# Normal Forms

COMP9311 25T3; Week 5.2

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# Notice

- No lectures/labs next week (Week 6)

- Consultation still available

# Normal Forms

Normal Forms:

- Criteria for a good database design (e.g., to resolve update anomalies)
- Formalized by functional (or other) dependencies

Types of Normal Forms:

- **1NF, 2NF, 3NF (Codd 1972)**
- **Boyce-Codd NF (1974)**
- Multivalued dependencies and 4NF (Zaniolo 1976 and Fagin 1977)
- Join dependencies (Rissanen 1977) and 5NF (Fagin 1979)

# First Normal Form (1NF)

This means that attribute values are ***atomic***, and are part of the definition of the relational model.

Atomic: multivalued attributes, composite attributes, and their combinations are disallowed.

There is still interest in non-first normal form databases.

# First Normal Form (1NF) (cont)

| Fac_Dept | Prof | Course Preferences | |
|---|---|---|---|
| | | Course | Course_Dept |
| Comp Sci | Smith | 353 | Comp Sci |
| | | 379 | Comp Sci |
| | | 221 | Decision Sci |
| | Clark | 353 | Comp Sci |
| | | 351 | Comp Sci |
| | | 379 | Comp Sci |
| | | 456 | Mathematics |
| Chemistry | Turner | 353 | Comp Sci |
| | | 456 | Mathematics |
| | | 272 | Chemsitry |
| Mathematics | Jameison | 353 | Comp Sci |
| | | 379 | Comp Sci |
| | | 221 | Decision Sci |
| | | 456 | Mathematics |
| | | 469 | Mathematics |

# First Normal Form (1NF) (cont)

| CRS_PREF | | | |
|---|---|---|---|
| Prof | Course | Fac_Dept | Crs_Dept |
| Smith | 353 | Comp Sci | Comp Sci |
| Smith | 379 | Comp Sci | Comp Sci |
| Smith | 221 | Comp Sci | Decision Sci |
| Clark | 353 | Comp Sci | Comp Sci |
| Clark | 351 | Comp Sci | Comp Sci |
| Clark | 379 | Comp Sci | Comp Sci |
| Clark | 456 | Comp Sci | Mathematics |
| Turner | 353 | Chemistry | Comp Sci |
| Turner | 456 | Chemistry | Mathematics |
| Turner | 272 | Chemistry | Chemistry |
| Jamieson | 353 | Mathematics | Comp Sci |
| Jamieson | 379 | Mathematics | Comp Sci |
| Jamieson | 221 | Mathematics | Decision Sci |
| Jamieson | 456 | Mathematics | Mathematics |
| Jamieson | 469 | Mathematics | Mathematics |

# First Normal Form (1NF)

The relation has the following **drawbacks**: (part 1)

(1) Repetition of data:

- The fact that (a given professor is in a given department) may be repeated,
- The fact that (a given course is offered by a given department) may be repeated.

Can result in insertion and modification anomalies

| CRS_PREF | | | |
|---|---|---|---|
| <u>Prof</u> | <u>Course</u> | Fac_Dept | Crs_Dept |
| Smith | 353 | Comp Sci | Comp Sci |
| Smith | 221 | Comp Sci | Decision Sci |
| Turner | 353 | Chemistry | Comp Sci |
| Turner | 456 | Chemistry | Mathematics |

# First Normal Form (1NF)

The relation has the following **drawbacks**: (part 2)

(2) Some associations aren't stored explicitly:

- The association between professor and department will not be recorded unless the professor has some course references,
- The association between course and department is not recorded unless someone prefers the course.

Can lead to deletion anomalies

| CRS_PREF | | | |
|---|---|---|---|
| Prof | Course | Fac_Dept | Crs_Dept |
| Smith | 353 | Comp Sci | Comp Sci |
| Smith | 379 | Comp Sci | Comp Sci |
| Turner | 353 | Chemistry | Comp Sci |

# Unspecified dependencies between Attr.

There is too much information in a table.

