RELATIONAL DATA MODEL

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Describing Data: Data Models

- A *data model* is a collection of concepts for describing data.

- A *schema* is a description of a particular collection of data, using a given data model.

- The *relational model of data* is the most widely used model today.
  - Main concept: *relation*, basically a table with rows and columns.
  - Use tables to represent data and relationships
  - Every relation has a *schema*, which describes the columns, or attributes.

Acknowledgement: Renee J. Miller

Relational Model

- Proposed by Edgar. F. Codd in 1970 as a data model which strongly supports data independence.
- Made available in commercial DBMSs in 1981 -- it is not easy to implement data independence efficiently and reliably!
- It is based on (a variant of) the mathematical notion of ***relation***.
- Relations are represented as tables.

A relation is a table

Relation Name

Attribute Names

Students

Tuples (Records)

ID	Name
2225555	Peter Jones
1234567	Amber Smith

The set of permitted values for an attribute is called the attribute ***domain.***
E.g., domain(ID) = {2225555, 1234567}.

Relational Data Model

- *Relation schema* = relation name and attribute list.
  - Optionally: types of attributes. For example:
  - *Students(id, name)*
  - *Students(id: string, name: string)*
- *Relation* = set of tuples conforming to schema
  - Example:
    - { (2225555, Peter Jones), (1234567, Amber Smith), …}
- *Database* = set of relations.
- *Database schema* = set of all relation schemas in the database.

Why Relations?

- Very simple model.
- *Often* matches how we think about data.
- Abstract model that underlies SQL, the most important database language today.

Relations are Unordered

- Order of tuples is irrelevant (tuples may be stored in an arbitrary order)
- E.g., *instructor* relation with unordered tuples

ID	*name*	*dept_name*	*salary*
22222	Einstein	Physics	95000
12121	Wu	Finance	90000
32343	El Said	History	60000
45565	Katz	Comp. Sci.	75000
98345	Kim	Elec. Eng.	80000
76766	Crick	Biology	72000
10101	Srinivasan	Comp. Sci.	65000
58583	Califieri	History	62000
83821	Brandt	Comp. Sci.	92000
15151	Mozart	Music	40000
33456	Gold	Physics	87000
76543	Singh	Finance	80000

Database

- Information about an enterprise is broken up into parts

  instructor
  student
  advisor

- Bad design:
  univ (*instructor_ID, name, dept_name, salary, student_Id*, ..)
  results in
  - repetition of information (e.g., two students have the same instructor)
  - the need for NULL values (e.g., represent an student with no instructor)

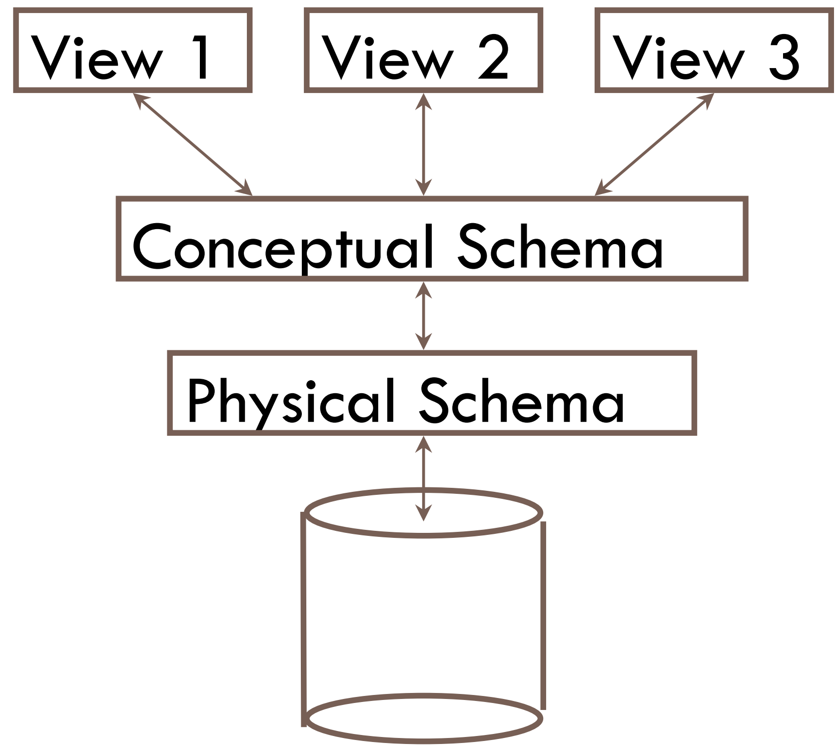
- Normalization theory deals with how to design "good" relational schemas

Database Schemas in SQL

- SQL is primarily a query language, for getting information from a database.
- But SQL also includes a *data-definition* component for describing database schemas.

