The Relational Data Model

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The Relational Data Model

- A particular way of structuring data (using relations) proposed in 1970 by E. F. Codd
  - Mathematically based
  - Expressions (≡ queries) can be analyzed by DBMS and transformed to equivalent expressions automatically (query optimization)
    - Optimizers have limits (⇒ the programmer still needs to know how queries are evaluated and optimized)
In Relational DBs, the data is stored in tables. The attributes (column headers) are

- Id
- Name
- Address
- Status

The tuples (rows) are:

<table>
<thead>
<tr>
<th>Id</th>
<th>Name</th>
<th>Address</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1111</td>
<td>John</td>
<td>123 Main</td>
<td>fresh</td>
</tr>
<tr>
<td>2222</td>
<td>Mary</td>
<td>321 Oak</td>
<td></td>
</tr>
<tr>
<td>1234</td>
<td>Bob</td>
<td>444 Pine</td>
<td></td>
</tr>
<tr>
<td>9999</td>
<td>Joan</td>
<td>777 Grand</td>
<td>senior</td>
</tr>
</tbody>
</table>
Table

- Set of rows (no duplicates)
- Each row/tuple describes a different entity
- Each column/attribute states a particular fact about each entity
  - Each column has an associated domain

<table>
<thead>
<tr>
<th>Id</th>
<th>Name</th>
<th>Address</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1111</td>
<td>John</td>
<td>123 Main</td>
<td>fresh</td>
</tr>
<tr>
<td>2222</td>
<td>Mary</td>
<td>321 Oak</td>
<td></td>
</tr>
<tr>
<td>1234</td>
<td>Bob</td>
<td>444 Pine</td>
<td></td>
</tr>
<tr>
<td>9999</td>
<td>Joan</td>
<td>777 Grand</td>
<td>senior</td>
</tr>
</tbody>
</table>

- Domain of Id: integers
- Domain of Name: strings
- Domain of Status = \{fresh, soph, junior, senior\}
A relation is the mathematical entity corresponding to a table:

- A relation $R$ can be thought of as predicate $R$
  - A tuple $(x, y, z)$ is in the relation $R$ iff $R(x, y, z)$ is true

Why Relations/Tables?

- Very simple model.
- Often matches how we think about data.
- Underlies Excel, the most important application in industry today.
Operations

- Operations on relations are precisely defined:
  - Take relation(s) as argument, produce new relation as result
    - Unary (e.g., selection, projection, delete certain rows)
    - Binary (e.g., natural join, Cartesian product, union)
  - Using mathematical properties, equivalence of expressions can be decided (important for query optimization)

\[ \text{op1}(T1,\text{op2}(T2)) = \text{op3}(\text{op4}(T1),T2) \]

- these expressions could have different execution time complexities
Relation Schema

- A relation schema is the heading of that table and the applicable constraints (integrity constraints).

- A relation schema is composed of:
  - Relation name
  - Attribute names & domains
  - Integrity constraints like:
    - The values of a particular attribute in all tuples are unique (e.g., PRIMARY KEY)
    - The values of a particular attribute are greater than 0 (although, the domain can be bigger)
  - Default values for some attributes

- A relation consists of a relation schema and a relation instance.
Schemas

- Relation schema example:

Example: `Student(id, name, address, status)` or `Student(id:int, name:string, address:string, status:string {fresh, soph, junior, senior})`

Underline an attribute means a key (tuples cannot have the same value in key attributes) - this is an example of a constraint on the relation.
Relational Database

• A database schema = the set of relation schemas and constraints among relations (inter-relational constraints)

• A relational database (or database instance) = a set of (corresponding) relation instances
Database Schema Example

- **Student** (Id: INT, Name: STRING, Address: STRING, Status: STRING)
- **Department** (DeptId: STRING, Name: STRING)
- **Professor** (Id: INT, Name: STRING, DeptId: STRING)
- **Course** (CrsCode: STRING, DeptId: STRING, CrsName: STRING, Descr: STRING)
- **Teaching** (ProfId: INTEGER, CrsCode: STRING, Semester: STRING)
- **Transcript** (StudId: INTEGER, CrsCode: STRING, Semester: STRING, Grade: STRING)
Relation Instance

