# Introduction to Management
# CSE 344

Lectures 16: Database Design

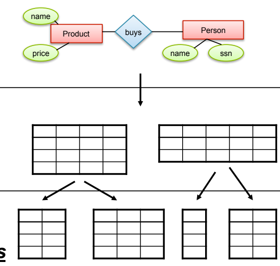


## Relational Schema Design

Conceptual Model:

Relational Model:
plus FD's

Normalization:
Eliminates ***anomalies***






## Relational Schema Design

| Name | SSN | PhoneNumber | City |
|---|---|---|---|
| Fred | 123-45-6789 | 206-555-1234 | Seattle |
| Fred | 123-45-6789 | 206-555-6543 | Seattle |
| Joe | 987-65-4321 | 908-555-2121 | Westfield |

One person may have multiple phones, but lives in only one city

Primary key is thus (SSN,PhoneNumber)

What is the problem with this schema?



## Relational Schema Design

| Name | SSN | PhoneNumber | City |
|---|---|---|---|
| Fred | 123-45-6789 | 206-555-1234 | Seattle |
| Fred | 123-45-6789 | 206-555-6543 | Seattle |
| Joe | 987-65-4321 | 908-555-2121 | Westfield |

Anomalies:
- Redundancy = repeat data
- Update anomalies = what if Fred moves to "Bellevue"?
- Deletion anomalies = what if Joe deletes his phone number?



## Relation Decomposition

**Break the relation into two:**

| Name | SSN | PhoneNumber | City |
|---|---|---|---|
| Fred | 123-45-6789 | 206-555-1234 | Seattle |
| Fred | 123-45-6789 | 206-555-6543 | Seattle |
| Joe | 987-65-4321 | 908-555-2121 | Westfield |

| Name | SSN | City |
|---|---|---|
| Fred | 123-45-6789 | Seattle |
| Joe | 987-65-4321 | Westfield |

| SSN | PhoneNumber |
|---|---|
| 123-45-6789 | 206-555-1234 |
| 123-45-6789 | 206-555-6543 |
| 987-65-4321 | 908-555-2121 |

Anomalies have gone:
- No more repeated data
- Easy to move Fred to "Bellevue" (how ?)
- Easy to delete all Joe's phone numbers (how ?)



## Relational Schema Design
## (or Logical Design)

How do we do this systematically?

- Start with some relational schema
- Find out its ***functional dependencies*** (FDs)
- Use FDs to ***normalize*** the relational schema

# Functional Dependencies (FDs)

**Definition**

If two tuples agree on the attributes

$A_1, A_2, \ldots, A_n$

then they must also agree on the attributes

$B_1, B_2, \ldots, B_m$

Formally:

$A_1 \ldots A_n$ **determines** $B_1..B_m$

$A_1, A_2, \ldots, A_n \rightarrow B_1, B_2, \ldots, B_m$

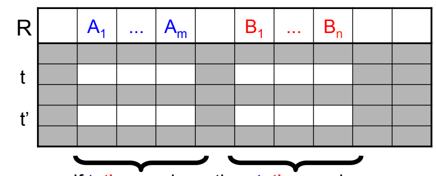


# Functional Dependencies (FDs)

**Definition** $A_1, \ldots, A_m \rightarrow B_1, \ldots, B_n$ **holds** in R if:

$\forall t, t' \in R,$

$(t.A_1 = t'.A_1 \wedge \ldots \wedge t.A_m = t'.A_m \Rightarrow t.B_1 = t'.B_1 \wedge \ldots \wedge t.B_n = t'.B_n)$




if t, t' agree here then t, t' agree here



# Example

An FD holds, or does not hold on an instance:

| EmpID | Name | Phone | Position |
|---|---|---|---|
| E0045 | Smith | 1234 | Clerk |
| E3542 | Mike | 9876 | Salesrep |
| E1111 | Smith | 9876 | Salesrep |
| E9999 | Mary | 1234 | Lawyer |

EmpID → Name, Phone, Position

Position → Phone

but not Phone → Position



# Example

| EmpID | Name | Phone | Position |
|---|---|---|---|
| E0045 | Smith | 1234 | Clerk |
| E3542 | Mike | 9876 ← | Salesrep |
| E1111 | Smith | 9876 ← | Salesrep |
| E9999 | Mary | 1234 | Lawyer |

