The Relational Model: Database Definition and Integrity Constraints

Chapter 3

Jennifer Widom Lectures

- Introduction and Relational Databases
- Relational Algebra
- SQL
- Constraints and Triggers

https://www.edx.org/course/databases-5-sql

Reminder

Relational and Other Data Models

- **DBMS using the relational DM**
  - IBM DB2
  - MS SQL Server
  - Informix
  - Oracle
  - Sybase
  - Microsoft Access
  - Tandem
  - Teradata
  - SQLite
  - MySQL
  - PostgreSQL…

- Other data models
  - Hierarchical
    - IBM IMS
  - Network
    - IDMS, IDS
  - Object-oriented
    - ObjectStore
  - Object-relational
    - Oracle
  - …

Reminder

Relational (Data) Model

- The most widely-used model today
- **Data model** = a collection of concepts for describing data
  - A collection of relations
  - Relation = set of records – think of it as a table with rows tuples and columns attributes

Students

sid	name	login	age
13	Lisa	lsimp	40
41	Bart	bart	20

Courses

cid	cname	Cr.
E-484	EECS484	4
E-584	EECS584	3

Enrolled

sid	cid	Grade
41	E-484	A-
13	E-584	A+

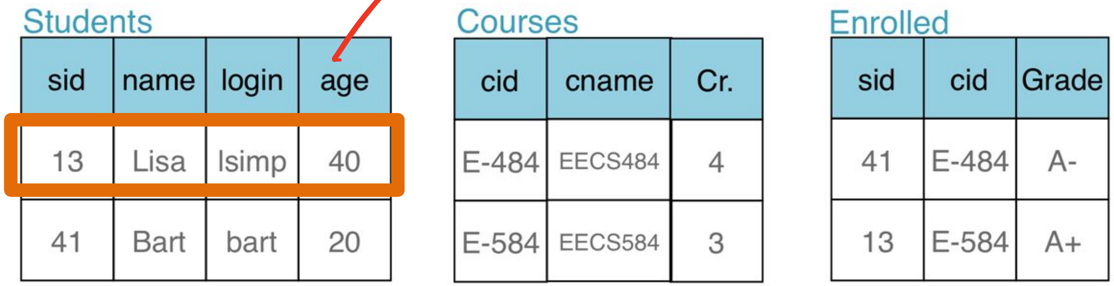
Reminder

Relational (Data) Model

- **Schema** = a description of data in terms of a data model
  - Every relation has a schema
  - Specifies the name of the relation, the name and type of the columns (or fields or attributes)
  - Each row also called a tuple or a record

```
Students(sid:string, name:string, login:string, age:integer)
Courses(cid:string, cname:string, credits:integer)
Enrolled(sid:string, cid:string, grade:string)
```

not a row in DB ⇒ it's schema.



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41	E-484	A-
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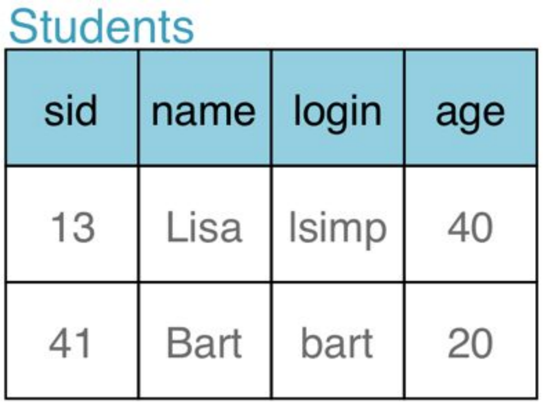
Relational (Data) Model

- **Schema** = a description of data in terms of a data model
- **Instance** = a table, with rows (aka tuples, records), and columns (aka fields, attributes) that match the schema
  - – # of rows: cardinality
  - – # of columns: degree or arity



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New Scenario: Olympic Games

- Some history:
  - Inspired by the ancient Olympic Games, which were held in Olympia, **Greece** (8th century BC).

