CSE 305 / CSE532

Lecture 02
The Big Picture

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Slide adapted from the author's slides and Dr. Ilchul Yoon's slides.

Databases

- Our interest - relational databases
- Data is stored in tables.

Table

- Set of rows (no duplicates)
- Each row - a different entity
- Each column - a particular fact about each entity
  - Each column has an associated domain

Id	*Name*	*Address*	*Status*
1111	John	123 Main	fresh
2222	Mary	321 Oak	soph
1234	Bob	444 Pine	soph
9999	Joan	777 Grand	senior

- Domain of Status = {fresh, soph, junior, senior}

Relation

- Mathematical entity corresponding to a table
  - row ~ tuple
  - column ~ attribute
- Values in a tuple are related to each other
  - John is a freshman and lives at 123 Main
- Relation **R** as predicate **R**
  - **R**(x,y,z) is true *iff* tuple (x,y,z) is in **R**

Operations

- Operations on relations are precisely defined
  - Take relation(s) as argument, **produce new relation as result**
  - Unary (e.g., delete certain rows)
  - Binary (e.g., union, Cartesian product)
- Corresponding operations defined on tables as well

- Using mathematical properties, equivalence can be decided
  - Important for query optimization:

$$\mathbf{op1(T1,op2(T2)) \overset{?}{=} op3(op2(T1),T2)}$$

Structured Query Language: SQL

- Language for manipulating **tables**
- **Declarative** – Statement specifies **what** needs to be obtained, **not how** it is to be achieved
  - e.g., how to access data, the order of operations
- **DBMS determines evaluation strategies** for query processing and optimization
  - *Simplifies application programs*
  - But DBMS is not infallible
    - Programmers must understand the mechanism behind SQL for better design and statements

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Structured Query Language (SQL)

SELECT <*attribute list*>
FROM <*table list* >
WHERE <*condition*>

- Language for constructing a new table from argument table(s).
  - FROM - source table(s)
  - WHERE - which rows to retain **(Filtering)**
  - SELECT - which columns to keep from retained rows **(Projection)**

- The result is also a table.

Example

SELECT *Name*
FROM *Student*
WHERE *Id* > 4999

Id	*Name*	*Address*	*Status*
1234	John	123 Main	fresh
5522	Mary	77 Pine	senior
9876	Bill	83 Oak	junior

Student

Name
Mary
Bill

Result

Examples

```
SELECT Id, Name FROM Student
```

```
SELECT Id, Name FROM Student
    WHERE Status = 'senior'
```

```
SELECT * FROM Student
    WHERE Status = 'senior'
```

result is a table with one column and one row

```
SELECT COUNT(*) FROM Student
    WHERE Status = 'senior'
```

More Complex Example

- Goal: table in which each row names a senior and gives a course taken and grade
- Combines information in two tables:
  - Student: Id, Name, Address, Status
  - Transcript: StudId, CrsCode, Semester, Grade

```
SELECT Name, CrsCode, Grade
FROM   Student, Transcript
WHERE  StudId = Id AND Status = 'senior'
```

Join

SELECT *a1*, *b1*
FROM T1, T2
WHERE *a2* = *b2*

T1

a1	*a2*	*a3*
A	1	xxy
B	17	rst

T2

b1	*b2*
3.2	17
4.8	17

FROM T1, T2
yields:

a1	*a2*	*a3*	*b1*	*b2*
A	1	xxy	3.2	17
A	1	xxy	4.8	17
B	17	rst	3.2	17
B	17	rst	4.8	17

WHERE *a2* = *b2*
yields:

B	17	rst	3.2	17
B	17	rst	4.8	17

SELECT *a1*, *b1*
yields result:

B	3.2
B	4.8

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Modifying Tables

```
UPDATE Student
SET Status = 'soph'
WHERE Id = 111111111

INSERT INTO Student (Id, Name, Address, Status)
VALUES (999999999, 'Bill', '432 Pine', 'senior')

DELETE FROM Student
WHERE Id = 111111111
```

Creating Tables

```
CREATE TABLE Student (
    Id          INTEGER,
    Name        CHAR(20),
    Address     CHAR(50),
    Status      CHAR(10),
    PRIMARY KEY (Id)   )
```

Integrity Constraints

- Rules (or limitations) enforced by the enterprise
  - Generally, limit the occurrence of certain real-world events.
  - Student cannot register for a course if current number of registrants = maximum allowed
  - Allowable database states are restricted
    - cur_reg <= max_reg
- Expressed as **integrity constraints**
  - assertions that must be satisfied by the database state.

