Schema Refinement and Normal Forms

PS2 graded, Midterm results on Thursday 🤞

THE COWS ARE TAKING HOSTAGES.
WHAT ARE YOU TALKING ABOUT?
RIGHT HERE, ON THE SIDE OF THE MILK CARTON, THEY PUT A PHOTO OF THIS OLD GUY WHO THEY SAY IS 'MISSING.' THEN THEY ADD, "HAVE YOU SEEN THIS PERSON?"
I HATE BEING TAUNTED BY DAIRY COWS.

Back to database design

- Which tables to include?
  - Are all choices equally good?
  - Were there other choices?
  - Are some choices better than others
- Which attributes in which tables?

Roster										
player	height	weight	college	dob	team	year	position	jersey	games	starts
Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Radiers	1991	LB	52	16	0

- What distinguishes a "good" database design from a "bad" one"

The Evils of Redundancy

- *Redundancy* is at the root of several problems associated with relational schemas:
  - redundant storage, insert/delete/update anomalies
- Integrity constraints, in particular *functional dependencies*, can be used to identify schemas with such problems and to suggest refinements.
- Main refinement technique: *decomposition* (replacing ABCD with, say, AB and BCD, or ACD and ABD).
- Decomposition should be used judiciously:
  - Is there reason to decompose a relation?
  - What problems (if any) does the decomposition cause?

Functional Dependencies (FDs)

- A <u>functional dependency</u> $X \rightarrow Y$ holds over relation R if, for every allowable instance *r* of R:
  - for all $t_1 \in r$, $t_2 \in r$, $\pi_X(t_1) = \pi_X(t_2)$ implies $\pi_Y(t_1) = \pi_Y(t_2)$
  - i.e., given two tuples in *r*, if the X values match, then the Y values must also match. (X and Y are *sets* of attributes.)
- An FD is a statement about *all* allowable relations.
  - Must be identified based on semantics of application.
  - Given some allowable instance r_1 of R, we can check if it violates some FD *f*, but we cannot tell if *f* holds over R!
- K is a candidate key for R means that $K \rightarrow R$
  - However, $K \rightarrow R$ does not require K to be *minimal*!

Example: Constraints on Entity Set

- Consider relation obtained from Hourly_Emps:

  Hourly_Emps (<u>*ssn*</u>, *name, lot, rating, hrly_wages, hrs_worked*)

- <u>*Notation*</u>: We will denote this relation schema by listing the attributes as a single letter: SNLRWH
  - This is really the *set* of attributes {S,N,L,R,W,H}.
  - Sometimes, we will refer to all attributes of a relation by using the relation name. (e.g., Hourly_Emps for SNLRWH)
- Some FDs on Hourly_Emps:
  - *ssn* is the key: S □ SNLRWH
  - *rating* determines *hrly_wages*: R □ W

Example (Contd.)

- Problems due to R □ W :
  - *Update anomaly*: Can we change W in just the 1st tuple of SNLRWH?
  - *Insertion anomaly*: What if we want to insert an employee and don't know the hourly wage for his rating?
  - *Deletion anomaly*: If we delete all employees with rating 5, we lose the information about the wage for rating 5!

Will 2 smaller tables be better?

Hourly_Emps

S	N	L	R	W	H
123-22-3666	Attishoo	48	8	10	40
231-31-5368	Smiley	22	8	10	30
131-24-3650	Smethurst	35	5	7	30
434-26-3751	Guldu	35	5	7	32
612-67-4134	Madayan	35	8	10	40

Hourly_Emps2

S	N	L	R	H
123-22-3666	Attishoo	48	8	40
231-31-5368	Smiley	22	8	30
131-24-3650	Smethurst	35	5	30
434-26-3751	Guldu	35	5	32
612-67-4134	Madayan	35	8	40

Wages

R	W
8	10
5	7

Reasoning About FDs

- Given some FDs, we can usually infer additional FDs:
  - *zip* □ *state*, *state* □ *senator* implies *zip* □ *senator*
- An FD *f* is *implied by* a set of FDs *F* if *f* holds whenever all FDs in *F* hold.
  - F^+ = *closure of F* is the ***set of all FDs*** that are implied by *F*.
- Armstrong's Axioms (X, Y, Z are sets of attributes):
  - *Reflexivity*: If X⊆Y, then Y □ X (*city,state,zip* □ *city,state*)
  - *Augmentation*: If X □ Y, then XZ □ YZ for any Z
    (*city,state* □ *zip*, then *addr,city,state* □ *addr,zip*)
  - *Transitivity*: If X □ Y and Y □ Z, then X □ Z
- These are *sound* and *complete* inference rules for FDs!
  - *sound*: they will generate only FDs in F^+
  - *complete*: repeated applications will generate all FDs in F^+

Reasoning About FDs (Contd.)

