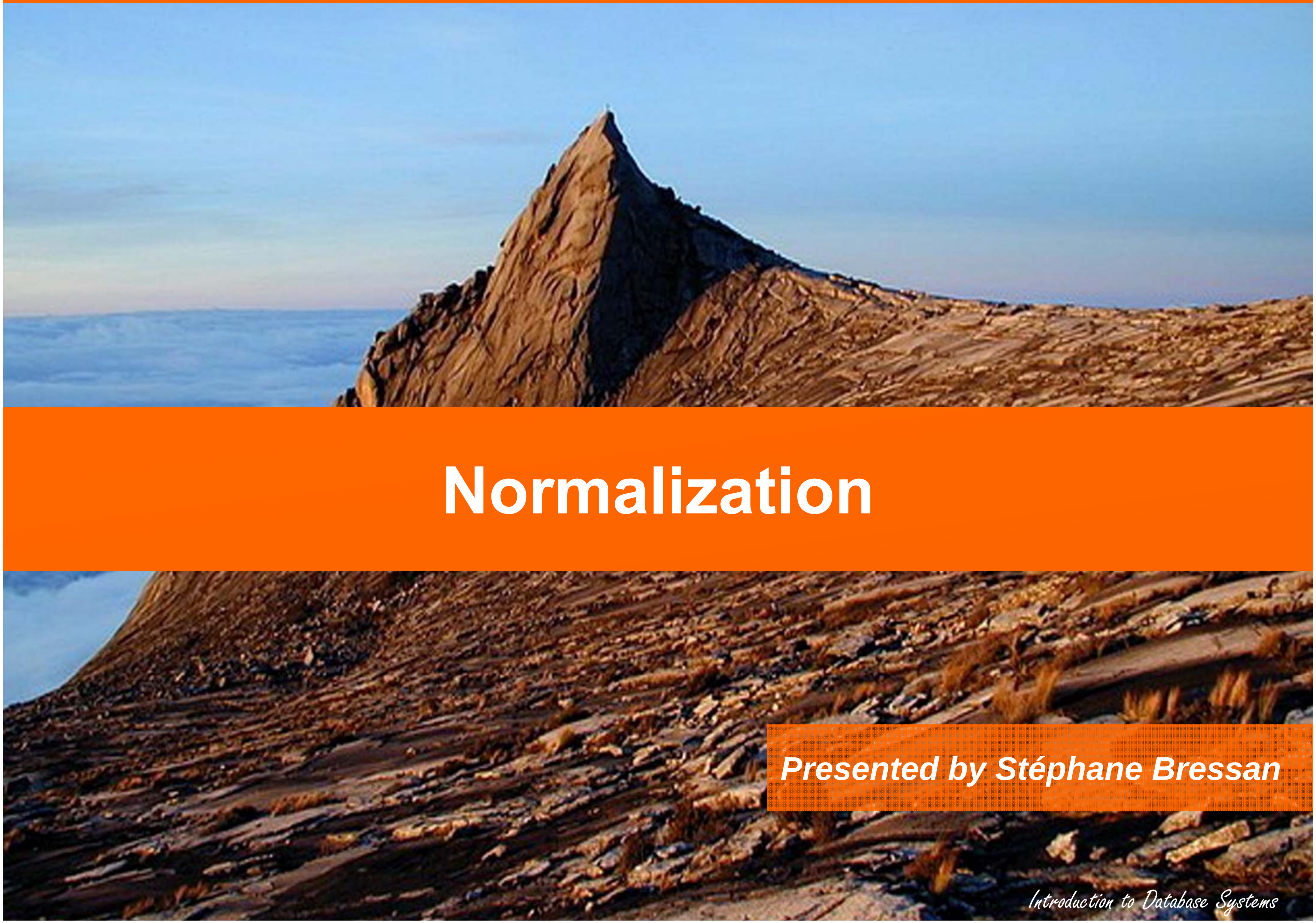
In the Lecture Series Introduction to Database Systems



Normalization

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Learning Objectives

- Understand the rationale (anomalies) and definition of the main **normal forms** based on functional dependencies (**BCNF**, **3NF**)

- Be able to **decompose** and **synthesize** a schema into a **lossless** and **dependency preserving** **BCNF** and **3NF**.

