# RDBMS and SQL

Madhavan Mukund

https://www.cmi.ac.in/~madhavan

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# Relational database design

- Set of attributes that one needs to keep track of
- Why not combine into a single table?

# Relational database design

| *ID* | *name* | *dept_name* | *salary* |
|---|---|---|---|
| 10101 | Srinivasan | Comp. Sci. | 65000 |
| 12121 | Wu | Finance | 90000 |
| 15151 | Mozart | Music | 40000 |
| 22222 | Einstein | Physics | 95000 |
| 32343 | El Said | History | 60000 |
| 33456 | Gold | Physics | 87000 |
| 45565 | Katz | Comp. Sci. | 75000 |
| 58583 | Califieri | History | 62000 |
| 76543 | Singh | Finance | 80000 |
| 76766 | Crick | Biology | 72000 |
| 83821 | Brandt | Comp. Sci. | 92000 |
| 98345 | Kim | Elec. Eng. | 80000 |

| *dept_name* | *building* | *budget* |
|---|---|---|
| Biology | Watson | 90000 |
| Comp. Sci. | Taylor | 100000 |
| Elec. Eng. | Taylor | 85000 |
| Finance | Painter | 120000 |
| History | Painter | 50000 |
| Music | Packard | 80000 |
| Physics | Watson | 70000 |

- Combine these into a single table?

# Relational database design

- Redundant storage
- Maintaining consistency
  - Updates
  - Inserts and deletes

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Create new dept

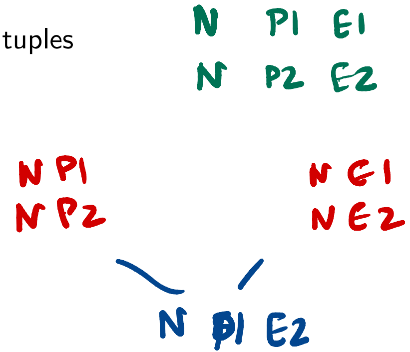
Allocate building & budget

No faculty! — null values

# Decomposition and information

- `(customer_name,regd_phone,regd_email)`
- Decompose as `(customer_name,regd_phone)` and `(customer_name,regd_email)`
- Name is not unique — loss of information
- Recombining decomposed relation should not add tuples
- Lossless decomposition
  - Decompose $R$ as $R_1$ and $R_2$
  - Want $R = R_1 \bowtie R_2$

Natural join



# Functional dependencies

- $A_1, A_2, \ldots, A_k \rightarrow B_1, B_2, \ldots B_m$
  - LHS atributes uniquely fix RHS attributes
  - Must hold for every instance — semantic property of attributes
- Need not correspond to superkeys
  - dept_name → building
  - dept_name → budget
- Use to identify sources of redundancy, guide decomposition

| *ID* | *name* | *salary* | *dept_name* | *building* | *budget* |
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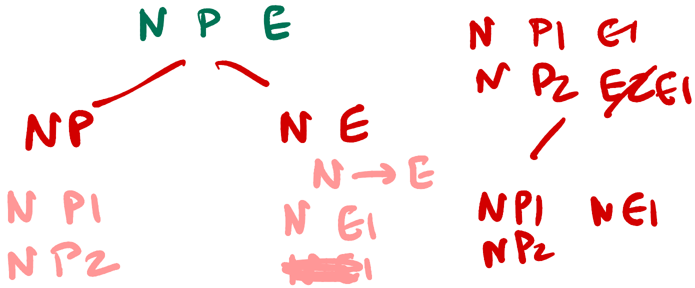
Assumption about data, given to us

# Lossless decomposition and functional dependencies

- Decompose $R$ as $R_1$ and $R_2$
- Decomposition is lossless if at least one of the following functional dependencies hold
  - $R_1 \cap R_2 \rightarrow R_1$
  - $R_1 \cap R_2 \rightarrow R_2$

Shared columns ⇒ natural join



# Lossless decomposition and functional dependencies

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  - $R_1 \cap R_2 \rightarrow R_1$
  - $R_1 \cap R_2 \rightarrow R_2$
- Decompose `Instructor-Department` as `Instructor` ($R_1$) and `Department` ($R_2$)
  - `Instructor` $\cap$ `Department` is `dept_name`
  - `dept_name` is primary key for `Department`

