Chapter 4: SQL

- Basic Structure
- Set Operations
- Aggregate Functions
- Null Values
- Nested Subqueries
- Derived Relations
- Views
- Modification of the Database
- Joined Relations
- Data Definition Language
- Embedded SQL, ODBC and JDBC

Schema Used in Examples

Diagram of the database schema including tables and relationships:

- **branch**
  - branch-name
  - branch-city
  - assets

- **account**
  - account-number
  - branch-name
  - balance

- **depositor**
  - customer-name
  - account-number

- **customer**
  - customer-name
  - customer-street
  - customer-city

- **loan**
  - loan-number
  - branch-name
  - amount

- **borrower**
  - customer-name
  - loan-number
Basic Structure

- SQL is based on set and relational operations with certain modifications and enhancements.
- A typical SQL query has the form:
  
  ```sql
  select A_1, A_2, ..., A_n
  from r_1, r_2, ..., r_m
  where P
  ```

  - $A_i$s represent attributes.
  - $r_i$s represent relations.
  - $P$ is a predicate.

- This query is equivalent to the relational algebra expression.

  $$\Pi_{A_1, A_2, ..., A_n}(\sigma_P(r_1 \times r_2 \times ... \times r_m))$$

- The result of an SQL query is a relation.

The select Clause

- The `select` clause corresponds to the projection operation of the relational algebra. It is used to list the attributes desired in the result of a query.
- Find the names of all branches in the `loan` relation
  
  ```sql
  select branch-name
  from loan
  ```

- In the “pure” relational algebra syntax, the query would be:

  $$\Pi_{\text{branch-name}}(\text{loan})$$

- An asterisk in the select clause denotes “all attributes”

  ```sql
  select *
  from loan
  ```

- **NOTE:** SQL does not permit the `-` character in names, so you would use, for example, `branch_name` instead of `branch-name` in a real implementation. We use `-` since it looks nicer!

- **NOTE:** SQL names are case insensitive, meaning you can use upper case or lower case.
  - You may wish to use upper case in places where we use bold font.
The select Clause (Cont.)

- SQL allows duplicates in relations as well as in query results.
- To force the elimination of duplicates, insert the keyword `distinct` after `select`.
  Find the names of all branches in the `loan` relations, and remove duplicates
  
  ```sql
  select distinct branch-name
  from loan
  ```

- The keyword `all` specifies that duplicates not be removed.
  
  ```sql
  select all branch-name
  from loan
  ```

The select Clause (Cont.)

- The `select` clause can contain arithmetic expressions involving the operation, `+`, `−`, `∗`, and `/`, and operating on constants or attributes of tuples.
- The query:
  
  ```sql
  select loan-number, branch-name, amount ∗ 100
  from loan
  ```

  would return a relation which is the same as the `loan` relations, except that the attribute `amount` is multiplied by 100.
The where Clause

- The where clause corresponds to the selection predicate of the relational algebra. If consists of a predicate involving attributes of the relations that appear in the from clause.
- The find all loan number for loans made at Perryridge branch with loan amounts greater than $1200.
  
  ```sql
  select loan-number
  from loan
  where branch-name = 'Perryridge' and amount > 1200
  ```

- Comparison results can be combined using the logical connectives and, or, and not.
- Comparisons can be applied to results of arithmetic expressions.

The where Clause (Cont.)

- SQL includes a between comparison operator in order to simplify where clauses that specify that a value be less than or equal to some value and greater than or equal to some other value.
- Find the loan number of those loans with loan amounts between $90,000 and $100,000 (that is, $90,000 and $100,000)
  
  ```sql
  select loan-number
  from loan
  where amount between 90000 and 100000
  ```
The from Clause

- The from clause corresponds to the Cartesian product operation of the relational algebra. It lists the relations to be scanned in the evaluation of the expression.
- Find the Cartesian product borrower x loan
  
  ```sql
  select *
  from borrower, loan
  ```
- Find the name, loan number and loan amount of all customers having a loan at the Perryridge branch.
  
  ```sql
  select customer-name, borrower.loan-number, amount
  from borrower, loan
  where borrower.loan-number = loan.loan-number and
  branch-name = 'Perryridge'
  ```

The Rename Operation

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

  ```sql
  old-name as new-name
  ```
- Find the name, loan number and loan amount of all customers; rename the column name loan-number as loan-id.

  ```sql
  select customer-name, borrower.loan-number as loan-id, amount
  from borrower, loan
  where borrower.loan-number = loan.loan-number
  ```
Tuple Variables

