The Relational Model

Database Models

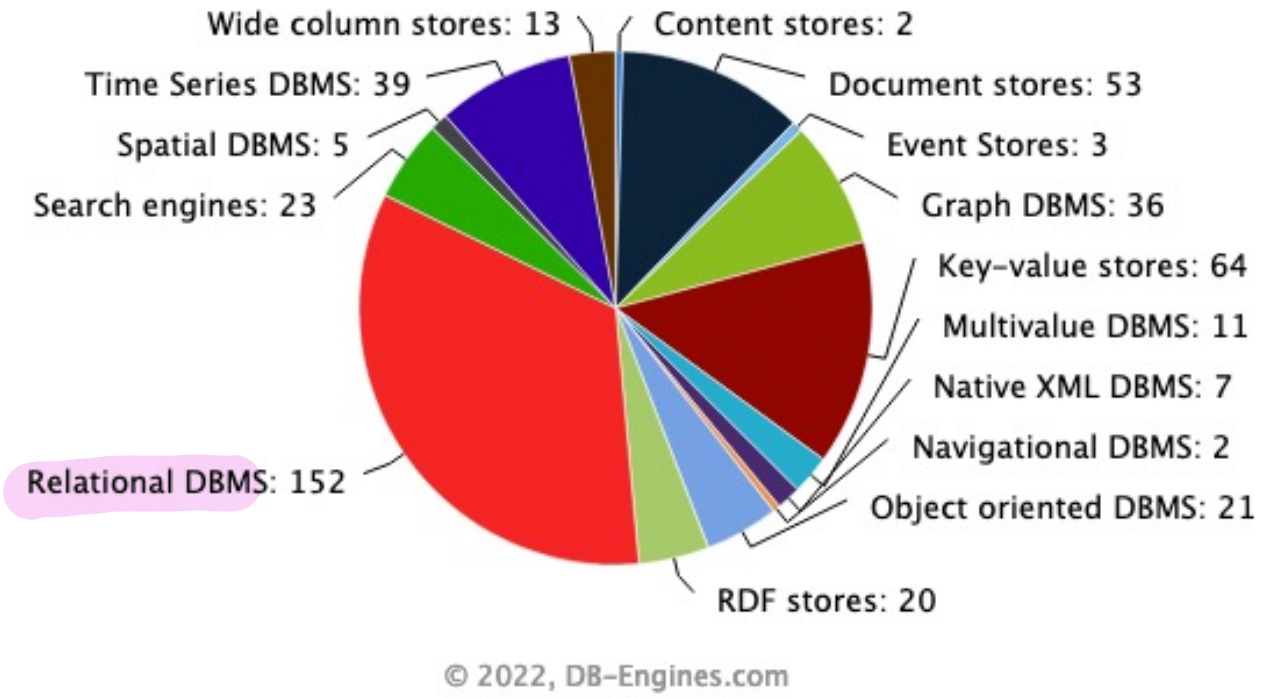
- The entity-relationship is a semantic model (quite rich in its expressiveness) but it is not used as a model in any DBS. good as high level for clients
- Relational model
  - Most common
  - Vendors: IBM DB2, Microsoft SQL Server, Oracle, SAP Hana, SAP Sybase, etc…
  - Open-source: PostgreSQL, MySQL, SQLite, Derby, MonetDB,
- "Legacy systems" have older models
  - E.g., IBM's IMS (hierarchical), CODASYL network model

Database Models

- Recent and future competitors:
  - object-oriented model: ObjectStore, Versant
  - Semi-structured (document-based): XML, JSON
    - *MongoDB*, CouchDB
  - Key-value
    - *Riak*, Voldemort, *Amazon's Dynamoth*
  - Column-store (key – basic relational)
    - *Google's BigTable*, Hadoop's Hbase, Cassandra
  - Integrated: object-relational, XML+relational …

