Normalisation

Database Systems Lectures 11-12
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In This Lecture

- Idea of normalisation
  - Functional dependencies
  - Normal forms
  - Decompositions
- 2NF, 3NF, BCNF

Functional Dependencies

- Redundancy is often caused by a functional dependency
- A functional dependency (FD) is a link between two sets of attributes in a relation
- We can normalise a relation by removing undesirable FDs
- A set of attributes, A, functionally determines another set, B, or: there exists a functional dependency between A and B ($A \to B$), if whenever two rows of the relation have the same values for all the attributes in A, then they also have the same values for all the attributes in B.

Example

- {ID, modCode} $\to$ {First, Last, modName}
- {modCode} $\to$ {modName}
- {ID} $\to$ {First, Last}

ID	First	Last	modCode	modName
111	Joe	Bloggs	G51PRG	Programming
222	Anne	Smith	G51DBS	Databases

FDs and Normalisation

- We define a set of 'normal forms'
  - Each normal form has fewer FDs than the last
  - Since FDs represent redundancy, each normal form has less redundancy than the last
- Not all FDs cause a problem
  - We identify various sorts of FD that do
  - Each normal form removes a type of FD that is a problem
  - We will also need a way to remove FDs

Key attributes and superkeys

- We call an attribute a *key attribute* if this attribute is part of some candidate key. Alternative terminology is \`prime' attribute.
- We call a set of attributes a *superkey* if it includes a candidate key (or is a candidate key).

Partial FDs and 2NF

- Partial FDs:
  - A FD, $A \rightarrow B$ is a partial FD, if some attribute of A can be removed and the FD still holds
  - Formally, there is some proper subset of A, $C \subset A$, such that $C \rightarrow B$
- Let us call attributes which are part of some candidate key, key attributes, and the rest non-key attributes.

Second normal form:

- A relation is in second normal form (2NF) if it is in 1NF and no non-key attribute is partially dependent on a candidate key
- In other words, no $C \rightarrow B$ where C is a strict subset of a candidate key and B is a non-key attribute.

Second Normal Form

1NF

Module	Dept	Lecturer	Text
M1	D1	L1	T1
M1	D1	L1	T2
M2	D1	L1	T1
M2	D1	L1	T3
M3	D1	L2	T4
M4	D2	L3	T1
M4	D2	L3	T5
M5	D2	L4	T6

- 1NF is not in 2NF
  - We have the FD
    {Module, Text} → {Lecturer, Dept}
  - But also
    {Module} → {Lecturer, Dept}
  - And so Lecturer and Dept are partially dependent on the primary key

Removing FDs

- Suppose we have a relation R with scheme S and the FD A → B where A ∩ B = { }
- Let C = S – (A U B)
- In other words:
  - A – attributes on the left hand side of the FD
  - B – attributes on the right hand side of the FD
  - C – all other attributes
- It turns out that we can split R into two parts:
- R1, with scheme C U A
- R2, with scheme A U B
- The original relation can be recovered as the natural join of R1 and R2:
- R = R1 NATURAL JOIN R2

1NF to 2NF – Example

1NF

Module	Dept	Lecturer	Text
M1	D1	L1	T1
M1	D1	L1	T2
M2	D1	L1	T1
M2	D1	L1	T3
M3	D1	L2	T4
M4	D2	L3	T1
M4	D2	L3	T5
M5	D2	L4	T6

A $\quad \underbrace{\text{Dept} \quad \text{Lecturer}}_{B}$ $\quad$ C

2NFa

Module	Dept	Lecturer
M1	D1	L1
M2	D1	L1
M3	D1	L2
M4	D2	L3
M5	D2	L4

A, B where A → B is the `bad' dependency – violating 2NF

2NFb

Module	Text
M1	T1
M1	T2
M2	T1
M2	T3
M3	T4
M4	T1
M4	T5
M1	T6

A, C

Problems Resolved in 2NF

- Problems in 1NF
  - INSERT – Can't add a module with no texts
  - UPDATE – To change lecturer for M1, we have to change two rows
  - DELETE – If we remove M3, we remove L2 as well
- In 2NF the first two are resolved, but not the third one