Transactions

- Many enterprises use databases to store information about their state
  - E.g., balances of all depositors
- Real world event → corporate database update
  - requires the execution of a program that changes the database state in a corresponding way
  - E.g., balance must be updated when you deposit
- A **transaction** is a program that accesses the database in response to real-world events

Transactions

- Transactions are not just ordinary programs
- Additional requirements

Atomicity
Consistency
Isolation
Durability

ACID properties

Atomicity

- A real-world event either **happens or does not happen**.
  - Student either registers or does not register.

- Whether the transaction runs to completion (**commits**) or,
- If it does not complete, it has no effect at all (**aborts**).

Consistency

- Transaction designer must ensure
  - **IF** the database is in a state that satisfies all integrity constraints when execution of a transaction is started
  - **THEN** when the transaction completes:
    - All integrity constraints are once again satisfied (constraints can be violated in intermediate states)
    - New database state satisfies specifications of transaction

Isolation

- **Deals with concurrent transaction execution**
  - If the initial database state is consistent and accurately reflects the real-world state,
  - then the serial (one after another) execution of a set of consistent transactions will preserve consistency.
  - However…. **Serial execution is inadequate** from a performance perspective.

- Overall effect of the transaction schedule must be the same as if the transactions had executed **serially** in some order.
  - The execution is thus not serial, but **serializable**

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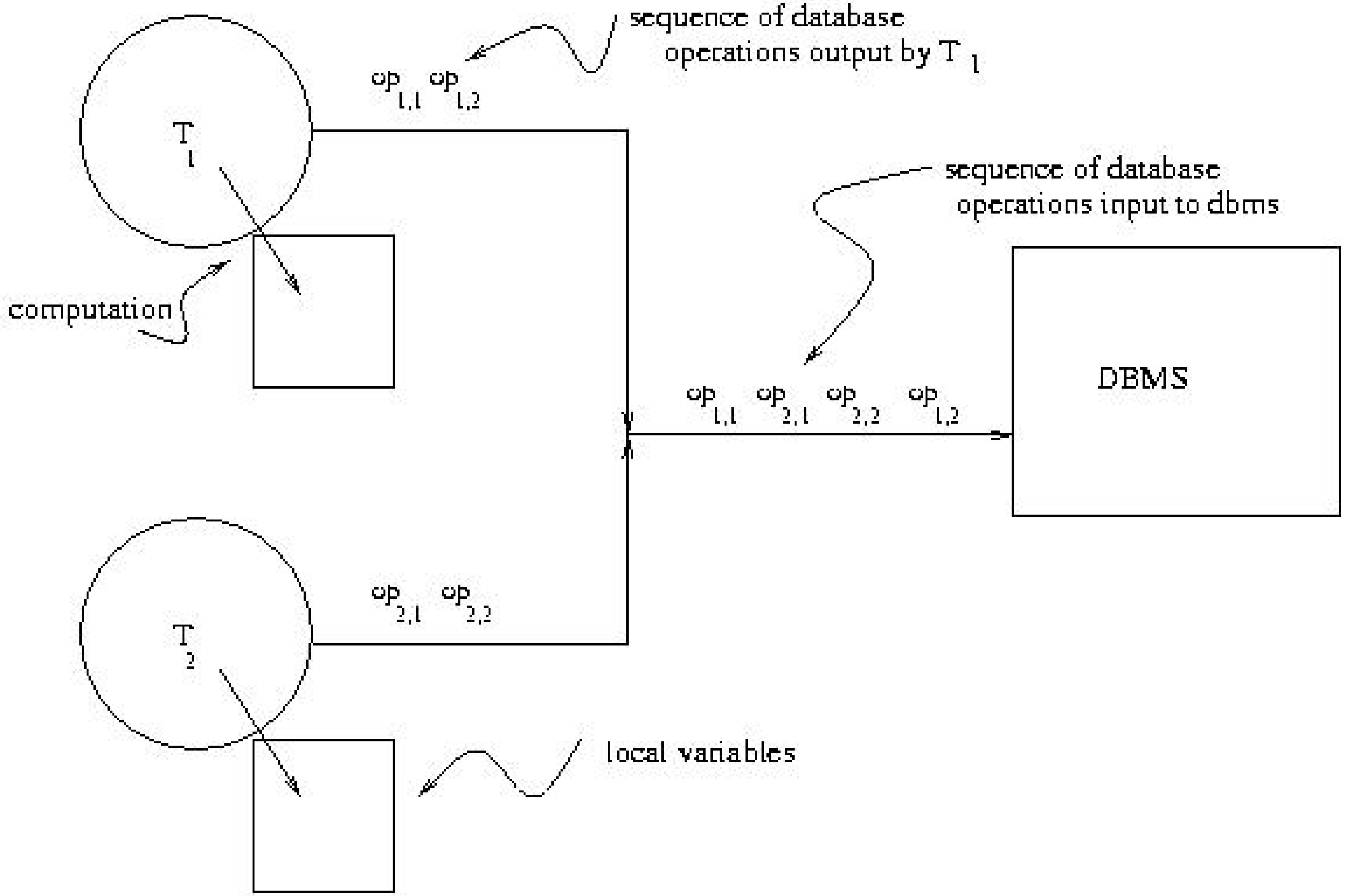
Concurrent Transaction Execution