- *CRS_PREF(Prof, Course, Fac_Dept, Crs_Dept)*
- The FD's for these attributes are *F = {Prof → Fac_Dept, Course → Crs_Dept}.*
- From F, the only candidate key is *{Prof, Course}.*

From the FDs, we see

- Fac_Dept depends only on Prof and not on Course,
- Crs_Dept depends only on Course and not on Prof.

| CRS_PREF | | | |
|---|---|---|---|
| **Prof** | **Course** | **Fac_Dept** | **Crs_Dept** |
| Smith | 353 | Comp Sci | Comp Sci |
| Smith | 379 | Comp Sci | Comp Sci |
| Smith | 221 | Comp Sci | Decision Sci |
| Clark | 353 | Comp Sci | Comp Sci |
| Clark | 351 | Comp Sci | Comp Sci |
| Clark | 379 | Comp Sci | Comp Sci |
| Clark | 456 | Comp Sci | Mathematics |
| Turner | 353 | Chemistry | Comp Sci |
| Turner | 456 | Chemistry | Mathematics |
| Turner | 272 | Chemistry | Chemistry |
| Jamieson | 353 | Mathematics | Comp Sci |
| Jamieson | 379 | Mathematics | Comp Sci |
| Jamieson | 221 | Mathematics | Decision Sci |
| Jamieson | 456 | Mathematics | Mathematics |
| Jamieson | 469 | Mathematics | Mathematics |

# Second Normal Form (2NF) (1)

**2NF Prerequisite (1)**

Definition (Prime attribute): An attribute of relation schema R is called a prime attribute of R if it is a member of some candidate key of R.

Definition (Nonprime attribute): An attribute is called nonprime if it is not a prime attribute—that is, if it is not a member of any candidate key.

# Second Normal Form (2NF) (2)

**2NF Prerequisite (2)**

Definition (Full functional dependency): In an FD $X \rightarrow Y$ , $Y$ is fully functionally dependent on $X$ if there is no $Z \subset X$ such that $Z \rightarrow Y$ .

Definition (Partial functional dependency): In an FD $X \rightarrow Y$ , $Y$ is partially functionally dependent on $X$ if there is any $Z \subset X$ such that $Z \rightarrow Y$ .

# Second Normal Form (2NF) (3)

Definition (Second Normal Form): A relation schema *R* is in second normal form (2NF) if every nonprime attribute *A* in *R* is not partially dependent on *any* key of *R*.

# Second Normal Form (2NF) (4)

Recall (Second Normal Form): A relation schema *R* is in second normal form (2NF) if every nonprime attribute *A* in *R* is not partially dependent on *any* key of *R*.

*Common confusion:* ***Can we consider just the primary key instead?***
Answer: Only if the relation has one candidate key only

*Common confusion:* ***Why all keys rather than just one key?***
Answer: No special consideration will be given to the primary key over other candidate keys.

# Second Normal Form (2NF)

Let's decompose this 1NF relation:

| CRS_PREF | | | |
|---|---|---|---|
| **Prof** | **Course** | **Fac_Dept** | **Crs_Dept** |
| Smith | 353 | Comp Sci | Comp Sci |
| Smith | 379 | Comp Sci | Comp Sci |
| Smith | 221 | Comp Sci | Decision Sci |
| Clark | 353 | Comp Sci | Comp Sci |
| Clark | 351 | Comp Sci | Comp Sci |
| Clark | 379 | Comp Sci | Comp Sci |
| Clark | 456 | Comp Sci | Mathematics |
| Turner | 353 | Chemistry | Comp Sci |
| Turner | 456 | Chemistry | Mathematics |
| Turner | 272 | Chemistry | Chemistry |
| Jamieson | 353 | Mathematics | Comp Sci |
| Jamieson | 379 | Mathematics | Comp Sci |
| Jamieson | 221 | Mathematics | Decision Sci |
| Jamieson | 456 | Mathematics | Mathematics |
| Jamieson | 469 | Mathematics | Mathematics |

# Second Normal Form (2NF)

(You can decompose a 1NF into a 2NF)

| COURSE_PREF | |
|---|---|
| Prof | Course |
| Smith | 353 |
| Smith | 379 |
| Smith | 221 |
| Clark | 353 |
| Clark | 351 |
| Clark | 379 |
| Clark | 456 |
| Turner | 353 |
| Turner | 456 |
| Turner | 272 |
| Jamieson | 353 |
| Jamieson | 379 |
| Jamieson | 221 |
| Jamieson | 456 |
| Jamieson | 469 |