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- Decompose `Instructor-Department` as `Instructor` and `Department`
  - `Instructor` $\cap$ `Department` is `dept_name`
  - `dept_name` is primary key for `Department`
- In general need to compute all implied dependencies
  - From $A \rightarrow B$ and $B \rightarrow C$, conclude that $A \rightarrow C$
- Closure of a set of dependencies $F$ — denoted $F^+$

$A \rightarrow B$
$A \rightarrow C$
$\overline{\qquad\qquad}$
$A \rightarrow B, C$

Instructor_Dept

Instructor

Dept + Bldg

Dept + Budget

# Computing the closure of a set of attributes

- Given $\mathcal{A} = \{A_1, A_2, \ldots, A_k\}$ and $B$, does $A_1, A_2, \ldots, A_k \to B$?

$A_1 \ldots A_k \to B_1 \ldots B_m$

Sufficient to show

$A_1 \ldots A_k \to B_i$ for each $B_i$

# Computing the closure of a set of attributes

- Given $\mathcal{A} = \{A_1, A_2, \ldots, A_k\}$ and $B$, does $A_1, A_2, \ldots, A_k \rightarrow B$?

- Iterative algorithm — check if $B$ is in closure $\mathcal{A}^+$

  Initialize $\mathcal{A}^+$ to $\{A_1, A_2, \ldots, A_k\}$
  **repeat**
      **for each** $\beta \rightarrow \gamma$ in $F$
          if $\beta \subseteq \mathcal{A}^+$, add $\gamma$ to $\mathcal{A}^+$
      **end**
  **until** no change in $\mathcal{A}^+$

Original set

$A \rightarrow B$

$B \rightarrow C$

$A \rightarrow C$

$\alpha, \beta$ sets of attributes

$\alpha \rightarrow \beta \in F^+$ if $\beta \subseteq \alpha^+$

# Normal forms

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- Criteria to determine if the collection of tables is “good”
- Normalization — decompose tables till they achieve a normal form
- Guided by functional dependencies

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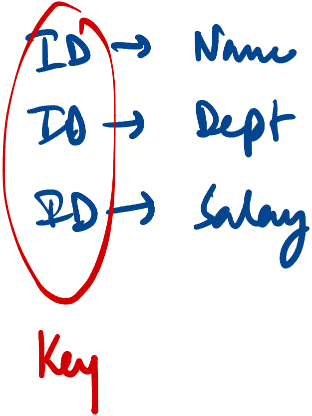
- $R$ is in BCNF if, for every $\alpha \to \beta \in F^+$, one of the following holds
  - $\alpha \to \beta$ is trivial (i.e., $\beta \subseteq \alpha$)
  - $\alpha$ is a superkey for $R$

$F^+$ has $\alpha \to \beta$ if $\alpha$ closure contains $\beta$

$R = (C_1, C_2, \ldots, C_n)$

$\alpha = (C_1, C_3, C_5)$ $\alpha^+$

# Instructor



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- `InstructorDepartment(ID,name,salary,dept_name,building,budget)` not in BCNF
- `Instructor(ID,name,dept_name,salary)` and `Department(dept_name,building,budget)` are in BCNF

# Achieving BCNF

- $\alpha \rightarrow \beta \in F^+$ is a BCNF violation for $R$ if neither of the following holds
  - $\alpha \rightarrow \beta$ is trivial (i.e., $\beta \subseteq \alpha$)
  - $\alpha$ is a superkey for $R$

$\alpha$ is not a superkey for R

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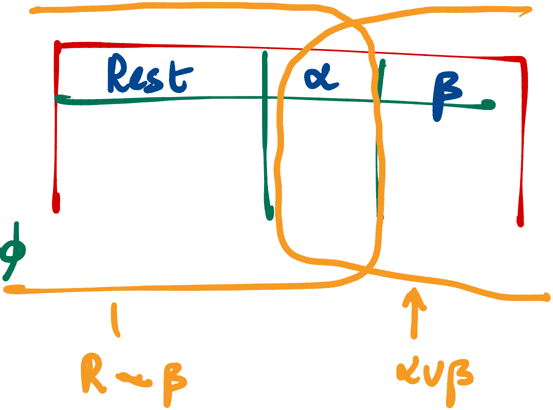
- To fix this, decompose $R$ as
  - $\alpha \cup \beta$
  - $R \setminus (\beta \setminus \alpha)$