- A relation instance is a set of tuples:
  - Tuple ordering immaterial
  - No duplicates

- All tuples in a relation have the same structure; constructed from the same set of attributes:
  - Attributes are named (ordering is immaterial)
  - Value of an attribute is drawn from the attribute's domain.
  - Arity of relation = number of attributes.
Relation Instance

- There is also a special value `NULL` (commonly referred to as a null value, value unknown or undefined), which we use a placeholder and store it in place of an attribute until more information becomes available.
- Null values arise because of a lack of information.
- Null values arise by design sometimes.
  - For instance, the attribute MaidenName is applicable to females but not to males.

Employee(Id:INT, Name:STRING, MaidenName:STRING)

- We do not allow null values in certain sensitive places, such as the primary key (see later).
Relation Instance of the Student relation

A relation instance can be represented as a table: the attributes are the column headers and the tuples are the rows:

<table>
<thead>
<tr>
<th>Id</th>
<th>Name</th>
<th>Address</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>11111111</td>
<td>John</td>
<td>123 Main</td>
<td>freshman</td>
</tr>
<tr>
<td>2345678</td>
<td>Mary</td>
<td>456 Cedar</td>
<td>sophomore</td>
</tr>
<tr>
<td>4433322</td>
<td>Art</td>
<td>77 So. 3rd</td>
<td>senior</td>
</tr>
<tr>
<td>7654321</td>
<td>Pat</td>
<td>88 No. 4th</td>
<td>sophomore</td>
</tr>
</tbody>
</table>

Student
Integrity Constraints

• An *integrity constraint* (IC) is a statement about all legal instances of a database:
  • Restriction on a state (or of sequence of states) of a database (it is a part of the schema)
  • Enforced/checked automatically by the DBMS
  • Protects database from errors
  • Enforces enterprise rules

• *Intra-relational* - involve only one relation
  • e.g., all Student Ids are unique (*key*)

• *Inter-relational* - involve several relations
  • e.g., the value of the attribute Id of each professor shown as Teaching a course must appear as the value of the Id attribute of some row of the table Professor (*foreign-key*)
Kinds of Integrity Constraints

- **Static** – restricts legal states of database
  - Syntactic (structural constraints)
    - e.g., all values in a column must be unique
  - Semantic (involve meaning of attributes)
    - e.g., cannot register for more than 18 credits
- **Dynamic constraints** – limitation on sequences of database states
  - e.g., cannot raise salary by more than 5% in one transaction
BEFORE WE Continue

• Install MariaDB: [https://mariadb.org/](https://mariadb.org/)
  • Easy install
  • It comes with HeidiSQL Client.
Kinds of Integrity Constraints

• Syntactic constraint example:

```sql
CREATE TABLE Student(
    ID INTEGER,
    NAME CHAR(50) NOT NULL,
    ADDRESS CHAR(50),
    STATUS CHAR(10) DEFAULT "fresh",
    PRIMARY KEY (ID)
);
```
Key Constraint

- A key constraint (or candidate key) is a sequence of attributes $A_1, \ldots, A_n$ ($n=1$ is possible) of a relation schema, $S$, with the following property:
  - A relation instance $s$ of $S$ satisfies the key constraint iff at most one row in $s$ can contain a particular set of values, $a_1, \ldots, a_n$, for the attributes $A_1, \ldots, A_n$.
- Minimality property: no subset of $A_1, \ldots, A_n$ is a key constraint.
- Key examples:
  - Set of attributes mentioned in a key constraint:
    - e.g., $\{\text{Id}\}$ in Student,
    - e.g., $\{\text{StudId, CrsCode, Semester}\}$ in Transcript.
  - It is minimal: no subset of a key is a key.
    - $\{\text{Id, Name}\}$ is not a key of Student.
Key Constraint

- **Student** (Id:INTEGER, Name:STRING, Address:STRING, Status:STRING)
  - Key: {Id}

- **Professor** (Id:INTEGER, Name:STRING, DeptId:STRING)
  - Key: {Id}

- **Teaching** (ProfId:INTEGER, CrsCode:STRING, Semester:STRING)
  - Key: {CrsCode, Semester}

- **Course** (CrsCode:STRING, DeptId:STRING, CrsName:STRING, Descr:STRING)
  - Keys: {CrsCode}, {DeptId, CrsName}

- **Transcript** (StudId:INTEGER, CrsCode:STRING, Semester:STRING, Grade:STRING)
  - Key: {StudId, CrsCode, Semester}
Key Constraint

• One of the keys of a relation is designated as the primary key.

