Normal Forms

The Evils of Redundancy

Dept_id	budget	Emp_id	Emp_name	salary
1	100	1	John Williams	60
1	100	2	Phil Coulter	50
2	200	3	Norah Jones	45
3	300	4	Anastacia	40

- Redundancy at the root of several relational schema problems
  - redundant storage, insert/delete/update anomalies
- Integrity constraints identify problems and suggest refinements
  - in particular: functional dependencies

Functional Dependencies

- Let R be relation, X and Y sets of attributes of R
- Functional dependency (FD) X → Y holds over relation R
  if, for every allowable instance r of R:
  - $t1 \in r$, $t2 \in r$:
    $\pi_X(t1) = \pi_X(t2) \Rightarrow \pi_Y(t1) = \pi_Y(t2)$
  - FDs in example?

Dept_id	budget	Emp_id	Emp_name	salary
1	100	1	John Williams	60
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- K is a candidate key for R means that K → R
  - K → R does not require K to be minimal!
- FD is a statement about all allowable relation instances
  - 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!

Example: Constraints on Entity Set

- Consider relation obtained from Hourly_Emps:
  - Hourly_Emps (ssn, name, lot, rating, hrly_wages, hrs_worked)
- Notation: relation schema by listing the attributes: SNLRWH
  - set of attributes {S,N,L,R,W,H}
  - Using equivalently to relation name (e.g., Hourly_Emps for SNLRWH)
- Some FDs on Hourly_Emps:
  - ssn is key: $S \rightarrow SNLRWH$
  - rating determines hrly_wages: $R \rightarrow W$

Example (Contd.)

- Problems due to R → W :
  - Update anomaly:
    change W in just the 1st tuple of SNLRWH?
  - Insertion anomaly:
    insert employee and don't know the hourly wage for his rating?
  - Deletion anomaly:
    delete all employees with rating 5
    ⇒ lose information about the wage for rating 5!

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
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Will 2 smaller tables be better?

Normal Forms & Functional Dependencies

- normal forms avoid / minimize certain kinds of problems
  - helps to decide on decomposing relation
- Role of FDs in detecting redundancy
  - No FDs hold: no redundancy
  - Given relation R with 3 attributes ABC and FD A → B:
    Several tuples might have the same A value; if so, they all have the same B value

It's all about <u>hidden repeating information</u> across tuples

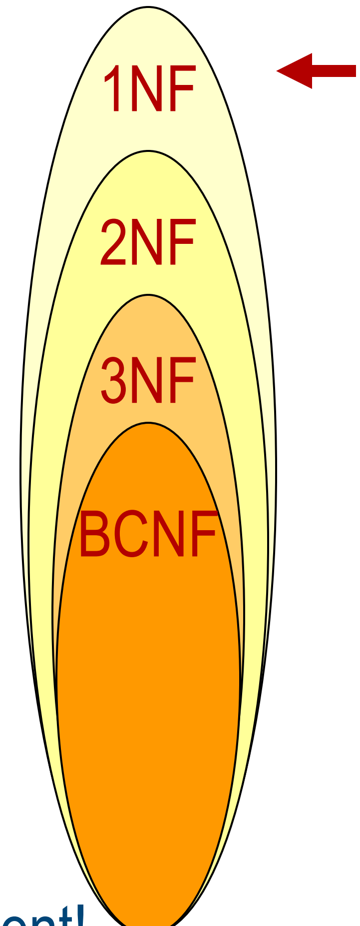
First Normal Form

- First Normal Form (1NF)
  - eliminates attributes containing sets = repeating groups
  - ...by flattening: introduce separate tuples with atomic values
- Ex:

id	name	skillsList
1	Jane	{C,C++,SQL}
2	John	{Java,python,SQL}

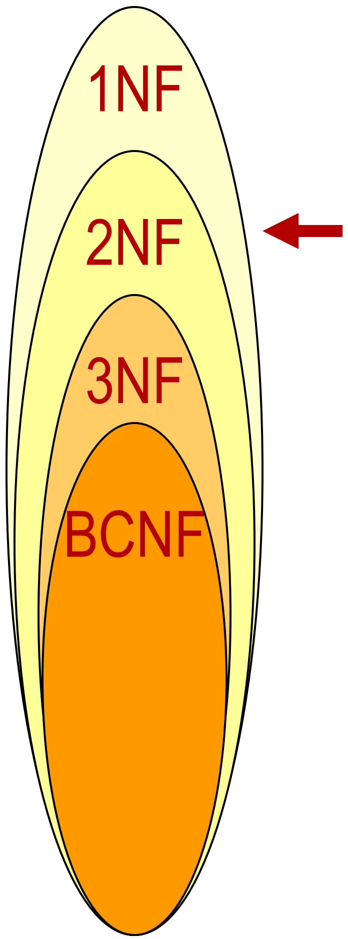
id	name	skill
1	Jane	C
1	Jane	C++
1	Jane	SQL
2	John	Java
2	John	Python
2	John	SQL