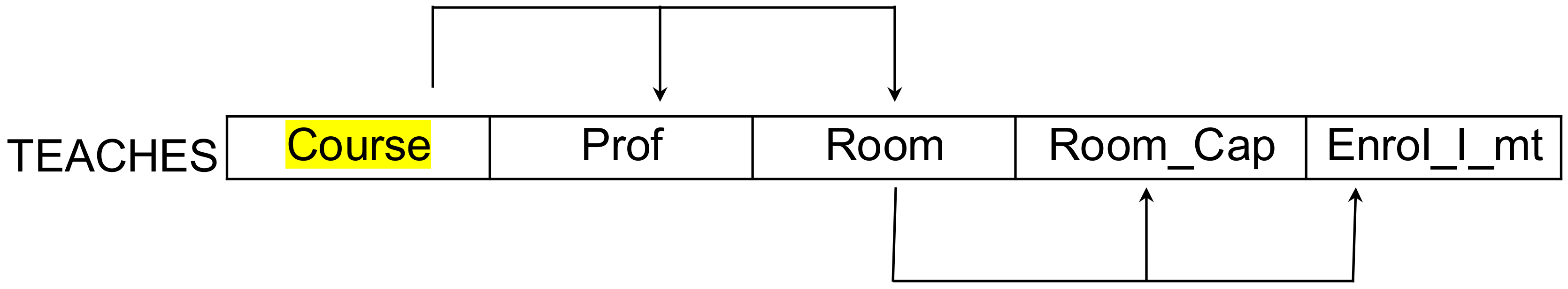
| COURSE | |
|---|---|
| Course | Dept |
| 353 | Comp Sci |
| 379 | Comp Sci |
| 221 | Decision Sci |
| 351 | Comp Sci |
| 456 | Mathematics |
| 272 | Chemistry |
| 469 | Mathematics |

| FACULTY | |
|---|---|
| Prof | Dept |
| Smith | Comp Sci |
| Clark | Comp Sci |
| Turner | Chemistry |
| Jamieson | Mathematics |

# Second Normal Form (2NF)

Recall (Second Normal Form): A relation schema *R* is in second normal form (2NF) if every nonprime attribute *A* in *R* is not partially dependent on *any* key of *R*.

E.g., Is this table 2NF?




The relation TEACHES is in 2NF

# Redundancy/Issue in 2NF

Do we resolve all issues? Not for all relations in 2NF.

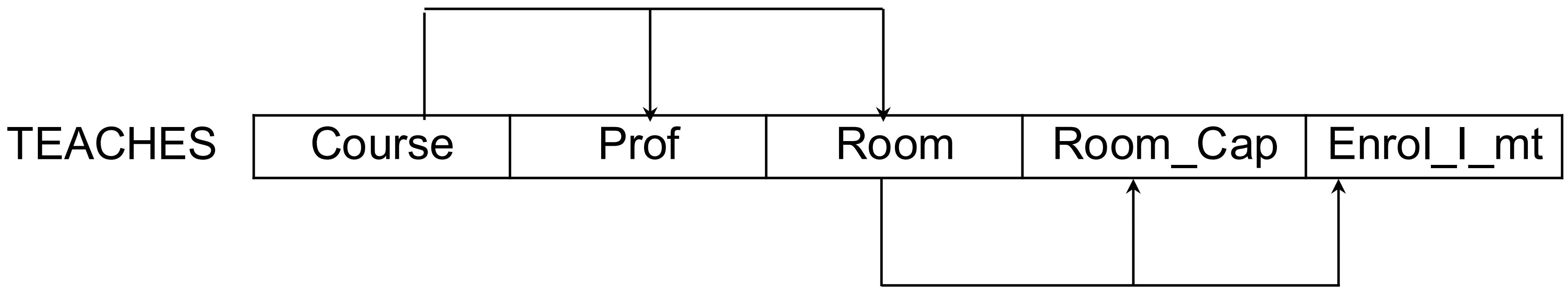
1. The fact that A532 has Room_Cap of 45 and Enrol_Lmt of 40 can still be stored twice.
2. If course 355 is deleted, then the fact that H940 has Room_Cap of 400 and Enrol_Lmt of 300 will be lost.