• Superkey - set of attributes containing a key
  • \{Id, Name\} is a superkey of Student
Key Constraint

• Every relation has a key:
  • the set of all attributes in a schema, S, is always a superkey because if a legal instance of S has a pair of tuples that agree on all attributes in S, then these must be identical tuples: since relations are sets, they cannot have identical elements
Key Constraint

• A schema can have several different keys.

• Example:
  
  • in the Course relation:
    
    • \{\text{CrsCode}\} can be one key.
    
    • \{\text{DeptId}, \text{CrsName}\} is also a key in the same relation because it is unlikely that the same department will offer two different courses with the same name.
Foreign Key Constraint

- **Referential integrity**: an item named in one relation must refer to tuples that describe that item in another relation.
Foreign Key Constraint

• Attribute $A_1$ is a foreign key of $R_1$ referring to attribute $A_2$ in $R_2$, if whenever there is a value $v$ of $A_1$, there is a tuple of $R_2$ in which $A_2$ has value $v$, and $A_2$ is a key of $R_2$

• This is a special case of referential integrity: $A_2$ must be a candidate key of $R_2$ (e.g., CrsCode is a key of Course relation)

• If no row exists in $R_2 \Rightarrow$ violation of referential integrity

• Not all rows of $R_2$ need to be referenced: relationship is not symmetric (e.g., some course might not be taught)

• Value of a foreign key might not be specified (DeptId column of some professor might be NULL)
Foreign Key Constraint

- Names of the attrs. in foreign key and candidate key need not be the same

Teaching(CrsCode: COURSES, Sem: SEMESTERS, ProfId: INT)
Professor(Id: INT, Name: STRING, DeptId: DEPTS)

- ProfId attribute of Teaching references Id attribute of Professor
Foreign Key Constraint

- $R_1$ and $R_2$ need not be distinct

Employee($Id$:INT, $MgrId$:INT, ....)

- Employee($MgrId$) references Employee($Id$)
  - Every manager is also an employee and hence has a unique row in Employee
Foreign Key Constraint

- Foreign key might consist of several columns
  - \( R_1(A_1, \ldots A_n) \) references \( R_2(B_1, \ldots B_n) \)
    - \( A_i \) and \( B_i \) must have same domains (although not necessarily the same names)
    - \( B_1, \ldots, B_n \) must be a candidate key of \( R_2 \)
- Example: \((\text{CrsCode}, \text{Semester})\) of Transcript references \((\text{CrsCode}, \text{Semester})\) of Teaching
  - Teaching(ProfId:INTEGER, CrsCode:STRING, Semester:STRING)
    - Key: \{CrsCode, Semester\}
  - Transcript(StudId:INTEGER, CrsCode:STRING, Semester:STRING, Grade:STRING)
    - Key: \{StudId, CrsCode, Semester\}
SQL

• SQL is a language for describing database schema and operations on tables
  • Data Definition Language (DDL): sublanguage of SQL for describing schema

• The SQL Keywords are case-insensitive (SELECT, FROM, WHERE, etc), but are often written in all caps.
  • The case sensitivity of the underlying operating system plays a part in the case sensitivity of database, table, and trigger names.
    • This means such names are not case sensitive in Windows, but are case sensitive in most varieties of Unix.
Data Definition Sublanguage

- An SQL schema is a description of a portion of a database
  
  CREATE SCHEMA SRS_StudInfo

- It usually is under the control of a single user who has the authorization to create and access the objects within it.
  
