# 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

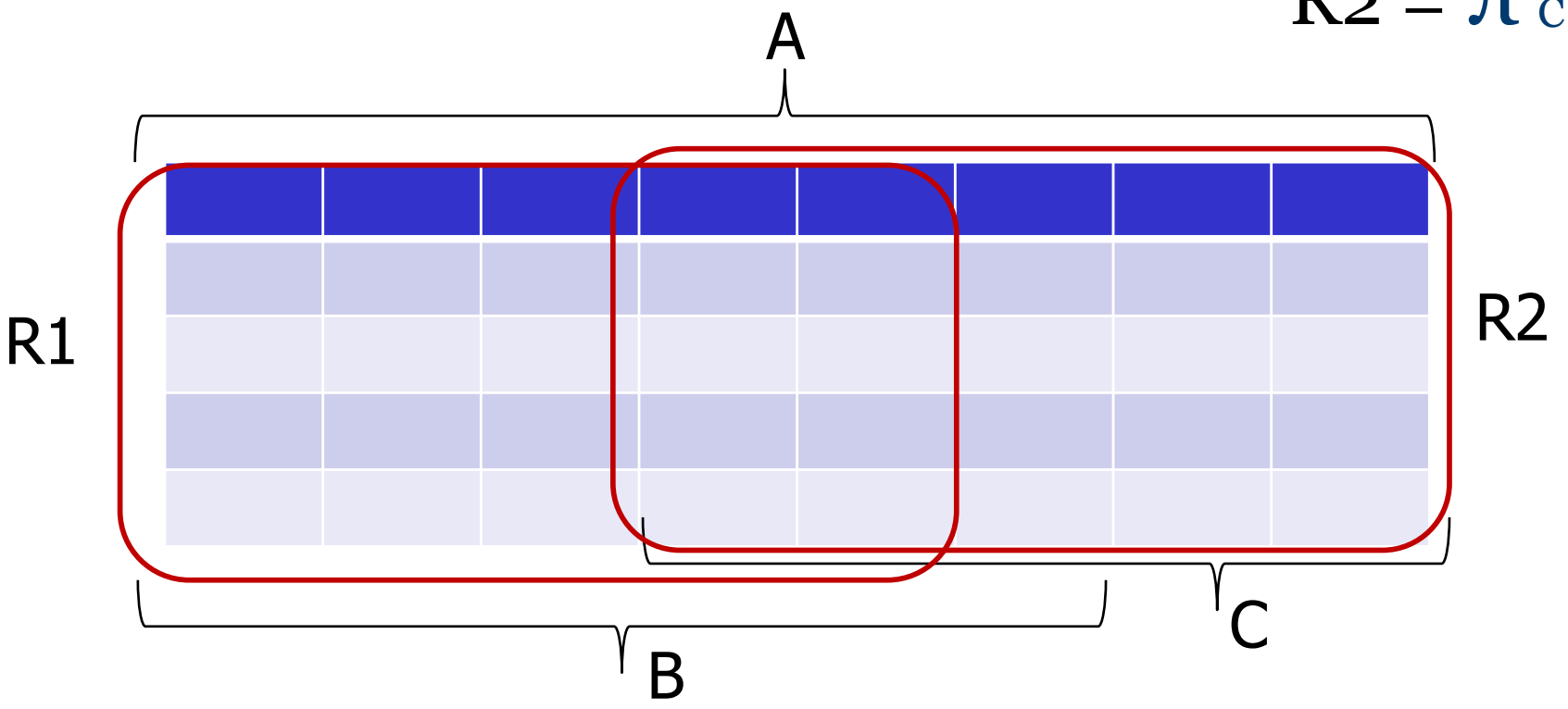
Decompose into:

- $R1(B_1, \ldots B_j)$ 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 FD *everything* can FD 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*):

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

Compute $X^+$.

