Projecting FDs

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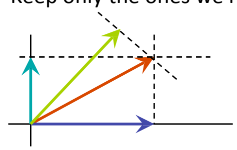
- Once we've split a relation, we have to re-factor our FDs to match
  - Each FDs must only mention attributes from one relation
- Similar to geometric projection
  - Many possible projections (depends on how we slice it)
  - Keep only the ones we need (minimal basis)



Projecting FDs

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- Given:
  - a relation *R*
  - the set *F* of FDs that hold in *R*
  - a relation $R_i \subset R$
- Determine the set of all FDs F_i that
  - Follow from *F* and
  - Involve only attributes of R_i

FD Projection Algorithm

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- Start with $F_i = \emptyset$
- For each subset X of R_i
  - Compute X^+
  - For each attribute A in X^+
    - If A is in R_i
      - add X -> A to F_i
- Compute the minimal basis of F_i

Making projection more efficient

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- Ignore trivial dependencies
  - No need to add *X -> A* if *A* is in *X* itself
- Ignore trivial subsets
  - The empty set or the set of all attributes (both are subsets of X)
- Ignore supersets of X if $X^+ = R$
  - They can only give us "weaker" FDs (with more on the LHS)

Example: Projecting FDs

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- *ABC* with FDs *A->B* and *B->C*
  - A^+=*ABC* ; yields *A->B, A->C*
    - We ignore A->A as trivial
    - We ignore the supersets of A, AB^+ and AC^+, because they can only give us "weaker" FDs (with more on the LHS)
  - B^+=*BC* ; yields *B->C*
  - C^+=*C* ; yields nothing.
  - BC^+=*BC* ; yields nothing.

Example cont'd

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- Resulting FDs: *A->B, A->C*, and *B->C*
- Projection onto *AC* : *A->C*
  - Only FD that involves a subset of {*A*,*C*}
- Projection on BC: *B->C*
  - Only FD that involves subset of {B, C}

Projection is expensive

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- Even with these tricks, projection is still expensive.
- Suppose R_1 has *n* attributes.
  How many subsets of R_1 are there?

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Part III:
Normal Forms

Database Design Theory

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- General idea:
  - Express constraints on the data
  - Use these to decompose the relations
- Ultimately, get a schema that is in a “normal form” that guarantees good properties, such as no anomalies.
- “Normal” in the sense of conforming to a standard.
- The process of converting a schema to a normal form is called normalization.

Acknowledgements: M. Papagelis, R. Johnson

Motivation for normal forms

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- Identify a “good” schema
  - For some definition of “good”
  - Avoid anomalies, redundancy, etc.
- Many normal forms
  - 1st
  - 2nd
  - 3rd
  - Boyce-Codd
  - ... and several more we won’t discuss...

BCNF ⊆ 3NF ⊆ 2NF ⊆ 1NF

1st Normal Form (1NF)

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- No multi-valued attributes allowed
  - Imagine storing a list of values in an attribute
- Counter example
  - Course(name, instructor, [student,email]*)

Name	Instructor	Student Name	Student Email
CS 3DB3	Chiang	Alice	alice@gmail
		Mary	mary@mac
		Mary	mary@mac
SE 3SH3	Miller	Nilesh	nilesh@gmail

2nd normal form (2NF)

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- Non-key attributes depend on candidate keys
  - Consider non-key attribute A
  - Then there exists an FD X s.t. X -> A, and X is a candidate key
- Counter-example
  - Movies(<u>title</u>, <u>year</u>, <u>star</u>, studio, studioAddress, salary)
  - FD: title, year -> studio; studio -> studioAddress; star->salary

Title	Year	Star	Studio	StudioAddr	Salary
Star Wars	1977	Hamill	Lucasfilm	1 Lucas Way	$100,000
Star Wars	1977	Ford	Lucasfilm	1 Lucas Way	$100,000
Star Wars	1977	Fisher	Lucasfilm	1 Lucas Way	$100,000
Patriot Games	1992	Ford	Paramount	Cloud 9	$2,000,000
Last Crusade	1989	Ford	Lucasfilm	1 Lucas Way	$1,000,000

3rd normal form (3NF)

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- Non-prime attr. depend *only* on candidate keys
  - Consider FD X -> A
  - Either X is a superkey OR A is *prime* (part of a key)
- Counter-example:
  - studio -> studioAddr

    (*studioAddr* depends on *studio* which is not a candidate key)

Title	Year	Studio	StudioAddr
Star Wars	1977	Lucasfilm	1 Lucas Way
Patriot Games	1992	Paramount	Cloud 9
Last Crusade	1989	Lucasfilm	1 Lucas Way

3NF, dependencies, and join loss

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- Theorem: always possible to convert a schema to lossless join, dependency-preserving 3NF
- Caveat: always *possible* to create schemas in 3NF for which these properties do not hold
- FD loss example 1:
  - MovieInfo(title, year, studioName)
  - StudioAddress(title, year, studioAddress)

  => Cannot enforce studioName -> studioAddress
- Join loss example 2:
  - Movies(title, year, star)
  - StarSalary(star, salary)

  => Movies ⋈ StarSalary yields additional tuples

Boyce-Codd normal form (BCNF)

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- One additional restriction over 3NF
  - All non-trivial FDs have superkey LHS
- Counterexample
  - CanadianAddress(street, city, province, postalCode)
  - Candidate keys: {street, postalCode}, {street, city, province}
  - FD: postalCode -> city, province
  - Satisfies 3NF: city, province both prime
  - Violates BCNF: postalCode is not a superkey

  => Possible anomalies involving postalCode

Boyce-Codd Normal Form

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- We say a relation *R* is in *BCNF* if whenever $X \rightarrow A$ is a nontrivial FD that holds in *R*, *X* is a superkey.
  - Remember: *nontrivial* means A is not contained in X.