  - Skills not f.d. on id, nor name!
- Oops: lost primary key property.
  - Will fix that later.
- Why good? Repeating groups complicate storage management!
  - Experimental DBMSs exist for non-1NF (NFNF, NF^2) tables



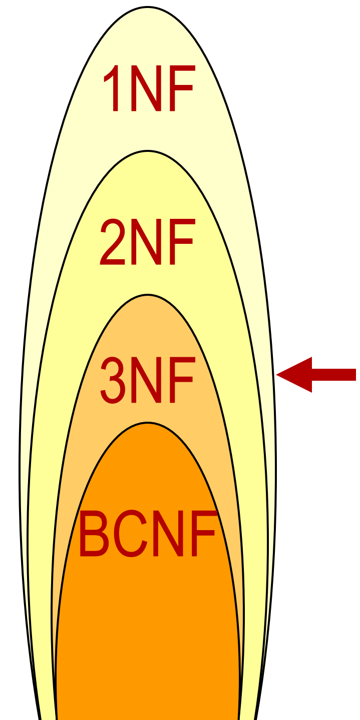
Second Normal Form

- Second Normal Form (2NF):
  - eliminates functional dependencies on a partial key
  - by putting the fields in a separate table
    from those that are dependent on the whole key
- Ex: ABCD with B→C
  becomes: ABD, BC



Third Normal Form (3NF)

- Relation R with FD set F is in 3NF if, for all X → A in F^+,
  - Either A∈X (called a *trivial* FD)
  - Or X contains a key for R
  - Or A is part of some key for R
- In plain words:
  - 3NF eliminates functional dependencies on non-key fields by putting them in a separate table
  - = in 3NF, all non-key fields are dependent on
    the key,
    the whole key,
    and nothing but the key
- Ex:



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Why Is 3NF Good?

- If 3NF violated by $X \rightarrow A$, one of the following holds:
- X subset of some key K
  - We store (X, A) pairs redundantly
- X not a proper subset of any key
  - Which means: for some key K, there is a chain of FDs $K \rightarrow X \rightarrow A$
  - Which means: we once introduced keys to capture dependencies, but now we have attributes dependent on a non-key attribute!
- …so non-3NF means dangerous updates!

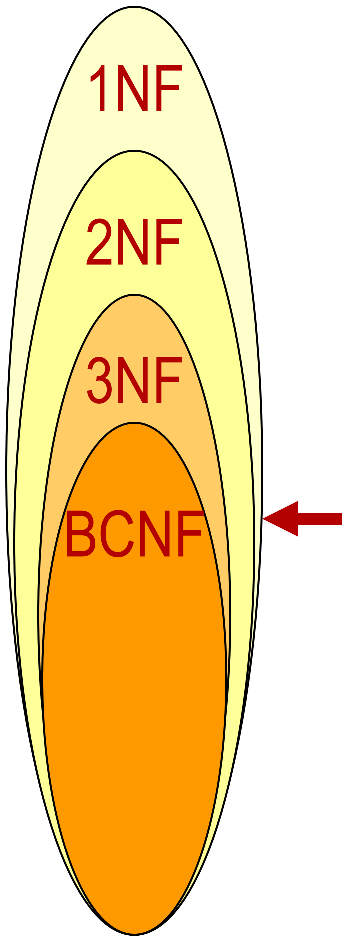
What Does 3NF NOT Achieve?

- Some redundancy possible with 3NF
- Ex: Reserves SBDC, $S \rightarrow C$, $C \rightarrow S$
  - is in 3NF
  - but $S \leftrightarrow C$ means:
    for each reservation of sailor S, same (S, C) pair is stored
- …so we still need to capture "nests" inside the keys

Boyce-Codd Normal Form (BCNF)

- Relation R with FDs F is in BCNF if, for all $X \rightarrow A$ in F^+,
  - Either $A \in X$ (called a *trivial* FD)
  - Or X contains a key for R
  - ~~Or A is part of some key for R~~

- In other words:
  R in BCNF ⇔ only key-to-nonkey constraints FDs left
  - ✓ = No redundancy in R that can be detected using FDs alone
  - ✓ = No FD constraints "hidden in data"



Discussion: 3NF vs. BCNF

- Always possible?
  - 3NF always possible, is “nice” (lossless-join, dependency-preserving)
  - BCNF not always possible
- 3NF compromise used when BCNF not achievable
  - Ex: performance considerations
  - Ex: cannot find ``good’’ decomp (see next)

Decomposition of a Relation Scheme

- Given relation R with attributes A1 ... An
- decomposition of R = replacing R by two or more relations such that:
  - Each new relation scheme contains a subset of the attributes of R (and no additional attributes), and
  - Every attribute of R appears as an attribute of one of the new relations
- E.g., decompose SNLRWH into SNLRH and RW

Example Decomposition

- SNLRWH has FDs
  S → SNLRWH, R ↔ W, N → SN
- 2nd FD causes 3NF violation:
  W values repeatedly associated with R values (and vice versa)!