Database Engines in Use

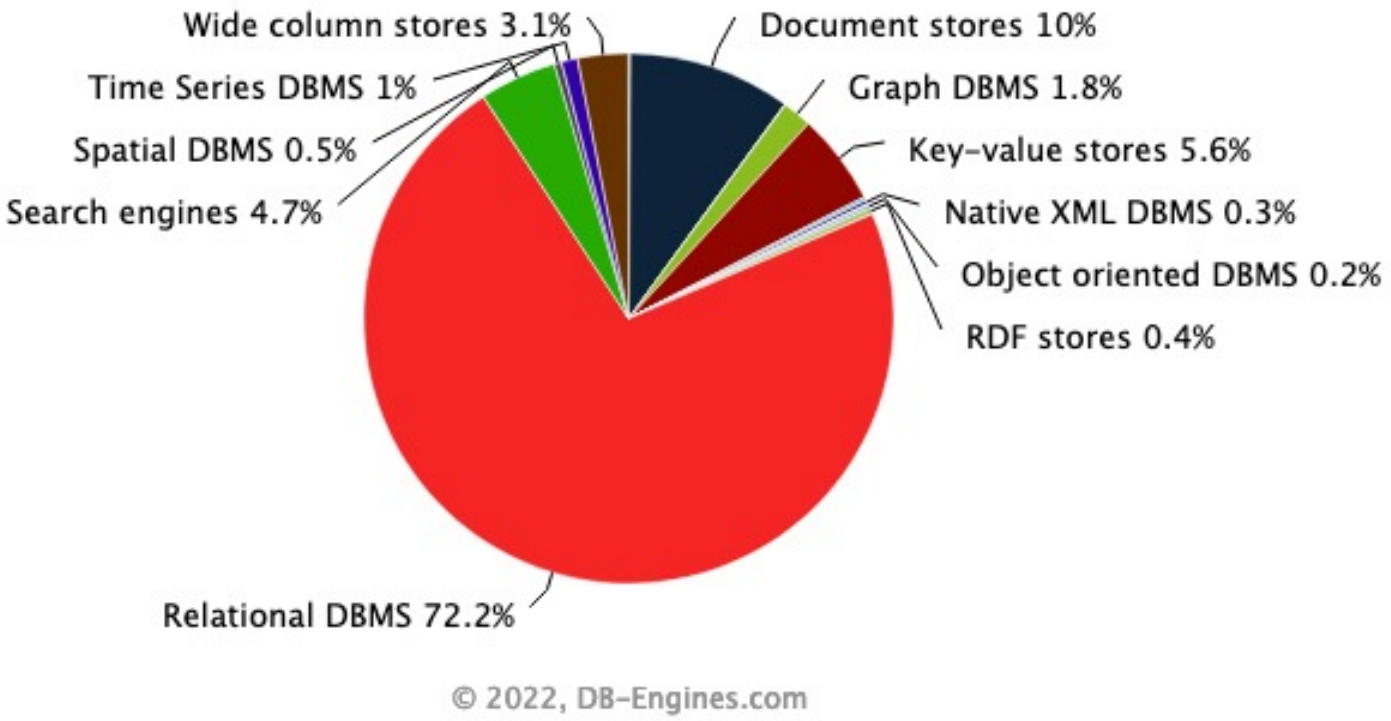
Number of systems per category, January 2022