Isolation

- Concurrent (interleaved) transaction execution offers performance benefits, but might not be correct.
- Example: Two students execute the course registration transaction at about the same time
  - *cur_reg* is the number of current registrants

T_1:	read(*cur_reg* : 29)		write(*cur_reg* : 30)
T_2:		read(*cur_reg* : 29) write(*cur_reg* : 30)	

time →

Result: Database state no longer corresponds to real-world state, integrity constraint violated.

Durability

- Once a transaction commits, its effect on the database state is not lost in spite of subsequently computer crashes.

ACID Properties

- The transaction monitor is responsible for ensuring atomicity, durability, and (the requested level of) isolation.
  - Hence it provides the abstraction of failure-free, non-concurrent environment, greatly simplifying the task of the transaction designer.
- The transaction designer is responsible for ensuring the consistency of each transaction, but doesn't need to worry about concurrency and system failures.

Data and Its Structure

- Schema: Description of data at some abstraction level. Each level has its own schema.
- We will be concerned with three schemas: **physical**, **conceptual**, and **external**.

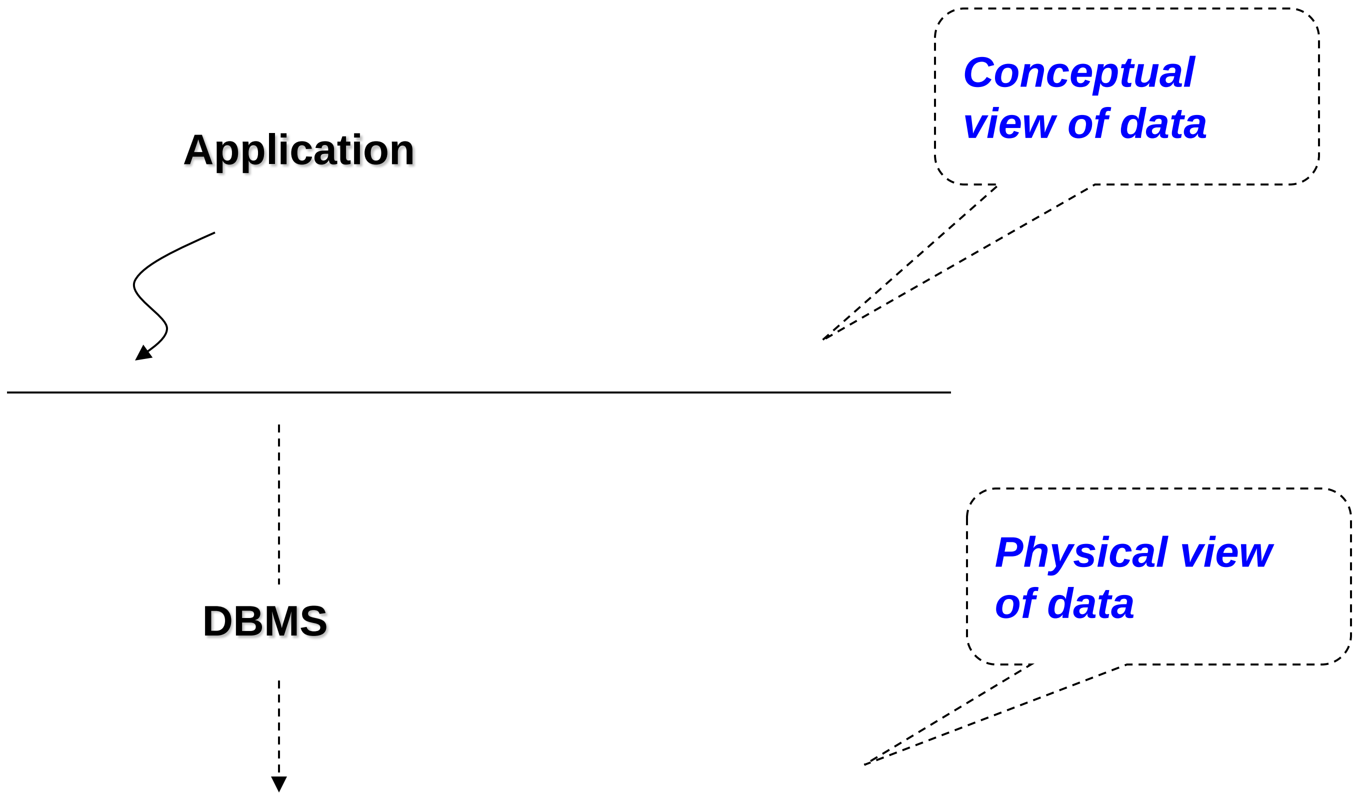
Physical Data Level

- **Physical schema** describes details of how data is stored
  - tracks, cylinders, indices etc.
  - Early applications worked at this level – explicitly dealt with details.
- **Problem**:
  - Routines were hard-coded to deal with physical representation.
  - Changes to data structure difficult to make.
  - Application code becomes complex since it must deal with details.
  - Rapid implementation of new features impossible.

Conceptual Data Level

- Hides details.
  - In the relational model, the **conceptual schema** presents data as a set of tables (or relations).
- DBMS maps from conceptual to physical schema automatically.
- **Physical schema can be changed without changing application:**
  - DBMS would change mapping from conceptual to physical transparently
  - This property is referred to as **physical data independence**

Conceptual Data Level (con't)