Position → Phone



# Example

| EmpID | Name | Phone | Position |
|---|---|---|---|
| E0045 | Smith | 1234 → | Clerk |
| E3542 | Mike | 9876 | Salesrep |
| E1111 | Smith | 9876 | Salesrep |
| E9999 | Mary | 1234 → | Lawyer |

But not Phone → Position



# Example

name → color
category → department
color, category → price

| name | category | color | department | price |
|---|---|---|---|---|
| Gizmo | Gadget | Green | Toys | 49 |
| Tweaker | Gadget | Green | Toys | 99 |

Do all the FDs hold on this instance?

## Example

name → color
category → department
color, category → price

| name | category | color | department | price |
|---|---|---|---|---|
| Gizmo | Gadget | Green | Toys | 49 |
| Tweaker | Gadget | Black | Toys | 99 |
| Gizmo | Stationary | Green | Office-supp. | 59 |

What about this one ?



## Terminology

- FD **holds** or **does not hold** on an instance
- If we can be sure that *every instance of R* will be one in which a given FD is true, then we say that **R satisfies the FD**
- If we say that R satisfies an FD F, we are **stating a constraint on R**



## An Interesting Observation

If all these FDs are true:

name → color
category → department
color, category → price

Then this FD also holds: name, category → price

If we find out from application domain that a relation satisfies some FDs, it doesn't mean that we found all the FDs that it satisfies!
There could be more FDs implied by the ones we have.



## Goal: Find ALL Functional Dependencies

- Anomalies occur when certain "bad" FDs hold
- We know some of the FDs
- Need to find *all* FDs
- Then look for the bad ones



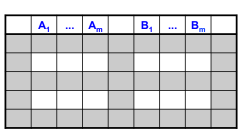
## Armstrong's Rules (1/3)

$A_1, A_2, \ldots, A_n \rightarrow B_1, B_2, \ldots, B_m$

**Splitting rule and Combing rule**

Is equivalent to

$A_1, A_2, \ldots, A_n \rightarrow B_1$
$A_1, A_2, \ldots, A_n \rightarrow B_2$
. . . . .
$A_1, A_2, \ldots, A_n \rightarrow B_m$





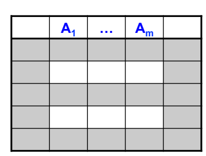

## Armstrong's Rules (2/3)

$A_1, A_2, \ldots, A_n \rightarrow A_i$

**Trivial Rule**

where i = 1, 2, ..., n

Why ?



## Armstrong's Rules (3/3)

**Transitive Rule**

If $A_1, A_2, \ldots, A_n \rightarrow B_1, B_2, \ldots, B_m$

and $B_1, B_2, \ldots, B_m \rightarrow C_1, C_2, \ldots, C_p$

then $A_1, A_2, \ldots, A_n \rightarrow C_1, C_2, \ldots, C_p$

Why ?



## Armstrong's Rules (3/3)

Illustration

| | $A_1$ | … | $A_m$ | | $B_1$ | … | $B_m$ | | $C_1$ | … | $C_p$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |
| | | | | | | | | | | | | |



## Example (continued)

Start from the following FDs:

1. name → color
2. category → department
3. color, category → price

Infer the following FDs:

| Inferred FD | Which Rule did we apply ? |
|---|---|
| 4. name, category → name | |
| 5. name, category → color | |
| 6. name, category → category | |
| 7. name, category → color, category | |
| 8. name, category → price | |



## Example (continued)

Answers:

1. name → color
2. category → department
3. color, category → price

| Inferred FD | Which Rule did we apply ? |
|---|---|
| 4. name, category → name | Trivial rule |
| 5. name, category → color | Transitivity on 4, 1 |
| 6. name, category → category | Trivial rule |
| 7. name, category → color, category | Split/combine on 5, 6 |
| 8. name, category → price | Transitivity on 3, 7 |

THIS IS TOO HARD ! Let's see an easier way.