- Couple of additional rules (that follow from AA):
  - *Union:* If X □ Y and X □ Z, then X □ YZ

  - *Decomposition:* If X □ YZ, then X □ Y and X □ Z
- Example: Contracts(*<u>cid</u>,sid,jid,did,pid,qty,value*), and:
  - C is the key: C □ CSJDPQV
  - Projects purchase each part using single contract: JP □ C
  - Dept purchase at most one part from a supplier: SD □ P
- JP □ C, C □ CSJDPQV imply JP □ CSJDPQV
- SD □ P implies SDJ □ JP
- SDJ □ JP, JP □CSJDPQV imply SDJ □ CSJDPQV

Reasoning About FDs (Contd.)

- Computing the closure of a set of FDs can be expensive. (Size of closure is exponential in # attrs!)
- Typically, we just want to check if a given FD *X* □ *Y* is in the closure of a set of FDs *F*. An efficient check:
  - Compute *attribute closure* of X (denoted X^+) wrt *F:*
    - Set of all attributes A such that X □A is in F^+
    - There is a linear time algorithm to compute this.
  - Check if Y is in X^+

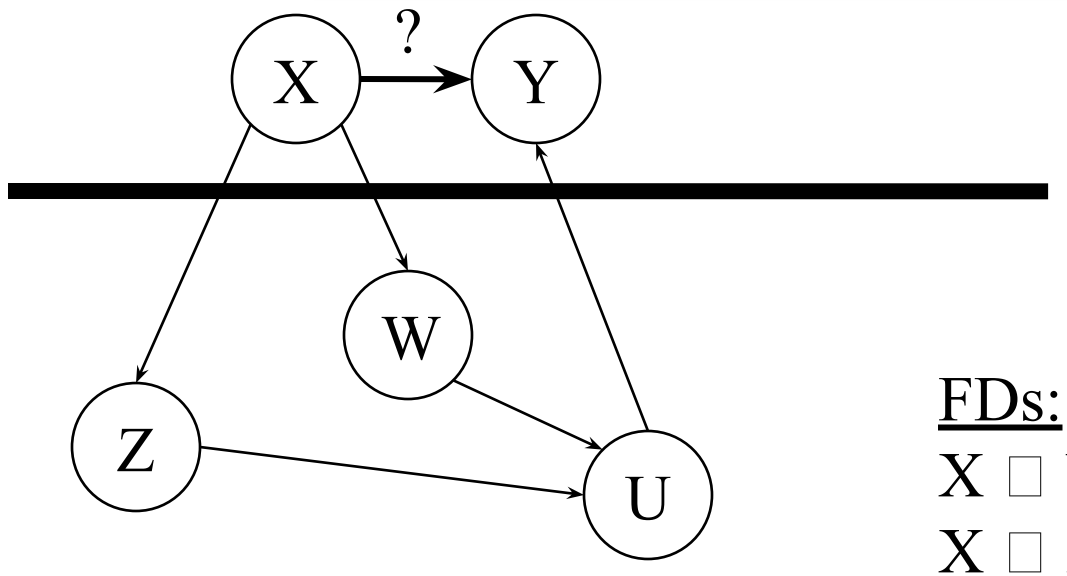
Algorithm for test if FD is in F^+

- Given X □ Y

```
closure = X;
repeat {
  if there is an FD U□ V in F such that $U \subseteq$ closure:
          closure = closure $\cup$ V
} until closure does not change
```

- Consider X □ Y as a graph with X and Y as nodes and a directed edge from X to Y.
- Traverse the set of *given* FDs to extend all existing paths
- When the path can be extended no farther determine if there is a path from X□ Y

Example Check



<u>FDs:</u>

X □ W

X □ Z

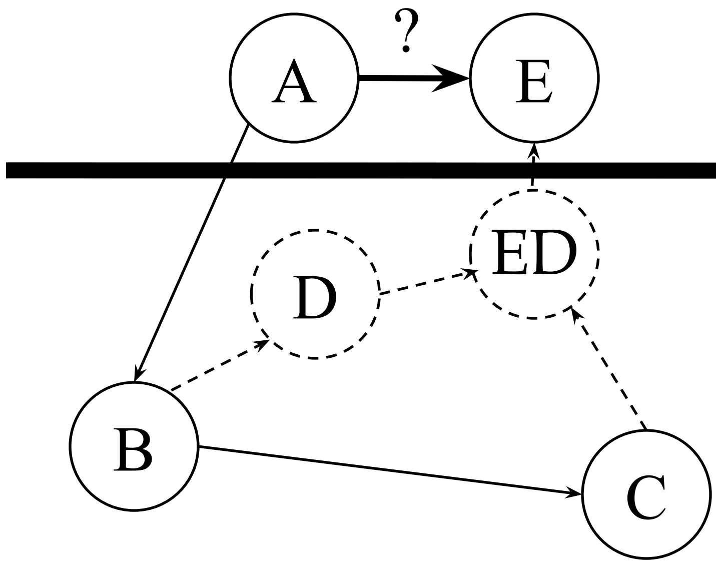
WZ □ U

U □ Y

- Does F = {A □ B, B □ C, CD □ ED } imply A □ E?
  - i.e, is A □ E in the closure F^+? Equivalently, is E in A^+?