Example:
Instance of Athlete Relation

AID	Name	Country	Sport
1	Mary Lou Retton	USA	Gymnastics
2	Jackie Joyner-Kersee	USA	Track
3	Guo Jingjing	China	Diving

What is the schema?

(aid: integer, name: `string`,
country: `string`, sport: `string`)

Example:
Instance of Athlete Relation

AID	Name	Country	Sport
1	Mary Lou Retton	USA	Gymnastics
2	Jackie Joyner-Kersee	USA	Track
3	Guo Jingjing	China	Diving

Cardinality & Degree?

3 4

(A) Cardinality: 3, Degree: 3
(B) Cardinality: 3, Degree: 4
(C) Cardinality: 4, Degree: 3

Relational Query Languages

- Supports simple, powerful querying of data
- Queries written declaratively ⇒ declare what would like to see
  - In contrast to procedural (C++) methods
- DBMS is responsible for efficient evaluation
  - System can optimize for efficient query execution, and still ensure that the answer does not change
- SQL is the standard database query language

Structured Query Language (SQL)

• Create a Table	`Create`
• Add new records	`Insert`
• Retrieve records	`Select`
• Update records	`Update`
• Delete records	`Delete`

• Create a View	`Create`
• Update a View	`Update`

external schema.

Structured Query Language (SQL)

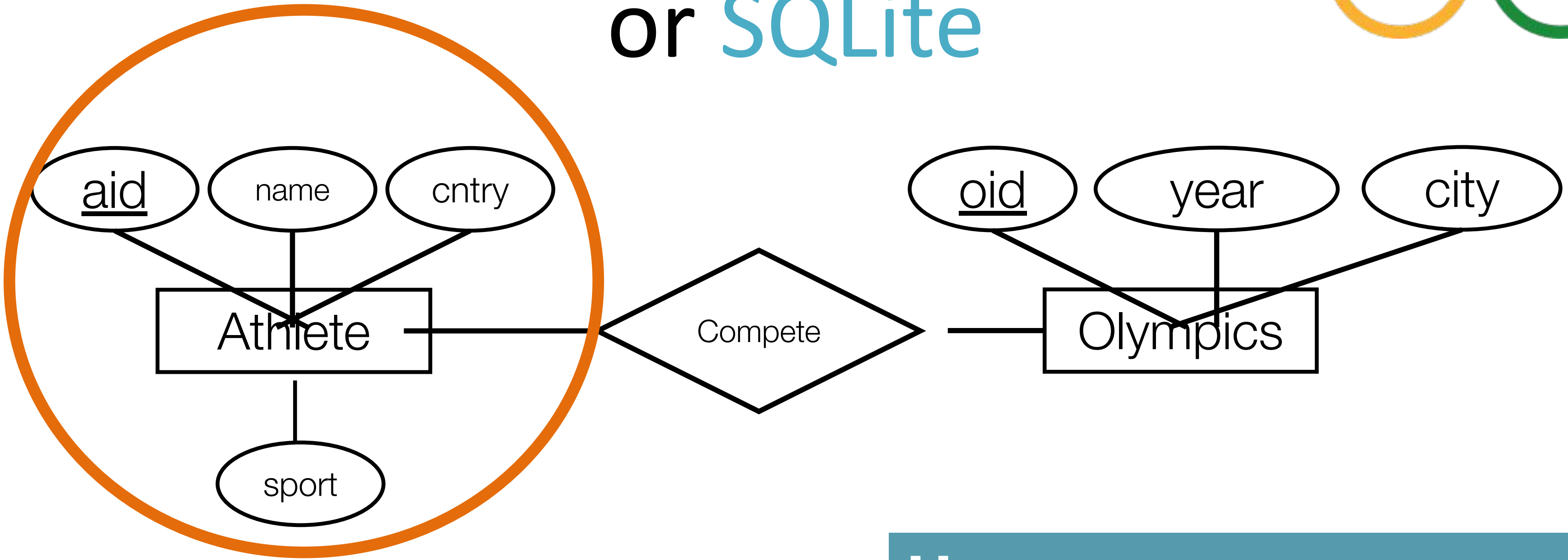
Create a Table	`Create`
– Integrity Constraints	
– Enforcing Constraints	
Add new records	`Insert`
Retrieve records	`Select`
Update records	`Update`
Delete records	`Delete`
Create a View	`Create`
Update a View	`Update`