| TEACHES | | | | |
|---|---|---|---|---|
| Course | Prof | Room | Room_Cap | Enrol_l_mt |
| 353 | Smith | *A532* | *45* | *40* |
| 351 | Smith | C320 | 100 | 60 |
| *355* | *Clark* | *H940* | *400* | *300* |
| 456 | Turner | B278 | 50 | 45 |
| 459 | Jamieson | D110 | 50 | 45 |
| *500* | *Bob* | *A532* | *45* | *40* |

# Transitive Functional Dependency

Definition (Transitive dependency):

A FD X→Y is a transitive dependency if there is a Z that is not a subset of any key, such that X → Z and Z → Y. The attributes of Y are transitively dependent on X.




*E.g., Room_Cap is transitively dependent on {Course}, since {Course} → {Room} and {Room} → {Room_Cap} hold, and {Room} is not a subset of any key.*

# Superkey

Recall (superkey): A superkey of a relation schema $R = \{A1, A2, \ldots, An\}$ is a set of attributes $S \rightarrow R$ with the property that no two tuples $t1$ and $t2$ in any legal relation state $r$ of $R$ will have $t1[S] = t2[S]$.

Recall (key): A key $K$ is a superkey with the additional property that removal of any attribute from $K$ will cause $K$ not to be a superkey anymore.

# Third Normal Form (3NF)

Definition (Third Normal Form):
A relation scheme is in third normal form (3NF) if for all non-trivial FD's of the form

$$X \rightarrow A$$

- Either
  X is a superkey
- or
  A is a prime attribute.

The 3NF disallows transitive dependencies

# Third Normal Form (3NF)

Recall (Third Normal Form):
A relation scheme is in third normal form (3NF) if for all non-trivial FD's of the form X → A.
Either X is a superkey or A is a prime attribute.

Let us enumerate all options:

| X | A |
|---|---|
| Superkey | Prime |
| Superkey | Nonprime |
| Not Superkey | Prime |
| ~~Not Superkey~~ | ~~Nonprime~~ |

**The 3NF disallows FDs of the form "Not superkey -> Nonprime"**

Note: not Superkey = either (1) *prime attributes that are proper subset of a key* or (2) *nonprime*

# Third Normal Form (3NF)

Lets compare the 2nf and the 3nf

<table>
<tr><th colspan="2">X</th><th>A</th></tr>
<tr><td colspan="2">Superkey</td><td>Prime</td></tr>
<tr><td colspan="2">Superkey</td><td>Nonprime</td></tr>
<tr><td colspan="2">Not Superkey</td><td>Prime</td></tr>
<tr><td rowspan="2">Not Super Key</td><td>Prime attributes (proper subsets)</td><td rowspan="2">Nonprime</td></tr>
<tr><td>Non prime</td></tr>
</table>

2NF allows FDs of the type nonprime -> nonprime

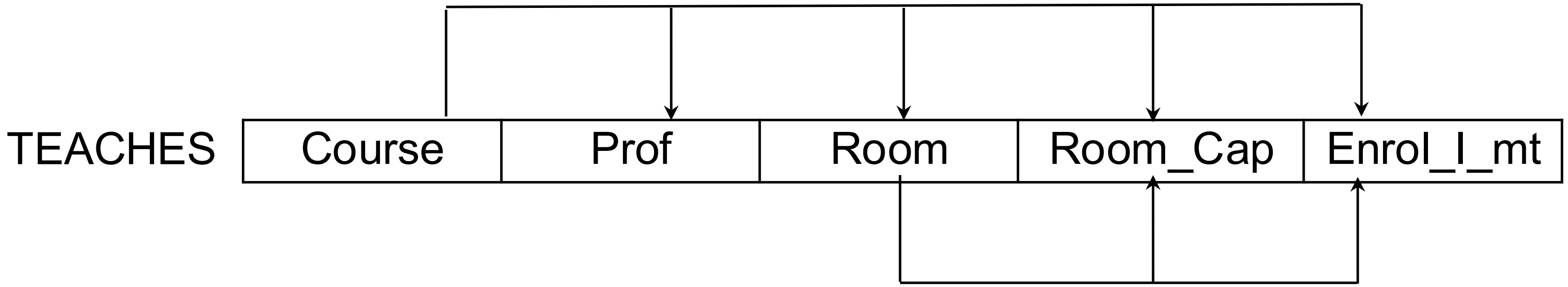
3NF disallows nonprime -> nonprime in addition

# Third Normal Form (3NF)

Definition (Transitive dependency):

A FD X→Y is a transitive dependency if there is a Z that is not a subset of any key, such that X → Z and Z → Y. The attributes of Y are transitively dependent on X.

