Lecture 7: Normal Forms, Relational Algebra

Monday, 10/15/2001

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Outline

- Normal forms: BCNF, 3NF (3.7)
- Multi-valued Dependencies, 4NF (3.8)
- Relational Algebra (4.1)

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Relational Schema Design (or Logical Design)

Main idea:

- Start with some relational schema
- Find out its FD's
- Use them to design a better relational schema

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Relational Schema Design

Goal: eliminate anomalies

- Redundancy anomalies
- Deletion anomalies
- Update anomalies

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Normal Forms

First Normal Form = all attributes are atomic

Second Normal Form (2NF) = old and obsolete

Third Normal Form (3NF) = this lecture

Boyce Codd Normal Form (BCNF) = this lecture

Fourth Normal Form (4NF) = this lecture (only briefly)

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Boyce-Codd Normal Form

A simple condition for removing anomalies from relations:

A relation R is in BCNF if and only if:

Whenever there is a nontrivial dependency $A_1, A_2, ..., A_n \rightarrow B$ for R , then $\{A_1, A_2, ..., A_n\}$ a super-key for R.

In English (though a bit vague):

Whenever a set of attributes of *R* is determining another attribute, should determine ***all*** the attributes of *R*.

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Example

Name	SSN	Phone Number
Fred	123-321-99	(201) 555-1234
Fred	123-321-99	(206) 572-4312
Joe	909-438-44	(908) 464-0028
Joe	909-438-44	(212) 555-4000

What are the dependencies?
SSN → Name
What are the keys?
Name, SSN, PhoneNumber
Is it in BCNF?

Decompose it into BCNF

SSN	Name
123-321-99	Fred
909-438-44	Joe

SSN → Name

SSN	Phone Number
123-321-99	(201) 555-1234
123-321-99	(206) 572-4312
909-438-44	(908) 464-0028
909-438-44	(212) 555-4000

SSN → PhoneNumber

What About This?

Name	Price	Category
Gizmo	$19.99	gadgets
OneClick	$24.99	camera

Name → Price, Category

It is already in BCNF

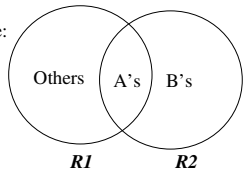
BCNF Decomposition Algorithm

Find a dependency that violates the BCNF condition:

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

Heuristics: choose $B_1, B_2, \ldots B_m$ "as large as possible"

Decompose:



Continue, until there are no BCNF violations left.

Example Decomposition

Person:

Name	SSN	Age	EyeColor	Draft-worthy	PhoneNumber

FDs: SSN → Name, Age, Eye Color, Draft-worthy
Age → Draft-worthy

BNCF Decomposition:

Step 1: Person1(SSN, Name, Age, EyeColor, Draft-worthy),
Person2(SSN, PhoneNumber)

Step 2: Person1a(SSN, Name, Age, EyeColor),
Person1b(Age, Draft-worthy)
Person2(SSN, PhoneNumber)

Keys ?
Meaning ?

Other Example

- R(A,B,C,D) $A \rightarrow B$, $B \rightarrow C$
- Key: A, D
- Violations of BCNF: $A \rightarrow B$, $A \rightarrow C$, $A \rightarrow BC$
- Pick $A \rightarrow BC$: split into R1(A,BC) R2(A,D)
- What happens if we pick $A \rightarrow B$ first ?

Correct Decompositions

A decomposition is *lossless* if we can recover:

R(A,B,C)

Decompose

{ R1(A,B) , R2(A,C) }

Recover

R'(A,B,C) = R(A,B,C)

R' is in general larger than R. Must ensure R' = R

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Decomposition Based on BCNF is Necessarily Lossless

R(A, B, C), $A \rightarrow C$

BCNF: R1(A,B), R2(A,C)

Some tuple	(a,b,c) in R	(a,b',c') also in R
decomposes into	(a,b) in R1	(a,b') also in R1
and	(a,c) in R2	(a,c') also in R2

Recover tuples in R: (a,b,c), (a,b,c'), (a,b',c), (a,b',c') also in R ?

Can (a,b,c') be a bogus tuple? What about (a,b',c') ?

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3NF: A Problem with BCNF

Unit	Company	Product

FD's: Unit → Company; Company, Product → Unit

So, there is a BCNF violation, and we decompose.

Unit	Company

Unit → Company

Unit	Product

No FDs

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So What's the Problem?

Unit	Company
Galaga99	UW
Bingo	UW

Unit	Product
Galaga99	databases
Bingo	databases

No problem so far. All *local* FD's are satisfied.

Let's put all the data back into a single table again:

Unit	Company	Product
Galaga99	UW	databases
Bingo	UW	databases

Violates the dependency: company, product -> unit!

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Solution: 3rd Normal Form (3NF)

A simple condition for removing anomalies from relations:

A relation R is in 3rd normal form if :

Whenever there is a nontrivial dependency $A_1, A_2, ..., A_n \rightarrow B$ for R , then $\{A_1, A_2, ..., A_n\}$ a super-key for R, or B is part of a key.

