CSE 544
Principles of Database Management Systems

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Lecture 4 - Schema Normalization

References

- R&G Book. **Chapter 19**: "**Schema refinement and normal forms**"
- Also relevant to this lecture. **Chapter 2**: "**Introduction to database design**" and **Chapter 3.5: "Logical database design: ER to relational"**

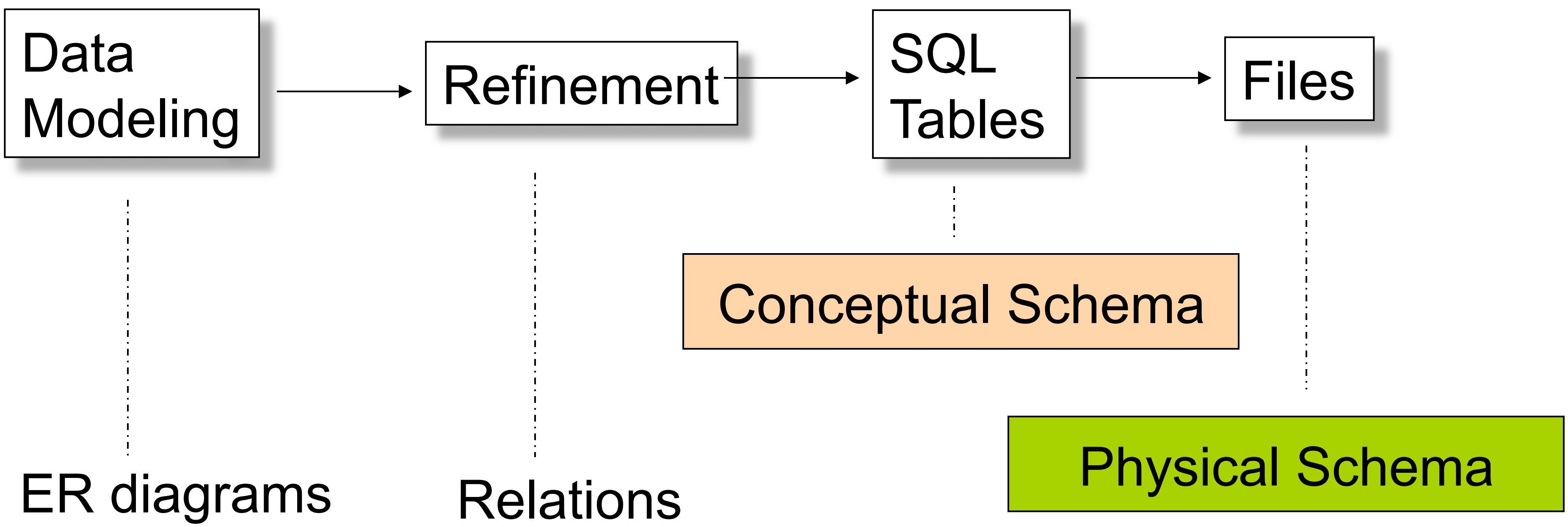
Goal

- Question: The relational model is great, but how do I go about designing my database schema?

Outline

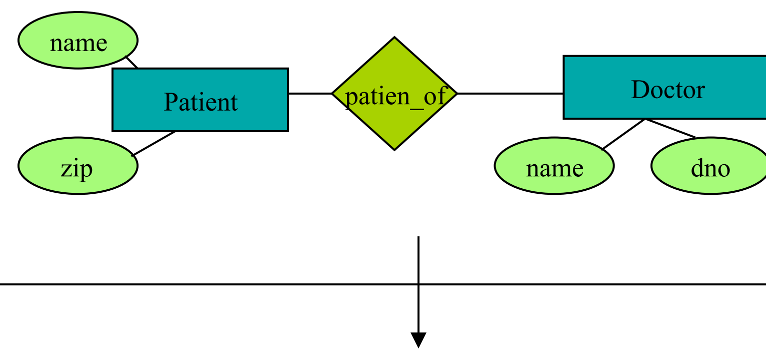
- Conceptual db design: entity-relationship model
- Problematic database designs
- Functional dependencies
- Normal forms and schema normalization

