Part II:
Using FD Theory to do Database Design

Recall that poorly designed table?

part	manufacturer	manAddress	seller	sellerAddress	price
1983	Hammers 'R Us	99 Pinecrest	ABC	1229 Bloor W	5.59
8624	Lee Valley	102 Vaughn	ABC	1229 Bloor W	23.99
9141	Hammers 'R Us	99 Pinecrest	ABC	1229 Bloor W	12.50
1983	Hammers 'R Us	99 Pinecrest	Walmart	5289 St Clair W	4.99

- We can now express the relationships as FDs:
  - part → manufacturer
  - manufacturer → address
  - seller → address
- The FDs tell us there can be redundancy, thus the design is bad.
- That's why we care about FDs.

Decomposition

- To improve a badly-designed schema $R(A_1, \ldots A_n)$, we will decompose it into smaller relations

  $R1(B_1, \ldots B_j)$ and $R2(C_1, \ldots C_k)$ such that:

  - $R1 = \pi_{B1, \ldots Bj}(R)$
  - $R2 = \pi_{C1, \ldots Ck}(R)$
  - $\{B_1, \ldots B_j\} \cup \{C_1, \ldots C_k\} = \{A_1, \ldots A_n\}$
  - $R1 \bowtie R2 = R$

$R(A_1, \ldots A_n)$ Set of attributes: A

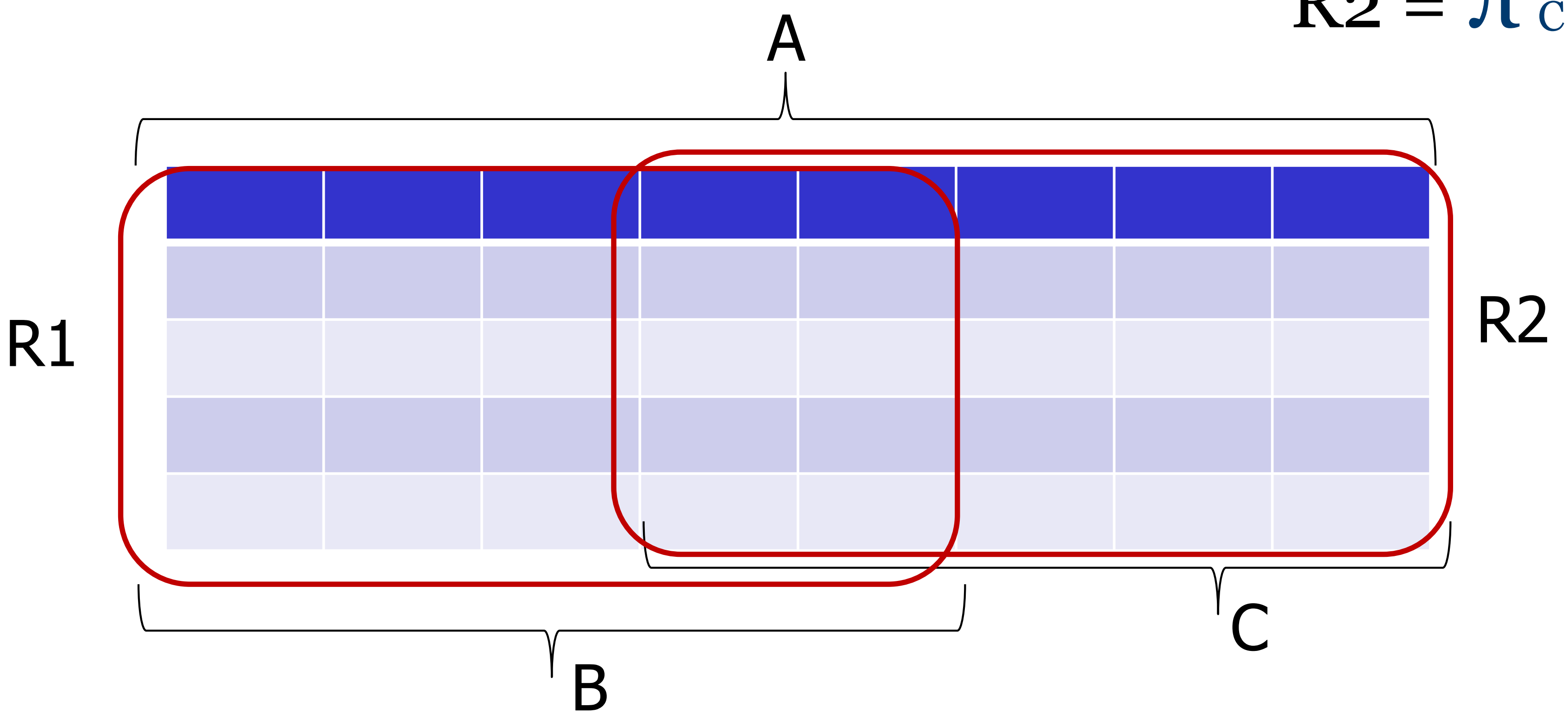
Decompose into:

- $R1(B_1, \ldots B_j)$ Set of attributes: B, and
- $R2(C_1, \ldots C_k)$ Set of attributes: C

$B \cup C = A$, $R1 \bowtie R2 = R$

$R1 = \pi_B(R)$

$R2 = \pi_C(R)$



But *which* decomposition?