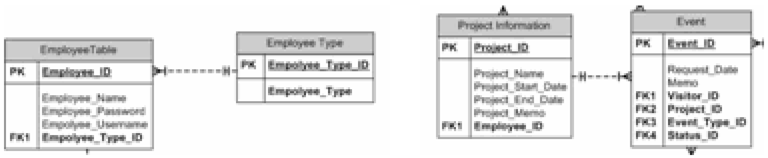
External Data Level

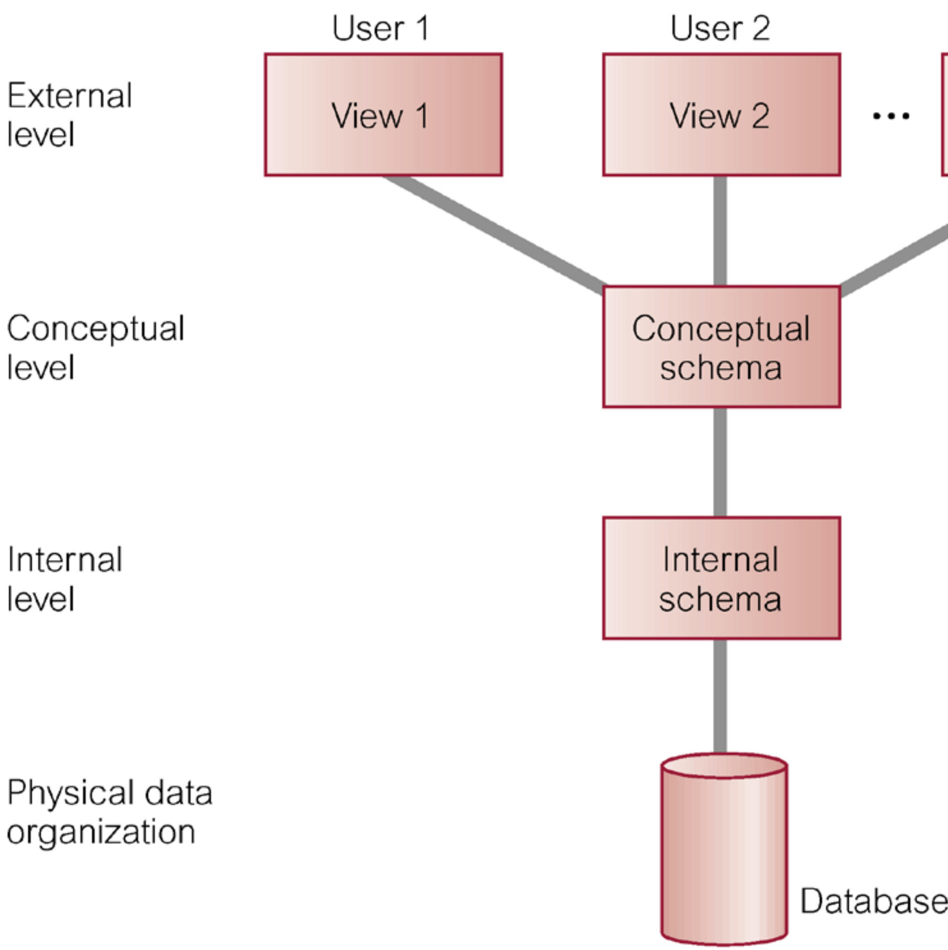
- <u>In the relational model</u>, the **external schema** also presents data as a set of relations.
- An external schema specifies a **view** of the data in terms of the conceptual level. It is tailored to the needs of a particular category of users.
  - Portions of stored data should not be seen by some users.
    - Students should not see their files in full.
    - Faculty should not see billing data.
  - Information that can be derived from stored data might be viewed as if it were stored.
    - GPA not stored, but calculated when needed.

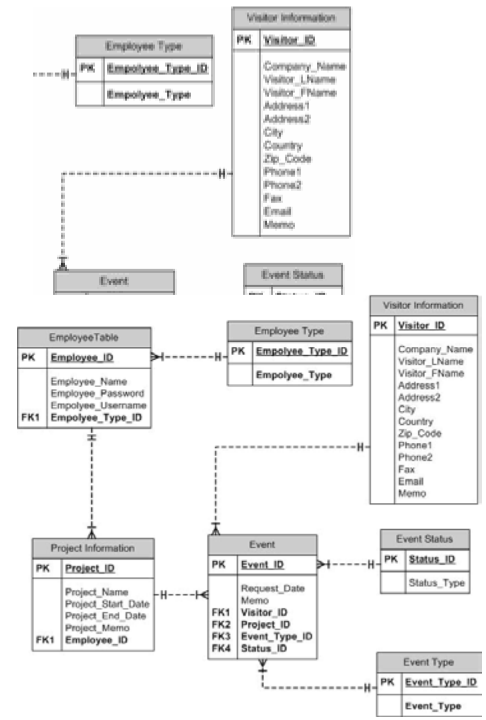
External Data Level (con’t)

- Application is written in terms of an external schema.
- A view is computed when accessed (not stored).
- Different external schemas can be provided to different categories of users.
- Translation from external to conceptual done automatically by DBMS **at run time**.
- Conceptual schema can be changed without changing application:
  - Mapping from external to conceptual must be changed.
- Referred to as **conceptual data independence**.

