The Relational Data Model

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Data Model

- Need a model for describing
  - The structure of data and constraints
  - Operations on data
- Describe data at some abstraction layer (schema)
  - External
  - Conceptual
  - Physical

Physical Level

- Data description: e.g.
  - Student data is stored in tracks 4 to 15 of Cylinder 3.
  - Student data is sorted on student id.
  - Course data is stored in an ASCII file named courses.dat
  - Records are separated by new-line characters.
  - Fields are separated by commas.
- Data manipulation: e.g.
  - Read all data in track 2 of cylinder 4.
  - Find John’s record in the data just read.
  - Update John’s record.
  - Write back the data in track 2 of cylinder 4.

Physical Level (Cont)

- **Problems of working with data:** Routines hard-coded to deal with physical representation.
  - Difficult to change the physical representation.
  - Application code becomes complex since it must deal with details.
  - Rapid implementation of new features impossible.

Conceptual Level

- Hides details.
  - In the relational model, the conceptual schema presents data as a set of tables.
- Mapping from conceptual to physical schema done by DBMS.
- Physical schema can be changed without changing applications.
  - Referred to as *physical data independence*.

Relational Databases

- Basic idea:
  - Organize data as a set of tables.
  - View each table as a set of rows.
- Advantages
  - simple
  - solid mathematical foundation
    - ✓ set theory
  - powerful query languages
  - efficient query optimizers

Definition

- *Relational database:* a set of relations (tables)
- *Relation:* consists of
  - *Instance* : *table content*, with rows and columns.
    - ✓ #Rows = *cardinality*, #fields = *degree / arity.*
  - *Schema* : *table structure, with* name and type of columns.
    - ✓ E.G. Students(*sid*: char(8), *name*: char(16), *login*: char(8), *age*: int, *gpa*: float).
- More formally, a relation is a *set* of rows (or *tuples*)
  - What does this imply for each tuple?

Example: Students Relation

sid	name	login	age	gpa
10310	Mary	mary@cs	19	3.6
10400	Bob	bob@physics	20	3.2
11001	Bob	bob@math	18	3.8

- Cardinality = 3, degree = 5, all rows distinct
- Domain: the set of values from which the values of an attribute are drawn.
    - e.g. name : char(16), age : {1,..,100}

Querying Relations

- Simple and powerful *querying* of data.
  - Queries can be written intuitively, and the DBMS is responsible for efficient evaluation.
  - Precise semantics for relational queries.
  - Allows the optimizer to extensively re-order operations, and still ensure that the answer does not change.

Example: Querying Relations in SQL

- To find all 18 year old students, we can write:

```
SELECT *
FROM Students S
WHERE S.age=18;
```

sid	name	login	age	gpa
10310	Mary	mary@cs	19	3.6
10400	Bob	bob@physics	20	3.2
11001	Bob	bob@math	18	3.8

- To find just names and logins, replace the first line with:

```
SELECT S.name, S.login
```

Example: Querying Multiple Relations

- What does the following query do?

```
SELECT S.name, E.cid
FROM Students S, Enrolled E
WHERE S.sid=E.sid AND E.grade='A';
```

Students

sid	name	login	age	gpa
10310	Mary	mary@cs	19	3.6
10400	Bob	bob@physics	20	3.2
11001	Bob	bob@math	18	3.8

Enrolled

sid	cid	grade
10310	CMPUT 201	C
10310	CMPUT 291	B
10400	BIO 101	A
11001	Math 101	B

result:

S.name	E.cid
Bob	BIO 101

Creating Relations in SQL

- Two tables (as examples)
- The type (domain) of each field is specified by user/ programmer, and enforced by the DBMS (whenever tuples are added or modified).

```
CREATE TABLE Students
        (sid: CHAR(5),
         name: CHAR(10),
         login: CHAR(15),
         age: INT,
         gpa: FLOAT);
```

```
CREATE TABLE Enrolled
        (sid: CHAR(5),
         cid: CHAR(10),
         grade: CHAR(2));
```

Adding and Deleting Tuples

- Insert a single tuple

```
INSERT INTO Students (sid, name, login, age, gpa)
VALUES (11010, 'Andrew', 'andrew@cs', 18, 3.3);
```

- Delete all tuples that satisfy a condition (e.g., name = Bob):

```
DELETE
FROM Students
WHERE name = 'Bob';
```

☛ *Will see more powerful versions of these commands later!*

Integrity Constraints (ICs)

- Conditions that hold for *any* instance of the database; e.g., *domain constraints.*
  - defined when schema is defined.
  - checked when relations are modified.
- A *legal* instance of a relation is one that satisfies all specified ICs.
  - DBMS should not allow illegal instances.
- If the DBMS checks ICs, stored data is more faithful to real-world meaning.
  - Avoids data entry errors, too!