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- Easiest fix: create relation RW to store assocs w/o dups, remove W from main schema
  = decompose SNLRWH into SNLRH and RW

Wages

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Hourly_Emps2

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If we just store projections of SNLRWH tuples onto SNLRH and RW, are there any potential problems?

3 Potential Problems with Decomp

- Some queries become more expensive
  - e.g., How much did sailor Joe earn? (salary = W*H)
- may not be able to reconstruct original relation
  - Fortunately, not in the SNLRWH example
  -

Lossless Join: A Counter Example

A	B	C
0	1	2
3	1	4

A	B
0	1
3	1

(A,B) x (B,C)

B	C
1	2
1	4

What's wrong?

3 Potential Problems with Decomp

- Some queries become more expensive
  - e.g., How much did sailor Joe earn? (salary = W*H)
- may not be able to reconstruct original relation
  - Fortunately, not in the SNLRWH example
- Checking some dependencies may require joining decomposed relations
  - Fortunately, not in the SNLRWH example

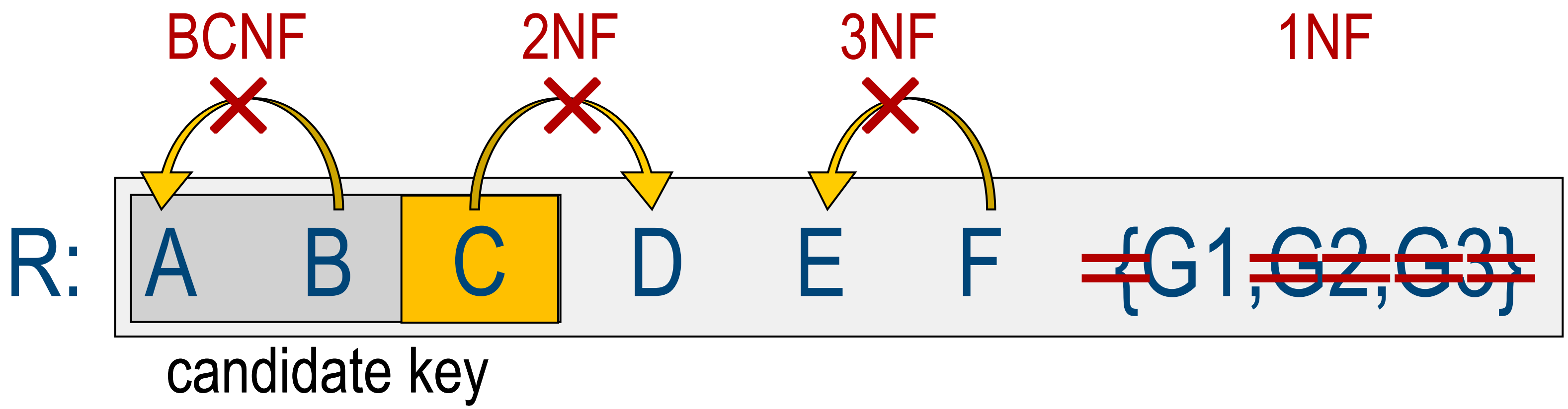
- Tradeoff: Must consider these issues vs. redundancy

Summary of Schema Refinement

- BCNF = free of redundancies that can be detected using FDs
  - BCNF good heuristic (consider typical queries!)
    - *Check FDs !*
  - Next best: 3NF
- When not BCNF?
  - not always possible
  - unsuitable, given typical queries - performance requirements
- Use decompositions only when needed!

↳NF pocket guide

Pocket Guide to NFs



- 1NF = no repeating groups
- 2NF = 1NF + no partial key → non-key
- 3NF = 2NF + no non-key → anything
- BCNF = 3NF + no key → key

Normalization of table R with FD set :

- For all FDs F = „X → Y“:
  - Create additional table $R_F(X,Y)$
  - Remove Y from R, but keep X
- Drop duplicates arising from „X → Y, Y → X“ cycles
- Crosscheck all new tables created against all FDs for decomposition need