  CREATE SCHEMA SRS_StudInfo AUTHORIZATION Joe

- Joe can also delete the schema:
  
  DROP SCHEMA SRS_StudInfo
Tables

- Table: is an SQL entity that corresponds to a relation
- SQL-92 is currently the most supported standard but is superseded by SQL:1999 (recursive queries, triggers, and some object-oriented features), SQL:2003 (SQL/XML), SQL:2006 (storing XML data in an SQL, xQuery), SQL:2008 (ORDER BY), SQL:2011 (Time Periods), SQL:2016 (JSON)
CREATE TABLE Student (  
  Id INTEGER,  
  Name CHAR(20),  
  Address CHAR(50),  
  Status CHAR(10)  
)
SQL Types

- Database vendors generally deviate from the standard even on basic features like the data types:
  - SQL Data Types for Various DBs:
    - [http://www.w3schools.com/sql/sql_datatypes.asp](http://www.w3schools.com/sql/sql_datatypes.asp)
  - We will focus on MariaDB here.
SQL CHAR Types

- **CHAR(n)**
  - Used to store character string value of fixed length.
  - The maximum no. of characters the data type can hold is 255 characters.
  - It's 50% faster than VARCHAR.
  - Uses static memory allocation.
  - Good for things of the same size (e.g., signatures, keys, zips, phone, ssn)

- **VARCHAR(n)**
  - Used to store variable length alphanumeric data.
  - The maximum this data type can hold is up to
    - Pre-MySQL 5.0.3: 255 characters.
    - In MySQL 5.0.3+: 65,535 characters shared for the row.
  - It's slower than CHAR.
  - Uses dynamic memory allocation.
SQL Numeric Types

- **INTEGER (INT)**
  - Integer numerical (no decimal). Precision 10 digits.

- **SMALLINT**
  - Integer numerical (no decimal). Precision 5.

- **BIGINT**
  - Integer numerical (no decimal). Precision 19.

- **DECIMAL(p,s)** (same with NUMERIC, DOUBLE)
  - Exact numerical, precision p, scale s. Example: `decimal(5,2)` is a number that has 3 digits before the decimal and 2 digits after the decimal.

- **REAL**
  - Approximate numerical, mantissa precision 7

- **FLOAT**
  - Approximate numerical, mantissa precision 16
SQL TIME Types

- DATE
  - Stores year, month, and day values.
  - Format: YYYY-MM-DD.
  - The supported range is from "1000-01-01" to "9999-12-31".

- TIME
  - Stores hour, minute, and second values
  - Format: HH:MI:SS.
  - The supported range is from "-838:59:59" to "838:59:59".

- DATETIME
  - A date and time combination.
  - Format: YYYY-MM-DD HH:MI:SS
Other SQL Types

- **BLOB**
  - For BLOBs (Binary Large OBjects). Holds up to 65,535 bytes of data

- **ENUM(x,y,z,etc.)**
  - Let you enter a list of possible values. You can list up to 65535 values in an ENUM list. If a value is inserted that is not in the list, a blank value will be inserted.

- **SET**
  - Similar to ENUM except that SET may contain up to 64 list items and can store more than one choice.

- **XML**
  - Stores XML formatted data.
  - Not in MySQL, but in DB2, Oracle, SQL Server.
Primary/Candidate Keys

CREATE TABLE Course (  
CrsCode CHAR(6),  
CrsName CHAR(20),  
DeptId CHAR(4),  
Descr CHAR(100),  
PRIMARY KEY (CrsCode),  
UNIQUE (DeptId, CrsName)  -- candidate key
)
Null

- Problem: Not all information might be known when row is inserted (e.g., a Grade might be missing from Transcript)
- A column might not be applicable for a particular row (e.g., MaidenName if row describes a male)
- Solution: Use place holder: null
  - Not a value of any domain (although called null value)
    - Indicates the absence of a value
  - Not allowed in certain situations
    - Primary keys and columns constrained by NOT NULL
Default Value

- Value to be assigned if attribute value in a row is not specified

```sql
CREATE TABLE Student (
    Id INTEGER,
    Name CHAR(20) NOT NULL,
    Address CHAR(50),
    Status CHAR(10) DEFAULT "freshman",
    PRIMARY KEY (Id)
)
```
Semantic Constraints in SQL