Create a Table (Relation)

field = attribute = column

```
CREATE TABLE table_name (
   field1 TYPE,
   field2 TYPE,
   …  …  …
);
```

Try it out on paper or SQLite



```
CREATE TABLE table_name
(
   field1 TYPE,
   field2 TYPE,
    …  …  …
);
```

Hints

- Examples of types:
- char(20), integer, real, (big) text, blob binary large object
- To create a DB named olympics:

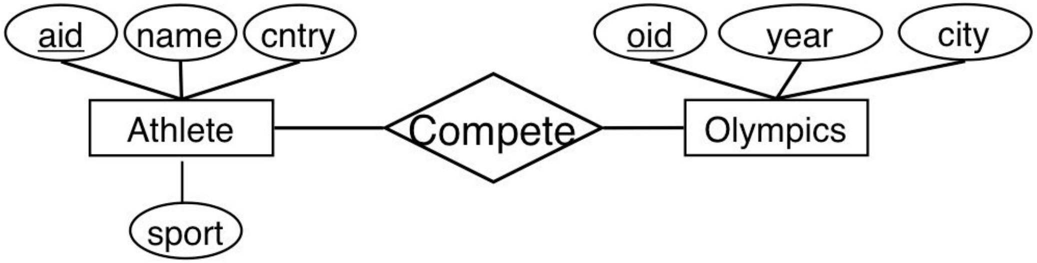
  >> sqlite3 olympics.db

Download SQLite:
https://www.sqlite.org/download.html

Creating Relations in SQL

- Create the Athlete relation
  - Domain constraint (type) enforced when tuples added or modified

```
CREATE TABLE Athlete
(aid INTEGER,
 name CHAR(30),
 country CHAR(20),
 sport CHAR(20));
```



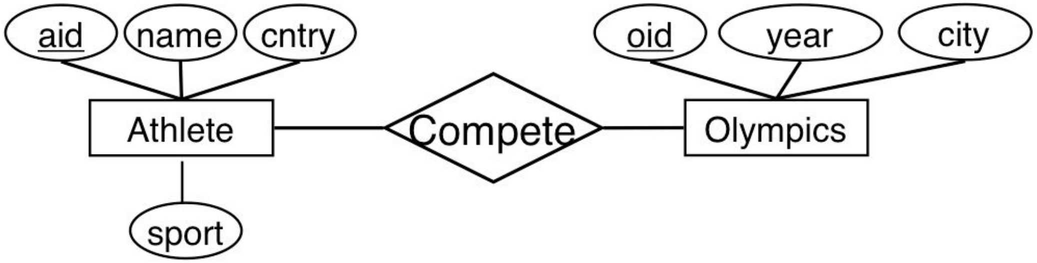
Creating Relations in SQL

- Create the Athlete relation
  - Domain constraint (type) enforced when tuples added or modified

```
CREATE TABLE Athlete
(aid INTEGER,
 name CHAR(30),
 country CHAR(20),
 sport CHAR(20));
```

- Create the Olympics relation

```
CREATE TABLE Olympics
(oid INTEGER,
 year INTEGER,
 city CHAR(20));
```



Creating Relations in SQL

- Create the Athlete relation
  - Domain constraint (type) enforced when tuples added or modified

```
CREATE TABLE Athlete
(aid INTEGER,
 name CHAR(30),
 country CHAR(20),
 sport CHAR(20));
```