Database Design Process

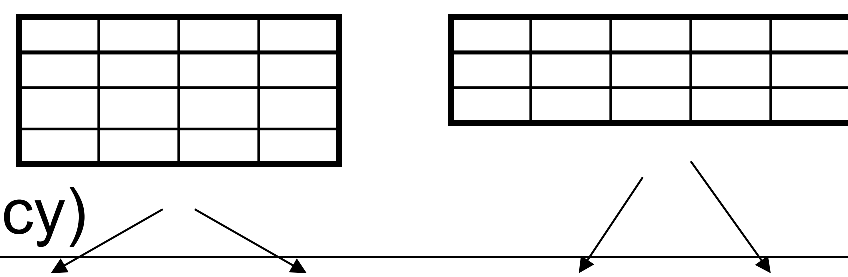


Conceptual Schema Design

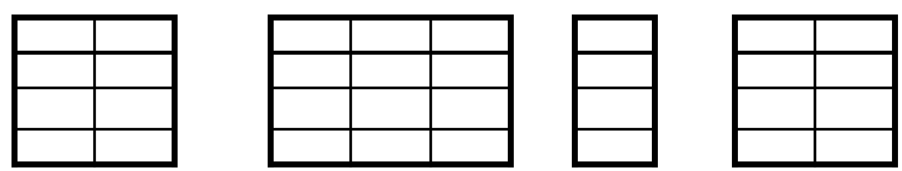
Conceptual Model:



Relational Model:
plus FD's
(FD = functional dependency)