Replace $R$ by two relations with schemas:

$$R_1 = X^+$$

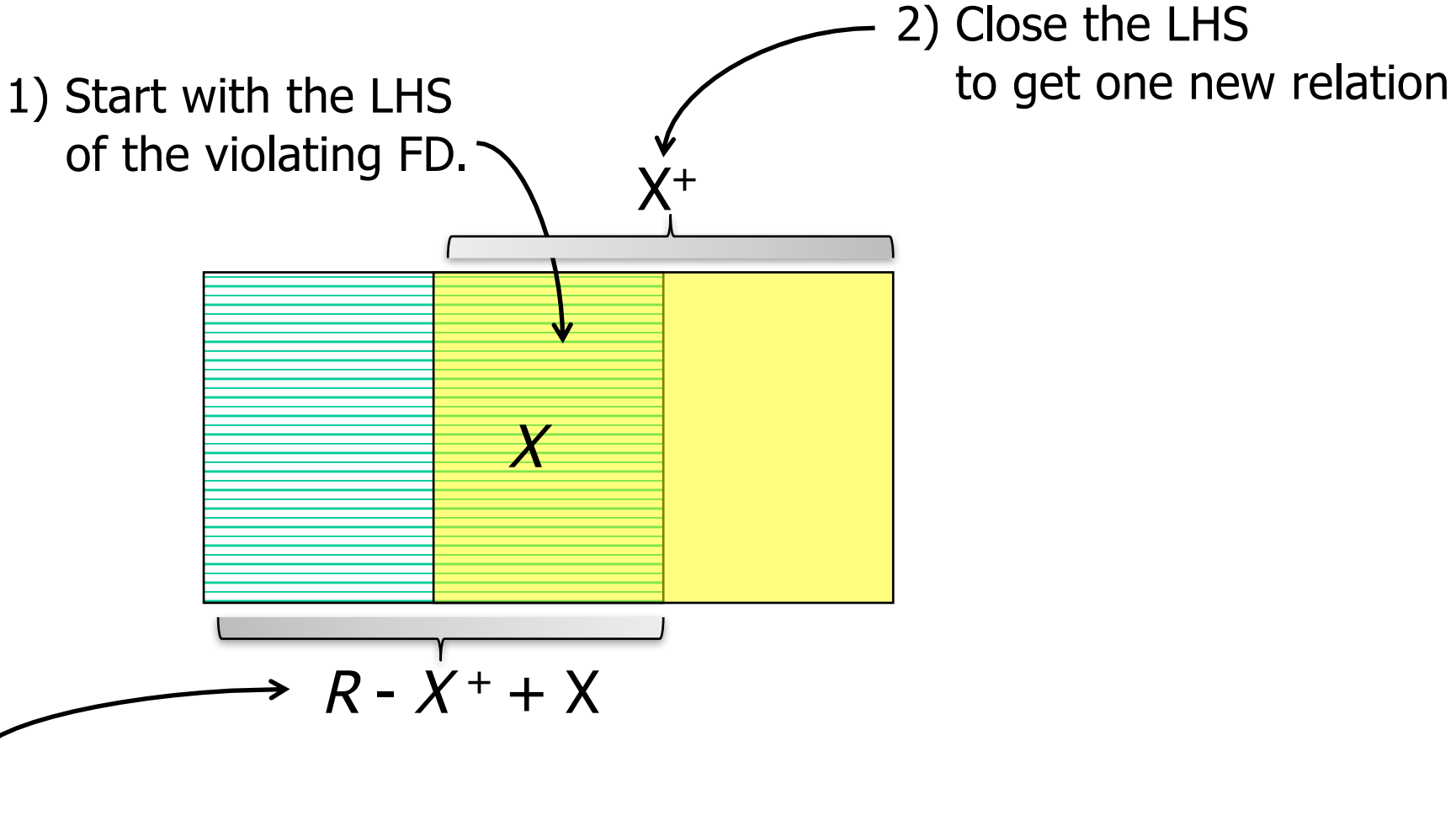
$$R_2 = R - (X^+ - X)$$

Project the FD's $F$ onto $R_1$ and $R_2$.

Recursively decompose $R_1$ and $R_2$ into BCNF.

[Example]

# Decomposition Picture



# 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.
- 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!).

# 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).

# Properties of Decompositions

# What we want from a decomposition

1. *No anomalies*.
2. *Lossless Join* : It should be possible to
   a) project the original relations onto the decomposed schema
   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:
  - $r \supseteq r_1 \bowtie \ldots \bowtie r$
  - I.e., we can get spurious tuples.
- [Exercise]

# 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
  - 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.

[Example]

# 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 ⇒ can't enforce all FDs.
- Not far enough ⇒ 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 don't need to test for lossless Join

- Both BCNF decomposition and 3NF synthesis guarantee lossless join.
- So we don'tneed 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]