- Create the Olympics relation

```
CREATE TABLE Olympics
(oid INTEGER,
 year INTEGER,
 city CHAR(20));
```

- Create the Compete relation

```
CREATE TABLE Compete
(aid INTEGER,
 oid INTEGER);
```

Structured Query Language (SQL)

✓ Create a Table	`Create`
– Integrity Constraints	
– Enforcing Constraints	
Add new records	`Insert`
Retrieve records	`Select`
Update records	`Update`
Delete records	`Delete`
Create a View	`Create`
Update a View	`Update`

Creating Relations: Constraints

- How to specify certain attributes as keys?
  - e.g., athlete ID (aid) or olympics ID (oid)
  - DBMS must prevent duplicate keys, e.g. two athletes with the same ID in the database

- How to say that the Athlete ID and Olympic ID values in Compete relation must have valid references?

Integrity Constraints (ICs)

- IC: condition that must be true for *every* instance of the database; e.g., domain constraints
  - ICs are specified when schema is defined
  - ICs are checked when relations are modified
- A legal instance of a relation satisfies *all* specified ICs
  - DBMS must not admit illegal instances

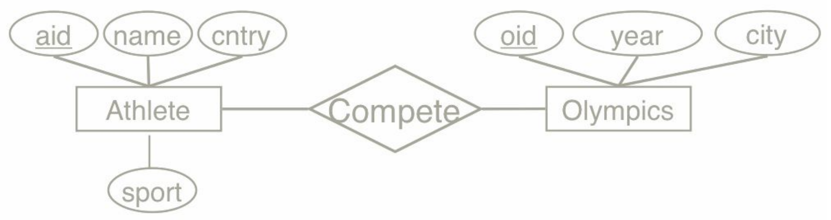
Integrity Constraint: Primary and Candidate Keys

- A **key** for a relation R
  - = minimal set of attributes $A_1, \ldots, A_n$ such that:
  - no two tuples in (any instance of) R can have the same values for $A_1, \ldots, A_n$
- A set of attributes that satisfies the above condition, without the minimal requirement, is called a superkey.
  - ⇒ Every key is a superkey.
- A relation can have more than one key:
  - One is designated as primary key.
  - Others are called candidate keys.

Examples: {aid}, {ssn},

- {aid} is a key in the Athlete relation
- {ssn} is a key for Citizen relation

Primary Key Constraint



A couple of ways to specify a Primary Key constraint:

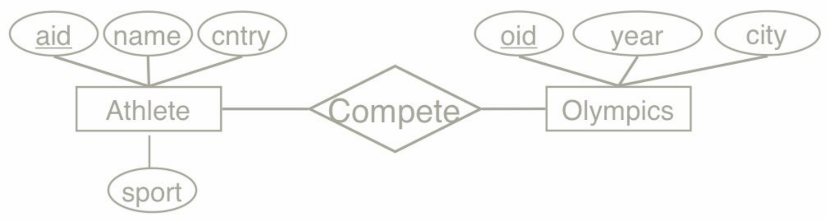
```
CREATE TABLE Athlete
(aid INTEGER PRIMARY KEY,
 name CHAR(30),
 country CHAR(20),
 sport CHAR(20));

CREATE TABLE Athlete
(aid INTEGER,
 name CHAR(30),
 country CHAR(20),
 sport CHAR(20),
 PRIMARY KEY(aid));
```

⇒ for more than 1 attribute key

Not Null Constraint

Disallow null values for a field



```
CREATE TABLE Athlete
(aid INTEGER PRIMARY KEY,
 name CHAR(30) NOT NULL,
 country CHAR(20),
 sport CHAR(20));
```

- NULL value = the value is unknown or inapplicable
- Example:
  - country and sport can be NULL (= not known or unspecified)
  - But, name must be specified.