• Primary key and foreign key are examples of structural constraints

• Semantic constraints
  • Express the logic of the application at hand:
    • e.g., number of registered students ≤ maximum enrollment
Semantic Constraints in SQL

• Often used for application dependent conditions

• Example: limit attribute values

```sql
CREATE TABLE Transcript (
    StudId  INTEGER,
    CrsCode  CHAR(6),
    Semester  CHAR(6),
    Grade  CHAR(1),
    CHECK (Grade IN ("A", "B", "C", "D", "F")),
    CHECK (StudId > 0 AND StudId < 1000000000)
)
```

• Each row in table must satisfy condition
Semantic Constraints in SQL

- Example: relate values of attributes in different columns

CREATE TABLE Employee (  
    Id    INTEGER,  
    Name  CHAR(20),  
    Salary    INTEGER,  
    MngrSalary    INTEGER,  
    CHECK ( MngrSalary > Salary)  
)
Constraints – Problems

• Problem 1:
  • The semantics of the CHECK clause requires that every tuple in the corresponding relation satisfy all of the conditional expressions associated with all CHECK clauses in the corresponding CREATE TABLE statement.
  • The empty relation (i.e., a relation that contains no tuples) always satisfies all CHECK constraints as there are no tuples to check.
 Assertion

• Symmetrically specifies an inter-relational constraint
• Applies to entire database (not just the individual rows of a single table)
  • hence it works even if Employee is empty
• Unlike the CHECK conditions that appear inside a table definition, those in the CREATE ASSERTION statement must be satisfied by the contents of the entire database rather than by individual tuples of a host table.
Assertion

- Example: the Employee table cannot be empty:

  \[
  \text{CREATE ASSERTION EmployeeNotEmpty}
  \quad \text{CHECK (0 < SELECT COUNT (*) FROM Employee)}
  \]

- If, at the time of specifying the constraint, the Employee relation is empty, the SQL standard states that if a new constraint is defined and the existing database does not satisfy it, the constraint is rejected.

- The database designer then has to find out the cause of constraint violation and either rectify the database or amend the constraint.

- MariaDB does not support ASSERTIONS.
Assertion

- Example: employees cannot earn more than their managers:

```
CREATE ASSERTION EmployeeSalariesDown
CHECK NOT EXISTS
(SELECT * FROM Employee, Manager
WHERE Employee.MngrId = Manager.Id AND
Employee.Salary > Manager.Salary )
```
User-Defined Domains

• Possible attribute values can be specified
  • Using a CHECK constraint or
  • Creating a new domain
    • An alternative SQL way to allow the user to define appropriate ranges of values, give them domain names, and then use these names in various table definitions.
  • Domain can be used in several declarations
Domains

• Examples:

CREATE DOMAIN Grades CHAR (1)
CHECK (VALUE IN ("A", "B", "C", "D", "F"));

CREATE TABLE Transcript (  
    ....,
    Grade: Grades,
    ...  )

• MariaDB doesn't support domains
SQL Foreign Key Constraints

CREATE TABLE Teaching (  
    ProfId INTEGER,  
    CrsCode CHAR(6),  
    Semester CHAR(6),  
    PRIMARY KEY (CrsCode, Semester),  
    FOREIGN KEY (CrsCode) REFERENCES Course(CrsCode),  
    FOREIGN KEY (ProfId) REFERENCES Professor (Id) );

• The Course table must have a CrsCode attribute and key.  
• In MariaDB, we must specify the attribute even if it is the same name.