ANSI-SPARC 3-level Architecture (1975)








```
struct STAFF {
    int staffNo;
    int branchNo;
    char fName [15];
    char lName [15];
    struct date dateOfBirth;
    float salary;
    struct STAFF *next;
};
index staffNo; index branchNo;
```

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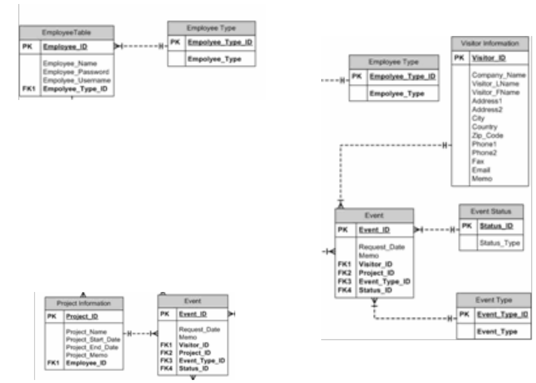
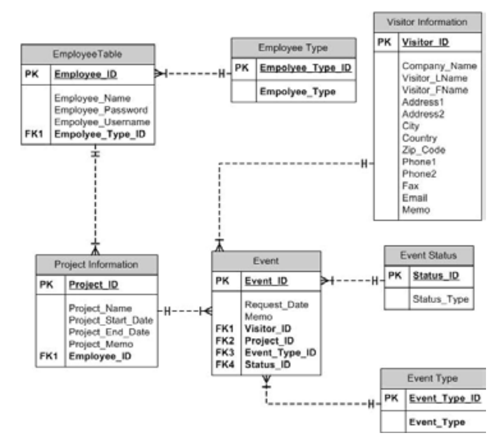
ANSI-SPARC 3-level Architecture

- External Level
  - Multiple independent users or applications
  - Users' view of the database
  - Focus on each user or application



- Conceptual Level
  - Community view of the database
  - Describes what data is stored in database and relationships among the data
  - Focus on the organization



ANSI-SPARC 3-level Architecture

- Internal Level
  - Physical representation of the database on the computer
  - Describes how the data is stored in the database
  - Focus on the DBMS

```
struct STAFF {
    int staffNo;
    int branchNo;
    char fName [15];
    char lName [15];
    struct date dateOfBirth;
    float salary;
    struct STAFF *next;
};
index staffNo; index branchNo;
```

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Lecture 03
The Big Picture

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Adapted from book authors' slides

Data Model

- **Schema**: description of data at some level
  - e.g., tables, attributes, constraints, domains

- <u>**Model**: tools and language for describing:</u>
  - Conceptual and external *schema*
    - Data definition language (DDL)
  - Integrity *constraints*, domains (DDL)
  - *Operations* on data
    - Data manipulation language (DML)
  - Directives that influence the physical schema (affects performance, not semantics)
    - Storage definition language (SDL)

Relational Model

- A particular way of structuring data (using relations)
- Simple
- Mathematically based
  - Expressions ($\equiv$ ***queries***) can be analyzed by DBMS
  - Queries are transformed to equivalent expressions automatically (query optimization)
    - Optimizers have limits

Relation Instance

- Relation is a set of tuples
  - Atomic values
  - Tuple ordering is unimportant
  - No duplicates
  - **Cardinality** of relation = number of tuples
- All tuples in a relation have the same structure; constructed from the same set of attributes
  - Attributes are named (ordering is immaterial)
  - Value of an attribute is drawn from the attribute's **domain**
    - There is also a special value **null** (value unknown or undefined), which belongs to no domain
  - **Arity** (or degree) of relation = number of attributes

Relation Instance (Example)

Id	*Name*	*Address*	*Status*
1111111	John	123 Main	freshman
2345678	Mary	456 Cedar	sophmore
4433322	Art	77 So. 3rd	senior
7654321	Pat	88 No. 4th	sophmore