2NFa

Module	Dept	Lecturer
M1	D1	L1
M2	D1	L1
M3	D1	L2
M4	D2	L3
M5	D2	L4

Problems Remaining in 2NF

- INSERT anomalies
  - Can't add lecturers who teach no modules
- UPDATE anomalies
  - To change the department for L1 we must alter two rows
- DELETE anomalies
  - If we delete M3 we delete L2 as well

2NFa

Module	Dept	Lecturer
M1	D1	L1
M2	D1	L1
M3	D1	L2
M4	D2	L3
M5	D2	L4

Transitive FDs and 3NF

- Transitive FDs:
  - A FD, $A \rightarrow C$ is a transitive FD, if there is some set B such that $A \rightarrow B$ and $B \rightarrow C$ are non-trivial FDs
  - $A \rightarrow B$ non-trivial means: B is not a subset of A
  - We have

    $A \rightarrow B \rightarrow C$
- Third normal form
  - A relation is in third normal form (3NF) if it is in 2NF and no non-key attribute is transitively dependent on a candidate key
  - Alternative (simpler) definition: a relation is in 3NF if in every non-trivial fd $A \rightarrow B$ either B is a key attribute or A is a superkey.

Third Normal Form

2NFa

Module	Dept	Lecturer
M1	D1	L1
M2	D1	L1
M3	D1	L2
M4	D2	L3
M5	D2	L4

- 2NFa is not in 3NF
  - We have the FDs

    $\{Module\} \rightarrow \{Lecturer\}$

    $\{Lecturer\} \rightarrow \{Dept\}$
  - So there is a transitive FD from the primary key {Module} to {Dept}

2NF to 3NF – Example

2NFa

Module	Dept	Lecturer
M1	D1	L1
M2	D1	L1
M3	D1	L2
M4	D2	L3
M5	D2	L4

3NFa

Lecturer	Dept
L1	D1
L2	D1
L3	D2
L4	D2

3NFb

Module	Lecturer
M1	L1
M2	L1
M3	L2
M4	L3
M5	L4

Problems Resolved in 3NF

- Problems in 2NF
  - INSERT – Can't add lecturers who teach no modules
  - UPDATE – To change the department for L1 we must alter two rows
  - DELETE – If we delete M3 we delete L2 as well
- In 3NF all of these are resolved (for this relation – but 3NF can still have anomalies!)

3NFa

Lecturer	Dept
L1	D1
L2	D1
L3	D2
L4	D2

3NFb

Module	Lecturer
M1	L1
M2	L1
M3	L2
M4	L3
M5	L4

Normalisation so Far

- First normal form
  - All data values are atomic
- Second normal form
  - In 1NF plus no non-key attribute is partially dependent on a candidate key
- Third normal form
  - In 2NF plus no non-key attribute depends transitively on a candidate key (or, no dependencies of non-key on non-superkey)

The Stream Relation

- Consider a relation, Stream, which stores information about times for various streams of courses
- For example: labs for first years
- Each course has several streams
- Only one stream (of any course at all) takes place at any given time
- Each student taking a course is assigned to a single stream for it

The Stream Relation

Student	Course	Time
John	Databases	12:00
Mary	Databases	12:00
Richard	Databases	15:00
Richard	Programming	10:00
Mary	Programming	10:00
Rebecca	Programming	13:00

Candidate keys: {Student, Course} and {Student, Time}

FDs in the Stream Relation

- Stream has the following non-trivial FDs
- {Student, Course} → {Time}
- {Time} → {Course}
- Since all attributes are key attributes, Stream is in 3NF

Anomalies in Stream

- INSERT anomalies
  - You can't add an empty stream
- UPDATE anomalies
  - Moving the 12:00 class to 9:00 means changing two rows
- DELETE anomalies
  - Deleting Rebecca removes a stream

Student	Course	Time
John	Databases	12:00
Mary	Databases	12:00
Richard	Databases	15:00
Richard	Programming	10:00
Mary	Programming	10:00
Rebecca	Programming	13:00

