Relational Database Model

Context: What is the Relational Model?

Two Key Points:

1. **Based on relational algebra**
    - A relation (entity) = table of intersecting rows (tuples) and columns (attributes)
2. **Tables are related by sharing common attributes**

Enhancement:

- Entity Relationship Model (ERM) adds graphical design notation (e.g., crow's foot)

> In this course: *Relational Model = Entity Relationship Model = ERM*

Tables: The Foundation

- **Relation** (mathematical) → **Table** (persistent storage)
    - Codd used these terms interchangeably
- A table contains a group of related entity instances (**entity set**)
- Table view makes it easy to spot and define entity relationships

Characteristics of a Relational Table

1. 2D structure: rows and columns
2. Each **row** (tuple) = one **entity instance** (record)
3. Each **column** = one **attribute** (field) with distinct name
4. Row-column intersection = single data value (also a **1NF** requirement)
5. All values in a column:
    - Have same data format
    - Drawn from the **attribute domain**
6. Order of rows/columns is immaterial (logically)
7. At least one attribute (or combination) **uniquely identifies each row** (also a **1NF** requirement)

> A table in at least 1NF is a relational table!

Example: Student Table

STU_ID	STU_LNAME	STU_FNAME	STU_INIT	STU_GPA	DEPT_CODE	ADVISOR_ID
10001	Martinez	Carlos	A	3.45	CS	201
10002	Johnson	Emily	R	3.82	MATH	205
10003	Chen	David	L	3.67	CS	201
10004	Williams	Sarah	M	3.91	BIO	210
10005	Anderson	Michael	J	3.28	ENG	215

Related Table: Advisors

ADVISOR_ID	ADV_LNAME	ADV_FNAME	ADV_INIT	DEPT_CODE	ADV_OFFICE	ADV_PHONE	ADV_EMAIL
201	Thompson	Robert	K	CS	SCI-312	555-234-5678	rthompson@university.edu
205	Patel	Anjali	S	MATH	MATH-208	555-234-5692	apatel@university.edu
210	Garcia	Maria	L	BIO	BIO-105	555-234-5703	mgarcia@university.edu
215	Brown	James	D	ENG	ENG-421	555-234-5715	jbrown@university.edu

Note: ADVISOR_ID connects these tables!

Keys: Definition

> A **key** consists of one or more attributes that *determine* other attributes.

Example:

- STU_ID determines all other student attributes
- STU_ID → (STU_LNAME, STU_FNAME, STU_INIT, STU_GPA, DEPT_CODE, ADVISOR_ID)

This is **functional dependence** (from Normalization)

Key Terminology: Structure

1. **Simple key**: consists of ONE attribute
    - e.g., STU_ID or ADVISOR_ID
2. **Composite key**: consists of MULTIPLE attributes
    - e.g., (STU_LNAME, STU_FNAME, STU_INIT)
3. **Key attribute**: an attribute that is part of a key
    - e.g., STU_LNAME or STU_FNAME or STU_INIT (when part of composite)

Key Terminology: Row Identification

Hierarchy:

- **Super Key**: uniquely identifies one row
    - e.g., (STU_ID) or (STU_ID, STU_LNAME) or (STU_LNAME, STU_FNAME, STU_INIT)
    - **Candidate Key**: irreducible Super Key
        - e.g., (STU_ID) or (STU_LNAME, STU_FNAME, STU_INIT)
        - NOT (STU_ID, STU_LNAME) ← reducible!
        - **Primary Key (PK)**: the chosen candidate key
            - e.g., (STU_ID)

More Key Types

Surrogate Key:

- Primary key created by designer
- Does NOT correspond to real-world attribute
- Examples: STU_ID, ADVISOR_ID
- Why use surrogate keys?
  - No identifying attribute exists naturally
  - Existing attribute inappropriate (e.g., SSN)
  - DBMS efficient at generating unique IDs

Foreign Key (FK):

- Attribute(s) that is the primary key of a related table
- e.g., ADVISOR_ID in Students table

Secondary Key (index key):

- For efficient/convenient retrieval
- e.g., STU_LNAME

Integrity Rules

A valid relational table MUST satisfy:

1. Entity Integrity

- All primary key entries are **unique**. Why?
- No part of primary key is **null**. Why?