- Tuple variables are defined in the `from` clause via the use of the `as` clause.
- Find the customer names and their loan numbers for all customers having a loan at some branch.
  ```sql
  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.
  ```sql
  select distinct T.branch-name
  from branch as T, branch as S
  where T.assets > S.assets and S.branch-city = 'Brooklyn'
  ```

String Operations

- SQL includes a string-matching operator for comparisons on character strings. Patterns are described using two special characters:
  - percent (%). The % character matches any substring.
  - underscore (_). The _ character matches any character.
- Find the names of all customers whose street includes the substring "Main".
  ```sql
  select customer-name
  from customer
  where customer-street like 'Main%'
  ```
- Match the name “Main%”
  ```sql
  like 'Main\%'
  ```
- SQL supports a variety of string operations such as
  - concatenation (using "||")
  - converting from upper to lower case (and vice versa)
  - finding string length, extracting substrings, etc.
Ordering the Display of Tuples

- List in alphabetic order the names of all customers having a loan in Perryridge branch

```sql
select distinct customer-name
from borrower, loan
where borrower loan-number - loan.loan-number and
branch-name = 'Perryridge'
order by customer-name
```

- We may specify desc for descending order or asc for ascending order, for each attribute; ascending order is the default.

  E.g. `order by customer-name desc`

Duplicates

- In relations with duplicates, SQL can define how many copies of tuples appear in the result.

- Multiset versions of some of the relational algebra operators – given multiset relations \( r_1 \) and \( r_2 \):
  1. If there are \( c_1 \) copies of tuple \( t_1 \) in \( r_1 \), and \( t_1 \) satisfies selections \( \sigma_\theta. \), then there are \( c_1 \) copies of \( t_1 \) in \( \sigma_\theta (r_1) \).
  2. For each copy of tuple \( t_1 \) in \( r_1 \), there is a copy of tuple \( \Pi_A(t_1) \) in \( \Pi_A(r_1) \) where \( \Pi_A(t_1) \) denotes the projection of the single tuple \( t_1 \).
  3. If there are \( c_1 \) copies of tuple \( t_1 \) in \( r_1 \) and \( c_2 \) copies of tuple \( t_2 \) in \( r_2 \), there are \( c_1 \times c_2 \) copies of the tuple \( t_1 \times t_2 \) in \( r_1 \times r_2 \)
Duplicates (Cont.)

- Example: Suppose multiset relations \( r_1 (A, B) \) and \( r_2 (C) \) are as follows:
  \[
  r_1 = \{(1, a), (2, a)\} \quad r_2 = \{(2), (3)\}
  \]
- Then \( \Pi_B(r_1) \) would be \( \{(a), (a)\} \), while \( \Pi_B(r_1) \times r_2 \) would be \( \{(a,2), (a,2), (a,3), (a,3), (a,3), (a,3)\} \)
- SQL duplicate semantics:
  
  ```sql
  select A_1, A_2, ..., A_n
  from r_1, r_2, ..., r_m
  where P
  
  ```
  is equivalent to the *multiset* version of the expression:
  
  \[
  \Pi_{A_1, A_2, ..., A_n}(\sigma_P (r_1 \times r_2 \times ... \times r_m))
  \]

Set Operations

- The set operations *union*, *intersect*, and *except* operate on relations and 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*.

Suppose a tuple occurs \( m \) times in \( r \) and \( n \) times in \( s \), then, it occurs:

- \( m + n \) times in \( r \textbf{ union all } s \)
- \( \min(m,n) \) times in \( r \textbf{ intersect all } s \)
- \( \max(0, m - n) \) times in \( r \textbf{ except all } s \)
**Set Operations**

- Find all customers who have a loan, an account, or both:
  
  \[
  \text{(select customer-name from depositor)} \cup \text{(select customer-name from borrower)}
  \]

- Find all customers who have both a loan and an account.
  
  \[
  \text{(select customer-name from depositor)} \cap \text{(select customer-name from borrower)}
  \]

- Find all customers who have an account but no loan.
  
  \[
  \text{(select customer-name from depositor)} \setminus \text{(select customer-name from borrower)}
  \]

**Aggregate Functions**

- These functions operate on the multiset of values of a column of a relation, and return a value
  
  avg: average value
  min: minimum value
  max: maximum value
  sum: sum of values
  count: number of values
Aggregate Functions (Cont.)

- Find the average account balance at the Perryridge branch.
  
  \[
  \text{select } \text{avg} \ (\text{balance}) \\
  \text{from } \text{account} \\
  \text{where } \text{branch-name} = \text{'Perryridge'}
  \]

- Find the number of tuples in the customer relation.
  
  \[
  \text{select count} \ (\text{*}) \\
  \text{from } \text{customer}
  \]

- Find the number of depositors in the bank.
  
  \[
  \text{select count (distinct customer-name)} \\
  \text{from } \text{depositor}
  \]

Aggregate Functions – Group By

- Find the number of depositors for each branch.
  
  \[
  \text{select branch-name, count (distinct customer-name)} \\
  \text{from depositor, account} \\
  \text{where depositor.account-number = account.account-number} \\
  \text{group by branch-name}
  \]

  **Note:** Attributes in select clause outside of aggregate functions must appear in group by list
### Aggregate Functions – Having Clause

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

```sql
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.