Primary Key Constraints

- A set of fields is a ***key*** for a relation if it is both:
  1. unique: no two distinct tuples can have same values in all key fields, and
  2. minimal: no subset of a key is a key.
- A relation can have more than one key
  - *Candidate key*: all keys of the relation
  - *Primary key*: one defined by DBA
- *Superkey*: 1st condition holds but the 2nd may not
- E.g., *sid* is a key for Students. What about *name*? The set {*sid, gpa*} is a superkey.

Primary and Candidate Keys in SQL

- A table can have many candidate keys (specified using UNIQUE), but only one *primary key*.

- "Given a student and a course in Enrolled1, there is a single grade."
- What are the constraints in Enrolled2?
- Used carelessly, an IC can prevent the storage of database instances that arise in practice!

```
CREATE TABLE Enrolled1
  (sid CHAR(8),
   cid  CHAR(8),
   grade CHAR(2),
   PRIMARY KEY  (sid,cid) );
```

```
CREATE TABLE Enrolled2
  (sid CHAR(8),
   cid  CHAR(8),
   grade CHAR(2),
   PRIMARY KEY  (sid),
   UNIQUE (cid, grade) );
```

Foreign Keys, Referential Integrity

- *Foreign key* : Set of fields in one relation that \`refers' to a tuple in another relation; a FK must correspond to a key (primary or candidate) of the other relation (like a \`logical pointer').
  - E.g. *sid* in Enrolled is a foreign key referring to Students:
    - ✓ Enrolled(*sid*: char(8), *cid*: char(8), *grade*: char(2))
  - *Referential integrity* is achieved if all foreign key constraints are enforced, i.e., no dangling references.
  - Can you name a data model w/o referential integrity?

Foreign Keys in SQL

- Only students listed in the Students relation should be allowed to enroll in courses.

```
CREATE TABLE Enrolled
  (sid CHAR(8), cid CHAR(8), grade CHAR(2),
   PRIMARY KEY (sid,cid),
   FOREIGN KEY (sid) REFERENCES Students );
```

Enrolled

Enrolled

sid	cid	grade
10310	CMPUT 201	C
10310	CMPUT 291	B
10400	BIO 101	A
11001	Math 101	B

Students

sid	name	login	age	gpa
10310	Mary	mary@cs	19	3.6
10400	Bob	bob@physics	20	3.2
11001	Bob	bob@math	18	3.8

Enforcing Referential Integrity

- *sid* in Enrolled is a foreign key that references Students.
- What if an Enrolled tuple with a non-existent student id is inserted?
  - *Reject it!*
- What if a tuple in Students is deleted?
  - Delete all Enrolled tuples that refer to it.
  - Disallow deletion of a Students tuple that is referred to.
  - Set sid in Enrolled tuples that refer to it to a *default sid*.
    (In SQL,also: Set sid in Enrolled tuples that refer to it to a special value *null*, denoting `*unknown*' or `*inapplicable*'.)
- Similar if primary key of Students tuple is updated.

Referential Integrity in SQL/92

- SQL/92 (and SQL/99) supports all options on deletes and updates.
  - Default is NO ACTION (*delete/update is rejected*)
  - CASCADE (also delete all tuples that refer to deleted tuple)
  - SET NULL / SET DEFAULT (sets foreign key value of referencing tuple)