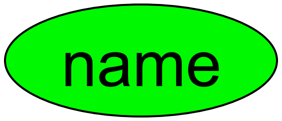


Normalization:
Eliminates anomalies



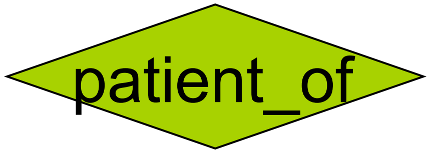
Entity-Relationship Diagrams

Attributes

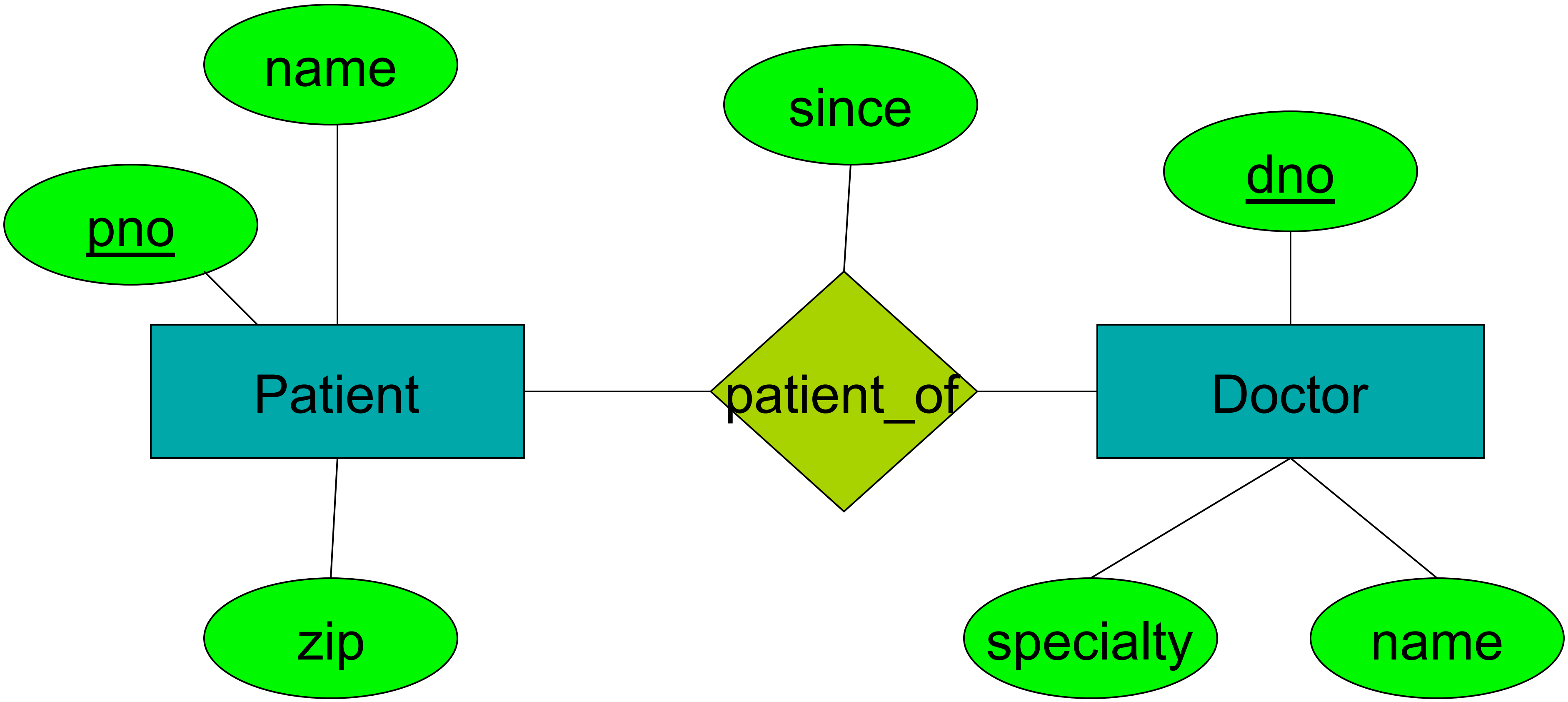


Entity sets

Relationship sets



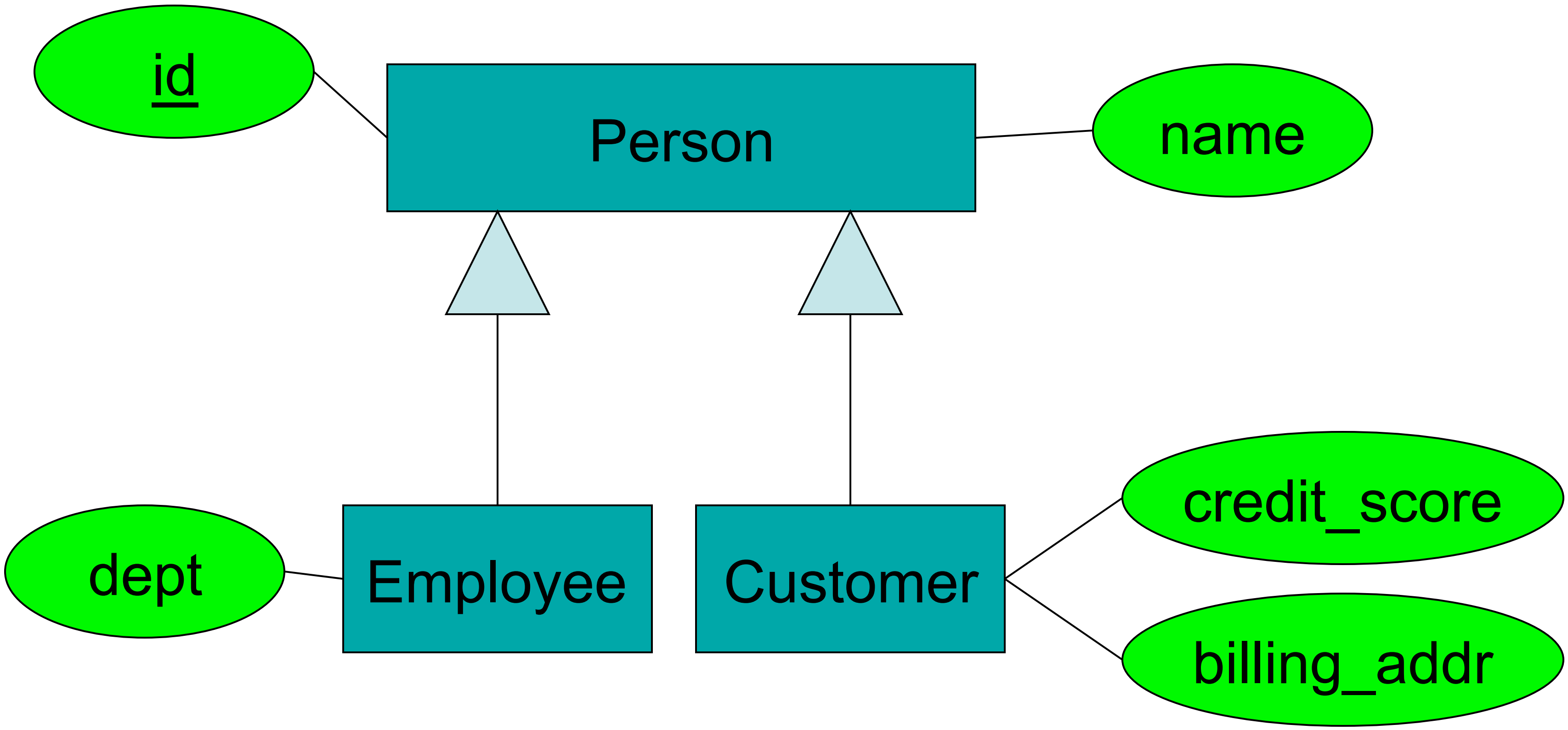
Example ER Diagram



Entity-Relationship Model

- Typically, each entity has a key
- ER relationships can include multiplicity
  - One-to-one, one-to-many, etc.
  - Indicated with arrows
- Can model multi-way relationships
- Can model subclasses
- And more...