Try Again

- Does F = {A □ B, B □ C, CD □ ED } imply A □ E?
  - i.e, is A □ E in the closure F^+? Equivalently, is E in A^+?



<u>FDs:</u>
A □ B
B □ C
CD □ ED

Since D is not in our set when we attempt to add CD → ED our algorithm terminates. In the resulting graph there is no edge from A to E.

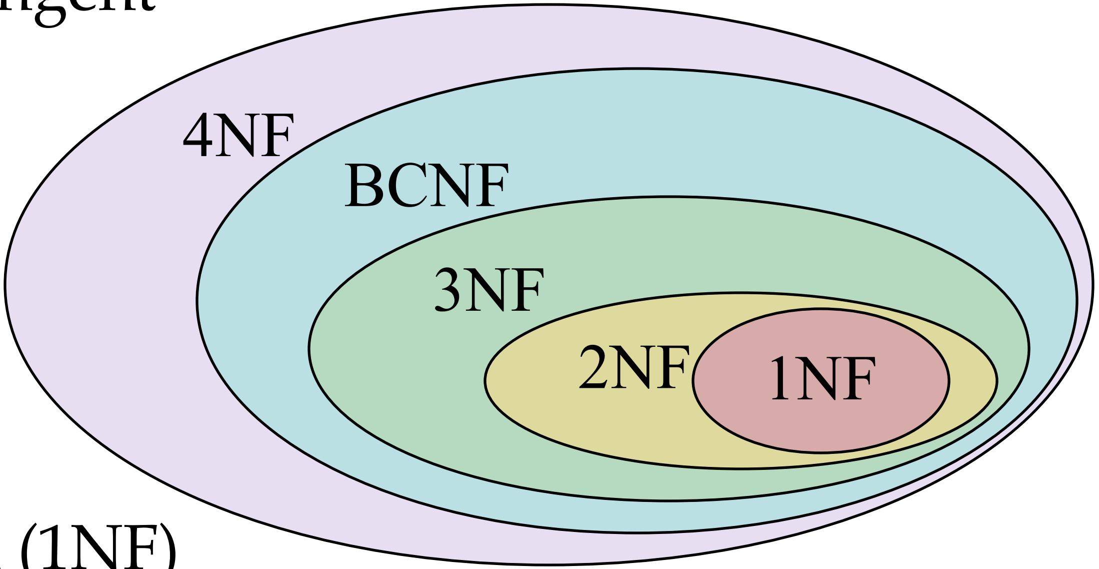
If B → D then a path would be created.

Normal Forms

- To eliminate redundancy and potential update anomalies, one can identify generic templates called “normal forms”
- If a relation is in a certain *normal form* (Boyce-Codd Normal Form (BCNF), third normal form (3NF) etc.), it is known that certain kinds of redundancy are avoided/minimized.
- This can be used to help us decide whether decomposing the relation will help.
- Role of FDs in detecting redundancy:
  - Consider a relation R with 3 attributes, ABC.
    - No FDs hold: There is no redundancy here.
    - Given A □ B: Several tuples could have the same A value, and if so, they’ll all have the same B value!

Normal Form Hierarchy

- An increasingly stringent hierarchy of "Normal Forms"
- Each outer form trivially satisfies the requirements of inner forms

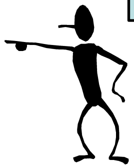


- The 1st normal form (1NF) is part of the definition of the relational model. Relations must be sets (unique) and all attributes atomic (not multiple fields or variable length records).
- The 2nd normal form (2NF) requires schemas not have any FD, X □ Y, where X as a strict subset of the schema's key.

Boyce-Codd Normal Form (BCNF)

- Relation R with FDs *F* is in BCNF
  if, for all X □ A in F^+
  - A ∈ X (called a *trivial* FD), or
  - X contains a key for R.

Includes silly FDs like:
(city, state) □ state



- In other words, R is in BCNF if the only non-trivial FDs that hold over R are key constraints.
- BCNF considers *all domain keys,* not just the *primary* one
- BCNF schemas do not contain redundant information that arise from FDs

BCNF Examples

- In BCNF

  Person(First, Last, Address, Phone)

  Functional Dependencies: FL □ A, FL □ P

- Not in BCNF

  Person(First, Last, Address, Phone, Email)

  An attempt to allow a person to have multiple emails.

  Functional Dependencies: FL □ A, FL □ P

Third Normal Form (3NF)

- Reln R with FDs *F* is in 3NF if, for all X □ A in F^+
  - $A \in X$ (called a *trivial* FD), *or*
  - X contains a key for R, *or*
  - A is part of some key for R.
- *Minimality* of a key is crucial in third condition above!
- If R is in BCNF, it is trivially in 3NF.
- If R is in 3NF, some redundancy is possible. It is a compromise, used when BCNF not achievable (e.g., no "good" decomp, or performance considerations).