### Null Values

- It is possible for tuples to have a null value, denoted by `null`, for some of their attributes.
- `null` signifies an unknown value or that a value does not exist.
- The predicate **is null** can be used to check for null values.
  - E.g. Find all loan number which appear in the `loan` relation with null values for `amount`.
    ```sql
    select loan-number
    from loan
    where amount is null
    ```
- The result of any arithmetic expression involving `null` is `null`.
  - E.g. `5 + null` returns `null`
- However, aggregate functions simply ignore nulls
  - more on this shortly
Null Values and Three Valued Logic

- Any comparison with null returns unknown
  - E.g. 5 < null or null <> null or null = null
- Three-valued logic using the truth value unknown:
  - OR: (unknown or true) = true, (unknown or false) = unknown
  - (unknown or unknown) = unknown
  - AND: (true and unknown) = unknown, (false and unknown) = false,
  - (unknown and unknown) = unknown
  - NOT: (not unknown) = unknown
  - “P is unknown” evaluates to true if predicate P evaluates to unknown
- Result of where clause predicate is treated as false if it evaluates to unknown

Null Values and Aggregates

- Total all loan amounts
  - select sum (amount)
  - from loan
  - Above statement ignores null amounts
  - result is null if there is no non-null amount, that is the
- All aggregate operations except count(*) ignore tuples with null values on the aggregated attributes.
Nested Subqueries

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

Example Query

- Find all customers who have both an account and a loan at the bank.
  
  ```sql
  select distinct customer-name
  from borrower
  where customer-name in (select customer-name
                           from depositor)
  ```

- Find all customers who have a loan at the bank but do not have an account at the bank.
  
  ```sql
  select distinct customer-name
  from borrower
  where customer-name not in (select customer-name
                               from depositor)
  ```
**Example Query**

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

**Set Comparison**

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

  ```sql
  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

  ```sql
  select branch-name
  from branch
  where assets > some
  (select assets
  from branch
  where branch-city = 'Brooklyn')
  ```
### Definition of Some Clause

- \( F \text{ <comp> some } r \Leftrightarrow \exists t \in r \text{ s.t. } (F \text{ <comp> } t) \)
- Where \(<\text{comp}>\) can be: \(<, \leq, >, =, \neq\)
- \( (5 < \text{some} \begin{array}{c} 0 \\ 5 \\ 6 \end{array}) = \text{true} \)  (read: 5 < some tuple in the relation)
- \( (5 < \text{some} \begin{array}{c} 0 \\ 5 \end{array}) = \text{false} \)
- \( (5 = \text{some} \begin{array}{c} 0 \\ 5 \end{array}) = \text{true} \)
- \( (5 \neq \text{some} \begin{array}{c} 0 \\ 5 \end{array}) = \text{true} \) (since 0 \(\neq\) 5)

\( (= \text{some}) \equiv \text{in} \)

However, \((\neq \text{some}) \neq \text{not in}\)

### Definition of all Clause

- \( F \text{ <comp> all } r \Leftrightarrow \forall t \in r \text{ s.t. } (F \text{ <comp> } t) \)
- \( (5 < \text{all} \begin{array}{c} 0 \\ 5 \\ 6 \end{array}) = \text{false} \)
- \( (5 < \text{all} \begin{array}{c} 6 \\ 10 \end{array}) = \text{true} \)
- \( (5 = \text{all} \begin{array}{c} 4 \\ 5 \end{array}) = \text{false} \)
- \( (5 \neq \text{all} \begin{array}{c} 4 \\ 6 \end{array}) = \text{true} \) (since 5 \(\neq\) 4 and 5 \(\neq\) 6)

\( (= \text{all}) \equiv \text{not in} \)

However, \((= \text{all}) \neq \text{in} \)
**Example Query**

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

```sql
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 \( r \leftrightarrow r \neq \emptyset \)
- **not exists** \( r \leftrightarrow r = \emptyset \)
Example Query

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

```sql
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))
```

(Schema used in this example)

- Note that $X - Y = \emptyset \iff X \subseteq Y$
- Note: Cannot write this query using `all` and its variants

Test for Absence of Duplicate Tuples

- The `unique` construct tests whether a subquery has any duplicate tuples in its result.
- Find all customers who have at most one account at the Perryridge branch.

```sql
select T.customer-name
from depositor as T
where 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')
```

(Schema used in this example)
Example Query

- Find all customers who have at least two accounts at the Perryridge branch.

```sql
select distinct T.customer-name
from depositor 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'
)
```

(Schema used in this example)

Views

- Provide a mechanism to hide certain data from the view of certain users. To create a view we use the command:

```sql
create view v as <query expression>
```

where:
- `<query expression>` is any legal expression
- The view name is represented by `v`
Example Queries