2. Referential Integrity

- Every **non-null** foreign key value must reference an **existing** primary key in the related table. Why?

🎯 Active Learning: Check Integrity

Do these tables satisfy Entity and Referential Integrity?

Students table: STU_ID (PK), ADVISOR_ID (FK)
Advisors table: ADVISOR_ID (PK)

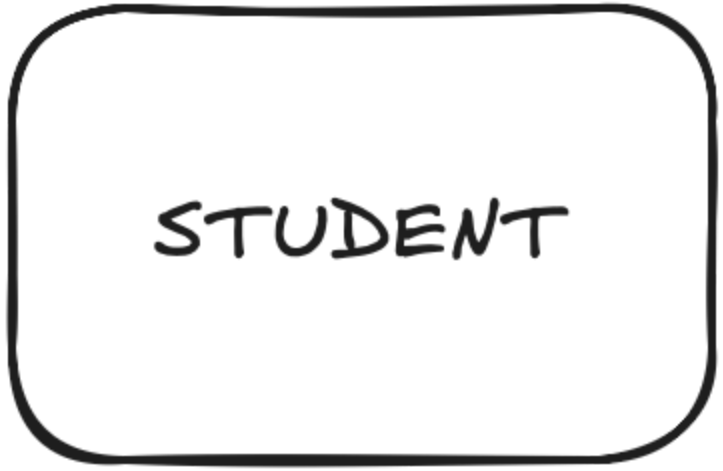
Verify:

1. Are all PKs unique and non-null?
2. Do all FK values reference existing PKs?

Discuss in pairs for 2 minutes

Entity

- An **object of interest** in the model
- Corresponds to a **table** (entity set), not a row
- **Notation:** Rectangle containing entity name
  - Name is a **noun**
  - Convention: UPPERCASE with underscore

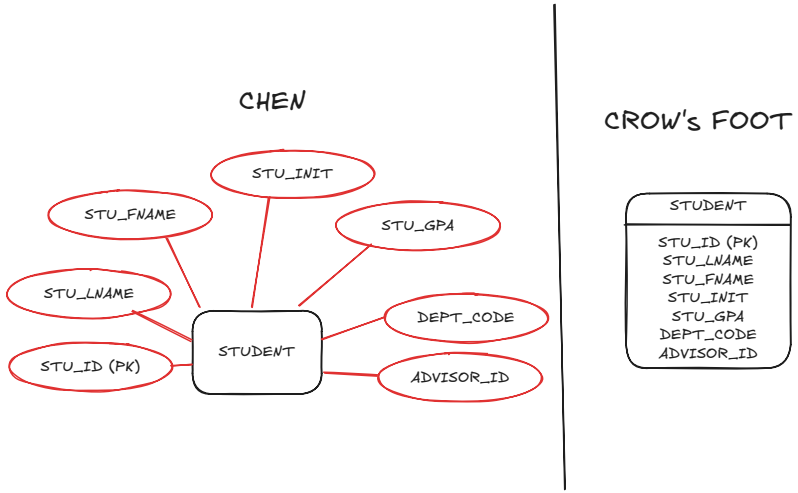


Attribute

- A **characteristic** of an entity

Notation:

- **Chen:** Oval with attribute name connected to entity
- **Crow's Foot:** Listed in entity rectangle below name



Conventions:

- Required attributed indicated by **bold**
- PK attributes indicated by
  - **Underline** or
  - **PK** notation next to attributes
- FK attributes indicated by **FK** notated next to attributes

Multivalued Attributes

Problem: Attributes with multiple values for same entity

- e.g., multiple phone numbers, multiple colors

Two Implementation Approaches:

1. **Decompose** into separate attributes
    - STU_HOMEPHONE, STU_CELLPHONE, STU_WORKPHONE
    - ❌ Brittle if number of values changes
2. **Create new entity** with 1:M relationship
    - ✅ Flexible and scalable

Multivalued Attributes: Approach 1

Decompose into separate attributes:

STU_ID (PK)	STU_HOMEPHONE	STU_CELLPHONE	STU_WORKPHONE
10001	555-123-4567	NULL	555-345-6789
10002	NULL	555-876-5432	555-345-6789