Levels of Abstraction

- Many *views*, single *conceptual (logical) schema* and *physical schema*.
  - Views describe how users see the data.
  - Conceptual schema defines logical structure
  - Physical schema describes the files and indexes used.



☛ *Schemas are defined using DDL (data definition language);*

☛ *Data is modified/queried using DML (data manipulation language).*

Example: University Database

- Conceptual schema:
  - *Students(sid: string, name: string, login: string, age: integer, gpa:real)*
  - *Courses(cid: string, cname:string, credits:integer)*
  - *Enrolled(sid:string, cid:string, grade:string)*
- Physical schema:
  - Relations stored as unordered files.
  - Index on first column of Students.
- External Schema (View):
  - *Course_info(cid:string,enrollment:integer)*

Integrity Constraints

- An *integrity constraint* is a property that must be satisfied by all meaningful database instances.

- A constraint can be seen as *a predicate*; a database is *legal* if it satisfies all integrity constraints.

- Types of constraints
  - Intra-relational constraints: e.g., *domain constraints* and *tuple constraints*
  - Inter-relational constraints: most common is *referential constraint*

Tuple and Domain Constraints

- A *tuple constraint* expresses conditions on the values of each tuple, independently of other tuples.
- E.g., **`Net = Amount-Deductions`**

- A *domain constraint* is a tuple constraint that involves a single attribute
- e.g., **`(GPA ≤ 4.0) AND (GPA ≥ 0.0)`**

Unique Values for Tuples

RegNum	Surname	FirstName	BirthDate	DegreeProg
284328	Smith	Luigi	29/04/59	Computing
296328	Smith	John	29/04/59	Computing
587614	Smith	Lucy	01/05/61	Engineering
934856	Black	Lucy	01/05/61	Fine Art
965536	Black	Lucy	05/03/58	Fine Art

- Registration number identifies students, i.e., there is no pair of tuples with the same value for **RegNum**.
- Personal data could identify students as well, i.e., there is no pair of tuples with the same values for all of **Surname**, **FirstName**, **BirthDate**.

Keys

- A *key* is a set of attributes that uniquely identifies tuples in a relation.
- More precisely:
  - A set of attributes K is a *superkey* for a relation r if r cannot contain two distinct tuples t_1 and t_2 such that $t_1[K]=t_2[K]$;
  - K is a (candidate) *key* for r if K is a minimal superkey

(that is, there exists no other superkey K' of r that is contained in K as proper subset, i.e, $K' \subset K$)

Example

RegNum	Surname	FirstName	BirthDate	DegreeProg
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- `RegNum` is a key: i.e., `RegNum` is a superkey and it contains a sole attribute, so it is minimal.
- `{Surname, Firstname, BirthDate}` is another key

Beware!

RegNum	Surname	FirstName	BirthDate	DegreeProg
296328	Smith	John	29/04/59	Computing
587614	Smith	Lucy	01/05/61	Engineering
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- There is no pair of tuples with the same values on both `Surname` and `DegreeProg`;

  i.e., in each program students have different surnames; can we conclude that `Surname` and `DegreeProg` form a key for this relation?

  No! There ***could be*** students with the same surname in the same program

Existence of Keys

- Relations are sets; therefore each relation is composed of distinct tuples.
- It follows that the whole set of attributes for a relation defines a **superkey**.
- Therefore **each relation has a key**, which is the set of all its attributes, or a subset thereof.
- The existence of keys guarantees that each piece of data in the database can be accessed,
- Keys are a major feature of the Relational Model and allow us to say that it is "**value-based**".

Keys and Null Values

If there are nulls, keys do not work that well:

- They do not guarantee unique identification;
- They do not help in establishing correspondences between data in different relations

RegNum	Surname	FirstName	BirthDate	DegreeProg
NULL	Smith	John	NULL	Computing
587614	Smith	Lucy	01/05/61	Engineering
934856	Black	Lucy	NULL	NULL
NULL	Black	Lucy	05/03/58	Engineering

- Are the third and fourth tuple the same?
- How do we access the first tuple?

Primary Keys

- The presence of nulls in keys has to be limited.
- Each relation must have a *primary key* on which nulls are not allowed (in any attribute)
- Notation: the attributes of the primary key are *underlined*
- References between relations are realized through primary keys

RegNum	Surname	FirstName	BirthDate	DegreeProg
643976	Smith	John	**NULL**	Computing
587614	Smith	Lucy	01/05/61	Engineering
934856	Black	Lucy	**NULL**	**NULL**
735591	Black	Lucy	05/03/58	Engineering

Do we Always Have Primary Keys?