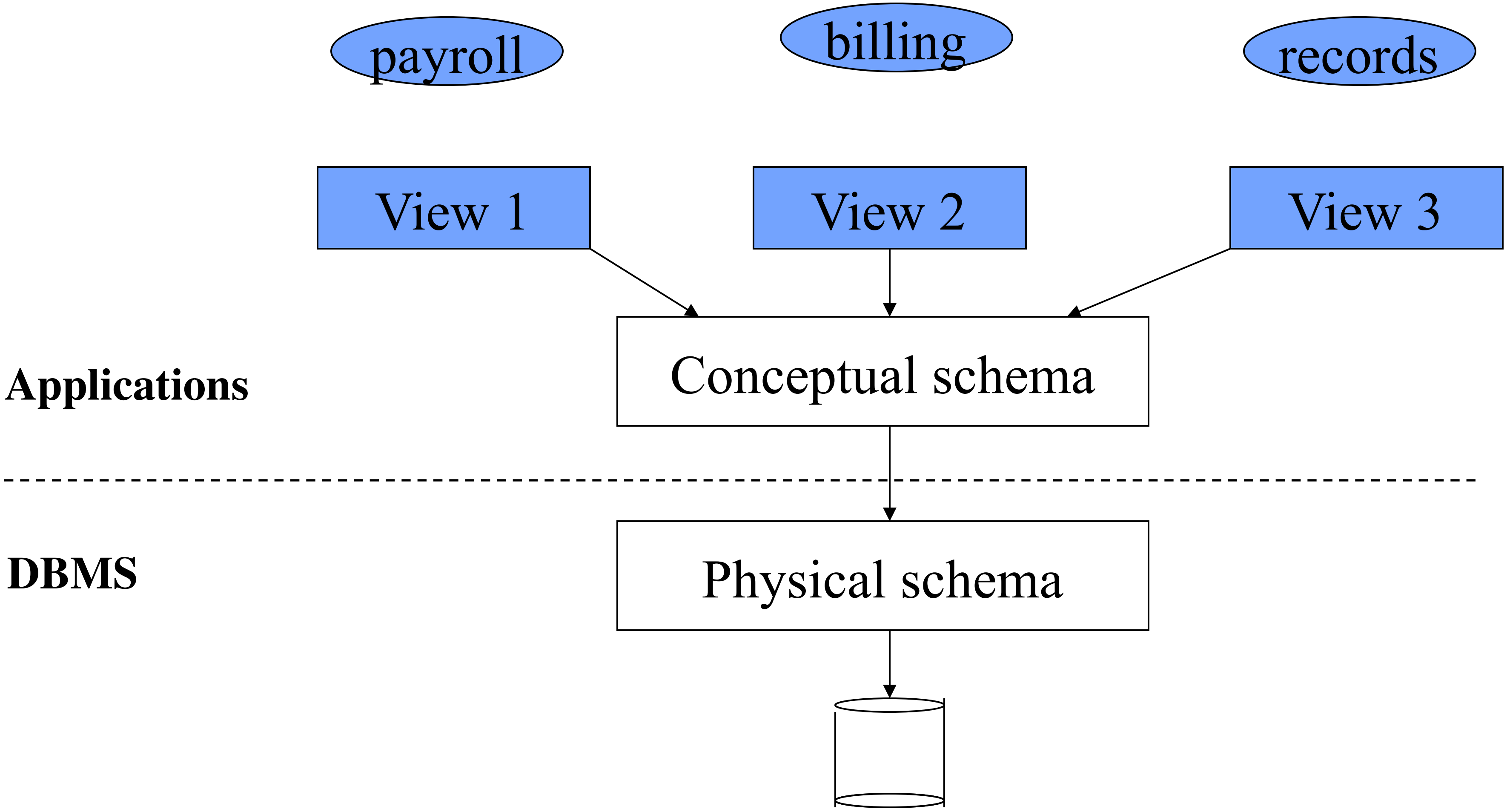
```
CREATE TABLE Enrolled
   (sid CHAR(8),
    cid CHAR(8),
    grade CHAR(2),
    PRIMARY KEY  (sid,cid),
    FOREIGN KEY (sid)
      REFERENCES Students
          ON DELETE CASCADE
          ON UPDATE SET NULL );
```

SQLite also has RESTRICT which is very similar to NO ACTION

Where do ICs Come From?

- ICs are based upon the semantics of the real-world enterprise that is being described in the database relations.
  - An IC is a statement about *all possible* instances!
  - We cannot infer that an IC is true by looking at an instance.
  - From example, we know *name* is not a key, but the assertion that *sid* is a key is given to us.
- Key and foreign key ICs are the most common; more general ICs supported too.

Levels of Abstraction



External Level

- Applications can access data through some views
  - Different views of data for different categories of users
  - A view is computed (from data in the conceptual level)
- Mapping from external to conceptual schema is done by DBMS.
- Conceptual schema can be changed without changing applications:
  - Referred to as *logical data independence*.

Views

- A *view* is just a relation, but we store a *definition*, rather than a set of tuples.

```
CREATE VIEW YoungActiveStudents (name)
        AS SELECT S.name
        FROM Students S, Enrolled E
        WHERE S.sid = E.sid and S.age<21;
```

- Views can be dropped using the DROP VIEW command.

Views and Security

- Views can be used to present necessary information (or a summary), while hiding details in underlying relation(s).
  - Given YoungActiveStudents, but not Students or Enrolled, we can find young students who are enrolled, but not the *cid's* of or *grade's* in the courses they are enrolled in.

Relational Model: Summary

- A tabular representation of data.
- Simple and intuitive, currently the most widely used.
- Integrity constraints can be specified by the DBA, based on application semantics. DBMS checks for violations.
  - Two important ICs: primary and foreign keys
  - In addition, we *always* have domain constraints.
- Powerful and natural query languages exist.

Relational Model: Summary

- Most widely used model.
  - Vendors: IBM, Informix (bought by IBM), Microsoft, Oracle, Sybase (bought by SAP), SQLite, etc.
- Old competitors:
  - hierarchical model, network model
- Recent competitors:
  - object-oriented model
    - ✓ ObjectStore, Versant, Ontos
    - ✓ A synthesis emerging: *object-relational model*
      - ✓ Informix Universal Server, O2, Oracle, DB2
  - XML graph model