Anomalies

- Redundant storage
- Update anomalies
- Insertion anomalies
- Deletion anomalies

Anomalies: Example

Assume that the position determines the salary:
position → salary

company

eNumber	firstName	lastName	address	depart-ment	position	salary
1XU3	Dewi	Srijaya	12a Jln Lempeng	Toys	Clerk	2000
4W3E	Izabel	Leong	10 Outram Park	Sports	Trainee	1200
3XXE	John	Smith	107 Clementi Rd	Toys	Clerk	2000
5SD2	Axel	Bayer	55 Cuscaden Rd	Sports	Trainee	1200
6RG5	Winnie	Lee	10 West Coast Rd	Sports	Manager	2500
755Y	Sylvia	Tok	22 East Coast Ln	Toys	Manager	2600
2SD3	Eric	Wei	100 Jurong drive	Toys	Assistant manager	2200
?	?	?	?	?	Security guard	1500

key key

Redundant storage

Update anomaly

Insertion anomaly

Potential deletion anomaly

Decomposition

- A decomposition of a relation scheme R is a set of relation scheme R_i such that:

$$\bigcup_i R_i = R$$

Namely, we have all the attributes.

The tables R_i are called ’fragments’

Decomposition: Example

employee

eNumber	firstName	lastName	address	depart-ment	position
1XU3	Dewi	Srijaya	12a Jln Lempeng	Toys	Clerk
4W3E	Izabel	Leong	10 Outram Park	Sports	Trainee
3XXE	John	Smith	107 Clementi Rd	Toys	Clerk
5SD2	Axel	Bayer	55 Cuscaden Rd	Sports	Trainee
6RG5	Winnie	Lee	10 West Coast Rd	Sports	Manager
755Y	Sylvia	Tok	22 East Coast Ln	Toys	Manager
2SD3	Eric	Wei	100 Jurong drive	Toys	Assistant manager

key key

salary

position	salary
Clerk	2000
Trainee	1200
Manager	2500
Assistant manager	2200
Security guard	1500

key

Lossless Decomposition: Example

- The decomposition is **lossless** if we can recover the initial table:

  SELECT firstName, lastName, address,
  department, e.position, salary
  FROM employee AS e, salary AS s
  WHERE e.position = s.position

- Some attributes must be repeated: the proistion appears in both fragments.

Lossless Decomposition: Example

employee

eNumber	firstName	lastName	address	depart-ment	position
1XU3	Dewi	Srijaya	12a Jln Lempeng	Toys	Clerk
4W3E	Izabel	Leong	10 Outram Park	Sports	Trainee
3XXE	John	Smith	107 Clementi Rd	Toys	Clerk
5SD2	Axel	Bayer	55 Cuscaden Rd	Sports	Trainee
6RG5	Winnie	Lee	10 West Coast Rd	Sports	Manager
755Y	Sylvia	Tok	22 East Coast Ln	Toys	Manager
2SD3	Eric	Wei	100 Jurong drive	Toys	Assistant manager

key key

salary

position	salary
Clerk	2000
Trainee	1200
Manager	2500
Assistant manager	2200
Security guard	1500

key

Lossless Decomposition: Counter Example

Flight Number	Departure time	Arrival time	Origin	Destination
SG12	12h00	13h00+	SIN	CDG
TG414	15h50	16h30	SIN	JKT
TG415	12h00	14h20	BKK	SIN

key

Lossless Decomposition: Counter Example

Flight Number	Departure time	Arrival time	Origin	Destination
SG12	12h00	13h00+	SIN	CDG
TG414	15h50	16h30	SIN	JKT
TG415	12h00	14h20	BKK	SIN

Flight Number	Departure time	Origin
SG12	12h00	SIN
TG414	15h50	SIN
TG415	12h00	BKK

?