3NF Examples

- Phonebook where friends have multiple addresses
- In 3NF, not in BCNF

  Person(First, Last, Addr, Phone)

  Functional Dependencies:

  FLA □ P, P □ A

- Not in 3NF or BCNF

  Person(First, Last, Addr, Phone, Mobile)

  Functional Dependencies:

  FLA □ P, P □ A, FL □ M

What Does 3NF Achieve?

- If 3NF is violated by X □ A, one of the following holds:
  - X is a proper subset of some key K (partial dependency)
    - We store (X, A) pairs redundantly.
  - X is not a proper subset of any key (transitive dependency).
    - There is a chain of FDs K □ X □ A, which means that we cannot associate an X value with a K value unless we also associate an A value with an X value.
- But, even if relation is in 3NF, problems can arise.

Lingering 3NF Redundancies

- Revisiting an old Schema

  Reserves(Sailor, Boat, Date, CreditCardNo)

  FDs: SBD□SBDC, C□S

- In 3NF, but database likely stores many redundant copies of the (C, S) tuple
- Thus, 3NF is indeed a compromise relative to BCNF.

Decomposition of a Relation Scheme

- Suppose that relation R contains attributes *A1 … An*. A *decomposition* of R consists of replacing R by two or more relations such that:
  - Each new relation scheme contains a subset of the attributes of R (and no attributes that do not appear in R), and
  - Every attribute of R appears as an attribute of one of the new relations.
- Intuitively, decomposing R means we will store instances of the relation schemes produced by the decomposition, instead of instances of R.
- E.g., Can decompose SNLRWH into SNLRH and RW.

Example Decomposition

- Decompositions should be used only when needed.
  - SNLRWH has FDs S □ SNLRWH and R □ W
  - Second FD violates 3NF
    (R is not a key, W is not part of a key)
  - Redundancy: W values repeatedly associated with R values.
  - Easiest fix; create a relation RW to store these associations, and to remove W from the main schema:
    - i.e., we decompose SNLRWH into SNLRH and RW
- Given SNLRWH tuples, we just store the projections SNLRH and RW, are there any potential problems that we should be aware of?

Problems with Decompositions

- There are three potential problems to consider:
  - Problem 1) Some queries become more expensive.
    - e.g., How much did Joe earn? (salary = W*H)
  - Problem 2) Given instances of the decomposed relations, we may not be able to reconstruct the corresponding original relation!
    - Fortunately, not in the SNLRWH example.
  - Problem 3) Checking some dependencies may require joining the instances of the decomposed relations.
    - Fortunately, not in the SNLRWH example.
- *Tradeoff*: Must consider these issues vs. redundancy.

Lossless Join Decompositions

- Decomposition of R into X and Y is *lossless-join* w.r.t. a set of FDs F if, for every instance *r* that satisfies F:

ABCD = (SELECT B,C FROM ABCD) NATURAL JOIN (SELECT A,B,D FROM ABCD)

- It is always true that ABCD $\subseteq$ BC NATURAL JOIN ABD
  - In general, the other direction does not hold!
    If equal, the decomposition is lossless-join.
- Definition extended to decomposition into 3 or more relations in a straightforward way.
- *It is essential that all decompositions used to eliminate redundancy be lossless! (Avoids Problem 2)*

More on Lossless Join

- The decomposition of R into X and Y is lossless-join wrt F if and only if the closure of F contains:
  - X ∩ Y □ X, or
  - X ∩ Y □ Y

  (in other words the attributes common to X and Y must contain a key for either X or Y)
- In particular, the decomposition of R into UV and R - V is lossless-join if U □ V holds over R.

ABC ⇒ AB, BC

A	B	C
1	2	3
4	5	6
7	2	8

A	B
1	2
4	5
7	2

JOIN

B	C
2	3
5	6
2	8

A	B	C
1	2	3
4	5	6
7	2	8
1	2	8
7	2	3

Not lossless

More on Lossless Join

- The decomposition of R into X and Y is lossless-join wrt F if and only if the closure of F contains:
  - X ∩ Y □ X, or
  - X ∩ Y □ Y

  (in other words the attributes common to X and Y must contain a key for either X or Y)
- In particular, the decomposition of R into UV and R - V is lossless-join if U □ V holds over R.

ABC ⇒ AB, AC

A	B	C
1	2	3
4	5	6
7	2	8

A	B
1	2
4	5
7	2

JOIN

A	C
1	3
4	6
7	8

A	B	C
1	2	3
4	5	6
7	2	8

Lossless

Dependency Preserving Decomposition

Contracts(*Cid,Sid,Jid,Did,Pid,Qty,Value*)

- Consider CSJDPQV, C is key, JP □ C and SD □ P.
  - BCNF decomposition: CSJDQV and SDP
  - Problem: Checking JP □ C requires a join!
- Dependency preserving decomposition (Intuitive):
  - If R is decomposed into X, Y and Z, and we enforce the FDs that hold on X, on Y and on Z, then all FDs that were given to hold on R must also hold.
- *Projection of set of FDs F*: If R is decomposed into X, ... projection of F onto X (denoted F_X) is the set of FDs U □ V in F^+ (*closure of F*) such that U, V are in X.