Issues:

- Many NULL values
- Fixed number of phone types
- Hard to add new types

Multivalued Attributes: Approach 2

Create new entity with 1:M relationship:

STUDENT table:

STU_ID (PK)
10001
10002

STUDENT_PHONE table:

STU_ID (PK,FK)	PHONE_TYPE (PK)	PHONE_NUMBER
10001	home	555-123-4567
10001	work	555-345-6789
10002	cell	555-876-5432
10002	work	555-345-6789

✅ **Flexible and scalable!**

Relationships

- An **association** between entities
- **Participant**: entity in the relationship
- **Name**: verb (active or passive)
    - Active: STUDENT *takes* CLASS
    - Passive: CLASS *is taken by* STUDENT

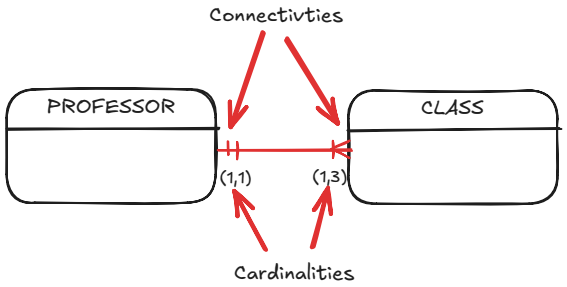
Bi-directional: Must know in both directions

- One A relates to how many B's?
- One B relates to how many A's?

Relationship Properties

Connectivity: Type of relationship

- 1:1 (one-to-one)
- 1:M (one-to-many)
- M:N (many-to-many)



SYMBOL	MEANING
o	Zero
|	One
<	Many

MIN/MAX	MEANING
o|	Zero or one (optional)
o<	Zero or more (optional)
||	Exactly one (mandatory)
|<	One or more (mandatory)

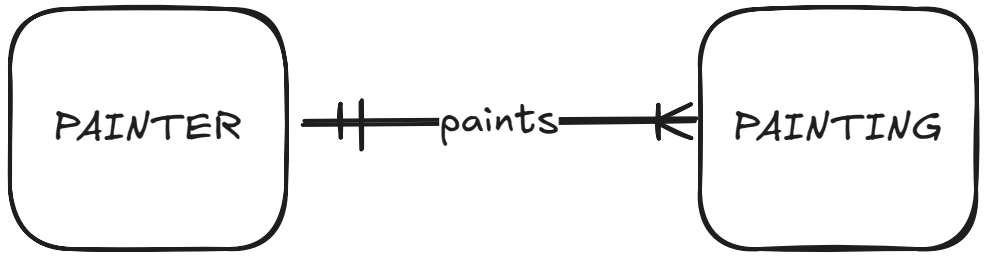
Cardinality: Min/max occurrences (constraints)

- Notated as (min, max) beside entity

1:M Relationship Example

Business Rule:

- A painter paints one or more paintings
- A painting is painted by exactly one painter



1:M: Foreign Key Placement

Question: Where does the FK go?

Option 1 - WRONG ❌: FK in PAINTER table (the "one" side)

PAINTER_ID (PK)	PAINTER_LNAME	PAINTING_ID (PK, FK)
101	Van Gogh	1001
101	Van Gogh	1002
101	Van Gogh	1005

Problems:

1. Redundant painter data
2. PAINTER_ID no longer unique

1:M: Foreign Key Placement (cont.)

Option 2 - CORRECT ✅: FK in PAINTING table (the "many" side)

PAINTING_ID (PK)	PAINTING_NAME	PAINTER_ID (FK)
1001	Starry Night	101
1002	Sunflowers	101
1003	Guernica	102
1004	The Old Guitarist	102
1005	The Potato Eaters	101

> **Rule:** PK of "one" side → FK in "many" side

🎯 Active Learning: 1:M Practice

Scenario:

- A department has many courses
- A course belongs to exactly one department

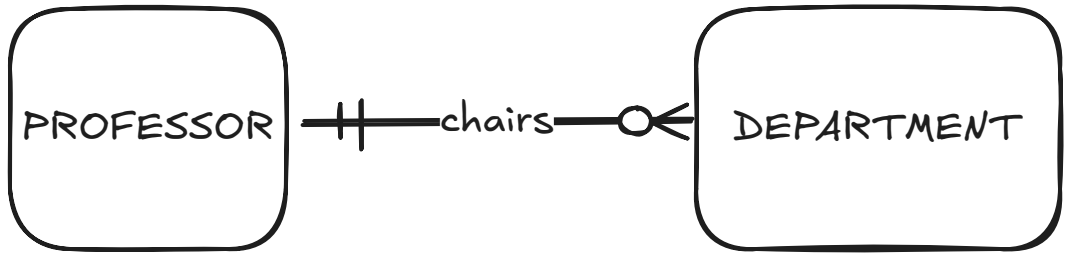
Questions:

1. Draw the crow's foot notation
2. Which table gets the foreign key?
3. What would happen if you put the FK in the wrong table?

1:1 Relationship Example

Business Rule:

- A professor optionally chairs at most one department
- A department is chaired by exactly one professor



1:1: Foreign Key Placement

Question: Where does FK go in 1:1 relationship?

Option 1 - WRONG ❌: FK in PROFESSOR (mandatory side)

PROF_ID (PK)	PROF_LNAME	CHAIR_DEPT_ID (FK)
301	Smith	NULL
302	Johnson	402
303	Khemani	NULL
304	Guerra Hahn	401

Problem: Many NULL values!

1:1: Foreign Key Placement (cont.)

Option 2 - CORRECT ✅: FK in DEPARTMENT (optional side)

DEPT_ID (PK)	DEPT_NAME	CHAIR_PROF_ID (FK)
401	Computer Science	304
402	Mathematics	302

No NULL values!

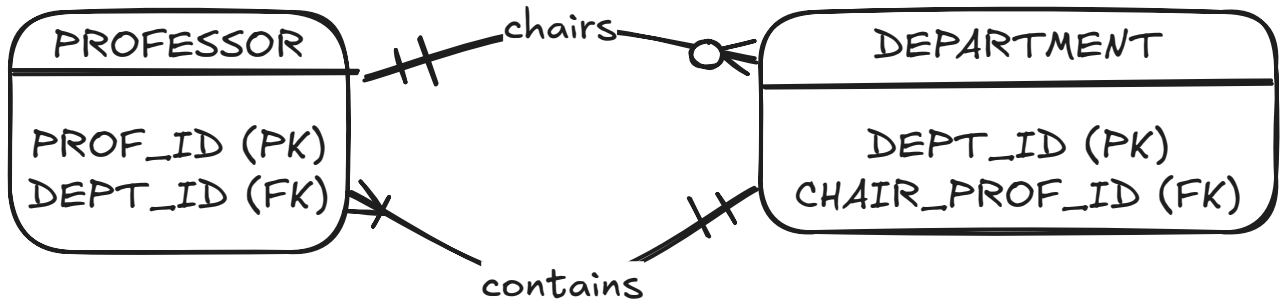
> **Rule:** In 1:1 with one optional entity, PK of "mandatory" side → FK in "optional" side

1:1: Both Sides Mandatory

When both entities are mandatory:

- Either table can contain the FK
- Choose based on other factors (e.g., additional relationships)

Example:



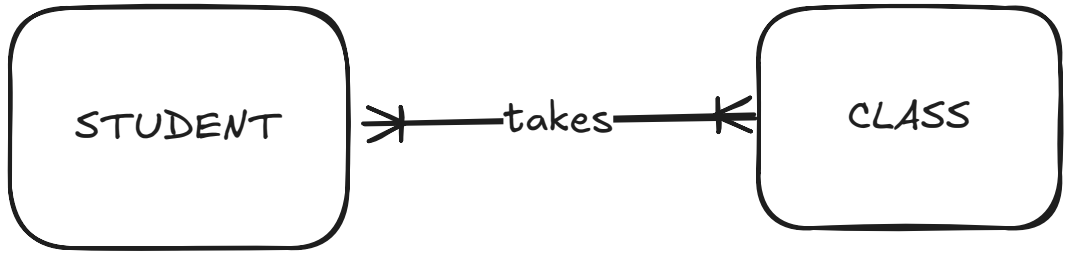
PROFESSOR has FK to DEPARTMENT (for "contains" relationship)

DEPARTMENT has FK to PROFESSOR (for "chairs" relationship)

M:N Relationship Example

Business Rule:

- A student takes many classes
- A class is taken by many students



Problem: M:N relationships are NOT directly supported in relational model!

