CS315: Database Systems
Normalization Theory

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Database Design

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  - Schemas should represent distinct entities
  - Little or no redundancy in storage
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  - Less number of or no null values
  - No spurious tuple
- Normalization theory answers in the formal manner

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- Insert anomaly
  - Admitting a student immediately requires a course and vice versa
- Delete anomaly
  - Deleting a course may delete all the corresponding students

Lossless Decomposition

- Must preserve losslessness of the corresponding join
- Lossy decomposition

Suppose

roll	name	batch
1	AB	2011
2	AB	2012
3	CD	2014

is decomposed into

roll	name
1	AB
2	AB
3	CD

and

name	batch
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- Try to preserve functional dependencies

Functional Dependencies

- Functional dependencies (FDs) are *constraints* derived from the meaning of and relationships among attributes
- A set of attributes X functionally determines Y, denoted by $X \rightarrow Y$, if the value of X determines a *unique* value of Y
  - roll $\rightarrow$ name
- For any two tuples t_1 and t_2 in any *legal* instance of $r(R)$, if $t_1.X = t_2.X$ then $t_1.Y = t_2.Y$
- A FD $X \rightarrow Y$ is trivial if it is satisfied for *all* instances of a relation
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- A candidate key functionally determines all attributes
- Functional dependencies and keys define normal forms for relations
- Normal forms are formal measures of how "good" a database design is

Armstrong's Axioms

- Given a set of FDs, additional FDs can be inferred using Armstrong's inference rules or Armstrong's axioms
  1. Reflexive: If $Y \subseteq X$, then $X \rightarrow Y$
  2. Augmentation: If $X \rightarrow Y$, then $X, Z \rightarrow Y, Z$
  3. Transitive: If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$

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- Other inferred rules
  4. Decomposition: If $X \rightarrow Y, Z$, then $X \rightarrow Y$ and $X \rightarrow Z$
  5. Union: If $X \rightarrow Y$ and $X \rightarrow Z$, then $X \rightarrow Y, Z$
  6. Pseudotransitivity: If $X \rightarrow Y$ and $W, Y \rightarrow Z$, then $W, X \rightarrow Z$

Properties of FDs

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- F and G are equivalent if $F^+ = G^+$
- F and G are equivalent if F covers G and G covers F
- A set of FDs is minimal if
  - Every FD in F has only a single attribute in RHS
  - Any $G \subset F$ is not equivalent to F
  - Any $F - (X \to A) \cup (Y \to A)$ where $Y \subset X$ is not equivalent to F
- Every set of FD has *at least one* equivalent minimal set

Normal Forms

- The process of decomposing relations into smaller relations that conform to certain norms is called normalization
- Keys and FDs of a relation determine which normal form a relation is in
- Different normal forms
  - 1NF: based on attributes only
  - 2NF, 3NF, BCNF: based on keys and FDs
  - 4NF: based on keys and multi-valued dependencies (MVDs)
  - 5NF or PJNF: based on keys and join dependencies
  - DKNF: based on all constraints

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2	B	$\{5\}$

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should be

Id	Name	Phone
1	A	3
1	A	4
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Nested Relations

- Nested relations or composite attributes should be decomposed
- Example

Faculty	Name	Course(CourseId, Title)
11	AB	(1, yz)
12	CD	(2, wx)
13	EF	(2, wx)
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Prime Attribute, Full and Transitive FD

- A prime attribute must be a member of some candidate key
  - Example: roll
- A non-prime attribute is not a member of any candidate key
  - Example: gender

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- A FD $X \rightarrow Y$ is a full functional dependency if the FD does not hold when any attribute from X is removed
  - Example: (roll, courseid) $\rightarrow$ (grade)
- It is a partial functional dependency otherwise
  - (roll, gender) $\rightarrow$ (name)