- A view consisting of branches and their customers
  ```sql
  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
  ```sql
  select customer-name
  from all-customer
  where branch-name = 'Perryridge'
  ```

Derived Relations

- Find the average account balance of those branches where the average account balance is greater than $1200.
  ```sql
  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
  ```

  Note that we do not need to use the `having` clause, since we compute the temporary (view) relation `result` in the `from` clause, and the attributes of `result` can be used directly in the `where` clause.
With Clause

- With clause allows views to be defined locally to a query, rather than globally. Analogous to procedures in a programming language.
- Find all accounts with the maximum balance

```sql
with max-balance(value) as
    select max (balance)
    from account
select account-number
from account, max-balance
where account.balance = max-balance.value
```

Complex Query using With Clause

- Find all branches where the total account deposit is greater than the average of the total account deposits at all branches

```sql
with branch-total (branch-name, value) as
    select branch-name, sum (balance)
    from account
    group by branch-name
with branch-total-avg(value) as
    select avg (value)
    from branch-total
select branch-name
from branch-total, branch-total-avg
where branch-total.value >= branch-total-avg.value
```
Modification of the Database – Deletion

- Delete all account records at the Perryridge branch
  
  ```sql
  delete from account 
  where branch-name = 'Perryridge'
  ```

- Delete all accounts at every branch located in Needham city.
  
  ```sql
  delete from account 
  where branch-name in (select branch-name 
  from branch 
  where branch-city = 'Needham')
  ```

  ```sql
  delete from depositor 
  where account-number in 
  (select account-number 
  from branch, account 
  where branch-city = 'Needham' 
  and branch.branch-name = account.branch-name)
  ```

- (Schema used in this example)

Example Query

- Delete the record of all accounts with balances below the average at the bank.
  
  ```sql
  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)
Modification of the Database – Insertion

- Add a new tuple to `account`
  
  ```sql
  insert into account
  values ('A-9732', 'Perryridge', 1200)
  ```
  
or equivalently
  
  ```sql
  insert into account (branch-name, balance, account-number)
  values ('Perryridge', 1200, 'A-9732')
  ```

- Add a new tuple to `account` with `balance` set to null
  
  ```sql
  insert into account
  values ('A-777', 'Perryridge', null)
  ```

- Provide as a gift for all loan customers of the Perryridge branch, a $200 savings account. Let the loan number serve as the account number for the new savings account
  
  ```sql
  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.account-number = borrower.account-number
  ```

- The select from where statement is fully evaluated before any of its results are inserted into the relation (otherwise queries like
  
  ```sql
  insert into table1 select * from table1
  ```
  
  would cause problems
Modification of the Database – Updates

- Increase all accounts with balances over $10,000 by 6%, all other accounts receive 5%.
  - Write two update statements:
    ```sql
    update account
    set balance = balance * 1.06
    where balance > 10000
    
    update account
    set balance = balance * 1.05
    where balance <= 10000
    ```
  - The order is important
  - Can be done better using the case statement (next slide)

Case Statement for Conditional Updates

- Same query as before: Increase all accounts with balances over $10,000 by 6%, all other accounts receive 5%.
  ```sql
  update account
  set balance = case
    when balance <= 10000 then balance * 1.05
    else balance * 1.06
  end
  ```
Update of a View

- Create a view of all loan data in loan relation, hiding the amount attribute
  
  ```sql
  create view branch-loan as
  select branch-name, loan-number
  from loan
  ```

- Add a new tuple to branch-loan
  
  ```sql
  insert into branch-loan
  values ('Perryridge', 'L-307')
  ```

  This insertion must be represented by the insertion of the tuple
  
  ```sql
  ('L-307', 'Perryridge', null)
  ```

  into the loan relation

- Updates on more complex views are difficult or impossible to translate, and hence are disallowed.
- Most SQL implementations allow updates only on simple views (without aggregates) defined on a single relation

Transactions

- A transaction is a sequence of queries and update statements executed as a single unit
  
  - Transactions are started implicitly and terminated by one of
    
    - **commit work**: makes all updates of the transaction permanent in the database
    
    - **rollback work**: undoes all updates performed by the transaction.

- Motivating example
  
  - Transfer of money from one account to another involves two steps:
    
    - deduct from one account and credit to another
    
    - If one steps succeeds and the other fails, database is in an inconsistent state
    
    - Therefore, either both steps should succeed or neither should

- If any step of a transaction fails, all work done by the transaction can be undone by **rollback work**.
- Rollback of incomplete transactions is done automatically, in case of system failures
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, but how to do so depends on the database system
  - Another option in SQL:1999: enclose statements within
    ```sql
    begin atomic
    ...
    end
    ```

Joined Relations

- Join operations take two relations and return as a result another relation.
- These additional operations are typically used as subquery expressions in the `from` clause
- Join condition – defines which tuples in the two relations match, and what attributes are present in the result of the join.
- Join type – defines how tuples in each relation that do not match any tuple in the other relation (based on the join condition) are treated.