FOREIGN KEY (CrsCode) REFERENCES Course(CrsCode)
Circularity in Foreign Key Constraints

- Candidate key: $A_1$
- Foreign key: $A_3$ references $B(B_1)$
- Candidate key: $B_1$
- Foreign key: $B_3$ references $A(A_1)$

**Chicken-and-egg problem:**

**Problem 1:** Creation of $A$ requires existence of $B$ and vice versa

**Solution:**

- `CREATE TABLE A ( .... ) -- no foreign key`
- `CREATE TABLE B ( .... ) -- include foreign key`
- `ALTER TABLE A`
- `ADD CONSTRAINT cons`
- `FOREIGN KEY (A_3) REFERENCES B (B_1)`
Circularity in Foreign Key Constraints

- Problem 2: Insertion of row in A requires prior existence of row in B and vice versa

Solution: use appropriate constraint checking mode:
- IMMEDIATE checking: a check is made after each SQL statement that changes the database
- DEFERRED checking: a check is made only when a transaction commits.

```
ALTER TABLE chicken ADD CONSTRAINT chickenREFegg
FOREIGN KEY (eID) REFERENCES egg(eID)
INITIALLY DEFERRED DEFERRABLE;

ALTER TABLE egg ADD CONSTRAINT eggREFchicken
FOREIGN KEY (cID) REFERENCES chicken(cID)
INITIALLY DEFERRED DEFERRABLE;
```
Reactive Constraints

- When a constraint is violated, the corresponding transaction is typically aborted.
  - However, in some cases, other remedial actions are more appropriate.
    - Foreign-key constraints are one example of this situation.
- It would be nice to have a mechanism that allows a user to specify how to react to a violation of a constraint.
  - A reactive constraint is a static constraint coupled with a specification of what to do if a certain event happens.
    - Triggers attached to foreign-key constraints
Handling Foreign Key Violations

- Insertion into A:
  - Reject if no row exists in B containing foreign key of inserted row!
Handling Foreign Key Violations

- Deletion from B:
  - Multiple possible responses.
  - **NO ACTION**: Reject if row(s) in A references row to be deleted (default response)

\[
\begin{array}{|c|}
\hline
\text{A} & \text{x} \\
\hline
\end{array}
\quad \rightarrow \quad
\begin{array}{|c|}
\hline
\text{B} & \text{x} & ? \\
\hline
\end{array}
\]

*Request to delete row rejected*
Handling Foreign Key Violations

- Deletion from B:
  - SET NULL: Set value of foreign key in referencing row(s) in A to NULL

```
<table>
<thead>
<tr>
<th>A</th>
<th>NULL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>

Row deleted
```
Handling Foreign Key Violations

- **Deletion from B:**
  - **SET DEFAULT:** Set value of foreign key in referencing row(s) in A to default value (y) which must exist in B

<table>
<thead>
<tr>
<th>A</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>y</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>B</th>
<th>y</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>x</td>
</tr>
</tbody>
</table>
Handling Foreign Key Violations

• Deletion from B:
  • CASCADE: Delete referencing row(s) in A as well
Handling Foreign Key Violations

- Update (change) foreign key in A: Reject if no row exists in B containing new foreign key
- Update candidate key in B (to z) – same actions as with deletion:
  - NO ACTION: Reject if row(s) in A references row to be updated (default response)
  - SET NULL: Set value of foreign key to null
  - SET DEFAULT: Set value of foreign key to default
  - CASCADE: Propagate z to foreign key

Cascading when key in B changed from x to z
Specifying Actions

CREATE TABLE Teaching ( 
    ProfId INTEGER, 
    CrsCode CHAR (6), 
    Semester CHAR (6), 
    PRIMARY KEY (CrsCode, Semester),

    FOREIGN KEY (ProfId) REFERENCES Professor (Id) 
    ON DELETE NO ACTION 
    ON UPDATE CASCADE, 

    FOREIGN KEY (CrsCode) REFERENCES Course (CrsCode) 
    ON DELETE NO ACTION 
    ON UPDATE CASCADE 
);
Handling Foreign Key Violations

- The action taken to repair the violation of a foreign key constraint in A may cause a violation of a foreign key constraint in C
  - The action specified in C controls how that violation is handled
  - If the entire chain of violations cannot be resolved, the initial deletion from B is rejected
Insert

• Inserting a single row into a table
• Attribute list can be omitted if it is the same as in CREATE TABLE (but do not omit it)
• NULL and DEFAULT values can be specified

```sql
INSERT INTO Student(Id, Name, Address, Status) VALUES (12345, "John Smith", "123 Main St, NYC", NULL);
```
Database Views