Boyce-Codd Normal Form

- A relation is in Boyce-Codd normal form (BCNF) if for every FD A → B either
  - B is contained in A (the FD is trivial), or
  - A contains a candidate key of the relation,
- In other words: every determinant in a non-trivial dependency is a (super) key.
- The same as 3NF except in 3NF we only worry about non-key Bs
- If there is only one candidate key then 3NF and BCNF are the same

Stream and BCNF

- Stream is not in BCNF as the FD {Time} → {Course} is non-trivial and {Time} does not contain a candidate key

Student	Course	Time
John	Databases	12:00
Mary	Databases	12:00
Richard	Databases	15:00
Richard	Programming	10:00
Mary	Programming	10:00
Rebecca	Programming	13:00

Conversion to BCNF

Student	Course	Time

Student	Time

Course	Time

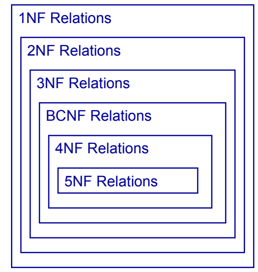
Stream has been put into BCNF but we have lost the FD {Student, Course} → {Time}

Decomposition Properties

- Lossless: Data should not be lost or created when splitting relations up
- Dependency preservation: It is desirable that FDs are preserved when splitting relations up
- Normalisation to 3NF is always lossless and dependency preserving
- Normalisation to BCNF is lossless, but may not preserve all dependencies

Higher Normal Forms

- BCNF is as far as we can go with FDs
  - Higher normal forms are based on other sorts of dependency
  - Fourth normal form removes multi-valued dependencies
  - Fifth normal form removes join dependencies



Denormalisation

- Normalisation
  - Removes data redundancy
  - Solves INSERT, UPDATE, and DELETE anomalies
  - This makes it easier to maintain the information in the database in a consistent state
- However
  - It leads to more tables in the database
  - Often these need to be joined back together, which is expensive to do
  - So sometimes (not often) it is worth 'denormalising'

Denormalisation

- You *might* want to denormalise if
  - Database speeds are unacceptable (not just a bit slow)
  - There are going to be very few INSERTs, UPDATEs, or DELETEs
  - There are going to be lots of SELECTs that involve the joining of tables

Address

Number	Street	City	Postcode

Not normalised since {Postcode} $\rightarrow$ {City}

Address1

Number	Street	Postcode

Address2

Postcode	City

Lossless decomposition

- To normalise a relation, we used projections
- If R(A,B,C) satisfies $A \rightarrow B$ then we can project it on A,B and A,C without losing information
- Lossless decomposition:

$R = \pi_{AB}(R) \bowtie \pi_{AC}(R)$

where $\pi_{AB}(R)$ is projection of R on AB and $\bowtie$ is natural join.

- Reminder of projection:

R

A	B	C

$\pi_{AB}(R)$

A	B

Relational algebra reminder: selection

R

A	B	C	D
1	x	c	c
2	y	d	e
3	z	a	a
4	u	b	c
5	w	c	d

$\sigma_{C=D}(R)$

A	B	C	D
1	x	c	c
3	z	a	a

Connection to SQL

SELECT A,B
FROM R1, R2, R3
WHERE (some property α holds)