<table>
<thead>
<tr>
<th>Join Types</th>
<th>Join Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner join</td>
<td>natural</td>
</tr>
<tr>
<td>left outer join</td>
<td>on &lt;predicate&gt;</td>
</tr>
<tr>
<td>right outer join</td>
<td>using (A₁, A₂, ..., Aₙ)</td>
</tr>
<tr>
<td>full outer join</td>
<td></td>
</tr>
</tbody>
</table>
Joined Relations – Datasets for Examples

- Relation `loan`

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
</tr>
<tr>
<td>L-260</td>
<td>Perryridge</td>
<td>1700</td>
</tr>
</tbody>
</table>

- Relation `borrower`

<table>
<thead>
<tr>
<th>customer-name</th>
<th>loan-number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jones</td>
<td>L-170</td>
</tr>
<tr>
<td>Smith</td>
<td>L-230</td>
</tr>
<tr>
<td>Hayes</td>
<td>L-155</td>
</tr>
</tbody>
</table>

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`

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
<th>loan-number</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
<td>L-170</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
<td>L-230</td>
</tr>
</tbody>
</table>

- `loan left inner join borrower on loan.loan-number = borrower.loan-number`

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
<th>loan-number</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
<td>L-170</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
<td>L-230</td>
</tr>
<tr>
<td>L-260</td>
<td>Perryridge</td>
<td>1700</td>
<td>null</td>
<td>null</td>
</tr>
</tbody>
</table>
**Joined Relations – Examples**

- **loan natural inner join** borrower

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
</tr>
</tbody>
</table>

- **loan natural right outer join** borrower

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
</tr>
<tr>
<td>L-155</td>
<td>null</td>
<td>null</td>
<td>Hayes</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
</tr>
<tr>
<td>L-260</td>
<td>Perryridge</td>
<td>1700</td>
<td></td>
</tr>
<tr>
<td>L-155</td>
<td>null</td>
<td>null</td>
<td>Hayes</td>
</tr>
</tbody>
</table>

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

```sql
select customer-name
from (depositor natural full outer join borrower)
where account-number is null or loan-number is null
```
Data Definition Language (DDL)

Allows the specification of not only a set of relations but 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 relation.
- 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 (a finite subset of the integers that is machine-dependent).
- smallint. Small integer (a machine-dependent subset of the integer domain type).
- numeric(p,d). 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.
- 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
  create domain person-name char(20) not null
Date/Time Types in SQL (Cont.)

- **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

Can extract values of individual fields from date/time/timestamp
- E.g. `extract (year from r.starttime)`

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 (A1 D1, A2 D2, ..., An Dn,
  (integrity-constraint1),
  ....,
  (integrity-constraintn))
  ```
  
  - `r` is the name of the relation
  - each `Ai` is an attribute name in the schema of relation `r`
  - `Di` is the data type of values in the domain of attribute `Ai`

Example:

```
create table branch
  (branch-name char(15) not null,
   branch-city char(30),
   assets integer)
```
### Integrity Constraints in Create Table

- **not null**
- **primary key** \((A_1, \ldots, A_n)\)
- **check** \((P)\), where \(P\) is a predicate

Example: Declare \textit{branch-name} as the primary key for \textit{branch} and ensure that the values of \textit{assets} are non-negative.

```sql
create table branch
  (branch-name char(15),
   branch-city char(30),
   assets integer,
   primary key (branch-name),
   check (assets >= 0))
```

**primary key** declaration on an attribute automatically ensures **not null** in SQL-92 onwards, needs to be explicitly stated in SQL-89.

### Drop and Alter Table Constructs

- The **drop table** command deletes all information about the dropped relation from the database.
- The **after table** command is used to add attributes to an existing relation. All tuples in the relation are assigned \textit{null} as the value for the new attribute. The form of the **alter table** command is

```sql
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 \(A\).

- The **alter table** command can also be used to drop attributes of a relation

```sql
alter table r drop A
```

where \(A\) is the name of an attribute of relation \(r\).

*Dropping of attributes not supported by many databases.*
Embedded SQL

- The SQL standard defines embeddings of SQL in a variety of programming languages such as Pascal, PL/I, Fortran, C, and Cobol.
- A language to which SQL queries are embedded is referred to as a **host** language, and the SQL structures permitted in the host language comprise **embedded** SQL.
- The basic form of these languages follows that of the System R embedding of SQL into PL/I.
- EXEC SQL statement is used to identify embedded SQL request to the preprocessor
  
  ```sql
  EXEC SQL <embedded SQL statement > END-EXEC
  ```

  Note: this varies by language. E.g. the Java embedding uses
  ```sql
  # SQL { .... } ;
  ```

Example Query

From within a host language, find the names and cities of customers with more than the variable `amount` dollars in some account.

- Specify the query in SQL and declare a **cursor** for it

  ```sql
  EXEC SQL
    declare c cursor for
    select customer-name, customer-city
    from depositor, customer, account
    where depositor.customer-name = customer.customer-name
      and depositor account-number = account.account-number
      and account.balance > :amount
  END-EXEC
  ```
Embedded SQL (Cont.)