- Decomposition can definitely improve a schema.
- But which decomposition?
  There are many possibilities.
- And how can we be sure a new schema doesn’t exhibit other anomalies?
- Boyce-Codd Normal Form *guarantees* it.

Boyce-Codd Normal Form

- We say a relation *R* is in *BCNF* if for every nontrivial FD $X \rightarrow Y$ that holds in *R*, *X* is a superkey.
  - Remember: *nontrivial* means *Y* is not contained in *X*.
  - Remember: a *superkey* doesn't have to be minimal.
- [Exercise]

Intuition

In other words, BCNF requires that:

Only things that functionally determine ***everything*** so any functional dependencies must have LHS as superkey

can functionally determine ***anything***.

Why is the BCNF property valuable?

Note:

- FDs are not the problem. They are facts!
- The schema (in the context of the FDs) is the problem.

R is a relation; F is a set of FDs.
Return the BCNF decomposition of R, given these FDs.

BCNF_decomp(R, F):

note this FD is arbitrarily chosen if multiple FD does not satisfy BCNF, may result in different schemas

If an FD $X \rightarrow Y$ in F violates BCNF

Compute X^+.

Replace R by two relations with schemas:

$R_1 = X^+$

$R_2 = R - (X^+ - X)$

Project the FD's F onto R_1 and R_2.

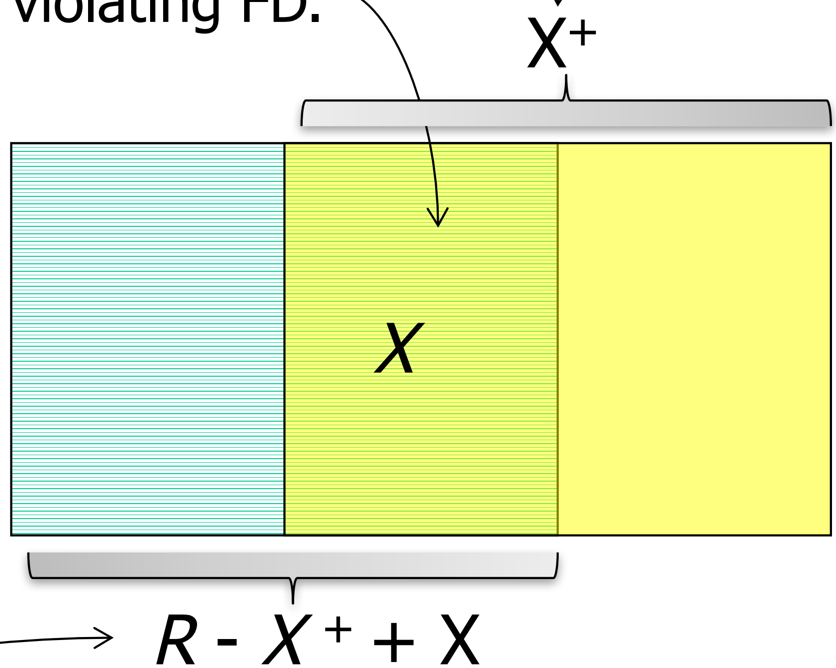
Recursively decompose R_1 and R_2 into BCNF.

[Example]

Decomposition Picture

1) Start with the LHS
of the violating FD.

2) Close the LHS
to get one new relation



3) Everything except the new stuff is the other new relation.
X is in both new relations to make a connection between them.

Some comments on BCNF decomp

- If more than one FD violates BCNF, you may decompose based on any one of them.
  - So there may be multiple results possible.
- The new relations we create may not be in BCNF. We must recurse.
  - We only keep the relations at the "leaves".
- How does the decomposition step help? [Exercise]

Speed-ups for BCNF decomposition

- Don't need to know any keys.
  - Only superkeys matter.

one is enough

- And don't need to know *all* superkeys.
  - Only need to check whether the LHS of each FD is a superkey.
  - Use the closure test (simple and fast!).

BCNF

- Every attribute depends on:
  - The key
  - The whole key
  - And nothing but the key…

so help me Codd….

More speed-ups

- When projecting FDs onto a new relation, check each new FD:
  - Does the new relation violate BCNF because of this FD?
- If so, abort the projection.
  - You are about to discard this relation anyway (and decompose further).

just use this FD to project again into subrelations.

Properties of Decompositions

What we want from a decomposition

1. *No anomalies*. i,e. No duplicates
2. *Lossless Join* : It should be possible to
   a) project the original relations onto the decomposed schema Project_{A,B,C}R natural join Project{C,D,E}R = R(A,B,C,D,E)
   b) then reconstruct the original by joining. We should get back exactly the original tuples.
3. *Dependency Preservation* :
   All the original FD's should be satisfied.

What is lost in a "lossy" join?

