Databases

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Overview

Example Database

STUDENTS			
SID	**FIRST**	**LAST**	**EMAIL**
101	Ann	Smith	...
102	Michael	Jones	null
103	Richard	Turner	...
104	Maria	Brown	...

- Columns in table STUDENTS:
  - SID: “student ID” (unique number)
  - FIRST, LAST: first and last name
  - EMAIL: email address (may be null)

Example Database

EXERCISES			
CAT	**ENO**	**TOPIC**	**MAXPT**
H	1	Rel.Alg.	10
H	2	SQL	10
M	1	SQL	14

- Columns in table `EXERCISES`:
  - `CAT`: category
    (`H`: Homework, `M`/`F`: midterm/final exam)
  - `ENO`: exercise number within category
  - `TOPIC`: topic of exercise
  - `MAXPT`: maximum number of points

Example Database

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RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
101	M	1	12
102	H	1	9
102	H	2	9
102	M	1	10
103	H	1	5
103	M	1	7

EXERCISES

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- Columns in table `RESULTS`:
  - `SID`: student who did the exercise (references `STUDENTS`)
  - `CAT`, `ENO`: identification of exercise (references `EXERCISE`)
  - `POINTS`: graded points

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The **domain** $val(D)$ of a type D is the set of possible values.

For example:

$$val(\texttt{NUMERIC(2)}) = \{\texttt{-99}, \ldots, \texttt{99}\}$$

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- In SQL, the user may define **application-specific domains** as names for (subsets of) standard data types:

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                       CHECK(VALUE > 0)
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- Domains are useful to document that two columns represent the same kind of real-world object (such that, for example, comparisons between values in the columns are meaningful).

Relation Schema

Relation schema

A **relation schema** s (schema of a single relation) defines

- A (finite) sequence $A_1, \ldots, A_n$ of distinct **attribute names.**
- For each attribute A_i a **data type** (or **domain**) D_i.

A relation schema can be written as $s = (A_1 : D_1, \ldots, A_n : D_n)$.

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Creating a relation schema in SQL

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Relation schema in SQL

```
CREATE TABLE EXERCISES
  (CAT   CHAR(1),
   ENO   NUMERIC(2),
   TOPIC VARCHAR(40),
   MAXPT NUMERIC(2))
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Relation Schema: Notation

- SQL `CREATE TABLE` statements represent a rather poor way to communicate schemas (from human to human).

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- If the column data types are not important, we can write

  `EXERCISES (CAT, ENO, TOPIC, MAXPT)`

- Also widely in use: sketch of the table header

EXERCISES			
CAT	**ENO**	**TOPIC**	**MAXPT**

Relational Database Schemas

Relational database schema

A **relational database schmema** $\mathcal{S}$ defines

- A finite set of **relation names** $\{R_1, \ldots, R_m\}$.
- For every relation R_i, a **relation schema** $sch(R_i)$.
- A set $\mathcal{C}$ of **integrity constraints** (defined below).

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Example: relational database schema

- relation names { `STUDENTS`, `EXERCISES`, `RESULTS` }
- relation schema for every relation name
  - `STUDENTS (SID, FIRST, LAST, EMAIL)`
  - `EXERCISES (CAT, ENO, TOPIC, MAXPT)`
  - `RESULTS (SID, CAT, ENO, POINTS)`

Tuples

Tuples are used to formalize table rows.

A **tuple** t with respect to the relation schema

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One tuple in table `EXERCISES` is `('H', 1, 'Rel.Alg.', 10)`.

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Given a tuple, we write $t.A_i$ (or $t[A_i]$) for d_i in column A_i.

- e.g. $(\texttt{'H'}, 1, \texttt{'Rel.Alg.'}, 10).\texttt{MAXPT} = 10$

Database States

Let a database schema $(\{R_1, \ldots, R_m\}, sch, \mathcal{C})$ be given.

A **database state** I for this database schema defines for every relation name R_i to a finite **set of tuples** $I(R_i)$ with respect to the relation schema $sch(R_i)$.

- That is, if $sch(R_i) = (A_1 : D_1, \ldots, A_n : D_n)$, then

$$I(R_i) \subseteq val(D_1) \times \cdots \times val(D_n)$$

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Thus $I(R_i)$ is **a relation in the mathematical sense**.

You can think of the state as tables conforming to the schema

STUDENTS			
SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
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103	Richard	Turner	...
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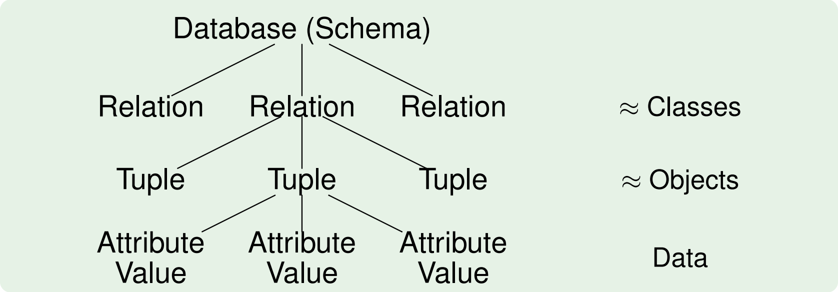
Except:

- there is no order on the tuples (rows)
- tables contain no duplicate tuples

Summary Relational Database Schemas



The Relational Model

Overview

1. Relational Model Concepts: Schema, State
2. Null Values
3. Constraints: General Remarks
4. Key Constraints
5. Foreign Key Constraints

Null Values

The relational model allows **missing attribute values**

- table entries may be empty

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“Null” is **not** the number 0 or the empty string.
A null value is different from all values of any data type.

Null Values

Null values are used to model a variety of scenarios:

- **A value exists (in the real world), but is not known.**

  In table `STUDENTS`*,* `EMAIL` *might be missing for a student.*

- **No value exists.**

  A student might not have an e-mail address.

- **The attribute is not applicable for this tuple.**

  Some exercises are for training only: no points will be given.

- **Any value will do.**

Null Values: Advantages

Without null values, it would be necessary to **split a relation** into many, more specific relations ("subclasses").

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Fake values

Why are fake values a bad idea in database design?

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  For users accustomed to two-valued logic (the majority), the outcome is often surprising—common equivalences do not hold.

Rows with `NULL` in column A will not appear in either result:

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- Some programming languages do not know about null values. This complicates application programs.

  When an attribute value is read into a program variable, an explicit null value check and treatment is required (SQL: indicator variables).

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Students may not have an e-mail address