Student

Relation Schema

- Relation name
- Attribute names & domains
- Integrity constraints like
  - The values of a particular attribute in all tuples are unique
  - The values of a particular attribute in all tuples are greater than 0
- Default values

Relational Database

- Finite set of relations
- Each relation consists of a schema and an instance

- **Database schema** = set of relation schemas constraints among relations (**inter-relational constraints**)
- **Database instance** = set of (corresponding) relation instances

Database Schema (Example)

- Student (*Id*: INT, *Name*: STRING, *Address*: STRING, *Status*: STRING)
- Professor (*Id*: INT, *Name*: STRING, *DeptId*: DEPTS)
- Course (*DeptId*: DEPTS, *CrsName*: STRING, *CrsCode*: COURSES)
- Transcript (*CrsCode*: COURSES, *StudId*: INT, *Grade*: GRADES, *Semester*: SEMESTERS)
- Department(*DeptId*: DEPTS, *Name*: STRING)

Integrity Constraints

- Part of schema
- Restriction on state (or of sequence of states) of data base
- Enforced by DBMS
- **Intra-relational** - involve only one relation
  - Part of relation schema
  - e.g., all Ids are unique
- **Inter-relational** - involve several relations
  - Part of relation schema or database schema

Constraint Checking

- Automatically checked by DBMS
- Protects database from errors
- Enforces enterprise rules

Kinds of Integrity Constraints

- Static – restricts legal states of database
  - Syntactic (structural)
    - e.g., all values in a column must be unique (atomic values)
  - Semantic (involve meaning of attributes)
    - e.g., cannot register for more than 18 credits
- Dynamic – limitation on sequences of database states
    - e.g., cannot raise salary by more than 5%

Key Constraint

- A ***key constraint*** is a sequence of attributes $A_1,\ldots,A_n$ of a relation schema, **S**, with the following property:
  - A relation instance **s** of **S** satisfies the key constraint *iff* at most one row in **s** can contain a particular (or **unique**) set of values, $a_1,\ldots,a_n$, for the attributes $A_1,\ldots,A_n$
  - ***Minimality***: no subset of $A_1,\ldots,A_n$ satisfies the key constraint
- **Key**
  - Set of attributes mentioned in a key constraint
    - e.g., Id in **Student**,
    - e.g., (StudId, CrsCode, Semester) in **Transcript**
  - It is minimal: no subset of a key is a key
    - (Id, Name) is not a key of **Student**

Key Constraint (cont'd)

- **Superkey** - set of attributes containing key
  - (Id, Name) is a superkey of Student
- Every relation has a key
- Relation can have several keys:
  - **Primary key**: Id in **Student** (can't be **null**)
  - **Candidate key**: (Name, Address) in **Student**