- For any decomposition, it is the case that:
  - $r \subseteq r_1 \bowtie \ldots \bowtie r_n$
  - I.e., we will get back every tuple.
- But it may *not* be the case that:
  - $r \supseteq r_1 \bowtie \ldots \bowtie r$ still lossy
  - I.e., we can get spurious tuples.
- [Exercise]

for relation with 2 attributes, guaranteed to be in BCNF for any set of FD

What BCNF decomposition offers

1. *No anomalies* : ✓ (Due to no redundancy)
2. *Lossless Join* : ✓ (Section 3.4.1 argues this)
3. *Dependency Preservation* : ✗

The BCNF *property* does not guarantee lossless join

- If you use the BCNF decomposition algorithm, a lossless join is guaranteed.
- If you generate a decomposition some other way i.e. just construct a table that somehow satisfies BCNF
  - you have to check to make sure you have a lossless join
  - even if your schema satisfies BCNF!
- We'll learn an algorithm for this check later.

Preservation of dependencies

- BCNF decomposition does not guarantee preservation of dependencies.
- I.e., in the schema that results, it may be possible to create an instance that:
  - satisfies all the FDs in the final schema,
  - but violates one of the original FDs.
- Why? Because the algorithm goes too far — breaks relations down too much.
- [Exercise]

3NF is less strict than BCNF

- *3rd Normal Form* (3NF) modifies the BCNF condition to be less strict.
- An attribute is *prime* if it is a member of any key.
- $X \rightarrow A$ violates 3NF iff X is not a superkey and A is not prime.
- I.e., it's ok if X is not a superkey as long as A is prime.
- [Exercise]

F is a set of FDs; L is a set of attributes.
Synthesize and return a schema in 3rd Normal Form.

3NF_synthesis(*F*, *L*):

Construct a minimal basis M for F.

For each FD $X \rightarrow Y$ in M

Define a new relation with schema $X \cup Y$.

If no relation is a superkey for *L*

Add a relation whose schema is some key.

not superkey

[Example]

dependencies are preserved, since there is no need for projection
every FD in minimal basis is preserved in sub-relations,
also added FDs are already enforced by virtue it being keys

3NF synthesis doesn’t “go too far”

- BCNF decomposition doesn’t stop decomposing until in all relations:
  - if $X \rightarrow A$ then X is a superkey.
- 3NF generates relations where:
  - $X \rightarrow A$ and yet X is *not* a superkey, but A is at least prime.
- [Example]

What a 3NF decomposition offers

1. *No anomalies* : ✗
2. *Lossless Join* : ✓
3. *Dependency Preservation* : ✓

- Neither BCNF nor 3NF can guarantee all three! We must be satisfied with 2 of 3.
- Decompose too far $\Rightarrow$ can't enforce all FDs.
- Not far enough $\Rightarrow$ can have redundancy.
- We consider a schema "good" if it is in either BCNF or 3NF.

How can we get anomalies?

- 3NF synthesis guarantees that the resulting schema will be in 3rd normal form.
- This allows FDs with a non-superkey on the LHS.
- This allows redundancy, and thus anomalies.

How do we know…?

… that the algorithm guarantees:

- 3NF: A property of minimal bases [see the textbook for more]
- Preservation of dependencies: Each FD from a minimal basis is contained in a relation, thus preserved.
- Lossless join: We'll return to this once we know how to test for lossless join.

“Synthesis” vs “decomposition”

- 3NF synthesis:
  - We build up the relations in the schema from nothing.
- BCNF decomposition:
  - We start with a bad relation schema and break it down.

Testing for a Lossless Join

- If we project R onto R_1, R_2,…, R_k, can we recover R by rejoining?
- We will get all of R.
  - Any tuple in R can be recovered from its projected fragments. This is guaranteed.
- But will we get only R?
  - Can we get a tuple we didn't have in R? This part we must check.

Aside: when we <u>don't</u> need to test for lossless Join

- Both BCNF decomposition and 3NF synthesis guarantee lossless join.
- So we don't need to test for lossless join if the schema was generated via BCNF decomposition or 3NF synthesis.
- But merely satisfying BCNF or 3NF does not guarantee a lossless join!

The Chase Test

- Suppose tuple t appears in the join.
- Then t is the join of projections of some tuples of R, one for each R_i of the decomposition.
- Can we use the given FD's to show that one of these tuples must be t ?
- [Example]

Setup for the Chase Test

- Start by assuming $t = abc\ldots$.
- For each i, there is a tuple s_i of R that has a, b, c,… in the attributes of R_i.
- s_i can have any values in other attributes.
- We'll use the same letter as in t, but with a subscript, for these components.

The algorithm

1. If two rows agree in the left side of a FD, make their right sides agree too.
2. Always replace a subscripted symbol by the corresponding unsubscripted one, if possible.
3. If we ever get a completely unsubscripted row, we know any tuple in the project-join is in the original (*i.e.,* the join is lossless).
4. Otherwise, the final tableau is a counterexample (*i.e.,* the join is lossy).

[Exercise]