https://db-engines.com/en/ranking_categories

Database Engines in Use

Ranking scores per category in percent, January 2022



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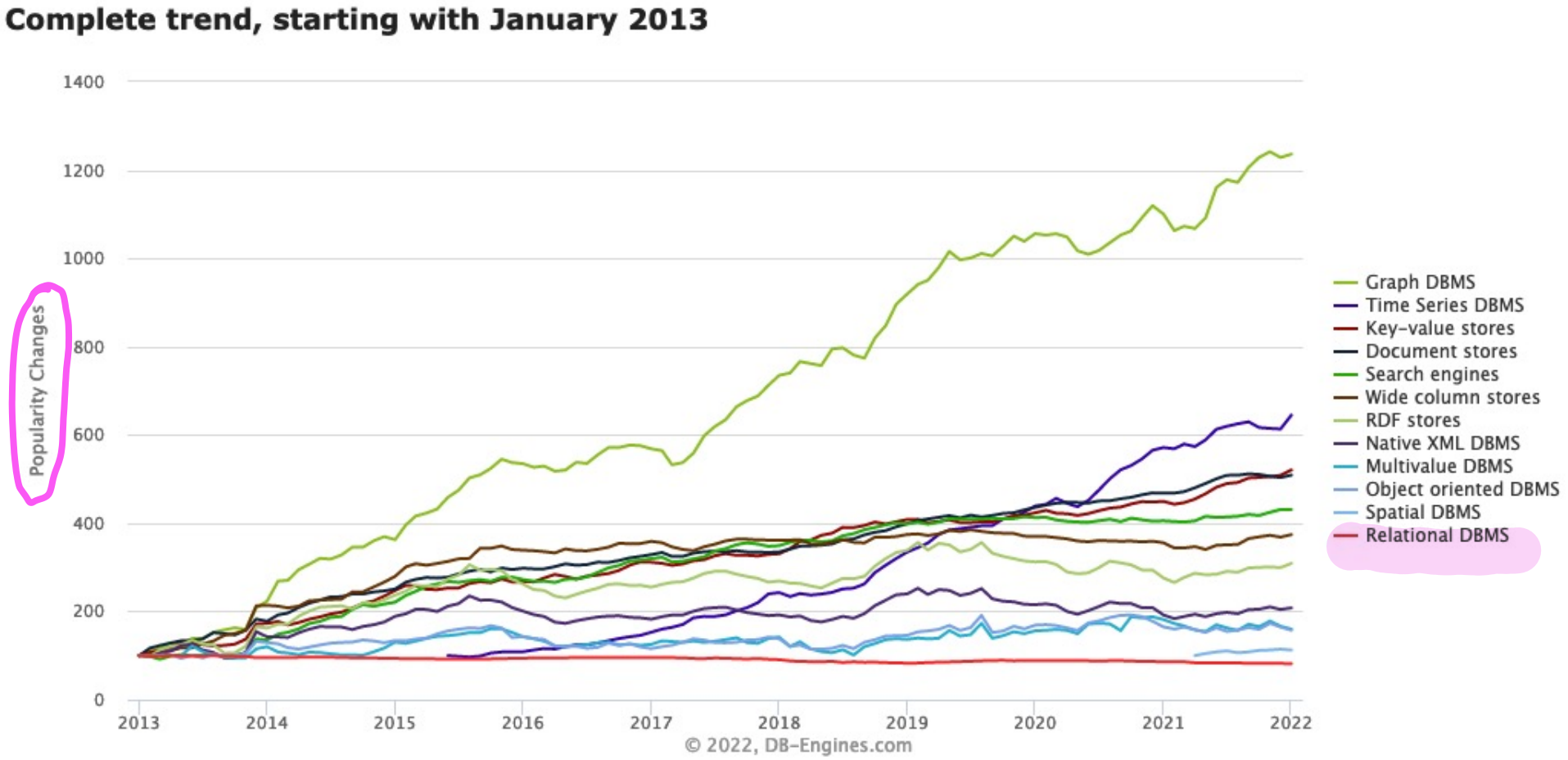
Database Engines in Use



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relational is very stable

Definitions

- **Relational Database:** a set of relations
- **Relation:** Consists of two parts:
  - **Schema:** specifies name of relation, plus a set of attributes, plus the domain/type of each attribute
    - E.g., `Students(sid:int, name:string, login:string, faculty:string, major:string)`
  - **Instance:** set of tuples (all tuples are distinct).
  - Compare with entity set and entity; or with object class and object instance
- A relation can be seen as a table:
  - Column headers = attribute names, rows = tuples/records, columns/fields = attribute values
- If clear from context, we say instead of "instance of a relation" simply "relation"
- Database Schema: collection of relation schemas

Example of *Students* Relation

instance is a row

Column headers = attributes

sid	name	login	faculty	major
53666	Bartoli	bartoli@cs	Science	Software Engineering
53688	Chang	chang@eecs	Eng	Software Engineering
53650	Chang	chang@math	Science	Computer Science
…				

- All rows are distinct (set-oriented)
- Rows are not ordered (a permutation of rows represents still the same table)
- Columns are per definition not ordered but in practice we often assume a fixed order
  - with this, a single tuple can be represented as
    - `(53666, Bartoli, bartoli@cs, Science, Software Engineering)`

interact w/ database using column names

Relational DDL and DML

- **Data Definition Language (DDL):** defines the schema of a database
- **Data Manipulation Language (DML):** "manipulates" the data, i.e., the instances of the relations
  - Insert, update, delete tuples
  - "Query" the relations: retrieve tuples that fulfill certain criteria (hence, often called "query language")
  - The Relational Model offers simple and powerful querying of data with precise semantics
  - Data-centric
- *Physical data independence*
  - User only sees relations
  - User does not need to know how data is stored
    - Mapping to files
    - Rows vs. columns
  - User does not need to know how queries are executed