Example: a relation not in BCNF

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Drinkers(<u>name</u>, addr, <u>beersLiked</u>, manf, favBeer)

FD's: name->addr, favBeer, beersLiked->manf

- Only key is {name, beersLiked}.
- In each FD, the left side is **not** a superkey.
- Any one of these FDs shows *Drinkers* is not in BCNF

Another Example

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Beers(<u>name</u>, manf, manfAddr)

FD's: name->manf, manf->manfAddr

- Beers w.r.t. name->manf does not violate BCNF, but manf->manfAddr does.

In other words, BCNF requires that:
the only FDs that hold are the result of key(s).
Why does that help?

Decomposition into BCNF

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- Given: relation R with FDs F
- Look among the given FDs for a BCNF violation $X \rightarrow Y$ (i.e., X is not a superkey)
- Compute X^+.
  - Find $X^+ \neq X \neq$ all attributes, (o.w. X is a superkey)
- Replace R by relations with:
  - $R_1 = X^+$.
  - $R_2 = R - (X^+ - X) = R - X^+ \cup X$
- Continue to recursively decompose the two new relations
- *Project* given FDs F onto the two new relations.

Decomposition on $X \rightarrow Y$

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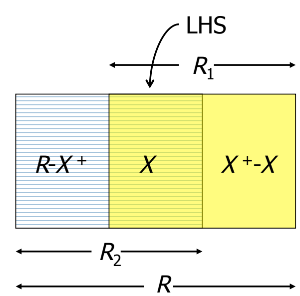

Example: BCNF Decomposition

Drinkers(name, addr, beersLiked, manf, favBeer)

F = name->addr, name -> favBeer, beersLiked->manf

Key = name, beersLiked

- Pick BCNF violation name->addr.
- Closure: $\{name\}^+$ = {name, addr, favBeer}.
- Decomposed relations:
  - Drinkers1(name, addr, favBeer)
  - Drinkers2(name, beersLiked, manf)

Example -- Continued

- We are not done; we need to check Drinkers1 and Drinkers2 for BCNF.
- Projecting FDs is easy here.
- For Drinkers1(name, addr, favBeer), relevant FDs are name->addr and name->favBeer.
  - Thus, {name} is the only key and Drinkers1 is in BCNF.

Example -- Continued

- For Drinkers2(name, beersLiked, manf), the only FD is beersLiked->manf, and the only key is {name, beersLiked}.
  - Violation of BCNF.
- $beersLiked^+$ = {beersLiked, manf}, so we decompose *Drinkers2* into:
  - Drinkers3(beersLiked, manf)
  - Drinkers4(name, beersLiked)

Example -- Concluded

- The resulting decomposition of *Drinkers* :
  - Drinkers1(name, addr, favBeer)
  - Drinkers3(beersLiked, manf)
  - Drinkers4(name, beersLiked)
- Notice: *Drinkers1* tells us about drinkers, *Drinkers3* tells us about beers, and *Drinkers4* tells us the relationship between drinkers and the beers they like.

What we want from a decomposition

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- *Lossless Join* : it should be possible to project the original relations onto the decomposed schema, and then reconstruct the original,
  i.e., get back exactly the original tuples.
- *No anomalies*
- *Dependency Preservation* : All the original FDs should be satisfied.

What we get from a BCNF decomposition

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- *Lossless Join* : ✓
- *No anomalies* : ✓
- *Dependency Preservation* : ✗

Example: Failure to preserve dependencies

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- Suppose we start with R(*A,B,C*) and FDs
  - *AB* ->C and C ->*B.*
- There are two keys, {*A,B* } and {*A,C* }.
- C ->*B* is a BCNF violation, so we must decompose into *AC*, *BC*.

The problem is that if we use *AC* and *BC* as our database schema, we cannot enforce the FD *AB* →C in these decomposed relations.

3NF Let's Us Avoid This Problem

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- *3rd Normal Form* (3NF) modifies the BCNF condition so we do not have to decompose in this problem situation.
- An attribute is *prime* if it is a member of any key.
- *X* →*A* violates 3NF if and only if *X* is not a superkey, and also *A* is not prime.
- i.e., it's ok if *X* is not a superkey, as long as *A* is prime.

Example: 3NF

101

- In our problem situation with FDs *AB* ->C and C ->*B*, we have keys *AB* and *AC*.
- Thus *A*, *B*, and C are each prime.
- Although C ->*B* violates BCNF, it does not violate 3NF.

What we get from a 3NF decomposition

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- *Lossless Join* : ✓
- *No anomalies* : ✗
- *Dependency Preservation* : ✓

Why?

Unfortunately, neither BCNF nor 3NF can guarantee all three properties we want.

3NF Synthesis Algorithm

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- We can always construct a decomposition into 3NF relations with a lossless join and dependency preservation.
- Need *minimal basis* for the FDs (same as used in projection)
  - Right sides are single attributes.
  - No FD can be removed.
  - No attribute can be removed from a left side.

3NF Synthesis – (2)

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- One relation for each FD in the minimal basis.
  - Schema is the union of the left and right sides.
- If no key is contained in an FD, then add one relation whose schema is some key.

Example: 3NF Synthesis

105

- Relation R = ABCD.
- FDs *A->B* and *A->C*.
- Decomposition: AB and AC from the FDs, plus AD for a key.

Limits of decomposition

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- Pick two…
  - Lossless join
  - Dependency preservation
  - Anomaly-free
- 3NF
  - Provides lossless join and dependency preserving
  - May allow some anomalies
- BCNF
  - Anomaly-free, lossless join
  - Sacrifice dependency preservation

Use domain knowledge to choose 3NF vs. BCNF