## Closure of a set of Attributes

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

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

Example:

1. name → color
2. category → department
3. color, category → price

Closures:

name$^+$ = {name, color}

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

color$^+$ = {color}



## Closure Algorithm

X={A1, …, An}.

**Repeat until** X doesn't change **do**:
**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.

Example:

1. name → color
2. category → department
3. color, category → price

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

Hence: name, category → color, department, price

## Example

In class:

R(A,B,C,D,E,F)

A, B → C
A, D → E
B → D
A, F → B

Compute $\{A,B\}^+$ X = {A, B, }

Compute $\{A, F\}^+$ X = {A, F, }

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## Example

In class:

R(A,B,C,D,E,F)

A, B → C
A, D → E
B → D
A, F → B

Compute $\{A,B\}^+$ X = {A, B, C, D, E }

Compute $\{A, F\}^+$ X = {A, F, }

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## Example

In class:

R(A,B,C,D,E,F)

A, B → C
A, D → E
B → D
A, F → B

Compute $\{A,B\}^+$ X = {A, B, C, D, E }

Compute $\{A, F\}^+$ X = {A, F, B, C, D, E }

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## Why Do We Need Closure

- With closure we can find all FD's easily
- To check if X → A
  - Compute $X^+$
  - Check if $A \in X^+$

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## Practice at Home

Find all FD's implied by:

A, B → C
A, D → B
B → D

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## Practice at Home

Find all FD's implied by:

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,
BC+=BCD, BD+=BD, CD+=CD
ABC+ = ABD+ = $ACD^+$ = ABCD (no need to compute– why ?)
$BCD^+$ = BCD, ABCD+ = ABCD

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## Practice at Home

Find all FD's implied by:

| | | |
|---|---|---|
| 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,
BC+=BCD, BD+=BD, CD+=CD
ABC+ = ABD+ = $ACD^+$ = ABCD (no need to compute– why ?)
$BCD^+$ = BCD, ABCD+ = ABCD

Step 2: Enumerate all FD's X → Y, s.t. Y ⊆ $X^+$ and X∩Y = ∅:

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



## Keys

- A **superkey** is a set of attributes $A_1, ..., A_n$ s.t. for any other attribute B, we have $A_1, ..., A_n$ → B
- A **key** is a minimal superkey
  - I.e. set of attributes which is a superkey and for which no subset is a superkey



## Computing (Super)Keys

- Compute $X^+$ for all sets X
- If $X^+$ = all attributes, then X is a superkey
- List only the minimal X's to get the keys



## Example

Product(name, price, category, color)

name, category → price
category → color

What is the key ?



## Example

Product(name, price, category, color)

name, category → price
category → color

What is the key ?

(name, category) + = { name, category, price, color }

Hence (name, category) is a key



## Key or Keys ?

Can we have more than one key ?

Given R(A,B,C) define FD's s.t. there are two or more keys

## Key or Keys ?

Can we have more than one key ?

Given R(A,B,C) define FD's s.t. there are two or more keys

| A → B<br>B → C<br>C → A | or | AB→C<br>BC→A | or | A→BC<br>B→AC |
|---|---|---|---|---|

what are the keys here ?



## Eliminating Anomalies

Main idea:

- X → A is OK if X is a (super)key
- X → A is not OK otherwise



## Example

| Name | SSN | PhoneNumber | City |
|---|---|---|---|
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| Fred | 123-45-6789 | 206-555-6543 | Seattle |
| Joe | 987-65-4321 | 908-555-2121 | Westfield |
| Joe | 987-65-4321 | 908-555-1234 | Westfield |

SSN → Name, City

What is the key?
{SSN, PhoneNumber}

Hence SSN → Name, City is a "bad" dependency



## Boyce-Codd Normal Form

There are no "bad" FDs:

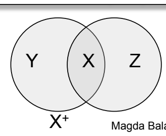
**Definition**. A relation R is in BCNF if:
Whenever X→ B is a non-trivial dependency, then X is a superkey.