```
CREATE TABLE STUDENTS (
             SID       NUMERIC(3)  NOT NULL,
             FIRST     VARCHAR(20) NOT NULL,
             LAST      VARCHAR(20) NOT NULL,
             EMAIL     VARCHAR(80)          )
```

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A valid database state?

CUSTOMER

CUST_NO	NAME	BIRTH_YEAR	CITY	...
1	Smith	1936	Pittsburgh	...
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3	Brown	64	New York	...
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- Customer numbers must be unique.
- The year of birth must be greater than `1870`.
- Customers must be at least 18 years old.

Constraints

Integrity constraints (IC) are conditions which every database state has to satisfy.

- This restricts the set of possible database states.
  Ideally only admits images of possible real world scenarios.
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The database management system will **refuse any update** leading to a database state that violates any of the constraints.

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- **Keys:** Each key value can appear once only.
- **Foreign keys:** Values in a column must also appear as key values in another table.
- `CHECK`: Column values must satisfy a given predicate.
  SQL allows for inter-column `CHECK` *constraints.*

Constraints

Which of the following are constraints?

1. It is possible that a student gets 0 points for a solution.
2. A student can get at most 3 points more than the maximum number of points stored in `EXERCISES` (extra credit).
3. The attribute `CAT` in can only have the values `H`, `M`, `F`.
4. The `CAT` means: `H` for homework, `M` for mid-term exam, `F` for final exam.
5. Student IDs should be unique.

Summary: Constraints

Why specify constraints?

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Summary: Constraints

Why specify constraints?

- (Some) protection against **data input errors.**
- Constraints **document** knowledge about DB states.
- **Enforcement of law / company standards.**
- **Protection against inconsistency** if data is stored redundantly.
- **Queries/application programs become simpler** if the programmer may assume that the data fulfills certain properties.

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Example

If attribute SID has been declared as key for STUDENTS, this database state is illegal:

STUDENTS			
SID	**FIRST**	**LAST**	**EMAIL**
101	Ann	Smith	...
101	Michael	Jones	(null)
103	Michael	Turner	...

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101	Ann	Smith	...
102	Michael	Jones	(null)
103	Michael	Turner	...

Even though the above DB state would allow the attribute `LAST` to serve as a key for `STUDENTS`, this would be **too restrictive.** The future insertion of `"John Smith"` would be impossible.

Composite Keys

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This relation satisfies the composite key `FIRST`, `LAST`:

STUDENTS			
SID	**FIRST**	**LAST**	**EMAIL**
101	Ann	Smith	...
102	John	Smith	...
103	John	Miller	...

Composite Keys

Implication between key constraints

A key constraint becomes **weaker** (i.e., less restrictive, more DB states are valid) if attributes are added to the key.

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This relation

- **violates** the key constraint `FIRST`,
- **violates** the key constraint `LAST`,
- but **satisfies** the key constraint `FIRST,LAST`.

Composite Keys

Implication between key constraints

A key constraint becomes **weaker** (i.e., less restrictive, more DB states are valid) if attributes are added to the key.

STUDENTS			
<u>**SID**</u>	**FIRST**	**LAST**	**EMAIL**
101	Ann	Smith	...
102	John	Smith	...
103	John	Miller	...

This relation

- **violates** the key constraint `FIRST`,
- **violates** the key constraint `LAST`,
- but **satisfies** the key constraint `FIRST,LAST`.

Weak keys

Do all relations have a key (what is the weakest possible key)?

Minimality of Keys

STUDENTS		
SID	**FIRST**	**LAST**
101	Ann	Smith
102	John	Smith
103	John	Miller

What keys satisfy the key constraints?

Minimality of Keys

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What keys satisfy the key constraints?

- {SID}

Minimality of Keys

STUDENTS		
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What keys satisfy the key constraints?

- {SID}
- {FIRST, LAST}

Minimality of Keys

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What keys satisfy the key constraints?

- {SID}
- {FIRST, LAST}
- {SID, FIRST}

Minimality of Keys

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What keys satisfy the key constraints?

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- {FIRST, LAST}
- {SID, FIRST}
- {SID, LAST}

Minimality of Keys

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If a set of attributes *A* satisfies the key constraint, then **any superset** *K* that includes *A* will automatically also have the unique identification property.

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A key with attribute set $\{A_1, \ldots, A_k\}$ is **minimal** if no A_i can be removed from the set without destroying the unique identification property.

Minimality of Keys

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SID	**FIRST**	**LAST**
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- {FIRST, LAST} minimal
- {SID, FIRST}
- {SID, LAST}
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Minimality of Keys

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What keys satisfy the key constraints?

- {SID} minimal
- {FIRST, LAST} minimal
- {SID, FIRST}
- {SID, LAST}
- {SID, FIRST, LAST}

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A key with attribute set $\{A_1, \ldots, A_k\}$ is **minimal** if no A_i can be removed from the set without destroying the unique identification property.

The usual definition of keys requires that the set of key attributes $\{A_1, \ldots, A_k\}$ is minimal.

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The primary key attributes are often marked by **underlining** them in the relation schema specifications:

$$R(\underline{A_1 : D_1}, \ldots, \underline{A_k : D_k}, A_{k+1} : D_{k+1}, \ldots, A_n : D_n)$$

STUDENTS			
<u>SID</u>	**FIRST**	**LAST**	**EMAIL**

Key Quiz

Keys for an appointment calendar

APPOINTMENTS				
DATE	**START**	**END**	**ROOM**	**EVENT**
Jan. 19	10:00	11:00	IS 726	Seminar
Jan. 19	14:00	16:00	IS 726	Lecture
May 24	14:00	18:00	Amsterdam	Meeting

- What would be correct (minimal) keys?
- What would be an example for a superkey?
- Are additional constraints useful to exclude database states that a key would still permit?

Overview

Foreign Keys

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To refer to tuples of R in a relation S

- add the **primary key attributes** of R to the attributes of S

Such a reference is only “stable” if the (logical) address of a tuple does not change (if the key attributes are not updated).

Foreign Keys

SID in RESULTS is a foreign key referencing STUDENTS

STUDENTS

SID	FIRST	LAST	EMAIL
101	Ann	Smith	...
102	Michael	Jones	(null)
103	Richard	Turner	...
104	Maria	Brown	...

RESULTS

SID	CAT	ENO	POINTS
101	H	1	10
101	H	2	8
102	H	1	9
102	H	2	9
103	H	1	5
105	M	1	7

?

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- A foreign key implements a **one-to-many relationship**.

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- A foreign key implements a **one-to-many relationship**.

We need some kind of **existence guarantee** for key values in STUDENTS.

Foreign Key Constraints

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```
CREATE TABLE RESULTS (
  ...
  FOREIGN KEY (SID) REFERENCES STUDENTS(SID)
)
```