- The `open` statement causes the query to be evaluated
  
  ```sql
  EXEC SQL open c END-EXEC
  ```

- The `fetch` statement causes the values of one tuple in the query result to be placed on host language variables.
  
  ```sql
  EXEC SQL fetch c into :cn, :cc END-EXEC
  ```
  Repeated calls to `fetch` get successive tuples in the query result

- A variable called SQLSTATE in the SQL communication area (SQLCA) gets set to ‘02000’ to indicate no more data is available

- The `close` statement causes the database system to delete the temporary relation that holds the result of the query.
  
  ```sql
  EXEC SQL close c END-EXEC
  ```

Note: above details vary with language. E.g. the Java embedding defines Java iterators to step through result tuples.

Updates Through Cursors

- Can update tuples fetched by cursor by declaring that the cursor is for update

  ```sql
  declare c cursor for
  select *
  from account
  where branch-name = ‘Perryridge’
  for update
  ```

- To update tuple at the current location of cursor

  ```sql
  update account
  set balance = balance + 100
  where current of c
  ```
**Dynamic SQL**

- Allows programs to construct and submit SQL queries at runtime.
- Example of the use of dynamic SQL from within a C program.

```c
char * sqlprog = “update account
    set balance = balance * 1.05
    where account-number = ?”
EXEC SQL prepare dynprog from :sqlprog;
EXEC SQL execute dynprog using :account;
```

- The dynamic SQL program contains a ?, which is a place holder for a value that is provided when the SQL program is executed.

---

**ODBC**

- Open DataBase Connectivity (ODBC) standard
  - standard for application program to communicate with a database server.
  - application program interface (API) to
    - open a connection with a database,
    - send queries and updates,
    - get back results.
- Applications such as GUI, spreadsheets, etc. can use ODBC
Each database system supporting ODBC provides a "driver" library that must be linked with the client program.

When client program makes an ODBC API call, the code in the library communicates with the server to carry out the requested action, and fetch results.

ODBC program first allocates an SQL environment, then a database connection handle.

Opens database connection using SQLConnect(). Parameters for SQLConnect:
- connection handle,
- the server to which to connect
- the user identifier,
- password

Must also specify types of arguments:
- SQL_NTS denotes previous argument is a null-terminated string.

```
int ODBCexample()
{
    RETCODE error;
    HENV env; /* environment */
    HDBC conn; /* database connection */
    SQLAllocEnv(&env);
    SQLAllocConnect(env, &conn);
    SQLConnect(conn, "aura.bell-labs.com", SQL_NTS, "avi", SQL_NTS, "avipasswd", SQL_NTS);
    { .... Do actual work ... }
    SQLDisconnect(conn);
    SQLFreeConnect(conn);
    SQLFreeEnv(env);
}
```
**ODBC Code (Cont.)**

- Program sends SQL commands to the database by using SQLExecDirect
- Result tuples are fetched using SQLFetch()
- SQLBindCol() binds C language variables to attributes of the query result
  - When a tuple is fetched, its attribute values are automatically stored in corresponding C variables.
  - Arguments to SQLBindCol()
    - ODBC stmt variable, attribute position in query result
    - The type conversion from SQL to C.
    - The address of the variable.
    - For variable-length types like character arrays,
      - The maximum length of the variable
      - Location to store actual length when a tuple is fetched.
    - Note: A negative value returned for the length field indicates null value

- Good programming requires checking results of every function call for errors; we have omitted most checks for brevity.

**Main body of program**

```c
char branchname[80];
float balance;
int lenOut1, lenOut2;
HSTMT stmt;
SQLAllocStmt(conn, &stmt);
char * sqlquery = "select branch_name, sum (balance) from account group by branch_name";
error = SQLExecDirect(stmt, sqlquery, SQL_NTS);
if (error == SQL_SUCCESS) {
    SQLBindCol(stmt, 1, SQL_C_CHAR, branchname, 80, &lenOut1);
    SQLBindCol(stmt, 2, SQL_C_FLOAT, &balance, 0, &lenOut2);
    while (SQLFetch(stmt) >= SQL_SUCCESS) {
        printf(" %s  %g
", branchname, balance);
    }
} SQLFreeStmt(stmt, SQL_DROP);
```
More ODBC Features

- Prepared Statement
  - SQL statement prepared: compiled at the database
  - Can have placeholders: E.g. insert into account values(?,?,?)
  - Repeatedly executed with actual values for the placeholders

- Metadata features
  - finding all the relations in the database and
  - finding the names and types of columns of a query result or a relation in the database.

- By default, each SQL statement is treated as a separate transaction that is committed automatically.
  - Can turn off automatic commit on a connection
    - SQLSetConnectOption(conn, SQL_AUTOCOMMIT, 0)
  - transactions must then be committed or rolled back explicitly by
    - SQLTransact(conn, SQL_COMMIT) or
    - SQLTransact(conn, SQL_ROLLBACK)

ODBC Conformance Levels

- Conformance levels specify subsets of the functionality defined by the standard.
  - Core
    - Level 1 requires support for metadata querying
    - Level 2 requires ability to send and retrieve arrays of parameter values and more detailed catalog information.

