Schema Refinement and Normal Forms

Chapter 19

The Evils of Redundancy

- *Redundancy* is at the root of several problems associated with relational schemas

SSN	Name	Lot	Rate	W	H
123223666	Attishoo	48	8	10	40
23315368	Smiley	22	8	10	30
131243650	Smethurst	35	5	7	30
434263751	Guldu	35	5	7	32
612674134	Madayan	35	8	10	40

- *Functional dependency:* R → W. R *determines* W
- Problems due to R →W :
  - *Update anomaly*: Can we change W in just the first tuple
  - *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!

Notations

- Consider relation obtained from Hourly_Emps:
  - Hourly_Emps (*ssn*, *name*, *lot*, *rating*, *hrly_wages*, *hrs_worked*)
- *Notation*: We will denote this relation schema by listing the attributes: SNLRWH
  - This is really the *set* of attributes {S,N,L,R,W,H}.
- Some FDs on Hourly_Emps:
  - *ssn* is the key: $S \rightarrow SNLRWH$
  - *rating* determines *hrly_wages*: $R \rightarrow W$

Example: Decomposition

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

Wages

R	W
8	10
5	7

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

Will 2 smaller tables be better?

Functional Dependencies (FDs)

- A <u>functional dependency</u> X → Y holds over relation R if, for every allowable instance *r* of R:
  - $t1 \in r,\ t2 \in r,\ \pi_X(t1) = \pi_X(t2)$ implies $\pi_Y(t1) = \pi_Y(t2)$
  - i.e., given two tuples in *r*, if the X values agree, then the Y values must also agree. (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 *r1* 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 → R

Reasoning About FDs

- Given some FDs, we can usually infer additional FDs:
  - $ssn \rightarrow did$, $did \rightarrow lot$ implies $ssn \rightarrow lot$
- 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 $X \subseteq Y$, then $Y \rightarrow X$
  - *Augmentation*: If $X \rightarrow Y$, then $XZ \rightarrow YZ$ for any Z
  - *Transitivity*: If $X \rightarrow Y$ and $Y \rightarrow Z$, then $X \rightarrow Z$

Reasoning About FDs (Contd.)

- Couple of additional rules (that follow from AA):
  - *Union*: If X $\rightarrow$ Y and X $\rightarrow$ Z, then X $\rightarrow$ YZ
  - *Decomposition*: If X $\rightarrow$ YZ, then X $\rightarrow$ Y and X $\rightarrow$ Z
- Example: Contracts(*cid,sid,jid,did,pid,qty,value*), and:
  - C is the key: C $\rightarrow$ CSJDPQV
  - Project purchases each part using single contract: JP $\rightarrow$ C
  - Dept purchases at most one part from a supplier: SD $\rightarrow$ P
- JP $\rightarrow$ C, C $\rightarrow$ CSJDPQV imply JP $\rightarrow$ CSJDPQV
- SD $\rightarrow$ P implies SDJ $\rightarrow$ JP
- SDJ $\rightarrow$ JP, JP $\rightarrow$ CSJDPQV imply SDJ $\rightarrow$ CSJDPQV