Example with Inheritance

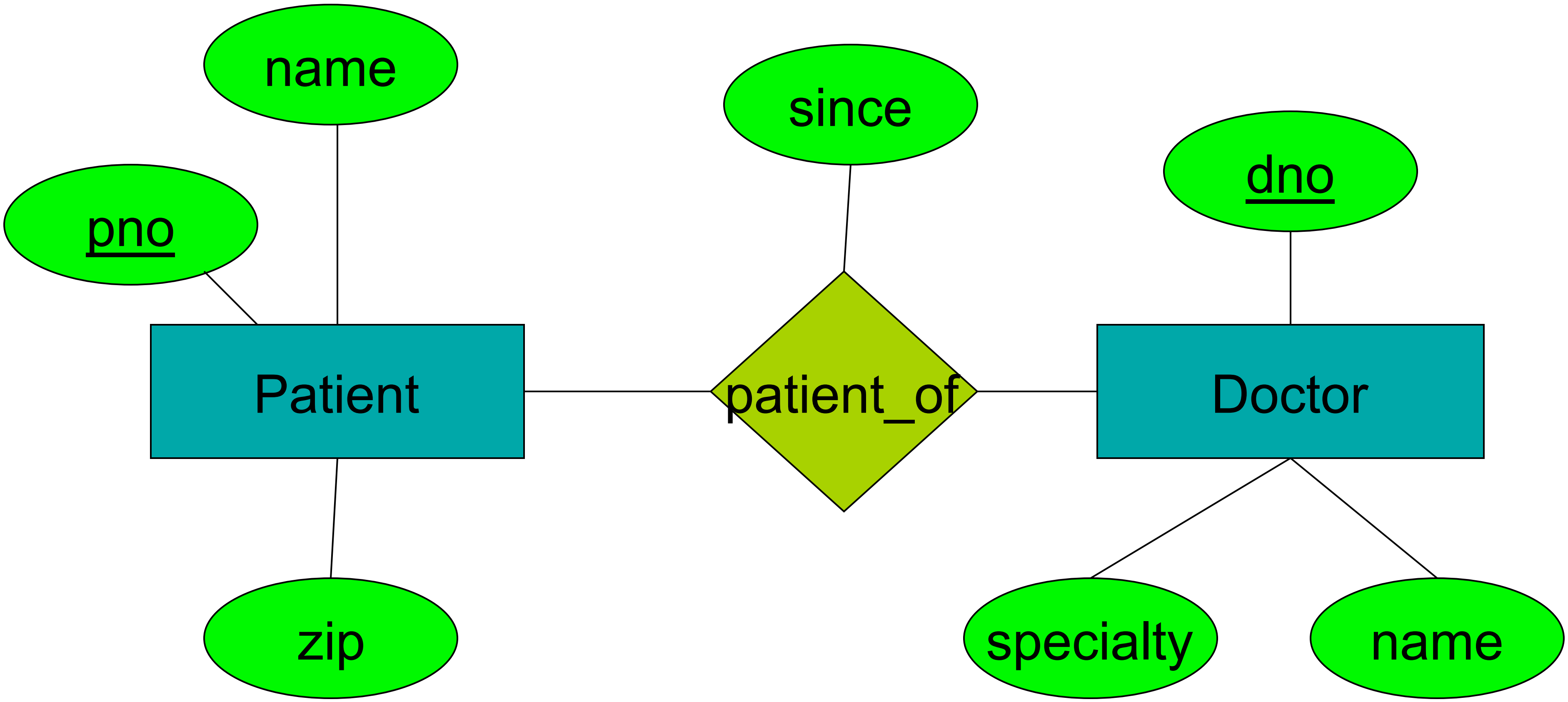


Example from Phil Bernstein's SIGMOD'07 keynote talk

Converting into Relations

- One way to translate our ER diagram into relations
  - HR (id, name)
  - Empl (id, dept) and id is also a foreign key referencing HR
  - Client (id, name, credit_score, billing_addr)
- Today, we only talk about using ER diagrams to help us design the conceptual schema of a database
- In general, apps may need to operate on a view of the data closer to ER model (e.g., OO view of data) while db contains relations
  - Need to translate between objects and relations
  - Can be hard → model management problem

Back to Our Simpler Example



Resulting Relations

- One way to translate diagram into relations

- **PatientOf (<u>pno</u>, name, zip, <u>dno</u>, since)**
- **Doctor (<u>dno</u>, dname, specialty)**

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- Conceptual db design: entity-relationship model
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Problematic Designs

- Some db designs lead to **redundancy**
  - Same information stored multiple times

- Problems
  - **Redundant storage**
  - **Update anomalies**
  - **Insertion anomalies**
  - **Deletion anomalies**

Problem Examples

PatientOf

pno	name	zip	dno	since
1	p1	98125	2	2000
1	p1	98125	3	2003
2	p2	98112	1	2002
3	p1	98143	1	1985

Redundant

If we update to 98119, we get inconsistency

What if we want to insert a patient without a doctor?
What if we want to delete the last doctor for a patient?
Illegal as (pno,dno) is the primary key, cannot have nulls

Solution: Decomposition

Patient

pno	name	zip
1	p1	98125
2	p2	98112
3	p1	98143

PatientOf

pno	dno	since
1	2	2000
1	3	2003
2	1	2002
3	1	1985

Decomposition solves the problem,
but need to be careful…

Lossy Decomposition

Patient

pno	name	zip
1	p1	98125
2	p2	98112
3	p1	98143

PatientOf

name	dno	since
p1	2	2000
p1	3	2003
p2	1	2002
p1	1	1985

Decomposition can cause us to lose information!

Schema Refinement Challenges

- How do we know that we should decompose a relation?
  - Functional dependencies
  - Normal forms
- How do we make sure decomposition does not lose info?
  - Lossless-join decompositions
  - Dependency-preserving decompositions

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Functional Dependency

- A functional dependency (FD) is an integrity constraint that generalizes the concept of a key

- An instance of relation R satisfies the **FD: X → Y**
  - if for every pair of tuples t1 and t2
  - if t1.X = t2.X then t1.Y = t2.Y
  - where X, Y are two nonempty sets of attributes in R
- We say that **X determines Y**

- **FDs come from domain knowledge**

Closure of FDs

- Some FDs imply others
  - For example: Employee(ssn,position,salary)
  - FD1: ssn $\rightarrow$ position and FD2: position $\rightarrow$ salary
  - Imply FD3: ssn $\rightarrow$ salary
- Can compute **closure** of a set of FDs
  - Set F+ of all FDs implied by a given set F of FDs
- **Armstrong's Axioms**: **sound** and **complete**
  - **Reflexivity**: if $Y \subseteq X$ then $X \rightarrow Y$
  - **Augmentation**: if $X \rightarrow Y$ then $XZ \rightarrow YZ$ for any Z
  - **Transitivity**: if $X \rightarrow Y$ and $Y \rightarrow Z$ then $X \rightarrow Z$

Closure of a Set of Attributes

Given a set of attributes $A_1, \ldots, A_n$

The **closure**, $\{A_1, \ldots, A_n\}^+$, is the set of attributes B s.t. $A_1, \ldots, A_n \rightarrow B$

Closure Algo. (for Attributes)

Start with $X=\{A_1, \ldots, A_n\}$.

Repeat until X doesn't change:

if $B_1, \ldots, B_n \rightarrow C$ is a FD and
$B_1, \ldots, B_n$ are all in X
then add C to X.