Departure time	Arrival time	Destination
12h00	13h00+	CDG
15h50	16h30	JKT
12h00	14h20	SIN

Lossless, Dependency Preserving

- The decomposition is lossy
- And we lost functional dependencies:

{**Flight Number**} $\rightarrow$ {**Arrival time**, **Destination**}

Decomposition: Example

- Consider the relation scheme

  $\{C,S,J,D,P,Q,V\}$

  with FDs

  $\{C\} \rightarrow \{S,J,D,P,Q,V\}$

  $\{J,P\} \rightarrow \{C\}$

  $\{S,D\} \rightarrow \{P\}$

Contracts(<u>Contractid</u>, Supplierid, proJectid, Deptid, Partid, Qty, Value)

Decomposition: Example

- Consider the decomposition into
  {C,S,J,D,Q,V},   {S,D,P}
- The decomposition is lossless
  - We can recover the initial relation thanks to S,D
- However the functional dependency $\{J,P\} \rightarrow \{C\}$ is lost across the two relations…
- This decomposition is NOT dependency preserving

Dependency Preserving Decomposition

- The decomposition of a relation scheme
  - R with FDs F
  - Is a set of relation schemes R_i with FDs F_i
- The decomposition is dependency preserving if and only if

$$(\cup_i F_i)+ = F+$$

Too Much Decomposition

- It might be tempting to decompose to the extreme
- Evaluation of queries may be inefficient since it will involve combining several relations

Too Much Decomposition: Example

Flight Number	Departure time	Origin
SG12	12h00	SIN
TG414	15h50	SIN
TG415	12h00	BKK

Flight Number	Arrival time	Destination
SG12	13h00+	CDG
TG414	16h30	JKT
TG415	14h20	SIN

Looking for a “Good” Design

- The designer needs guidelines:
  - Normalization theory
    - Minimal redundancy and no anomalies
    - Lossless decompositions
    - Dependency preserving decompositions

- But ultimately the designer needs to look at the workload (the queries and their efficiency requirement)

Boyce-Codd Normal Form (BCNF)

- R is a relation schema, with the set F of FDs
- R is in BCNF if and only if
  - For all X: $X \subset R$
  - And, for all $A \in R$
  - such that there exists a FD: $X \rightarrow \{A\}$ in F+
- Then
  - $A \in X$ ($X \rightarrow \{A\}$ is trivial), or
  - X is a superkey for R

Second Normal Form (2NF)

- R is a relation schema, with the set F of FDs
- R is in 2NF if and only if
  - For all X: $X \subset R$
  - and, for all $A \in R$
  - such that there exists a FD: $X \rightarrow \{A\}$ in F+
- Then
  - $A \in X$ ($X \rightarrow \{A\}$ is trivial), or
  - X is NOT a proper subset of a candidate key for R, or
  - A is part of some candidate key for R

Third Normal Form (3NF)

- R is a relation schema, with the set F of FDs
- R is in 3NF if and only if
  - For all X: $X \subset R$
  - And, for all $A \in R$
  - such that there exists a FD: $X \rightarrow \{A\}$ in F+
- Then
  - $A \in X$ ($X \rightarrow \{A\}$ is trivial), or
  - X is a superkey for R, or
  - A is part of some candidate key for R
    (A is called a prime attribute)

BCNF $\subset$ 3NF $\subset$ 2NF $\subset$ 1NF

- BCNF:
  - Trivial, or
  - X is a superkey for R
- 3NF:
  - Trivial, or
  - X is a superkey for R, or
  - A is part of some candidate key for R
- 2NF:
  - Trivial, or
  - X is not a proper subset of a candidate key for R, or
  - A is part of some candidate key for R

Decomposition into BCNF

Let S be the initial set of schemes with FDs F

Until all relation schemes in S are in BCNF

for each R in S

if FD $X \rightarrow Y$ in F+ violates BCNF for R

($X \rightarrow R$ not hold, not superkey

$X \cap Y = \emptyset$, not trivial)

then

use $X \rightarrow X+$

let S be $(S - \{R\}) \cup \{(R\text{-}X+) \cup X,\ X+\}$

endfor

enduntil

Decomposition into BCNF

$X \rightarrow Y$

$X=\{C,D\}$

$X+=\{C,D,E,F\}$

A	B	C	D	E	F

A	B	C	D

C	D	E	F

Decomposition into BCNF

- The different possible orders* in which we may consider the dependencies violating BCNF in the algorithm application may lead to different decompositions

**orders in which we consider the constraints violating the BCNF condition*

Decomposition into BCNF

- Let us consider the relation scheme $R=\{A,B,C,D,E\}$ and the FDs:

  $\{A\} \rightarrow \{B\}$

  $\{A\} \rightarrow \{E\}$

  $\{C\} \rightarrow \{D\}$

- Candidate key: $\{A, C\}$

Decomposition into BCNF

- R is not in BCNF
- Because (for instance):
  - $\{A\} \rightarrow \{B\}$ holds
  - It is NOT trivial
  - $\{A\}$ is NOT a superkey

Decomposition into BCNF

- Pick $\{A\} \rightarrow \{B\}$ for decomposition
- Expand into $\{A\} \rightarrow \{A,B,E\}$
- $\{A,B,C,D,E\}$ becomes
  - $\{A,C,D\}$ and $\{A,B,E\}$
- With FDs: (we need projected FDs)

  $\{A\} \rightarrow \{B\}$, on $\{A,B,E\}$

  $\{A\} \rightarrow \{E\}$, on $\{A,B,E\}$

  $\{C\} \rightarrow \{D\}$, on $\{A,C,D\}$

Remark: Projecting FDs

- If S is a fragment after decomposition of a relation R with FDs F
- The set of projected FDs on S is the set G of FDs
  - If $X \rightarrow Y$ is in G
    - Then X and Y are subsets of S
    - $X \rightarrow Y$ is in F+
  - If $X \rightarrow Y$ is in F+ and X and Y are subsets of S
    - Then $X \rightarrow Y$ is in G+

Decomposition into BCNF

- Pick $\{C\} \rightarrow \{D\}$ for decomposition
- Expand into $\{C\} \rightarrow \{C,D\}$
- $\{A,C,D\}$ and $\{A,B,E\}$ become
  - $\{A,C\}$, $\{C,D\}$ and $\{A,B,E\}$
- With FDs: (*we need projected FDs*)

  $\{A\} \rightarrow \{B\}$, *on* $\{A,B,E\}$

  $\{A\} \rightarrow \{E\}$, *on* $\{A,B,E\}$

  $\{C\} \rightarrow \{D\}$, *on* $\{C,D\}$

Decomposition into BCNF

- Finally the BCNF decomposition of R={A,B,C,D,E} with the FDs:

  $\{A\} \rightarrow \{B\}$,
  $\{A\} \rightarrow \{E\}$,
  $\{C\} \rightarrow \{D\}$

- is: R1={A,C}, R2={C,D} and R3={A,B,E}

Decomposition into BCNF

- BCNF decomposition may not be dependency preserving

- Example: {A,B,C} with FDs

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

  $\{C\} \rightarrow \{A\}$

- The first FD (the key!) is not preserved.

Decomposition into 3NF (Synthesis)

Let S be the set of relation scheme R with FDs F

for each $X \subset R$ such that $X \rightarrow \{A_i\}$ is in the minimal cover of F
 if no scheme contains $X \cup_i \{A_i\}$
 then create relation with scheme $X \cup_i \{A_i\}$
endfor

if no scheme contains a key for R
then create a relation with scheme with key for R

Decomposition into 3NF (Synthesis)

- Let us consider the relation scheme R={A,B,C,D,E} and the FDs:

  $\{A\} \rightarrow \{B\}$

  $\{A\} \rightarrow \{E\}$

  $\{C\} \rightarrow \{D\}$

- Candidate key: {A, C}

Decomposition into 3NF (Synthesis)

- Minimal cover:

  $\{A\} \rightarrow \{B\}$
  $\{A\} \rightarrow \{E\}$
  $\{C\} \rightarrow \{D\}$

- Decomposition:
  - R1 = {A,B}
  - R2 = {A,E}
  - R3 = {C,D}
  - R4 = {A,C}

Decomposition into 3NF

- (Extended) Minimal cover:

  $\{A\} \rightarrow \{B,E\}$

  $\{C\} \rightarrow \{D\}$

- Decomposition:
  - R1 = {A,B,E}
  - R2 = {C,D}
  - R3 = {A,C}

Dependency preserving

- The 3NF synthesis algorithm always finds a lossless dependency preserving decomposition

Credits

The content of this lecture is based on chapter 8 of the book "Introduction to database Systems" By S. Bressan and B. Catania, McGraw Hill publisher

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