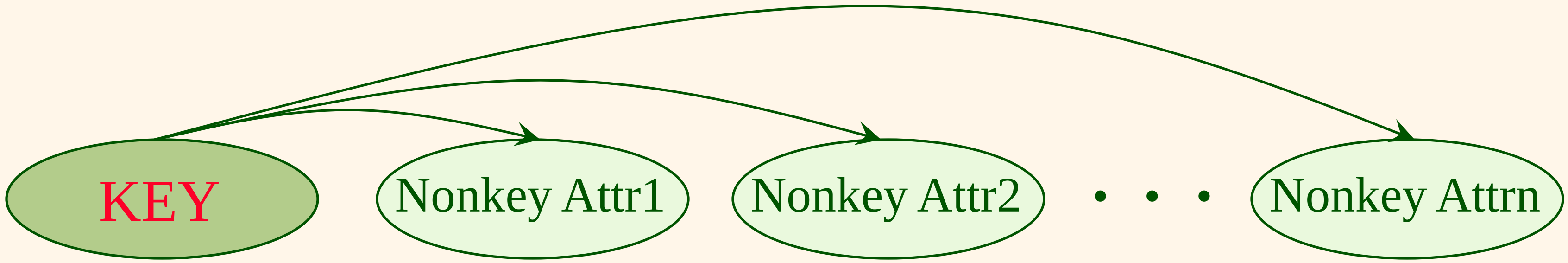
Normal Forms

- Returning to the issue of schema refinement, the first question to ask is whether any refinement is needed!
- If a relation is in a certain *normal form*, then we know that certain kinds of problems cannot arise:
  - *First normal form* (1NF)
  - *Second normal form* (2NF)
  - *Third normal form* (3NF)
  - *Boyce-Codd normal form* (BCNF)
  - *Fourth normal form* (4NF)
  - *Fifth normal form* (5NF)

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

Boyce-Codd Normal Form (BCNF)

- Reln R with FDs *F* is in BCNF if, for all possible X $\rightarrow$ A
  - A $\in$ X (called a *trivial* FD), or
  - X contains a key for R.
- In other words, R is in BCNF if the only non-trivial FDs that hold over R are key constraints.
- BCNF ensures that no redundancy can be detected using FD information alone.



Third Normal Form (3NF)

- Reln R with FDs *F* is in 3NF if, for all possible X $\rightarrow$ A
  - 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, obviously in 3NF.
- If R is in 3NF, some redundancy is possible. It is a compromise, used when BCNF not achievable (e.g., no ``good'' decomposition, or performance considerations).

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 at least 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 $\rightarrow$ SNLRWH and R $\rightarrow$ W
  - Second FD causes violation of 3NF; W values repeatedly associated with R values. Easiest way to fix this is to 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
- The information to be stored consists of SNLRWH tuples. If we just store the projections of these tuples onto SNLRH and RW, *are there any potential problems that we should be aware of?*

Problems with Decompositions

- There are three potential problems to consider:
  1. Some queries become more expensive.
     - e.g., How much did sailor Joe earn? (salary = W*H)
  2. Given instances of the decomposed relations, we may not be able to reconstruct the corresponding instance of the original relation!
     - Fortunately, not in the SNLRWH example.
  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 <u>*lossless-join*</u> w.r.t. a set of FDs F if, for every instance *r* that satisfies F:
  - $\pi_X(r) \bowtie \pi_Y(r) = r$
- It is always true that $r \subseteq \pi_X(r) \bowtie \pi_Y(r)$
  - In general, the other direction does not hold! If it does, 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 deal with redundancy be lossless! <u>(Avoids Problem (2).)</u>*

More on Lossless Join

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

A	B
1	2
4	5
7	2

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

- The decomposition of R into X and Y is lossless-join wrt F if and only if the closure of F contains:
  - $X \cap Y \rightarrow X$, or
  - $X \cap Y \rightarrow Y$

Dependency Preserving Decomposition

- Consider CSJDPQV, C is key, JP → C and SD → P.
  - BCNF decomposition: CSJDQV and SDP (lossless-join)
  - Problem: Checking (Enforcing) JP → C requires a join!
- Dependency preserving decomposition (Intuitive):
  - If R is decomposed into X, Y and Z, and we enforce the FDs on X, on Y and on Z, *(separately)* then all FDs that were given to hold on R must also hold. *(Avoids Problem (3).)*

Decomposition into BCNF

- Consider relation R with FDs F. If X → Y violates BCNF, decompose R into R - Y and XY.
  - Repeated application of this idea will give us a collection of relations that are in BCNF; lossless join decomposition, and guaranteed to terminate.
  - e.g., CSJDPQV, key C, JP → C, SD → P, J → S
  - To deal with SD → P, decompose into SDP, CSJDQV.
  - To deal with J → S, decompose CSJDQV into JS and CJDQV
- In general, several dependencies may cause violation of BCNF. The order in which we ``deal with'' them could lead to very different sets of relations!

Decomposition into 3NF

- Obviously, the algorithm for lossless join decomposition into BCNF can be used to obtain a lossless join decomposition into 3NF (typically, can stop earlier).
- To ensure dependency preservation, one idea:
  - If $X \rightarrow Y$ is not preserved, add relation XY.
  - Problem is that XY may violate 3NF! e.g., consider the addition of CJP to `preserve' $JP \rightarrow C$. What if we also have $J \rightarrow C$?