Dependency Preserving Decomposition

- Decomposition of R into X and Y is *dependency preserving* if $(F_X \cup F_Y)^+ = F^+$
  - i.e., if we consider only dependencies in the closure F^+ that can be checked in X without considering Y, and in Y without considering X, these imply all dependencies in F^+.
- MUST consider F^+, (not just F), in this definition:
  - ABC, A □ B, B □ C, C □ A, decomposed into AB and BC.
  - Is this dependency preserving? Is C □ A preserved?????
- Dependency preserving *does not imply* lossless join:
  - ABC, A □ B, decomposed into AB and BC.
- And vice-versa!

Decomposition into BCNF

- Consider relation R with FDs F.
  If X □ Y violates BCNF,
  decompose R into R - Y and XY.
  - Repeated applications of this rule gives relations in BCNF; lossless join decomposition, and is guaranteed to terminate.
- Example: CSJDPQV, SD □ P, J □ S (new), (ignoring JP □ C for now)
  - To deal with SD □ P, decompose into SDP, CSJDQV.
  - To deal with J □ S, decompose CSJDQV into JS and CJDQV
- The order in which we process violations can lead to a different set of relations!

BCNF and Dependency Preservation

- In general, there may not be a dependency preserving decomposition into BCNF.
  - e.g., CSZ, CS □ Z, Z □ C
  - Can't decompose while preserving 1st FD; not in BCNF.
- Similarly, decomposition of CSJDQV into SDP, JS and CJDQV is not dependency preserving (w.r.t. the FDs: JP □ C, SD □ P and J □ S).
  - However, it is a lossless join decomposition.
  - In this case, adding JPC to the collection of relations gives us a dependency preserving decomposition.
    - JPC tuples stored *only* for checking FD! (*Adds Redundancy!*)

Decomposition into 3NF

- Obviously, the algorithm for lossless join decomp into BCNF can be used to obtain a lossless join decomp into 3NF (typically, it can stop earlier).
- To ensure dependency preservation, one idea:
  - If X □ Y is not preserved, add relation XY.
  - Problem is that XY may violate 3NF! e.g., consider the addition of CJP to "preserve" JP □ C. What if we also have J □ C ?
- Refinement: Instead of the given set of FDs F, use a *minimal cover for F*.

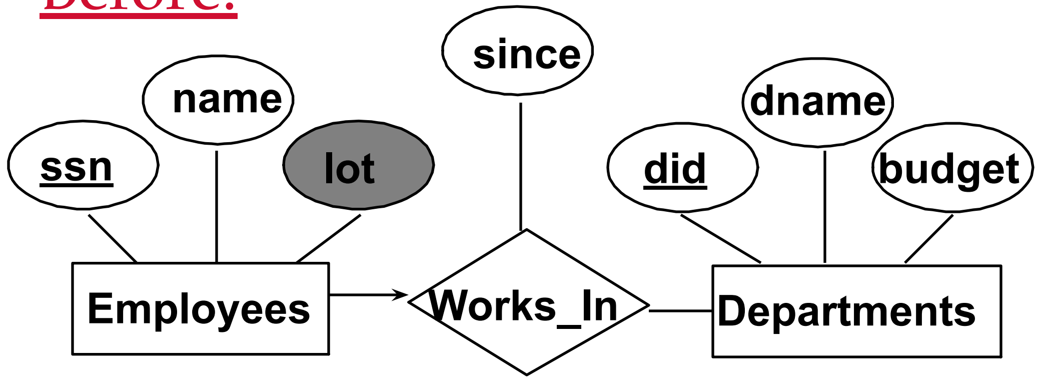
Minimal Cover for a Set of FDs

- Properties of a *Minimal cover*, G, for a set of FDs F:
  - Closure of F = closure of G.
  - Right hand side of each FD in G is a single attribute.
  - If we modify G by deleting a FD or by deleting attributes from an FD in G, the closure changes.
- Intuitively, every FD in G is needed, and is "*as small as possible*" in order to get the same closure as F.
- e.g., A □ B, ABCD □ E, EF □ GH, ACDF □ EG has the following minimal cover:
  - A □ B, ACD □ E, EF □ G and EF □ H
- M.C. → Lossless-Join, Dep. Pres. Decomp!!!