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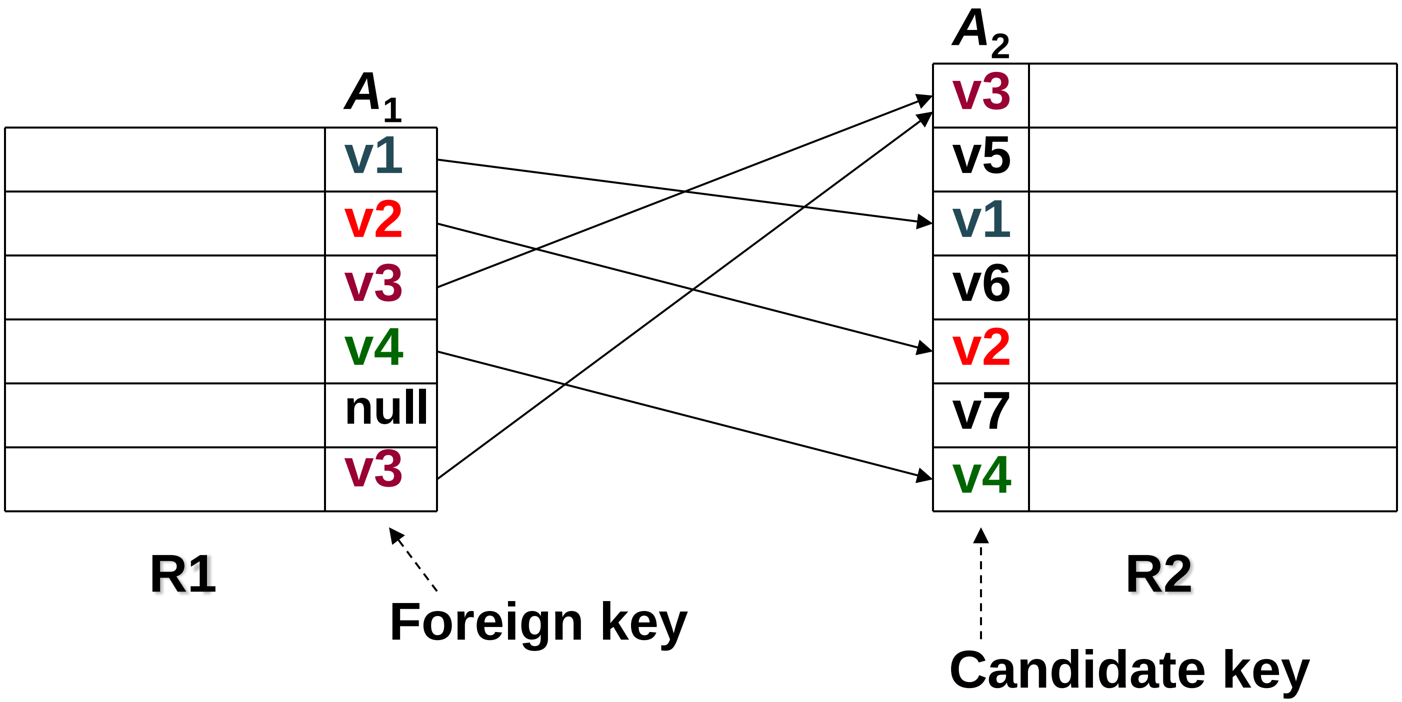
Foreign Key Constraint

- **Referential integrity**: Item named in one relation must refer to tuples that describe that item in another
  - **Transcript** (CrsCode) references **Course** (CrsCode)
  - **Professor(DeptId**) references **Department** (DeptId)

- Attribute A_1 is a **foreign key** of **R1** referring to attribute A_2 in **R2**, if whenever there is a value **v** of A_1, there is a tuple of **R2** in which A_2 has value **v**, and A_2 is a key of **R2**
  - This is a special case of referential integrity: *A_2 must be a candidate key of* ***R2*** (e.g., CrsCode is a key of **Course** in the above)
  - If no row exists in R2 => violation of referential integrity
  - Not all rows of R2 need to be referenced: relationship is not symmetric (e.g., some course might not be taught)
  - Value of a foreign key might not be specified (DeptId column of some professor might be null)

Foreign Key Constraint (Example)



Foreign Key (cont'd)

- Names of the attributes A_1 and A_2 can be different.
  - With tables:

    Teaching(*CrsCode*: COURSES, *Sem*: SEMESTERS, *ProfId*: INT)
    Professor(*Id*: INT, *Name*: STRING, *DeptId*: DEPTS)

  - *ProfId* attribute of Teaching references Id attribute of Professor

- R1 and R2 need not be distinct.
  - Employee(Id:INT, MgrId:INT, ….)
    - Employee(MgrId) references Employee(Id)
  - Every manager is also an employee and hence has a unique row in Employee

Foreign Key (cont'd)

- Foreign key might consist of several columns

  (CrsCode, Semester) of Transcript *references*
  (CrsCode, Semester) of Teaching

- **R1**(A_1, …A_n) references **R2**(B_1, …B_n)
  - A_i and B_i must have same domains (although not necessarily the same names)
  - B_1,…,B_n must be a candidate key of R2

Inclusion Dependency

- Referential integrity constraint that is not a foreign key constraint

  (CrsCode, Semester) of Teaching *references*
  (CrsCode, Semester) of Transcript

- Target attributes is not a CK in Transcript

- No simple enforcement mechanism for inclusion dependencies in SQL (requires *assertions*)