Can use this algorithm to find keys

- Compute X^+ for all sets X
- If X^+ = all attributes, then X is a superkey
- Consider only the minimal superkeys

Closure Example (for Attributes)

Example:

name → color
category → department
color, category → price

Closures:

$name^+ = \{name, color\}$

$\{name, category\}^+ = \{name, category, color, department, price\}$

$color^+ = \{color\}$

Closure Algo. (for FDs)

Example:

A, B	→	C
A, D	→	B
B	→	D

Step 1: Compute X^+, for every X:

A+ = A,   B+ = BD,   C+ = C,   D+ = D
AB+ = ABCD,   AC+ = AC, AD+ = ABCD
ABC+ = ABD+ = ACD^+ = ABCD
BCD^+ = BCD,   ABCD+ = ABCD

Step 2: Enumerate all X, output X → X+ - X

AB → CD, AD→BC, ABC → D, ABD → C, ACD → B

Decomposition Problems

- FDs will help us identify possible redundancy
  - Identify redundancy and split relations to avoid it.
- Can we get the data back correctly ?
  - **Lossless-join decomposition**
- Can we recover the FD's on the 'big' table from the FD's on the small tables?
  - **Dependency-preserving decomposition**
  - So that we can enforce all FDs without performing joins

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Normal Forms

- Based on Functional Dependencies
  - 2nd Normal Form (obsolete)
  - **3rd Normal Form**
  - **Boyce Codd Normal Form (BCNF)**

  } We only discuss these two

- Based on Multivalued Dependencies
  - 4th Normal Form
- Based on Join Dependencies
  - 5th Normal Form

BCNF

A simple condition for removing anomalies from relations:

A relation R is in BCNF if:

If $A_1, ..., A_n \rightarrow B$ is a non-trivial dependency in R ,

then $\{A_1, ..., A_n\}$ is a superkey for R

BCNF ensures that no redundancy can be detected using FD information alone

Our Example

PatientOf

pno	name	zip	dno	since
1	p1	98125	2	2000
1	p1	98125	3	2003
2	p2	98112	1	2002
3	p1	98143	1	1985

pno,dno is a key, but pno $\rightarrow$ name, zip
BCNF violation so we decompose

Decomposition in General

$R(A_1, ..., A_n, B_1, ..., B_m, C_1, ..., C_p)$

$R_1(A_1, ..., A_n, B_1, ..., B_m)$

$R_2(A_1, ..., A_n, C_1, ..., C_p)$

R_1 = projection of R on $A_1, ..., A_n, B_1, ..., B_m$

R_2 = projection of R on $A_1, ..., A_n, C_1, ..., C_p$

Theorem If $A_1, ..., A_n \rightarrow B_1, ..., B_m$
Then the decomposition is lossless

Note: don't need necessarily $A_1, ..., A_n \rightarrow C_1, ..., C_p$

BCNF Decomposition Algorithm

Repeat

choose $A_1, \ldots, A_m \rightarrow B_1, \ldots, B_n$ that violates BCNF condition

split R into

$R_1(A_1, \ldots, A_m, B_1, \ldots, B_n)$ and $R_2(A_1, \ldots, A_m, [rest])$

continue with both R1 and R2

Until no more violations

Lossless-join decomposition: Attributes common to R_1 and R_2 must contain a key for either R_1 or R_2

BCNF and Dependencies

Unit	Company	Product

FD's: Unit → Company; Company, Product → Unit

So, there is a BCNF violation, and we decompose.

BCNF and Dependencies

Unit	Company	Product

FD's: Unit → Company; Company, Product → Unit

So, there is a BCNF violation, and we decompose.

Unit	Company

Unit → Company

Unit	Product

No FDs

In BCNF we lose the FD: Company, Product → Unit

3NF

A simple condition for removing anomalies from relations:

A relation R is in 3rd normal form if :

Whenever there is a nontrivial dep. $A_1, A_2, ..., A_n \rightarrow B$ for R,
then $\{A_1, A_2, ..., A_n\}$ is a super-key for R,
or B is part of a key.

3NF Discussion

- 3NF decomposition v.s. BCNF decomposition:
  - Use same decomposition steps, for a while
  - 3NF may stop decomposing, while BCNF continues
- Tradeoffs
  - BCNF = no anomalies, but may lose some FDs
  - 3NF = keeps all FDs, but may have some anomalies

Summary

- Database design is not trivial
  - Use ER models
  - Translate ER models into relations
  - Normalize to eliminate anomalies

- Normalization tradeoffs
  - BCNF: no anomalies, but may lose some FDs
  - 3NF: keeps all FDs, but may have anomalies
  - Too many small tables affect performance