Refining an Entities and Relations

- 1st diagram translated:
  EmpWorksIn(S,N,L,D,C)
  Dept(D,M,B)
  - Lots associated with workers.
- Suppose all workers in a dept are assigned the same lot: D □ L
- And Employees start their new lot at a given date: SL□C
- Redundancy is fixed by:
  Emp(S,N)
  WorksIn(S,L,D,C) (note 3NF)
  Dept(D,M,B)
- Enforcement of FD: D □ L is supported by
  DeptLot(D,L)

Before:



Normalization example

Consider our NFL Roster table

Roster											
id	player	height	weight	college	dob	team	year	position	jersey	games	starts
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Radiers	1991	LB	52	16	0

Initial list of functional dependancies:

$I \rightarrow PHWCD$

$PCD \rightarrow I$

$ITY \rightarrow PJGS$

$JTY \rightarrow I$

1st Normal Form (1NF)

A relation is 1NF if *all rows are distinct* and *all columns are single-valued*. A typical unnormalized table is shown below. Notice how repeated items are expanded

	Roster Unnormalized										
id	name	height	weight	college	dob	team	year	position	jersey	games	starts
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Raiders	1991	LB	52	16	0
						Los Angeles Raiders	1992	LB	52	16	0
						Los Angeles Raiders	1993	LB	52	16	2
						Los Angeles Raiders	1994	LB	52	16	1
						Oakland Raiders	1995	LB	52	16	16
						Oakland Raiders	1996	LB	52	15	15
						St Louis Rams	1997	LB	52	16	16
						St Louis Rams	1998	LB	52	16	16
						St Louis Rams	1999	LB	52	16	16
						St Louis Rams	2000	LB	52	16	16
						Pittsburgh Steelers	2001	LB	51	15	0
						Pittsburgh Steelers	2002	LB	95	6	1
						Oakland Raiders	2002	LB	52	3	0
20001	Mike Jones	5-11	181	NC State	???	Pheonix Cardinals	1991	DT	96	11	3

1st Normal Form (1NF)

The following "normalized" version of is in 1NF, but now there is considerable redundancy...

Roster

id	name	height	weight	college	dob	team	year	position	jersey	games	starts
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Raiders	1991	LB	52	16	0
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Raiders	1992	LB	52	16	0
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Raiders	1993	LB	52	16	2
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Los Angeles Raiders	1994	LB	52	16	1
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Oakland Raiders	1995	LB	52	16	16
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Oakland Raiders	1996	LB	52	15	15
20000	Mike Jones	6-1	240	Missouri	1969-04-15	St Louis Rams	1997	LB	52	16	16
20000	Mike Jones	6-1	240	Missouri	1969-04-15	St Louis Rams	1998	LB	52	16	16
20000	Mike Jones	6-1	240	Missouri	1969-04-15	St Louis Rams	1999	LB	52	16	16
20000	Mike Jones	6-1	240	Missouri	1969-04-15	St Louis Rams	2000	LB	52	16	16
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Pittsburgh Steelers	2001	LB	51	15	0
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Pittsburgh Steelers	2002	LB	95	6	1
20000	Mike Jones	6-1	240	Missouri	1969-04-15	Oakland Raiders	2002	LB	52	3	0
20001	Mike Jones	5-11	181	NC State	null	Pheonix Cardinals	1991	DT	96	11	3

1st Normal Form (1NF)

A decomposition of Roster into two 1NF tables that eliminates redundancy in the same spirit as the original unnormailzed table.

FD: $I \rightarrow NHWCD$
$PCD \rightarrow I$
$ITY \rightarrow PJGS$
$JTY \rightarrow I$

There is still lots of redundancy…

Player

id	name	height	weight	college	dob
20000	Mike Jones	6-1	240	Missouri	1969-04-15
20001	Mike Jones	5-11	181	NC State	???

PlayedFor

id	team	year	position	jersey	games	starts
20000	Los Angeles Raiders	1991	LB	52	16	0
20000	Los Angeles Raiders	1992	LB	52	16	0
20000	Los Angeles Raiders	1993	LB	52	16	2
20000	Los Angeles Raiders	1994	LB	52	16	1
20000	Oakland Raiders	1995	LB	52	16	16
20000	Oakland Raiders	1996	LB	52	15	15
20000	St Louis Rams	1997	LB	52	16	16
20000	St Louis Rams	1998	LB	52	16	16
20000	St Louis Rams	1999	LB	52	16	16
20000	St Louis Rams	2000	LB	52	16	16
20000	Pittsburgh Steelers	2001	LB	51	15	0
20000	Pittsburgh Steelers	2002	LB	95	6	1
20000	Oakland Raiders	2002	LB	52	3	0
20001	Pheonix Cardinals	1991	DT	96	11	3

Discovery of new FDs

At this point we notice the the notion of a "team" and a "team's location" are not well represented in our table, so we split the team column into two.

