide direct support.

Encryption

- Data may be *encrypted* when database authorization provisions do not offer sufficient protection.

- Properties of good encryption technique:
  - Relatively simple for authorized users to encrypt and decrypt data.
  - Encryption scheme depends not on the secrecy of the algorithm but on the secrecy of a parameter of the algorithm called the encryption key.
  - Extremely difficult for an intruder to determine the encryption key.