M:N: Why Not Directly Supported?

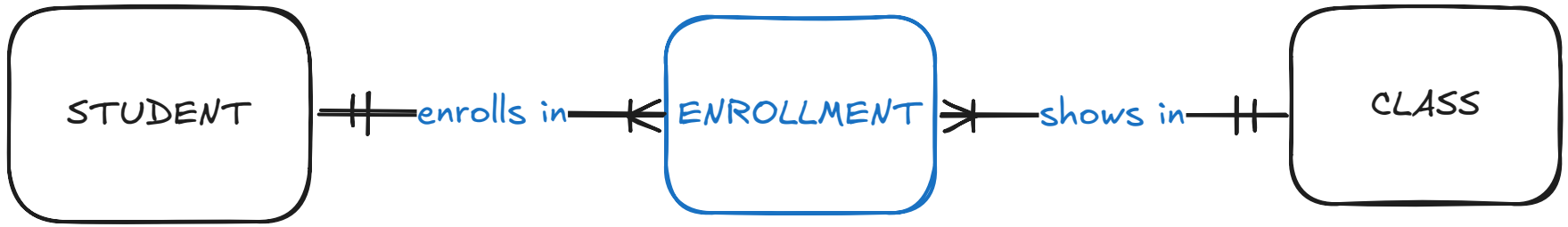
Wrong implementation ❌:

CLASS_CODE (PK)	CLASS_ROOM	STU_ID (FK)
CS101	Room 201	501
CS101	Room 201	502
MA201	Room 105	501
MA201	Room 105	502

Problem: Massive redundancy! CLASS_ROOM repeated for every student.

M:N: The Solution

Create a composite (bridge/associative/junction) entity



ENROLLMENT entity:

- Contains FKs to both tables
- PK options:
    i. (FK1, FK2) ← composite key
    ii. Separate surrogate PK

M:N: Complete Example

STUDENT table:

STU_ID (PK)	STU_LNAME
501	Miller
502	Davis

CLASS table:

CLASS_CODE (PK)	CLASS_ROOM
CS101	Room 201
MA201	Room 105

ENROLLMENT table:

STU_ID (PK,FK)	CLASS_CODE (PK,FK)
501	CS101
501	MA201
502	CS101

🎯 Active Learning: Design Challenge

Scenario:

- An author writes many books
- A book can have many authors (co-authored)

Tasks:

1. What type of relationship is this?
2. Can it be directly implemented?
3. Design the solution with table names and key attributes
4. Draw the ERD

Relationship Verb Guidelines

1:M relationships:

- "One" side is subject of verb
- Read from "one" to "many"

1:1 relationships:

- If one optional: mandatory side is subject
- If both mandatory: follow logical/business dependency

Example verbs:

- Active: paints, teaches, manages, contains
- Passive: is painted by, is taught by, is managed by

Summary: Key Takeaways

1. **Tables** = entities with rows (tuples) and columns (attributes)
2. **Keys** uniquely identify rows; FKs connect related tables
3. **Integrity rules** ensure data validity
4. **1:M:** FK goes in "many" side
5. **1:1:** FK goes in "optional" side (if one optional)
6. **M:N:** Requires composite/bridge entity

Practice Exercise: Complete Database

Given these tables:

REGION_ID	REGION_NAME	STORE_ID	STORE_NAME	REGION_ID
1001	West Coast	2001	Downtown	1001
1002	East Coast	2002	Hillside	1001

STORE_ID	STORE_NAME	REGION_ID
2001	Downtown	1001
2002	Hillside	1001

EMP_ID	EMP_LNAME	STORE_ID
3001	Anderson	2001
3002	Brown	2001

Questions:

1. Identify all PKs and FKs
2. Check entity and referential integrity

Tools for Drawing ERDs

Free Recommendations:

1. **Mermaid** - embedded in markdown
2. **Excalidraw** - web-based drawing
3. **Lucidchart** - professional diagrams
4. **MySQL Workbench** - database-specific

Practice using at least one tool for your assignments!