The SQL Query Language

- Developed by IBM (system R) in the 1970s
- Need for a standard since it is used by many vendors
- Standards:
  - SQL-86
  - …
  - SQL-99 / SQL3 (adds object-relational features)
  - SQL:2003 (adds XML features)
  - …
  - SQL:2011
- Used to define relations (Data definition)
- Used to write and query data (Data manipulation)
- Standard is very slow to develop
- Many dialects in various DBS

Concepts vs. Details

- We will discuss the main concepts of SQL (data definition and data manipulation) in class
- To figure out the details, students have to use the handbook
  - In particular: DBS specific dialects, variations…

SQL Data Types

- All attributes must have a data type.
- SQL supports several basic data types
  - Just as any programming language does
  - Notation somewhat "old-fashioned" as language very old
- Character and string types
  - CHAR(n) denotes a character string of fixed length (containing trailing blanks for padding if necessary).
  - VARCHAR(n) denotes a string of up to n characters (between 0 and n characters).
  - SQL permits reasonable coercion between values of character-string types
- Integer Types
  - INT or INTEGER (names are synonyms)
  - SHORTINT

Data Types (contd.)

- Floating point numbers
  - FLOAT or REAL (names are synonyms)
  - DOUBLE PRECISION
  - DECIMAL(n,d): real number with fixed decimal point. Value consists of n digits, with the decimal point d positions from the right.
- Dates and time:
  - DATE: has the form '9999-MM-DD'
  - TIME: has the form '15:00:02' or '15:00:02.5'
  - May be compared and converted to string types

very important

- Bit strings
- User defined domains
  - New name for a data type
  - Possibility to define restrictions on values of domain (< 10)

Data Definition: Table Creation

- Defines all attributes of the relation
- The type/domain of each attribute is specified
- DBMS enforce correct type whenever a tuple is added or modified
- SQL is case insensitive
- It is possible to define default values

```
CREATE TABLE Students
  (sid INTEGER,
   name VARCHAR(30),
   login VARCHAR(30),
   faculty VARCHAR(20),
   major VARCHAR(20) DEFAULT 'undefined' )
```

Data Manipulation: Insert

Data Manipulation: Insert

- Insert a single tuple

```
INSERT INTO Students
     VALUES (53666, 'Bartoli', 'bartoli@cs',
             'Science', 'Software Engineering')
```

same order as creation

  - can contain all or only a subset of attributes:
    - Not indicated attributes have special NULL value

```
INSERT INTO Students (sid,name,faculty)
     VALUES(53688, 'Chang', 'Eng')
```

specify different orders

```
INSERT INTO Students (sid,name,major)
     VALUES (53650, 'Chang', 'Computer Science')
```

sid	name	login	faculty	major
53666	Bartoli	bartoli@cs	Science	Software Engineering
53688	Chang	NULL	Eng	undefined
53650	Chang	NULL	NULL	Computer Science

Data Manipulation: Delete

- Can delete all tuples satisfying some condition

```
DELETE
FROM Students
WHERE name = 'Chang'
```

sid	name	login	faculty	major
53666	Bartoli	bartoli@cs	Science	Software Engineering
53688	Chang	NULL	Eng	NULL
53650	Chang	NULL	NULL	Computer Science

deletes entire row

Data Manipulation: Update

- Can update all tuples satisfying some condition

```
UPDATE Students
SET major = 'Software Engineering'
WHERE sid = 53688
```

sid	name	login	faculty	major
53666	Bartoli	bartoli@cs	Science	Software Engineering
53688	Chang	NULL	Eng	Software Engineering
53650	Chang	NULL	NULL	Computer Science

Querying the Data

- Find the names and major of all students in the Faculty of Science

```
SELECT name, major
FROM Students
WHERE faculty = 'Science'
```

select x y from students
gives all rows

sid	name	login	faculty	major
53666	Bartoli	bartoli@cs	Science	Software Engineering
53688	Chang	NULL	Eng	NULL
53650	Chang	NULL	Science	Computer Science

