Chapter 4: SQL

- Basic Structure
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- Aggregate Functions
- Null Values
- Nested Subqueries
- Derived Relations
- Views
- Modification of the Database
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- Data Definition Language
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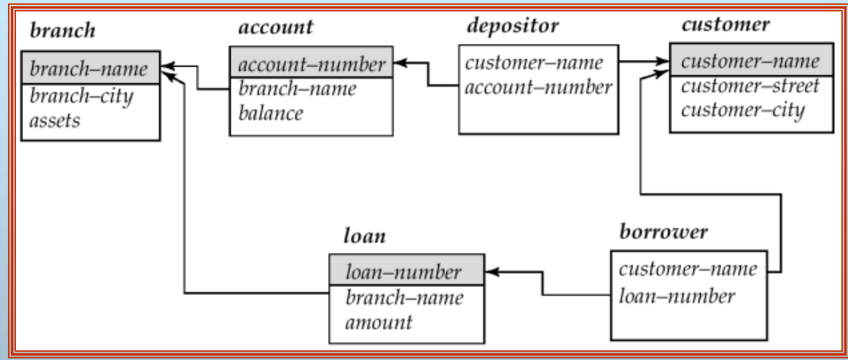
Schema Used in Examples



Basic Structure

- SQL is based on set and relational operations with certain modifications and enhancements
- A typical SQL query has the form:

  select $A_1, A_2, ..., A_n$
  from $r_1, r_2, ..., r_m$
  where P

  - A_is represent attributes
  - r_is represent relations
  - P is a predicate.
- This query is equivalent to the relational algebra expression.

$$\Pi_{A1,\ A2,\ ...,\ An}(\sigma_P\ (r_1 \ \mathrm{x}\ r_2 \ \mathrm{x}\ ...\ \mathrm{x}\ r_m))$$

- The result of an SQL query is a relation.

The select Clause

- The **select** clause list the attributes desired in the result of a query
  - 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*
- In the "pure" relational algebra syntax, the query would be:

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

- NOTE: SQL does not permit the '-' character in names,
  - Use, e.g., *branch_name* instead of *branch-name* in a real implementation.
  - We use '-' since it looks nicer!
- NOTE: SQL names are case insensitive, i.e. you can use capital or small letters.
  - You may wish to use upper case where-ever 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

  select distinct *branch-name*
  from *loan*

- The keyword **all** specifies that duplicates not be removed.

  select all *branch-name*
  from *loan*

The select Clause (Cont.)

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

  select *
  from *loan*

- The **select** clause can contain arithmetic expressions involving the operation, +, –, ∗, and /, and operating on constants or attributes of tuples.
- The query:

  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 specifies conditions that the result must satisfy
  - corresponds to the selection predicate of the relational algebra.
- To 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 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
- E.g. 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

The from Clause

- The **from** clause lists the relations involved in the query
  - corresponds to the Cartesian product operation of the relational algebra.
- 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'

The Rename Operation

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

  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.*

  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.

  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'

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".

  select *customer-name*
  from *customer*
  where *customer-street* **like** '%Main%'

- Match the name "Main%"

  like 'Main\%' **escape** '\'

- 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

  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. $\sigma_\theta(r_1)$: If there are c_1 copies of tuple t_1 in r_1, and t_1 satisfies selections σ_θ, then there are c_1 copies of t_1 in $\sigma_\theta(r_1)$.
  2. $\Pi_A(r)$: 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. r_1 **x** r_2 : 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 x c_2 copies of the tuple t_1. t_2 in r_1 x 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*)} r_2 = {(2), (3), (3)}

- Then $\Pi_B(r_1)$ would be {(a), (a)}, while $\Pi_B(r_1)$ x r_2 would be

  {(*a*,2), (*a*,2), (*a*,3), (*a*,3), (*a*,3), (*a*,3)}

- SQL duplicate semantics:

  select $A_1, A_2, \ldots, A_n$
  from $r_1, r_2, \ldots, r_m$
  where *P*

  is equivalent to the *multiset* version of the expression:

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

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* **union all** *s*
  - min(*m,n)* times in *r* **intersect all** *s*
  - max(0, *m – n)* times in *r* **except all** *s*

Set Operations

- Find all customers who have a loan, an account, or both:

```
(select customer-name from depositor)
    union
    (select customer-name from borrower)
```

- Find all customers who have both a loan and an account.

```
(select customer-name from depositor)
    intersect
    (select customer-name from borrower)
```

- Find all customers who have an account but no loan.

```
(select customer-name from depositor)
    except
    (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.

```
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
```


Aggregate Functions – 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

Aggregate Functions – Having Clause

- 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

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.*

    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.

```
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

```
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

```
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.