$R \setminus \beta$ if $\alpha \cap \beta = \phi$

$\alpha = A_1, A_2$

$\beta = B_1, B_2, A_1$



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- Example: `dept_name` $\rightarrow$ `building,budget` is a BCNF violation for `InstructorDepartment(ID,name,salary,dept_name,building,budget)`
- Decompose as
  - `Department(dept_name,building,budget)`
  - `Instructor(ID,name,dept_name,salary)`

- `Advisor(student_id,faculty_id,dept_name)`
- Each faculty member is in only one department
- Students can be across multiple departments
- Each student has at most one advisor in each department

✓ fac-id →? dept

stud-id not a key

✓ stud-id, dept → fac-id

NOT A PROBLEM

| | | |
|---|---|---|
| S1 | F1 | D1 |
| S2 | F1 | D1 |

Split

(Stud, Fac) (Fac, Dept)

R ~ B & UB

No FD either way

# Dependency preservation

- `Advisor(student_id,faculty_id,dept_name)`
- Each faculty member is in only one department
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- BCNF decomposition is `(student_id,faculty_id)`, `(faculty_id,dept_name)`

Fac_id → Dept

Stud_id, Dept → Fac_id

Fac_id → Dept

Need join to check second FD

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- Functional dependencies
  - `faculty_id` $\rightarrow$ `dept_name`
  - `student_id,dept_name` $\rightarrow$ `faculty_id`

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- Functional dependencies
  - `faculty_id` → `dept_name`
  - `student_id,dept_name` → `faculty_id`
- Need join to check second dependency

All dependencies can be checked without joins

# Dependency preservation, formally

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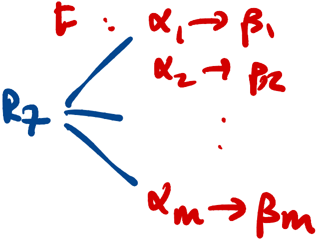
- Let $F_i$ be set of dependencies in $F^+$ locally checkable in $R_i$



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- Let $F_i$ be set of dependencies in $F^+$ locally checkable in $R_i$
- Let $G = F_1 \cup F_2 \cup \cdots \cup F_k$. Is $G^+ = F^+$
- How do we compute $F_i$ for each $R_i$?
  - Let $R_i$ have attributes $A_1, A_2, \ldots, A_m$
  - For each subset $\alpha$ of $A_1, A_2, \ldots, A_m$, compute $\alpha^+$ with respect to $F^+$
  - For each $B \in \alpha^+ \cap \{A_1, A_2, \ldots, A_m\}$, add $\alpha \rightarrow B$ to $R_i$

# Third normal form (3NF)

- $R$ is in 3NF if, for every $\alpha \rightarrow \beta \in F^+$, one of the following holds
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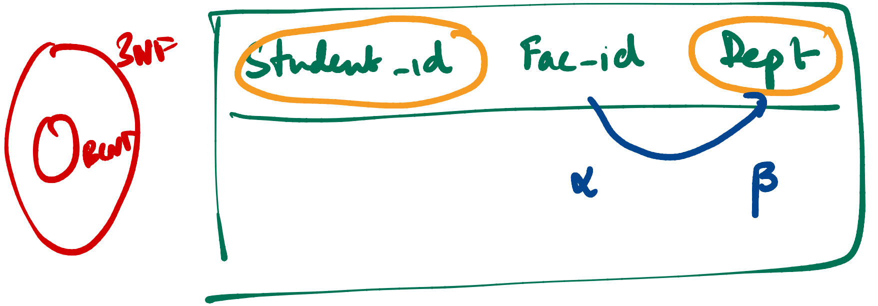
FacId → Dept

Stud, Dept → Fac




BCNF

1 or 2

3NF

1 or 2 or 3

Violation

$$B \rightarrow C, D$$

A, C is a key

E, D is a key

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- BCNF is a stricter condition than 3NF
- Priorities
  - Lossless decomposition
  - BCNF
  - Dependency preservation

1NF – all attributes are "simple"

2NF ≈ BCNF

# Beyond functional dependencies

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  - At least two emergency contacts of each type

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- 4NF

# Practical matters

- Validating functional dependencies

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- Redundancy vs computing joins — materialized views