Bartoli	Software Engineering
Chang	Computer Science

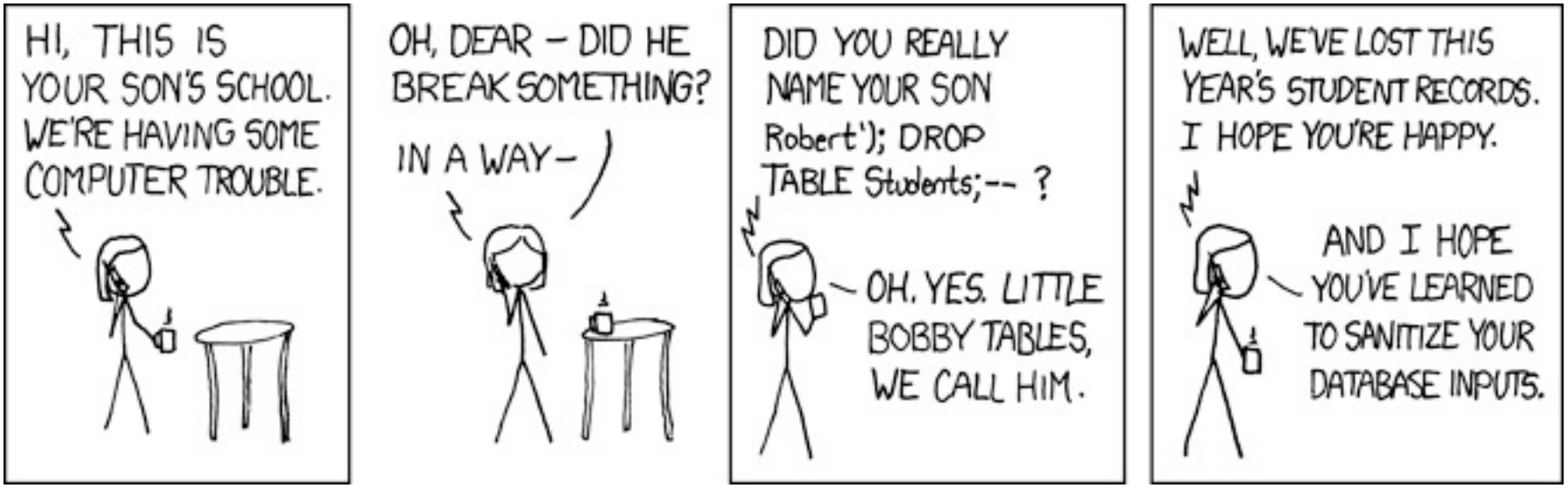
select * from students where ...
for all rols

Much more of that in a few weeks…

Data Definition: Destroying Relations

```
DROP TABLE Students
```

- Destroys the relation Students. The schema information *and* the tuples are deleted.



Data Definition: Altering Tables

```
DROP TABLE Students
```

- Destroys the relation Students. The schema information *and* the tuples are deleted.

```
ALTER TABLE Students
    ADD COLUMN firstYear:integer
```

- The schema of students is altered by adding a new field;
- every existing tuple in the current instance is extended with a **null** value in the new field.

Integrity Constraints (ICs)

- Integrity Constraints must be true for any instance of the database;
  - Domain definitions (INT or FLOAT) are already a form of constraint
  - Database designer specifies ICs when schema is defined
  - DBMS checks whether ICs remain true whenever relations are modified.
    - If modification violates an IC, the DBMS disallows the modification (throws an error message)
  - Of course, DBMS can only check what is specified in the schema

Not Null

IC

```
CREATE TABLE Students
  (sid CHAR(9),
   name VARCHAR(30) NOT NULL,
   login VARCHAR(30),
    faculty VARCHAR(20),
   major VARCHAR(20)
      DEFAULT 'undefined' )
```

requires an attribute to always have a proper value

Primary Key Constraints

- A set of fields is a **key candidate** for a relation if
  - No two distinct tuples can have same values in all key fields, and
  - This is not true for any subset of the key.
    - Minimum subset of attributes that fulfill uniqueness property
- If there are two or more keys, one of the candidates is chosen to be the **primary key.**
- The primary key attributes of a tuple may not be NULL.
- E.g. **`sid`** is a key for **`Students`**. (What about **`name`**?).
- Example of combined keys:
  - `Location(building, roomNo, capacity)`
  - Attributes `building` and `roomNo` together build the primary key

unique row identifier

for combined key

want minimum subset

Primary and Candidate Keys in SQL

- Possibly many candidate keys exist, one of which is chosen as the primary key
  - Each student has a unique id.
  - Each student has a unique login

```
CREATE TABLE Students
   (sid CHAR(9) PRIMARY KEY,
    login VARCHAR(30) NOT NULL UNIQUE,
    name VARCHAR(20),
    …)
```