FD: $I \rightarrow NHWCD$

$PCD \rightarrow I$

$ITY \rightarrow LPJGS$

$JTY \rightarrow I$

$TY \rightarrow L$

PlayedFor

id	location	team	year	position	jersey	games	starts
20000	Los Angeles	Raiders	1991	LB	52	16	0
20000	Los Angeles	Raiders	1992	LB	52	16	0
20000	Los Angeles	Raiders	1993	LB	52	16	2
20000	Los Angeles	Raiders	1994	LB	52	16	1
20000	Oakland	Raiders	1995	LB	52	16	16
20000	Oakland	Raiders	1996	LB	52	15	15
20000	St Louis	Rams	1997	LB	52	16	16
20000	St Louis	Rams	1998	LB	52	16	16
20000	St Louis	Rams	1999	LB	52	16	16
20000	St Louis	Rams	2000	LB	52	16	16
20000	Pittsburgh	Steelers	2001	LB	51	15	0
20000	Pittsburgh	Steelers	2002	LB	95	6	1
20000	Oakland	Raiders	2002	LB	52	3	0
20001	Pheonix	Cardinals	1991	DT	96	11	3

Discovery of new FDs

Our notion of a "team" is still less than ideal since a scan through the table exposes that 1) mascots of teams have changed and 2) old mascots have been reused by later teams, 3) But, in no year did two teams have the same mascot.

We remedy this by adding a *tid* number, which allows mascots of teams to change

$I \rightarrow NHWCD$
$PCD \rightarrow I$
$ITY \rightarrow LPJGS$
$JTY \rightarrow I$
$TY \rightarrow LM$
$MY \rightarrow T$

PlayedFor								
id	location	tid	mascot	year	position	jersey	games	starts
20000	Los Angeles	1024	Raiders	1991	LB	52	16	0
...								
20000	Oakland	1024	Raiders	1995	LB	52	16	16
20000	Oakland	1024	Raiders	1996	LB	52	15	15
20000	St Louis	1025	Rams	1997	LB	52	16	16
...								
20000	Pittsburgh	1030	Steelers	2001	LB	51	15	0
20000	Pittsburgh	1030	Steelers	2002	LB	95	6	1
20000	Oakland	1024	Raiders	2002	LB	52	3	0
20001	Pheonix	1007	Cardinals	1991	DT	96	11	3

2nd Normal Form

A relation is in 2nd Normal Form if it is in 1NF and *every non-primary-key attribute* of a table is *fully functionally dependent on the primary key*.
In other words there are no partial dependances. A partial dependancy is when a subset of attributes depend only upon a *subset* of the attributes of the table's primary key.

I → PHWCD
PCD → I
ITY → LMPJGS
TY→ LM
MY→ T
JTY → I

Player

id	name	height	weight	college	dob
20000	Mike Jones	6-1	240	Missouri	1969-04-15
20001	Mike Jones	5-11	181	NC State	???

PlayedFor

id	location	tid	mascot	year	position	jersey	games	starts
20000	Los Angeles	1024	Raiders	1991	LB	52	16	0
...								
20000	Oakland	1024	Raiders	1995	LB	52	16	16
20000	Oakland	1024	Raiders	1996	LB	52	15	15
20000	St Louis	1025	Rams	1997	LB	52	16	16
...								
20000	Pittsburgh	1030	Steelers	2001	LB	51	15	0
20000	Pittsburgh	1030	Steelers	2002	LB	95	6	1
20000	Oakland	1024	Raiders	2002	LB	52	3	0
20001	Pheonix	1007	Cardinals	1991	DT	96	11	3

2nd Normal Form

At this point we can decompose PlayedFor into two tables all of which are in 2NF. What redundancies are eliminated? What redundacies remain?

$\underline{I} \rightarrow PHWCD,\ PCD \rightarrow I$

$\underline{ITY} \rightarrow PJGS,\ JTY \rightarrow I$

$\underline{TY} \rightarrow LM,\ MY \rightarrow L$

Player

<u>id</u>	name	height	weight	college	dob
20000	Mike Jones	6-1	240	Missouri	1969-04-15
20001	Mike Jones	5-11	181	NC State	???

Team

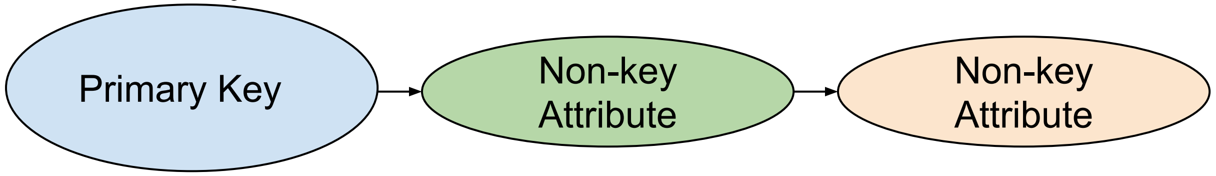
<u>tid</u>	<u>year</u>	location	mascot
1024	1991	Los Angeles	Raiders
...			
1024	1995	Oakland	Raiders
1024	1996	Oakland	Raiders
1025	1997	St Louis	Rams
...			
1030	2001	Pittsburgh	Steelers
1030	2002	Pittsburgh	Steelers
1024	2002	Oakland	Raiders
1007	1991	Pheonix	Cardinals