Primary Keys Properties

- Can **never** be null (DBMS enforces this)
  - NO parts of a composite primary key can be NULL.
- Need not be an integer ID
  - though they often are for efficient search

An implementation detail

- IDs used as primary keys do not necessarily auto-increment in databases.
  - Additional features of SQL must be used to make them auto-increment. You will see that in the projects.

Candidate Keys

- Candidate keys specified using UNIQUE
- One of the candidate keys is chosen as the *primary key*.

```
CREATE TABLE Athlete
    (aid INTEGER,
     name CHAR(30) NOT NULL,
     country CHAR(20),
     sport CHAR(20),
    UNIQUE (name, country),
    PRIMARY KEY (aid));
```

candidate key .
as a contraint !!!
more contraints ⇒ less likely
to have errors

WARNING: If used carelessly, ICs can prevent storing instances that arise in practice!

too rigorous.

Foreign Keys in SQL

- Only people listed in Athletes relation should be allowed to compete

```
CREATE TABLE Compete
    (aid INTEGER,  oid INTEGER,
      PRIMARY KEY  (aid, oid),
      FOREIGN KEY (aid) REFERENCES Athlete);
```

restrict aid domain.

- … and only in games stored in the Olympics relation

```
CREATE TABLE Compete
    (aid INTEGER,  oid INTEGER,
      PRIMARY KEY  (aid, oid),
      FOREIGN KEY (aid) REFERENCES Athlete,
      FOREIGN KEY (oid) REFERENCES Olympics);
```

user implemented ptr.

Foreign Keys: Definition and Rules

- **Foreign key** = set of fields in one relation that is used to refer to a tuple in another relation.
- Must refer to primary key of the second relation
  - Like a 'logical pointer'
- Example:

```
CREATE TABLE Athlete
(aid INTEGER PRIMARY KEY,
 name CHAR(30),
 country CHAR(20),
 sport CHAR(20));
```

```
CREATE TABLE Compete
    (aid INTEGER,   oid INTEGER,
     PRIMARY KEY  (aid, oid),
     FOREIGN KEY (aid) REFERENCES Athlete,
     FOREIGN KEY (oid) REFERENCES Olympics);
```

If all foreign key constraints are enforced, referential integrity (no dangling references) is achieved.

Like no dangling references

Structured Query Language (SQL)

✓ • Create a Table	Create
– Integrity Constraints	
➡ – Enforcing Constraints	
• Add new records	Insert
• Retrieve records	Select
• Update records	Update
• Delete records	Delete
• Create a View	Create
• Update a View	Update

Enforcing ICs

- Whenever we modify the database
  - the DBMS must check for violations of ICs

- Enforcing Domain, Primary Key, Unique ICs is straightforward ① ② ③
  - Reject offending UPDATE / INSERT command

Enforcing Referential Integrity

- If a Compete tuple is inserted with no corresponding Athlete aid:
  - Insert operation is REJECTED!

```
CREATE TABLE Compete
      (aid INTEGER,  oid INTEGER,
        PRIMARY KEY  (aid, oid),
        FOREIGN KEY (aid) REFERENCES Athlete,
        FOREIGN KEY (oid) REFERENCES Olympics);
```

Enforcing Referential Integrity

- If a Compete tuple is inserted with no corresponding Athlete aid:
  - Insert operation is REJECTED!

- What if an Athlete tuple is deleted? Possible actions:
  - ✓ **Disallow deletion** if a Compete tuple refers to athlete
  - **Delete all** Compete tuples that refer to deleted athlete
  - **Set to default or null** value for all references to the deleted athlete

- Similar choices on update of primary key of Athlete default: IC check happens at the end: set of transactions all completed,

Referential Integrity in SQL

transaction:
Valid
take money out of account A
invalid
add money to account B
Valid