• Part of external schema
• A virtual table constructed from actual tables on the fly
  • Can be accessed in queries like any other table
  • Not materialized, constructed when accessed
  • Similar to a subroutine in ordinary programming
Views - Examples

• Part of external schema suitable for use in Bursar's office:

```sql
CREATE VIEW CoursesTaken (StudId, CrsCode, Semester) AS
    SELECT StudId, CrsCode, Semester
    FROM Transcript T;
SELECT * FROM CoursesTaken;
```

• Part of external schema suitable for student with Id 123456789:

```sql
CREATE VIEW CoursesITook (CrsCode, Semester, Grade) AS
    SELECT CrsCode, Semester, Grade
    FROM Transcript T
    WHERE StudId = 123456789;
SELECT * FROM CoursesITook;
```
Modifying the Schema

- Although database schemas are not supposed to change frequently, they do evolve (new fields are added, etc.)

  ALTER TABLE Student
  ADD COLUMN Gpa INTEGER DEFAULT 0;

  ALTER TABLE Student
  ADD CONSTRAINT GpaRange
  CHECK (Gpa >= 0 AND Gpa <= 4);

  ALTER TABLE Student
  DROP CONSTRAINT GpaRange;  -- constraint names are useful

  DROP TABLE Employee
Access Control

- Databases might contain sensitive information
- Access has to be limited:
  - Users have to be identified – authentication
    - Generally done with passwords
  - Each user must be limited to modes of access appropriate to that user - authorization
- SQL:92 provides tools for specifying an authorization policy but does not support authentication (i.e., vendor specific)
Controlling Authorization in SQL

CREATE USER "joe"@"localhost" IDENTIFIED BY "password";

GRANT ALL PRIVILEGES ON * . * TO "joe"@"localhost";
Controlling Authorization in SQL

```
GRANT access_list
   ON table
   TO user_list

access modes: SELECT, INSERT, DELETE, UPDATE, REFERENCES, ALL PRIVILEGES

GRANT UPDATE (Grade) ON Transcript TO prof_smith
   – The Grade column can be updated only by prof_smith

GRANT SELECT ON Transcript TO joe
   – Individual columns cannot be specified for SELECT access (in the SQL standard) – all columns of Transcript can be read
   – But SELECT access control to individual columns can be simulated through views
```
Controlling Authorization in SQL Using Views

GRANT access
ON view
TO user_list

GRANT SELECT ON Course Taken TO joe

• Thus views can be used to simulate access control to individual columns of a table
REVOKE

- Privileges, or the grant option for privileges, can be revoked using the REVOKE statement.

    REVOKE [ GRANT OPTION FOR ] privilege-list
    ON object
    FROM user-list {CASCADE | RESTRICT}

- CASCADE means that if some user, U₁, whose user name appears on the list userlist, has granted those privileges to another user, U₂, the privileges granted to U₂ are also revoked.
  - If U₂ has granted those privileges to still another user, those privileges are revoked as well, and so on.

- RESTRICT means that if any such dependent privileges exist, the REVOKE statement is rejected.
REFERENCE Access mode

• The GRANT REFERENCES permission on a table is needed to create a FOREIGN KEY constraint that references that table.

GRANT REFERENCES ON Student TO joe

• Now Joe can create tables that have foreign keys to Student keys
Access mode problem

- Granting privileges at the level of database operations, such as SELECT or UPDATE, is not adequate.
- For example, only a depositor can deposit in a bank account and only a bank official can add interest to the account, but both the deposit and interest transactions might use the same UPDATE statement.
- For such applications, it is more appropriate to grant privileges at the level of subroutines or transactions.
Triggers

• The ON DELETE/UPDATE triggers are simple and powerful, but they are not powerful enough to capture a wide variety of constraint violations that arise in database applications and are not due to foreign keys

• A more general mechanism for handling events
  • Whenever a specified event occurs, execute some specified action
  • Not in SQL-92, but is in SQL:1999

CREATE TRIGGER CrsChange
  AFTER UPDATE OF CrsCode, Semester ON Transcript
  WHEN (Grade IS NOT NULL)
  ROLLBACK

• Trigger is a schema element (like table, assertion, etc.)