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- It is a partial functional dependency otherwise
  - (roll, gender) $\rightarrow$ (name)
- A FD $X \rightarrow Y$ is a transitive functional dependency if it can be derived from two FDs $X \rightarrow Z$ and $Z \rightarrow Y$ where Z is not a set of prime attributes
  - Example: (roll) $\rightarrow$ (hod) since (roll) $\rightarrow$ (dept) and (dept) $\rightarrow$ (hod) hold
- It is non-transitive otherwise
  - Example: (roll) $\rightarrow$ (name)

Second Normal Form (2NF)

- A relation is in 2NF if
  - Every non-prime attribute is fully functionally dependent on every candidate key
- Alternatively, every attribute should either be
  - In a candidate key or
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- After 2NF normalization,
  - (roll, courseid, grade) with FD: (roll, courseid) $\rightarrow$ (grade)
  - (roll, name) with FD: (roll) $\rightarrow$ (name)
  - (courseid, title) with FD: (courseid) $\rightarrow$ (title)

Third Normal Form (3NF)

- A relation is in 3NF if
  - It is in 2NF, and
  - No non-prime attribute is transitively functionally dependent on the candidate keys
- Alternatively, every non-prime attribute should be
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  - (<u>roll</u>, name, courseid) with FD: (facultyid) → (name, courseid)
  - (<u>courseid</u>, title) with FD: (courseid) → (title)

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- BCNF decomposition can *lose* FDs
- Consider (<u>Id</u>, Dist, Lot, Area) with FDs:
  (Id) $\rightarrow$ (Dist, Lot, Area); (Dist, Lot) $\rightarrow$ (Id, Area); (Area) $\rightarrow$ (Dist)

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  - (<u>Id</u>, Lot, Area) with FD: (Id) → (Dist, Lot, Area)
  - (Dist, <u>Area</u>) with FD: (Area) → (Dist)
  - Loses (Dist, Lot) → (Id, Area)

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- Not in BCNF as (mall) → (city) violates with (mall) not being a superkey
- BCNF decomposition is *not possible* while guaranting both losslessness and dependency preservation
- Therefore, "good" design ensures either BCNF or its relaxation, i.e., 3NF

Lossy Decomposition

showroom	city	mall
tata	kanpur	iit
maruti	kanpur	zsq
tata	kolkata	quest

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- If (mall, showroom) and (showroom, city)

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showroom	city
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Joining *correctly* produces

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Loss of Functional Dependency

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- FD (city, showroom) $\rightarrow$ (mall) is lost

Loss of Functional Dependency

- Possible decomposition is
  - (mall, city) and (mall, showroom)
- FD (city, showroom) → (mall) is lost
- This is *allowed*

mall	city
iit	kanpur
zsq	kanpur

mall	showroom
iit	tata
zsq	tata

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- Possible decomposition is
  - (mall, city) and (mall, showroom)
- FD (city, showroom) → (mall) is lost
- This is *allowed*

mall	city
iit	kanpur
zsq	kanpur

mall	showroom
iit	tata
zsq	tata

although joining them produces

mall	city	showroom
iit	kanpur	tata
zsq	kanpur	tata

that *violates* the FD (city, showroom) → (mall)

Example of Normalization

- L = (<u>Id</u>, Dist, Lot, Area, Price, Rate) with FDs:
  - (Id) $\rightarrow$ (Dist, Lot, Area, Price, Rate)
  - (Dist, Lot) $\rightarrow$ (Id, Area, Price, Rate)
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- L_2 is in 2NF and in 3NF

Example (contd.)

- L_1 = (<u>Id</u>, Dist, Lot, Area, Price) with FDs:
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- L_{11} = (<u>Id</u>, Dist, Lot, Area) with FDs:
  - (Id) $\rightarrow$ (Dist, Lot, Area)
  - (Dist, Lot) $\rightarrow$ (Id, Area)
- L_{12} = (<u>Area</u>, Price) with FD:
  - (Area) $\rightarrow$ (Price)

Example (contd.)