Test for 3NF (for simple one key): There should be no transitive dependency of a nonkey attribute on the primary key.



# Third Normal Form (3NF)

You can decompose TEACHES from 2NF into 3NF:

| TEACHES | | | | |
|---|---|---|---|---|
| Course | Prof | Room | Room_Cap | Enrol_l_mt |
| 353 | Smith | *A532* | *45* | *40* |
| 351 | Smith | C320 | 100 | 60 |
| *355* | *Clark* | *H940* | *400* | *300* |
| 456 | Turner | B278 | 50 | 45 |
| 459 | Jamieson | D110 | 50 | 45 |
| *500* | *Bob* | *A532* | *45* | *40* |

2NF
(but not 3NF)

| COURSE_DETAILS | | |
|---|---|---|
| Course | Prof | Room |
| 353 | Smith | A532 |
| 351 | Smith | C320 |
| 456 | Turner | B278 |
| 459 | Jamieson | D110 |
| 355 | Clark | H940 |

| ROOM_DETAILS | | |
|---|---|---|
| Room | Room_Cap | Enrol_l_mt |
| A532 | 45 | 40 |
| C320 | 100 | 60 |
| B278 | 50 | 45 |
| D110 | 50 | 45 |
| H940 | 400 | 300 |

3NF

# Summary

We have covered 1NF, 2NF, 3NF (Codd 1972)

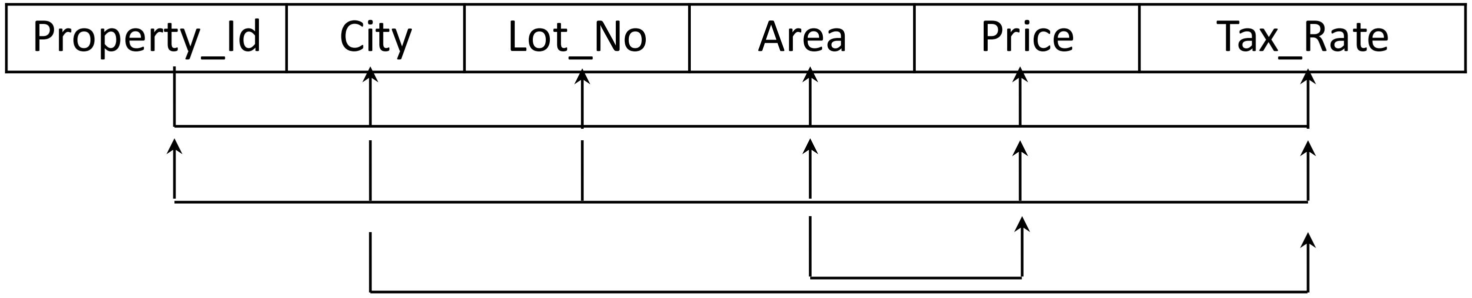
Details:

- Each normal form satisfies the requirements of the lower normal forms
- The normal form of a relation is the highest normal form it satisfies.
- A relation is “normalized“ if it meets the 3NF

# Review

What normal form is this?