translates into relational algebra

$\pi_{A,B}\, \sigma_{\alpha}\, (R1 \times R2 \times R3)$

Relational algebra reminder: product

R1

A	B
1	x
2	y

R2

A	C
1	w
2	v
3	u

R1×R2

A	B	A	C
1	x	1	w
1	x	2	v
1	x	3	u
2	y	1	w
2	y	2	v
2	y	3	u

Relational algebra: natural join

$R1 \bowtie R2 = \pi_{R1.A,B,C}\, \sigma_{R1.A = R2.A}\, (R1 \times R2)$

R1

A	B
1	x
2	y

R2

A	C
1	w
2	v
3	u

R1 ⋈ R2

A	B	C
1	x	w
2	y	v

When is decomposition lossless: Module → Lecturer

R

Module	Lecturer	Text
DBS	nza	CB
DBS	nza	UW
RDB	nza	UW
APS	rcb	B

$\pi_{Module,Lecturer} R$

Module	Lecturer
DBS	nza
RDB	nza
APS	rcb

$\pi_{Module,Text} R$

Module	Text
DBS	CB
DBS	UW
RDB	UW
APS	B

When is decomposition is not lossless: no fd

S

First	Last	Age
John	Smith	20
John	Brown	30
Mary	Smith	20
Tom	Brown	10

$\pi_{First,Last} S$

First	Last
John	Smith
John	Brown
Mary	Smith
Tom	Brown

$\pi_{First,Age} S$

First	Age
John	20
John	30
Mary	20
Tom	10

When is decomposition is not lossless: no fd

$\pi_{First,Last} S \bowtie \pi_{First,Last} S$

First	Last	Age
John	Smith	20
John	*Smith*	*30*
John	*Brown*	*20*
John	Brown	30
Mary	Smith	20
Tom	Brown	10

$\pi_{First,Last} S$

First	Last
John	Smith
John	Brown
Mary	Smith
Tom	Brown

$\pi_{First,Age} S$

First	Age
John	20
John	30
Mary	20
Tom	10

Heath's theorem

- A relation R(A,B,C) that satisfies a functional dependency $A \rightarrow B$ can always be non-loss decomposed into its projections $R1=\pi_{AB}(R)$ and $R2=\pi_{AC}(R)$.

Proof.

- First we show that $R \subseteq \pi_{AB}(R) \bowtie_A \pi_{AC}(R)$. This actually holds for any relation, does not have to satisfy $A \rightarrow B$.
- Assume $r \in R$. We need to show $r \in \pi_{AB}(R) \bowtie_A \pi_{AC}(R)$. Since $r \in R$, $r(A,B) \in \pi_{AB}(R)$ and $r(A,C) \in \pi_{AC}(R)$. Since r(A,B) and r(A,C) have the same value for A, their join $r(A,B,C) = r$ is in $\pi_{AB}(R) \bowtie_A \pi_{AC}(R)$.

Heath's theorem

- Now we show that $\pi_{AB}(R) \bowtie_A \pi_{AC}(R) \subseteq R$. This only holds if R satisfies $A \rightarrow B$.
- Assume $r \in \pi_{AB}(R) \bowtie_A \pi_{AC}(R)$.
- So, $r(A,B) \in \pi_{AB}(R)$ and $r(A,C) \in \pi_{AC}(R)$.
- By the definition of projection, if $r(A,B) \in \pi_{AB}(R)$, then there is a tuple $s_1 \in R$ such that $s_1(A,B) = r(A,B)$. Similarly, since $r(A,C) \in \pi_{AC}(R)$, there is $s_2 \in R$ such that $s_2(A,C) = r(A,C)$.
- Since $s_1(A,B) = r(A,B)$ and $s_2(A,C) = r(A,C)$, $s_1(A) = s_2(A)$. So because of $A \rightarrow B$, $s_1(B) = s_2(B)$. This means that $s_1(A,B,C) = s_2(A,B,C) = r$ and $r \in R$.

Normalisation in exams

- Consider a relation Book with attributes Author, Title, Publisher, City, Country, Year, ISBN. There are two candidate keys: ISBN and (Author, Title, Publisher, Year). City is the place where the book is published, and there are functional dependencies Publisher $\rightarrow$ City and City $\rightarrow$ Country. Is this relation in 2NF? Explain your answer. (4 marks)
- Is this relation in 3NF? Explain your answer. (5 marks)
- Is the relation above in BCNF? If not, decompose it to BCNF and explain why the resulting tables are in BCNF. (5 marks).

Next Lecture

- Physical DB Issues
  - RAID arrays for recovery and speed
  - Indexes and query efficiency
- Query optimisation
  - Query trees
- For more information
  - Connolly and Begg chapter 21 and appendix C.5, Ullman and Widom 5.2.8

Next Lecture

- More normalisation
  - Lossless decomposition; why our reduction to 2NF and 3NF is lossless
  - Boyce-Codd normal form (BCNF)
  - Higher normal forms
  - Denormalisation
- For more information
  - Connolly and Begg chapter 14
  - Ullman and Widom chapter 3.6