- SQL Call Level Interface (CLI) standard similar to ODBC interface, but with some minor differences.
JDBC is a Java API for communicating with database systems supporting SQL. It supports a variety of features for querying and updating data, and for retrieving query results. JDBC also supports metadata retrieval, such as querying about relations present in the database and the names and types of relation attributes.

Model for communicating with the database:
- Open a connection
- Create a "statement" object
- Execute queries using the Statement object to send queries and fetch results
- Exception mechanism to handle errors

JDBC Code

```java
public static void JDBCexample(String dbid, String userid, String passwd)
{
    try {
        Class.forName("oracle.jdbc.driver.OracleDriver");
        Connection conn = DriverManager.getConnection(
            "jdbc:oracle:thin:@aura.bell-labs.com:2000:bankdb", userid, passwd);
        Statement stmt = conn.createStatement();
        ... Do Actual Work ....
        stmt.close();
        conn.close();
    } catch (SQLException sqle) {
        System.out.println("SQLException : "+ sqle);
    }
}
```
**JDBC Code (Cont.)**

- Update to database
  
  ```java
  try {
    stmt.executeUpdate(  "insert into account values
                        ('A-9732', 'Perryridge', 1200)";)
  } catch (SQLException sqle) {
    System.out.println("Could not insert tuple. " + sqle);
  }
  ```

- Execute query and fetch and print results
  
  ```java
  ResultSet rset = stmt.executeQuery( "select branch_name, avg(balance)
                        from account
                        group by branch_name";
  while (rset.next()) {
    System.out.println(
      rset.getString("branch_name") + "  " + rset.getFloat(2)
    );
  }
  ```

**JDBC Code Details**

- Getting result fields:
  
  - `rs.getString("branchname")` and `rs.getString(1)` equivalent if `branchname` is the first argument of select result.

- Dealing with Null values
  
  ```java
  int a = rs.getInt("a");
  if (rs.wasNull()) Systems.out.println("Got null value");
  ```
Prepared Statement

- Prepared statement allows queries to be compiled and executed multiple times with different arguments
  
  ```java
  PreparedStatement pStmt = conn.prepareStatement("insert into account values(?,?,?)");
  pStmt.setString(1, "A-9732");
  pStmt.setString(2, "Perryridge");
  pStmt.setInt(3, 1200);
  pStmt.executeUpdate();
  pStmt.setString(1, "A-9733");
  pStmt.executeUpdate();
  ```

- NOTE: If value to be stored in database contains a single quote or other special character, prepared statements work fine, but creating a string and executing it directly would result in a syntax error!

Other SQL Features

- SQL sessions
  - ```java
  client connects to an SQL server, establishing a session
  ```
  - executes a series of statements
  - ```java
disconnects the session
  ```
  - ```java
can commit or rollback the work carried out in the session
  ```

- An SQL environment contains several components, including a user identifier, and a schema, which identifies which of several schemas a session is using.
Schemas, Catalogs, and Environments

- Three-level hierarchy for naming relations.
  - Database contains multiple catalogs
  - each catalog can contain multiple schemas
  - SQL objects such as relations and views are contained within a schema
  - e.g. catalog5.bank-schema.account
- Each user has a default catalog and schema, and the combination is unique to the user.
- Default catalog and schema are set up for a connection
- Catalog and schema can be omitted, defaults are assumed
- Multiple versions of an application (e.g. production and test) can run under separate schemas

Procedural Extensions and Stored Procedures

- SQL provides a module language
  - permits definition of procedures in SQL, with if-then-else statements, for and while loops, etc.
  - more in Chapter 9
- Stored Procedures
  - Can store procedures in the database
  - then execute them using the call statement
  - permit external applications to operate on the database without knowing about internal details
- These features are covered in Chapter 9 (Object Relational Databases)
Transactions in JDBC

- As with ODBC, each statement gets committed automatically in JDBC.
- To turn off auto commit use
  `conn.setAutoCommit(false);`
- To commit or abort transactions use
  `conn.commit()` or `conn.rollback()`
- To turn auto commit on again, use
  `conn.setAutoCommit(true);`
**Procedure and Function Calls in JDBC**

- JDBC provides a class CallableStatement which allows SQL stored procedures/functions to be invoked.
  
  ```java
  CallableStatement cs1 = conn.prepareCall("{call proc (?,?)}");
  CallableStatement cs2 = conn.prepareCall("{? = call func (?,?)}");
  ```

**Result Set MetaData**

- The class ResultSetMetaData provides information about all the columns of the ResultSet.
- Instance of this class is obtained by getMetaData() function of ResultSet.
- Provides Functions for getting number of columns, column name, type, precision, scale, table from which the column is derived etc.
  