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  - (Id) $\rightarrow$ (Dist, Lot, Area)
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- L_{12} = (<u>Area</u>, Price) with FD:
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- L_{11} and L_{12} are in 3NF

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- BCNF: Decompose and set up a relation for each nonkey attribute with attributes functionally dependent on it

Anomalies with BCNF

- Consider (<u>course</u>, <u>teacher</u>, <u>book</u>)
  - (c, t, b): t can teach c, and b is a textbook for c
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course	teacher	book
C1	AB	B1
C1	AB	B2
C1	CD	B1
C1	CD	B2
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C2	EF	B4
C2	AB	B3
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  - Inserting a new teacher for C1 requires two tuples
- Better design if (<u>course</u>, <u>teacher</u>) and (<u>course</u>, <u>book</u>)

Multi-Valued Dependency (MVD)

- A multi-valued dependency (MVD) $X \twoheadrightarrow Y$ holds for a relation schema R if for all *legal* relations $r(R)$, if for a pair of tuples t_1 and t_2, $t_1.X = t_2.X$, then there exists another pair of tuples t_3 and t_4
  - $t_1.X = t_2.X = t_3.X = t_4.X$
  - $t_3.Y = t_1.Y$
  - $t_3.R - Y - X = t_2.R - Y - X$
  - $t_4.Y = t_2.Y$
  - $t_4.R - Y - X = t_1.R - Y - X$

	X	Y	R - Y - X
t_1	a	b	c
t_2	a	d	e
t_3	a	b	e
t_4	a	d	c

- Example: (course) $\twoheadrightarrow$ (teacher) in (course, teacher, book)
  - If (C1, AB, B1) and (C1, CD, B2) exist, then (C1, AB, B2) and (C1, CD, B1) must exist
  - Otherwise, AB (resp. CD) has something special to do with B1 (resp. B2)

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- Then, decomposition into (X, Y) and (X, Z) will be lossless
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MVD and Lossless Join

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- R = (<u>X</u>, <u>Y</u>, <u>Z</u>)
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- For any relation $r = \Pi_{X,Y}(r) \bowtie \Pi_{X,Z}(r)$
- A MVD $X \twoheadrightarrow Y$ on R is trivial if either $Y \subseteq X$ or $R = X \cup Y$
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- Closure of a set of MVDs is the set of all MVDs that can be inferred

Fourth Normal Form (4NF)

- A relation is in 4NF
  - If $X \twoheadrightarrow Y$ is a non-trivial MVD, then X is a superkey of R
- Alternatively, for every MVD $X \twoheadrightarrow Y$, either
  - It is trivial, or
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  - (course, teacher) with trivial MVD: (course) $\twoheadrightarrow$ (teacher)
- Decompose R with X $\twoheadrightarrow$ Y into (X,Y) and (X,R-Y-X)

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Join Dependency (JD)

- General way of decomposing a relation into multi-way joins
- A join dependency (JD) $(R_1 \subseteq R, \ldots, R_n \subseteq R)$ holds for a schema R if for all *legal* relations $r(R)$,

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Salesman	Brand	Product
J	A	V
J	A	B
W	A	V
W	A	B
W	R	V
W	R	P

- If S sells products of brand B and if S sells product type P, then S *must* sell product type P of brand B (assuming B makes P)
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- A MVD is a special case of JD with $n = 2$

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- Consider that J starts selling brand R's products
- Insertion anomaly since multiple tuples need to be inserted
- Better design if broken into three relations (B,P), (S,B), and (P,S)

Brand	Product
A	V
A	B
R	V
R	P

Salesman	Brand
J	A
W	A
W	R

Product	Salesman
V	J
B	J
V	W
B	W
P	W

- Now, insertion requires only one tuple (J, R) in (Salesman, Brand)

Domain-Key Normal Form (DKNF)

- A relation schema is in domain-key normal form (DKNF) if all constraints and relations that should hold can be enforced simply by domain constraints and key constraints
- *Ideal* normal form
- Once a relation is in DKNF, there is no anomaly
- Mostly theoretical