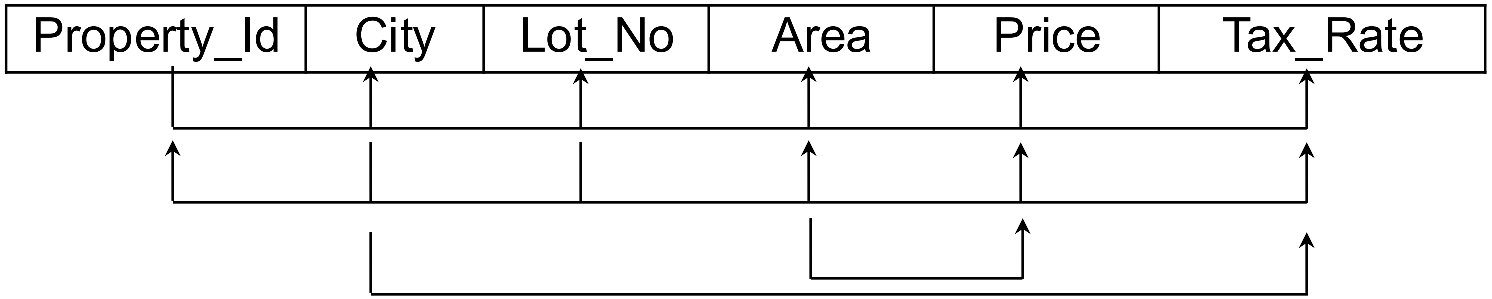
(Assume given that this is 1NF)




Is it in 2NF?

# Review

## LOTS

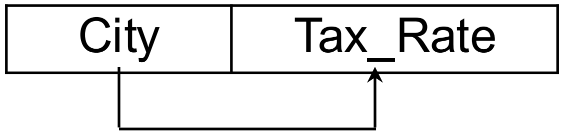



LOTS is **not in 2NF**:
*Since City→Tax_Rate, Tax_Rate* is not prime, and *{City,Lot_No}* is a key, making Tax_Rate partially dependent on a key.

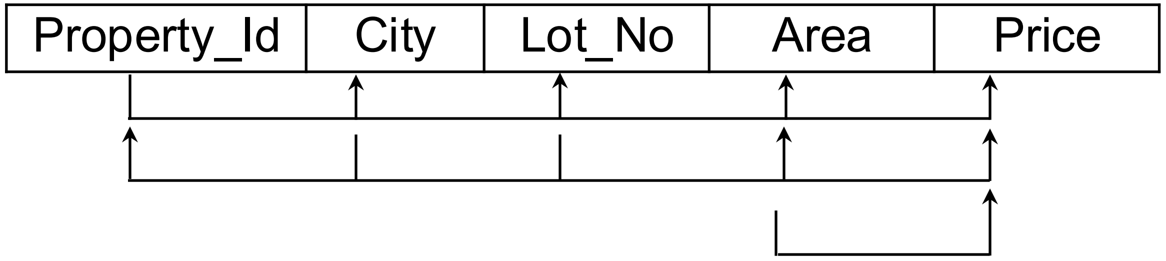
# Review

Now we have 2NF

LOTS1




LOTS2

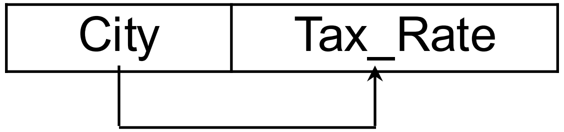



Is this in 3NF?

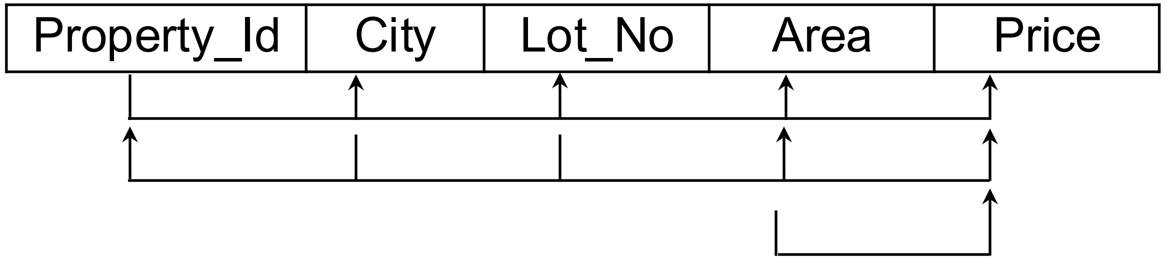
# Review

Now we have 2NF

LOTS1




LOTS2




Is this in 3NF?

Since Area → Price, {Area} is not a superkey and Price is not prime.