  ```java
  ResultSetMetaData rsmd = rs.getMetaData();
  for (int i = 1; i <= rsmd.getColumnCount(); i++) {
      String name = rsmd.getColumnName(i);
      String typeName = rsmd.getColumnTypeName(i);
  }
  ```
**Database Meta Data**

- The class `DatabaseMetaData` provides information about database relations.
- Has functions for getting all tables, all columns of the table, primary keys etc.
- E.g. to print column names and types of a relation:

  ```java
  DatabaseMetaData dbmd = conn.getMetaData();
  ResultSet rs = dbmd.getColumns( null, "BANK-DB", "account", "%" );
  // Arguments: catalog, schema-pattern, table-pattern, column-pattern
  // Returns: 1 row for each column, with several attributes such as
  //          COLUMN_NAME, TYPE_NAME, etc.
  while ( rs.next( ) ) {
    System.out.println( rs.getString("COLUMN_NAME") ,
                        rs.getString("TYPE_NAME") );
  }
  ```

- There are also functions for getting information such as:
  - Foreign key references in the schema
  - Database limits like maximum row size, maximum no. of connections, etc.

**Application Architectures**

- Applications can be built using one of two architectures:
  - Two tier model
    - Application program running at user site directly uses JDBC/ODBC to communicate with the database
  - Three tier model
    - Users/programs running at user sites communicate with an application server. The application server in turn communicates with the database
Two-tier Model

- E.g. Java code runs at client site and uses JDBC to communicate with the backend server
- Benefits:
  - flexible, need not be restricted to predefined queries
- Problems:
  - Security: passwords available at client site, all database operation possible
  - More code shipped to client
  - Not appropriate across organizations, or in large ones like universities

Three Tier Model

- CGI Program
- Application/HTTP Server
- Servlets
- JDBC
- Database Server
- HTTP/Application Specific Protocol
- Network
- Client
- Client
- Client
Three-tier Model (Cont.)

- E.g. Web client + Java Servlet using JDBC to talk with database server
- Client sends request over http or application-specific protocol
- Application or Web server receives request
- Request handled by CGI program or servlets
- Security handled by application at server
  - Better security
  - Fine granularity security
- Simple client, but only packaged transactions

End of Chapter
The loan and borrower Relations

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
<th>loan-number</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
<td>L-170</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
<td>L-230</td>
</tr>
<tr>
<td>L-260</td>
<td>Perryridge</td>
<td>1700</td>
<td>Hayes</td>
<td>L-155</td>
</tr>
</tbody>
</table>

The Result of loan inner join borrower on loan.loan-number = borrower.loan-number

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
<th>loan-number</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
<td>L-170</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
<td>L-230</td>
</tr>
</tbody>
</table>
The Result of *loan* left outer join *borrower* on *loan-number*

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
<th>loan-number</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
<td>L-170</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
<td>L-230</td>
</tr>
<tr>
<td>L-260</td>
<td>Perryridge</td>
<td>1700</td>
<td><strong>null</strong></td>
<td><strong>null</strong></td>
</tr>
</tbody>
</table>

The Result of *loan* natural inner join *borrower*

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
</tr>
</tbody>
</table>
**Join Types and Join Conditions**

<table>
<thead>
<tr>
<th>Join types</th>
<th>Join Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>inner join</td>
<td>natural</td>
</tr>
<tr>
<td>left outer join</td>
<td>on &lt; predicate&gt;</td>
</tr>
<tr>
<td>right outer join</td>
<td>using ((A_1, A_1, ..., A_n))</td>
</tr>
<tr>
<td>full outer join</td>
<td></td>
</tr>
</tbody>
</table>

**The Result of** \textit{loan} natural right outer join \textit{borrower}

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
</tr>
<tr>
<td>L-155</td>
<td>null</td>
<td>null</td>
<td>Hayes</td>
</tr>
</tbody>
</table>
The Result of \textit{loan} full outer join \textit{borrower} using(loan-number)

<table>
<thead>
<tr>
<th>loan-number</th>
<th>branch-name</th>
<th>amount</th>
<th>customer-name</th>
</tr>
</thead>
<tbody>
<tr>
<td>L-170</td>
<td>Downtown</td>
<td>3000</td>
<td>Jones</td>
</tr>
<tr>
<td>L-230</td>
<td>Redwood</td>
<td>4000</td>
<td>Smith</td>
</tr>
<tr>
<td>L-260</td>
<td>Perryridge</td>
<td>1700</td>
<td>null</td>
</tr>
<tr>
<td>L-155</td>
<td>\textit{null}</td>
<td>\textit{null}</td>
<td>Hayes</td>
</tr>
</tbody>
</table>

SQL Data Definition for Part of the Bank Database

```sql
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),
        check (assets >= 0))

create table account
    (account-number char(10),
        branch-name  char(15),
        balance      integer,
        primary key (account-number),
        check (balance >= 0))

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