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Multi-valued Dependencies

SSN	Phone Number	Course
123-321-99	(206) 572-4312	CSE-444
123-321-99	(206) 572-4312	CSE-341
123-321-99	(206) 432-8954	CSE-444
123-321-99	(206) 432-8954	CSE-341

The multi-valued dependencies are:

SSN ↠ Phone Number

SSN ↠ Course

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Definition of Multi-valued Dependecy

Given $R(A1,\ldots,An,B1,\ldots,Bm,C1,\ldots,Cp)$

the MVD $A1,\ldots,An \twoheadrightarrow B1,\ldots,Bm$ holds if:

for any values of $A1,\ldots,An$
the "set of values" of $B1,\ldots,Bm$
is "independent" of those of $C1,\ldots Cp$

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Definition of MVDs Continued

Equivalently: the decomposition into

$R1(A1,\ldots,An,B1,\ldots,Bm)$, $R2(A1,\ldots,An,C1,\ldots,Cp)$

is lossless

Note: an MVD $A1,\ldots,An \twoheadrightarrow B1,\ldots,Bm$
Implicitly talks about "the other" attributes $C1,\ldots Cp$

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Rules for MVDs

If $A1,\ldots An \rightarrow B1,\ldots,Bm$

then $A1,\ldots,An \twoheadrightarrow B1,\ldots,Bm$

Other rules in the book

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4th Normal Form (4NF)

R is in 4NF if whenever:
$A1,\ldots,An \twoheadrightarrow B1,\ldots,Bm$
is a nontrivial MVD,
then $A1,\ldots,An$ is a superkey

Same as BCNF with FDs replaced by MVDs

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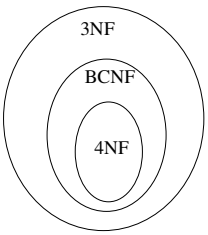
Confused by Normal Forms ?



In practice: (1) 3NF is enough, (2) don't overdo it !

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Querying the Database

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Querying the Database

- *Find all the employees who earn more than $50,000 and pay taxes in New Jersey.*
- We design *high-level query languages:*
  - SQL (used everywhere)
  - Datalog (used by database theoreticians, their students, friends and family)
  - Relational algebra: a basic set of operations on relations that provide the *basic principles*.

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Relational Algebra at a Glance

- Operators: relations as input, new relation as output
- Five basic RA operators:
  - Basic Set Operators
    - union, difference (no intersection, no complement)
  - Selection: σ
  - Projection: π
  - Cartesian Product: X
- Derived operators:
  - Intersection, complement
  - Joins (natural,equi-join, theta join, semi-join)
- When our relations have attribute names:
  - Renaming: ρ

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Set Operations

- Binary operations
- Union: all tuples in R1 or R2
  - R1 U R2
  - Example:
    - ActiveEmployees U RetiredEmployees
- Difference: all tuples in R1 and not in R2
  - R1 – R2
  - Example
    - AllEmployees - RetiredEmployees

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Selection

- Unary operation: returns a subset of the tuples which satisfy some condition
- Notation: σ_c (R)
- *c* is a condition:
  - =, <, >, and, or, not
- Find all employees with salary more than $40,000:
  - $\sigma_{Salary > 40000}$ (Employee)

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Selection Example

Employee

SSN	Name	DepartmentID	Salary
999999999	John	1	30,000
777777777	Tony	1	32,000
888888888	Alice	2	45,000

Find all employees with salary more than $40,000.

SSN	Name	DepartmentID	Salary
888888888	Alice	2	45,000

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Projection

- Unary operation: returns certain columns
- Eliminates duplicate tuples !
- Notation: $\Pi_{A1,...,An}$ (R)
- Example: project social-security number and names:
  - $\Pi_{SSN, Name}$ (Employee)

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Projection Example

Employee

SSN	Name	DepartmentID	Salary
999999999	John	1	30,000
777777777	Tony	1	32,000
888888888	Alice	2	45,000

SSN	Name
999999999	John
777777777	Tony
888888888	Alice

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Cartesian Product

- Binary Operation
- Result is tuples combining any element of R1 with any element of R2, for R1 X R2
- Schema is union of Schema(R1) & Schema(R2)
- Notation: R1 x R2
- Example: Employee x Dependents
- Very rare in practice; but joins are very often

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Cartesion Product Example

Employee

Name	SSN
John	999999999
Tony	777777777

Dependents

EmployeeSSN	Dname
999999999	Emily
777777777	Joe

Employee_Dependents

Name	SSN	EmployeeSSN	Dname
John	999999999	999999999	Emily
John	999999999	777777777	Joe
Tony	777777777	999999999	Emily
Tony	777777777	777777777	Joe

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Join (Natural)

- Most important, expensive and exciting.
- Combines two relations, selecting only related tuples
- Equivalent to a cross product followed by selection
- Resulting schema has all attributes of the two relations, but one copy of join condition attributes

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Join Example

Employee

Name	SSN
John	999999999
Tony	777777777

Dependents

EmployeeSSN	Dname
999999999	Emily
777777777	Joe

Employee_Dependents

Name	SSN	Dname
John	999999999	Emily
Tony	777777777	Joe

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