# Third Normal Form (3NF) (cont)

LOTS1A

| Property_Id | City | Lot_No | Area |
|---|---|---|---|

LOTS1B

| Area | Price |
|---|---|

LOTS2

| City | Tax_Rate |
|---|---|

# Third Normal Form (3NF) (cont)

## LOTS1A

possible

| Property_Id | City | Lot_No | Area |
|---|---|---|---|

## LOTS1B

| Area | Price |
|---|---|

## LOTS2

| City | Tax_Rate |
|---|---|

It is possible that the dependency *Area* → *City* exists

The relations schemes are still in 3NF since City is a prime attribute. However, there can be anomalies, just as before.

To illustrate the anomalies, we will use a simpler example in next slide.

# 3NF Example

Consider the booking relation *R*

- *R* = (*title, theater, city*)
  *F* = {*theater* → *city, title city* → *theater*}
- Two candidate keys: {*title, city*} and {*theater, title*}
- R is in 3NF
  - *title city* → *theater*
    {*title, city*} is a superkey
  - *theater* → *city*
    *city* is contained in a candidate key

# Redundancy in 3NF

There is some **redundancy** in this schema

Example of problems due to redundancy in 3NF

- R = (title, theater, city)
  F = {theater → city, title city → theater }

| *title* | *theater* | *city* |
|---|---|---|
| $j_1$ | $l_1$ | $k_1$ |
| $j_2$ | $l_1$ | $k_1$ |
| $j_3$ | $l_1$ | $k_1$ |

repetition of information (e.g., the relationship $l_1$, $k_1$)

# Boyce-Codd Normal Form (BCNF)

Definition (Boyce-Codd Normal Form): A relation scheme is in Boyce-Codd Normal Form (BCNF) if whenever $X \rightarrow A$ holds and $X \rightarrow A$ is non-trivial, $X$ is a superkey.

BCNF is also known as 3.5NF

# Boyce-Codd Normal Form (BCNF)

Definition (Boyce-Codd Normal Form): A relation scheme is in Boyce-Codd Normal Form (BCNF) if whenever X→A holds and X→A is non-trivial, X is a superkey.

Let us enumerate all options:

| X | A |
|---|---|
| Superkey | Prime |
| Superkey | Nonprime |
| ~~Not Superkey~~ | ~~Prime~~ |
| ~~Not Superkey~~ | ~~Nonprime~~ |

Note: not Superkey = either (1) *prime attributes that are proper subset of a key* or (2) *nonprime*

# Comparisons

BCNF implies 3NF

| Property | 3NF | BCNF |
|---|---|---|
| Elimination of redundancy due to functional dependency | Most | Yes |
| Lossless Join | Yes | Yes |
| Dependency preservation due to functional dependency | Yes | Maybe |

It is not always possible to get a BCNF decomposition that is dependency preserving ( dependency preservation discussed in future lectures )

# Boyce-Codd Normal Form (BCNF)(cont)

We can make our example into BCNF:

LOTS1AA

| Property_Id | Lot_No | Area |
|---|---|---|

LOTS1AB

| Area | City |
|---|---|

LOTS1B

| Area | Price |
|---|---|

LOTS2

| City | Tax_Rate |
|---|---|

(One possible decomposition to satisfy BCNF)

# Boyce-Codd Normal Form (BCNF)(cont)

We can make our example into BCNF:

LOTS1AA

| Property_Id | Lot_No | Area |
|---|---|---|

LOTS1C

| Area | City | Price |
|---|---|---|

LOTS2

| City | Tax_Rate |
|---|---|

(LOTS1AB and LOTS1B (from prev slide) into LOTS1C)

# Discussion

We discussed that the normal form of a relation is the highest NF it satisfies. E.g., R is 2NF means that R is not 3NF or BCNF.

In terms of the database scheme as a whole…

- A database scheme is in 1NF if all its relations are in 1NF.
- A database scheme is in 2NF if all its relations are in 2NF.
- A database scheme is in 3NF if all its relations are in 3NF.
- A database scheme is in BCNF if all its relations are in BCNF.

# Learning Outcomes

1. Definitions of 1NF, 2NF, 3NF and BCNF
2. (3NF and BCNF is the key NFs to understand)
3. How the presence of some types of functional dependencies can contribute to update anomalies
4. Determine the highest NF of a relation