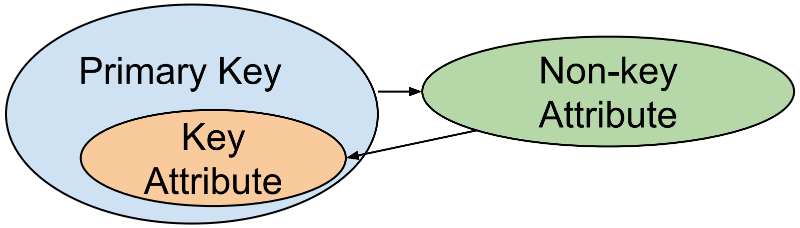
PlayedFor

<u>*id*</u>	<u>tid</u>	<u>year</u>	position	jersey	games	starts
20000	1024	1991	LB	52	16	0
...						
20000	1024	1995	LB	52	16	16
20000	1024	1996	LB	52	15	15
20000	1025	1997	LB	52	16	16
...						
20000	1030	2001	LB	51	15	0
20000	1030	2002	LB	95	6	1
20000	1024	2002	LB	52	3	0
20001	1007	1991	DT	96	11	3

3rd Normal Form (3NF)

A table is in 3NF if it is in 1NF, 2NF, and *no non-primary-key attribute is transitively dependent on the primary key*. Transitive dependance occurs when through a series of FDs a primary key implies a correlation between non-key elements. This can happen in one of two ways.





Various forms of transitive dependence in a list of functional dependences

3rd Normal Form

These FDs don't actually have nice transitive dependencies, and, this table is still full of redundancies. But, we can modify a FD, and if are willing to accept it we can significantly reduce the redundancy, and simplfy many common joins.

~~$\underline{TY} \rightarrow LM, MY \rightarrow L$~~ $\underline{T} \rightarrow M, MY \rightarrow L\ (TY \rightarrow M, \underline{TY} \rightarrow L)$

Team

tid	year	location	mascot
1024	1991	Los Angeles	Raiders
...			
1024	1995	Oakland	Raiders
1024	1996	Oakland	Raiders
1025	1997	St Louis	Rams
...			
1030	2001	Pittsburgh	Steelers
1030	2002	Pittsburgh	Steelers
1024	2002	Oakland	Raiders
1007	1991	Pheonix	Cardinals

Team

tid	mascot
1024	Raiders
...	
1025	Rams
...	
1030	Steelers
1007	Cardinals

TeamLocation

tid	year	location
1024	1991	Los Angeles
...		
1024	1995	Oakland
1024	1996	Oakland
1025	1997	St Louis
...		
1030	2001	Pittsburgh
1030	2002	Pittsburgh
1024	2002	Oakland
1007	1991	Pheonix

Boyce-Codd Normal Form

A relation is in BCNF, iff every set of determinant attributes (left-hand-side of an FD) is a candidate key of some relation.

$\underline{I} \rightarrow PHWCD,\ PCD \rightarrow I,$

$\underline{ITY} \rightarrow PJGS,\ JTY \rightarrow I,$

$\underline{T} \rightarrow M,\ MY \rightarrow L,$

$\underline{TY} \rightarrow L$

In our case this is true, thus, we are already in BCNF.

Player

id	name	height	weight	college	dob
20000	Mike Jones	6-1	240	Missouri	1969-04-15
20001	Mike Jones	5-11	181	NC State	???

Team

tid	mascot
1024	Raiders
1025	Rams
1030	Steelers
1007	Cardinals

TeamLocation

tid	year	location
1024	1991	Los Angeles
	...	
1024	1995	Oakland
1024	1996	Oakland
1025	1997	St Louis
	...	
1030	2001	Pittsburgh
1030	2002	Pittsburgh
1024	2002	Oakland
1007	1991	Pheonix

PlayedFor

id	tid	year	position	jersey	games	starts
20000	1024	1991	LB	52	16	0
			...			
20000	1024	1995	LB	52	16	16
20000	1024	1996	LB	52	15	15
20000	1025	1997	LB	52	16	16
			...			
20000	1030	2001	LB	51	15	0
20000	1030	2002	LB	95	6	1
20000	1024	2002	LB	52	3	0
20001	1007	1991	DT	96	11	3

Summary of Schema Refinement

- If a relation is in BCNF, it is free of redundancies that can be detected using FDs. Thus, trying to ensure that all relations are in BCNF is a good heuristic.
- If a relation is not in BCNF, we can try to decompose it into a collection of BCNF relations.
  - Must consider whether all FDs are preserved. If a lossless-join, dependency preserving decomposition into BCNF is not possible (or unsuitable, given typical queries), should consider decomposition into 3NF.
  - Decompositions should be carried out and/or re-examined while keeping *performance requirements* in mind.