- In most cases, we do have reasonable primary keys (e.g., student number, SIN)

- There may be multiple keys, one of which is designated as primary.

Recap

- A set of fields is a *key* for a relation if:
  1. No two distinct tuples can have same values in all key fields, and
  2. This is not true for any subset of the key.
- If #2 false, then a *superkey*.
- If there's >1 key for a relation, one of the keys is chosen to be the *primary key*.
- E.g., *sid* is a key for Students. (What about *name*?) The set {*sid*, *gpa*} is a superkey.

Primary and Candidate Keys

Enrolled(sid, cid, grade)

1. "For a given student and course, there is a single grade." vs.
2. "Students can take only one course, and receive a single grade for that course; further, no two students in a course receive the same grade."

Enrolled(<u>sid, cid</u>, grade)

Enrolled(<u>sid</u>, cid, grade)

- key (cid, grade)

- Be careful to define Integrity Constraints (ICs) correctly at design time.
- ICS are checked when data is updated.

Foreign Keys

- Pieces of data in different relations are correlated by means of values of primary keys.

- Referential integrity constraints are imposed in order to guarantee that the values refer to existing tuples in the referenced relation.

- A *foreign key* requires that the values on a set X of attributes of a relation R_1 must appear as values for the primary key of another relation R_2.
  - In other words, set of attributes in one relation that is used to `refer' to a tuple in another relation. (Must correspond to primary key of the second relation.) Like a `logical pointer'.

Referential Integrity

- E.g. *sid* is a foreign key referring to Students:
  - Enrolled(*sid*: string, *cid*: string, *grade*: string)
  - If all foreign key constraints are enforced, *referential integrity* is achieved, i.e., no dangling references.

Referential Integrity (cont'd)

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

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

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Enforcing Referential Integrity

- Consider Students and Enrolled; *sid* in Enrolled is a foreign key that references Students.
- What should be done if an Enrolled tuple with a non-existent student id is inserted? *Reject it!*
- What should be done if a Students tuple is deleted?
  - Also 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*.
  - Set sid in Enrolled tuples that refer to it to NULL.
- Similar if primary key of Students tuple is updated.

Where do ICs Come From?

- ICs are based upon the semantics of the real-world enterprise that is being described in the database relations.
- We can check a database instance to see if an IC is violated, but we cannot infer that an IC is true by looking at an instance.
  - An IC is a statement about *all possible* instances
- Key and foreign key ICs are the most common; more general ICs supported too.

One More Example

Offences

Code	Date	Officer	Dept	Registration
143256	25/10/1992	567	75	5694 FR
987554	26/10/1992	456	75	5694 FR
987557	26/10/1992	456	75	6544 XY
630876	15/10/1992	456	47	6544 XY
539856	12/10/1992	567	47	6544 XY

Officers

RegNum	Surname	FirstName
567	Brun	Jean
456	Larue	Henri
638	Larue	Jacques

Cars

Registration	Dept	Owner
6544 XY	75	Cordon Edouard
7122 HT	75	Cordon Edouard
5694 FR	75	Latour Hortense
6544 XY	47	Mimault Bernard

- Offences[Officer] $\subseteq$ Officers[RegNum]
- Offences[Registration,Dept] $\subseteq$ Cars[Registration,Dept]

Violation of Foreign keys

Offences

Code	Date	Officer	Dept	Registration
987554	26/10/1992	456	75	5694 FR
630876	15/10/1992	456	47	6544 XY

Officers

RegNum	Surname	FirstName
567	Brun	Jean
638	Larue	Jacques

Cars

Registration	Dept	Owner	…
7122 HT	75	Cordon Edouard	…
5694 FR	93	Latour Hortense	…
6544 XY	47	Mimault Bernard	…

Referential Constraints: Comments

- Referential constraints play an important role in making the relational model value-based.
- Care is needed in case of referential constraints that involve two or more attributes.

Example

Accidents

Code	Dept1	Registration1	Dept2	Registration2
6207	75	6544 XY	93	9775 GF
6974	93	5694 FR	93	9775 GF

Cars

Registration	Dept	Owner	…
7122 HT	75	Cordon Edouard	…
5694 FR	93	Latour Hortense	…
9775 GF	93	LeBlanc Pierre	
6544 XY	75	Mimault Bernard	…

Here we have two referential constraints for **`Accidents`**:

- **`Registration1`**, **`Dept1`** to **`Cars`**
- **`Registration2`**, **`Dept2`** to **`Cars`**.