- SQL supports all four options on deletes and updates
- Default is NO ACTION: action is rolled back at commit;
  - Similar to RESTRICT: action is disallowed at delete/update time.
  - CASCADE: also delete all tuples that refer to deleted tuple
  - SET NULL / SET DEFAULT: sets foreign key value of referencing tuple

check right away

```
CREATE TABLE Compete
    (aid INTEGER,  oid INTEGER,
      PRIMARY KEY  (aid, oid),
      FOREIGN KEY (aid)
   REFERENCES Athlete
   ON DELETE CASCADE
   ON UPDATE SET NULL)
```

What happens to the Compete relation if we add a new athlete (with a new ID) to the Athlete table? Nothing

Primary Keys and ICs

- The primary key (or any of its parts, if it is composite) cannot get NULL value.
  - True in most DBMS. In this class, we will stick with this rule
    - despite the fact that there are exceptions
- Although you can choose how to handle UPDATE/DELETE actions when there are references (via foreign keys), some options may be in conflict with the Primary Key constraints
  - The system will not allow changes that violate the Primary Key constraints.

Where do ICs Come From?

- Based on real-world enterprise being modeled
- An IC is a statement about all possible instances!
- We can **check** a database instance to see if an IC is **violated**, but we can NEVER infer that an IC is true by looking at an instance.
- Key and foreign key ICs are the most common
- Also table constraints and assertions cross-table constraint

general constraints

Destroying & Altering Relations

- To destroy the relation Olympics.
  - Schema information and tuples are deleted

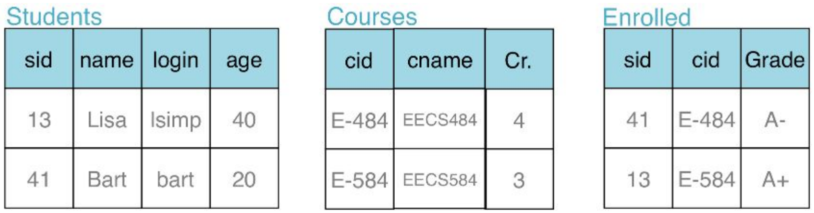
```
DROP TABLE Olympics
```

- To alter the Athlete schema by adding a new column

```
ALTER TABLE Athlete
    ADD COLUMN age: INTEGER
```

- What do we put in the new field?
  - A null value: ‘unknown’ or ‘inapplicable’

Relational Model: Summary



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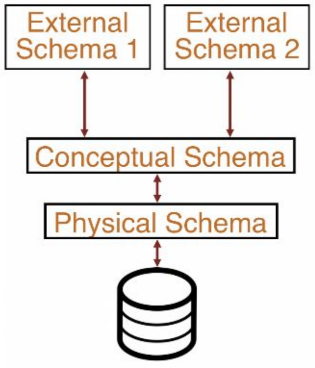
- A tabular representation of data
- Simple and intuitive
- The most widely used database model by far
- Integrity constraints can be specified by the DBA, based on application semantics. DBMS checks for violations.
  - Two important ICs: primary and foreign keys
  - We always have domain constraints

    e.g. `INTEGER` fields must always contain integer values
- Views can be used for external schemas, and provide logical data independence



Terminology Parade

- Database: A set of relations or tables in the database:
- Relation: Defined by:
  - Schema: Describes the columns and constraints
    - Relation name
    - Name and domain (i.e., type) for each column
    - E.g., Student (sid: integer, name: string, gpa: real)
  - Instance: A table, with rows (aka tuples, records), and columns (aka fields, attributes) that match the schema
    - # Rows = cardinality
    - # Columns = degree / arity

set of tuples
(no duplicate).

- Set semantics: (classical relational model) *Every row is unique*
- Multiset semantics: (modern systems, SQL) *Duplicate rows allowed*

exactly same entry
twice in a table

Integrity Constraints

- Describes conditions that must be satisfied by every legal instance
- Types of integrity constraints
  - Domain constraints
  - Primary key constraints
  - Foreign key constraints
  - General constraints