(Schema used in this example)

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

- F <comp> **some** $r \Leftrightarrow \exists\, t \in r$ *s.t.* (F <comp> *t*)
  Where <comp> can be: $<, \leq, >, =, \neq$

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

(= **some**) $\equiv$ **in**
However, ($\neq$ **some**) $\not\equiv$ **not in**

Definition of all Clause

- F <comp> **all** $r \Leftrightarrow \forall\, t \in r$ (F <comp> *t*)

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

($\neq$ **all**) $\equiv$ **not in**
However, (= **all**) $\not\equiv$ **in**

Example Query

- 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** $r \Leftrightarrow r \neq \emptyset$
- **not exists** $r \Leftrightarrow r = \emptyset$

Example Query

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

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 $X - Y = \emptyset \Leftrightarrow X \subseteq Y$
- *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.

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.

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:

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

  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'

Derived Relations

- Find the average account balance of those branches where the average account balance is greater than $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

  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

  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.

  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

  delete from *account*
  where *branch-name* = 'Perryridge'

- Delete all accounts at every branch located in Needham city.

  delete from *account*
  where *branch-name* **in** (**select** *branch-name*
  from *branch*
  where *branch-city* = 'Needham')
  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.

  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*

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

  or equivalently

  insert into *account (branch-name, balance, account-number)*
  values ('Perryridge', 1200, 'A-9732')

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

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

Modification of the Database – Insertion

- 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

  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

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

  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:

    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%.

  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

  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 the tuple

  ('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

    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.

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 – Datasets for Examples

- Relation *loan*

loan-number	*branch-name*	*amount*
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

- Relation *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*

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 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 (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* (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)

Integrity Constraints in Create Table

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

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

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 **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

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

  EXEC SQL <embedded SQL statement > END-EXEC

  Note: this varies by language. E.g. the Java embedding uses
  # 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

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

  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.

  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.

  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

  declare *c* **cursor for**
  select *
  from *account*
  where *branch-name* = 'Perryridge'
  for update

- To update tuple at the current location of cursor

  update *account*
  set *balance* = *balance* + 100
  where current of *c*

Dynamic SQL

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

char * *sqlprog* = "**update** *account*
set *balance* = *balance* * 1.05
where *account-number* = ?"
EXEC SQL **prepare** *dynprog* **from** *:sqlprog;*
char *account* [10] = "A-101";
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

ODBC (Cont.)

- 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.

ODBC Code

```
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.

ODBC Code (Cont.)

- Main body of program

```
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\n", 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

- JDBC is a Java API for communicating with database systems supporting SQL
- JDBC 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

```
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

```
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

```
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

```
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

```
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();
```

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

Other SQL Features

- SQL sessions
  - client *connects* to an SQL server, establishing a session
  - executes a series of statements
  - *disconnects* the session
  - 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)

Extra Material on JDBC and Application Architectures

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.

```
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.

```
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

```
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

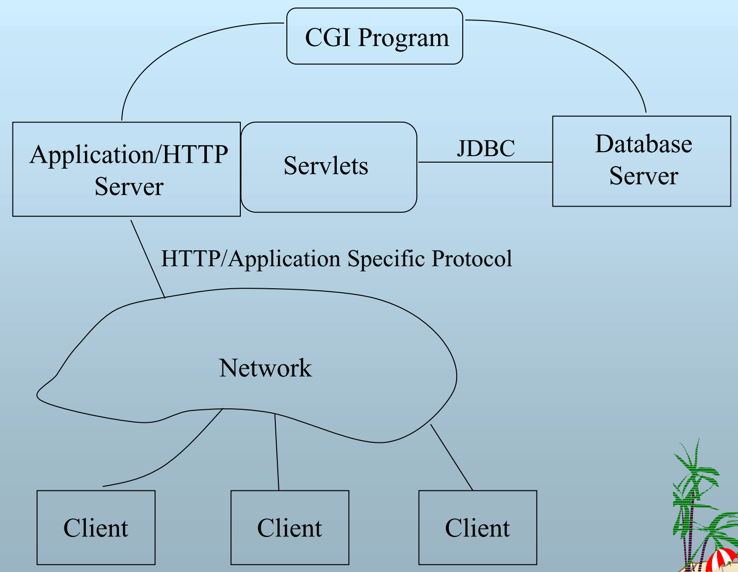
Application Architectures

- 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



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

loan-number	*branch-name*	*amount*
L-170	Downtown	3000
L-230	Redwood	4000
L-260	Perryridge	1700

loan

customer-name	*loan-number*
Jones	L-170
Smith	L-230
Hayes	L-155

borrower

The Result of *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

The Result of *loan* left outer join *borrower* on *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*

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

loan-number	*branch-name*	*amount*	*customer-name*
L-170	Downtown	3000	Jones
L-230	Redwood	4000	Smith

Join Types and Join Conditions

Join types
inner join
left outer join
right outer join
full outer join

Join Conditions
natural
on < predicate>
using $(A_1, A_1, \ldots, A_n)$

The Result of *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

The Result of *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

SQL Data Definition for Part of the Bank Database

```
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))
```