- unique by definition

← other candidate

- Defining primary keys that have more than one attribute

```
CREATE TABLE Location
   (building VARCHAR(20),
    roomNo    INT,
   capacity INT,
   PRIMARY KEY(building, roomNo)
   )
```

← last line

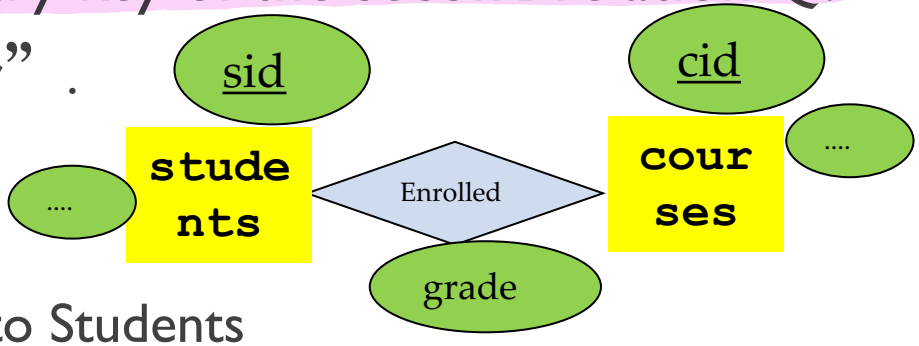
Note

- Specifics of individual database systems
  - E.g., DB2 required the following
    - If primary key, then also NOT NULL must be defined
  - If there are error messages ←
    - Consult the handbooks of the resp. database system

- Multi-Set good for importing data to clean
  - Tables do not require to have a primary key
  - If there is no primary key
    - Two records/tuples can have the same value in all attributes
    - That is, duplicates are allowed
  - Different to Relational Algebra Assumptions
    - Relations are set → no identical tuples in a relation

Foreign Key

- **Foreign Key**: Set of attributes in one relation R that is used to "refer" to a tuple in another relation Q.
  - Must correspond to the primary key of the second relation Q.
  - Represents a "logical pointer".
- Examples
  - in relation **`Enrolled`**,
    - **`sid`** is a foreign key referring to Students



Q

sid	name	login	faculty	...
53666	Bartoli	bartoli@cs	Science	...
53688	Chang	chang@eecs	Eng	...
53650	Chang	chang@math	Science	...
...				

R

sid	cid	grade
53666	Topology112	C
53666	Reggae203	B
53650	Topology112	A
53668	History105	B

Referential Integrity

- **Foreign Key Constraint:** the foreign key value of a tuple must represent an existing tuple in the referred relation
  - A tuple with this value in the primary key must exist in the referred relation
  - Enrollment may only contain a tuple referring to a student who exists in the Students relation
- If all foreign key constraints are enforced, **referential integrity** is achieved, i.e., no dangling references

Foreign Keys in SQL

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

```
CREATE TABLE Enrolled
(
    sid CHAR(9),
    cid VARCHAR(20),
    grade CHAR(2),
    PRIMARY KEY (sid,cid),
    FOREIGN KEY (sid) REFERENCES Students,
    FOREIGN KEY (cid) REFERENCES Courses
)
```

Student

sid	name	login	faculty	...
53666	Bartoli	bartoli@cs	Science	...
53688	Chang	chang@eecs	Eng	...
53650	Chang	chang@math	Science	...
...				

Enrolled

sid	cid	grade
53666	Topology112	C
53666	Reggae203	B
53650	Topology112	A
53668	History105	B

Enforcing Referential Integrity: Default

- An **`Enrolled`** tuple with a sid is inserted but no tuple with this sid exists in **`Students`**
  - Disallow insertion
- A **`Students`** tuple is deleted
  - Disallow the deletion of a **`Students`** tuple to which **`Enrolled`** tuples point
- Other options:
  - cascade

remove reference first