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- Enforcing foreign key constraints ensures the **referential integrity** of the database.
- The set of SID value actually appearing in STUDENTS are a kind of **dynamic domain** for the attribute REULTS.SID.

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  - deletion **cascades**, that is, tuples in `RESULTS` referencing the deleted tuple will also be deleted, or
  - the foreign key is **set to null** in `RESULTS`.

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Typically, foreign keys are denotes with arrows ($\rightarrow$) in the relation schema, composite keys appear in parentheses:

RESULTS (<u>SID</u> $\rightarrow$ STUDENTS,
(<u>CAT</u>, <u>ENO</u>) $\rightarrow$ EXERCISES,
POINTS)
STUDENTS (<u>SID</u>,FIRST,LAST,EMAIL)
EXERCISES (<u>CAT</u>,<u>ENO</u>,TOPIC,MAXPT)

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```
   RESULTS (SID → STUDENTS,
            (CAT, ENO) → EXERCISES,
            POINTS)
  STUDENTS (SID,FIRST,LAST,EMAIL)
 EXERCISES (CAT,ENO,TOPIC,MAXPT)
```

- Since typically only the primary key is referenced, it is sufficient to simply list the target relation.

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  foreign keys may be null.

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Foreign keys are not themselves keys.

The Relational Model: Objectives

After completing this chapter, you should be able to

- explain the concepts of the **Relational Model**,
  - Schemas, state, domains
- explain applications and problems of **null values**,
- explain **integrity constraints** and their importance,
- explain the meaning of **keys** and **foreign keys**,
- read various notations for **relational schema**,
- develop simple relational schemas.