Equivalently: **Definition**. A relation R is in BCNF if:
∀ X, either $X^+ = X$ or $X^+$ = [all attributes]



## BCNF Decomposition Algorithm

```
Normalize(R)
  find X s.t.: X ≠ X+ ≠ [all attributes]
  if (not found) then "R is in BCNF"
  let Y = X+ - X;    Z = [all attributes] - X+
  decompose R into R1(X ∪ Y) and R2(X ∪ Z)
  Normalize(R1); Normalize(R2);
```






## Example

| Name | SSN | PhoneNumber | City |
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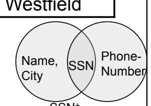
| Joe | 987-65-4321 | 908-555-1234 | Westfield |

SSN → Name, City



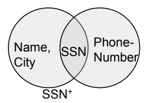

The only key is: {SSN, PhoneNumber}
Hence SSN → Name, City is a "bad" dependency

In other words:
SSN+ = Name, City and is neither SSN nor All Attributes

## Example BCNF Decomposition

| Name | SSN | City |
|---|---|---|
| Fred | 123-45-6789 | Seattle |
| Joe | 987-65-4321 | Westfield |

SSN → Name, City




| SSN | PhoneNumber |
|---|---|
| 123-45-6789 | 206-555-1234 |
| 123-45-6789 | 206-555-6543 |
| 987-65-4321 | 908-555-2121 |
| 987-65-4321 | 908-555-1234 |

Let's check anomalies:
- Redundancy ?
- Update ?
- Delete ?



Find X s.t.: X ≠ $X^+$ ≠ [all attributes]

## Example BCNF Decomposition

Person(name, SSN, age, hairColor, phoneNumber)
SSN → name, age
age → hairColor

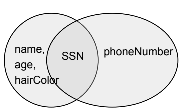


Find X s.t.: X ≠ $X^+$ ≠ [all attributes]

## Example BCNF Decomposition

Person(name, SSN, age, hairColor, phoneNumber)
SSN → name, age
age → hairColor

Iteration 1: Person: SSN+ = SSN, name, age, hairColor
Decompose into: P(SSN, name, age, hairColor)
Phone(SSN, phoneNumber)






Find X s.t.: X ≠ $X^+$ ≠ [all attributes]

## Example BCNF Decomposition

Person(name, SSN, age, hairColor, phoneNumber)
SSN → name, age
age → hairColor

What are the keys ?

Iteration 1: Person: SSN+ = SSN, name, age, hairColor
Decompose into: P(SSN, name, age, hairColor)
Phone(SSN, phoneNumber)

Iteration 2: P: age+ = age, hairColor
Decompose: People(SSN, name, age)
Hair(age, hairColor)
Phone(SSN, phoneNumber)



Find X s.t.: X ≠ $X^+$ ≠ [all attributes]

## Example BCNF Decomposition

Person(name, SSN, age, hairColor, phoneNumber)
SSN → name, age
age → hairColor

Note the keys!

Iteration 1: Person: SSN+ = SSN, name, age, hairColor
Decompose into: P(<u>SSN</u>, name, age, hairColor)
Phone(<u>SSN, phoneNumber</u>)

Iteration 2: P: age+ = age, hairColor
Decompose: People(<u>SSN</u>, name, age)
Hair(<u>age</u>, hairColor)
Phone(<u>SSN, phoneNumber</u>)



R(A,B,C,D)

## Practice at Home

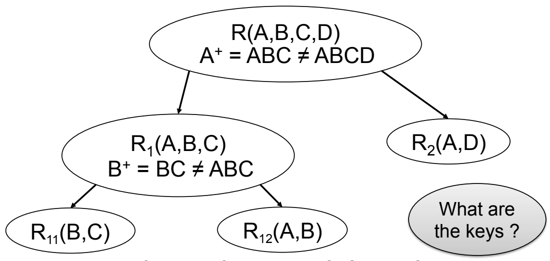
A → B
B → C

R(A,B,C,D)
$A^+$ = ABC ≠ ABCD

R(A,B,C,D)

$A \rightarrow B$
$B \rightarrow C$

## Practice at Home




What happens if in R we first pick $B^+$ ? Or $AB^+$ ?



## Schema Refinements = Normal Forms

- 1st Normal Form = all tables are flat
- 2nd Normal Form = obsolete
- Boyce Codd Normal Form = today
- 3rd Normal Form = see book