Introduction to normalization

TEAM INFDEV

Hogeschool Rotterdam
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Introduction
Reasons behind normalization

- It is a process to improve the design of the database.
- Objective 1: minimize the storage space used by the relations.
- Objective 2: eliminate anomalies in the database.
- Objective 3: eliminate spurious tuples.

Introduction

Create tables with a lot of information is prone to waste of storage space.

EMPLOYEE

ENAME	SSN	BDATE	ADDRESS	DNUMBER
Smith,John B.	123456789	1965-01-09	731 Fondren,Houston,TX	5
Wong,Franklin T.	333445555	1955-12-08	638 Voss,Houston,TX	5
Zelaya,Alicia J.	999887777	1968-07-19	3321 Castle,Spring,TX	4
Wallace,Jennifer S.	987654321	1941-06-20	291 Berry,Bellaire,TX	4
Narayan,Ramesh K.	666884444	1962-09-15	975 Fire Oak,Humble,TX	5
English,Joyce A.	453453453	1972-07-31	5631 Rice,Houston,TX	5
Jabbar,Ahmad V.	987987987	1969-03-29	980 Dallas,Houston,TX	4
Borg,James E.	888665555	1937-11-10	450 Stone,Houston,TX	1

DEPARTMENT

DNAME	DNUMBER	DMGRSSN
Research	5	333445555
Administration	4	987654321
Headquarters	1	888665555

VS

ENAME	SSN	BDATE	ADDRESS	DNUMBER	DNAME	DMGRSSN
Smith,John B.	123456789	1965-01-09	731 Fondren,Houston,TX	5	Research	333445555
Wong,Franklin T.	333445555	1955-12-08	638 Voss,Houston,TX	5	Research	333445555
Zelaya, Alicia J.	999887777	1968-07-19	3321 Castle,Spring,TX	4	Administration	987654321
Wallace,Jennifer S.	987654321	1941-06-20	291 Berry,Bellaire,TX	4	Administration	987654321
Narayan,Ramesh K.	666884444	1962-09-15	975 FireOak,Humble,TX	5	Research	333445555
English,Joyce A.	453453453	1972-07-31	5631 Rice,Houston,TX	5	Research	333445555
Jabbar,Ahmad V.	987987987	1969-03-29	980 Dallas,Houston,TX	4	Administration	987654321
Borg,James E.	888665555	1937-11-10	450 Stone,Houston,TX	1	Headquarters	888665555

Introduction
Waste of storage space

- Using two separate tables and joining them uses less storage space then putting everything in the same table.
- The values of the attributes of the department are repeated for every employee who works in that department.
- It means that, if a department has 300 employees, we waste 300 times the memory space than the approach with two tables.

Introduction
Update Anomalies

redundancy

EMP_DEPT

ENAME	SSN	BDATE	ADDRESS	DNUMBER	DNAME	DMGRSSN
Smith,John B.	123456789	1965-01-09	731 Fondren,Houston,TX	5	Research	333445555
Wong,Franklin T.	333445555	1955-12-08	638 Voss,Houston,TX	5	Research	333445555
Zelaya, Alicia J.	999887777	1968-07-19	3321 Castle,Spring,TX	4	Administration	987654321
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Narayan,Ramesh K.	666884444	1962-09-15	975 FireOak,Humble,TX	5	Research	333445555
English,Joyce A.	453453453	1972-07-31	5631 Rice,Houston,TX	5	Research	333445555
Jabbar,Ahmad V.	987987987	1969-03-29	980 Dallas,Houston,TX	4	Administration	987654321
Borg,James E.	888665555	1937-11-10	450 Stone,Houston,TX	1	Headquarters	888665555

- The values contained in `DNAME` are always coupled with the same values in `DMGRSSN`. For example ‘Research’ is always coupled with 333445555. This is called redundancy.
- Inserting a new employee requires to repeat this coupling manually (manual consistency).
- If you add a new department, then we have to enter a null value for each attribute of the employee.

Introduction
Update Anomalies (deletion)

- Deleting the tuple of the last employee of the department also removes all the information about that department.
- We must manually apply null values to the attributes of the employee in order to remove the last employee from the department.
- Example: Deleting Borg, James E. also removes all the information about the 'Headquarters' department.

Introduction
Update Anomalies (modification)

- Modifying the information of a department in one tuple is not reflected in the other tuples.
- If we want to update the information about a department we must repeat the update for all the tuples containing the employees of that department
- **Example:** If we change the name of the department 'Research' into 'Research and development' we have to repeat this change for 4 tuples.

Introduction
Spurious tuples

EMP_LOCS

ENAME	PLOCATION
Smith, John B.	Bellaire
Smith, John B.	Sugarland
Narayan, Ramesh K.	Houston
English, Joyce A.	Bellaire
English, Joyce A.	Sugarland
Wong, Franklin T.	Sugarland
Wong, Franklin T.	Houston
Wong, Franklin T.	Stafford
Zelaya, Alicia J.	Stafford
Jabbar, Ahmad V.	Stafford
Wallace, Jennifer S.	Stafford
Wallace, Jennifer S.	Houston
Borg,James E.	Houston

EMP_PROJ1

SSN	PNUMBER	HOURS	PNAME	PLOCATION
123456789	1	32.5	Product X	Bellaire
123456789	2	7.5	Product Y	Sugarland
666884444	3	40.0	Product Z	Houston
453453453	1	20.0	Product X	Bellaire
453453453	2	20.0	Product Y	Sugarland
333445555	2	10.0	Product Y	Sugarland
333445555	3	10.0	Product Z	Houston
333445555	10	10.0	Computerization	Stafford
333445555	20	10.0	Reorganization	Houston
999887777	30	30.0	Newbenefits	Stafford
999887777	10	10.0	Computerization	Stafford
987987987	10	35.0	Computerization	Stafford
987987987	30	5.0	Newbenefits	Stafford
987654321	30	20.0	Newbenefits	Stafford
987654321	20	15.0	Reorganization	Houston
888665555	20	null	Reorganization	Houston

EMP_PROJ

redundancy redundancy

SSN	PNUMBER	HOURS	ENAME	PNAME	PLOCATION
123456789	1	32.5	Smith,John B.	ProductX	Bellaire
123456789	2	7.5	Smith,John B.	ProductY	Sugarland
666884444	3	40.0	Narayan,Ramesh K.	ProductZ	Houston
453453453	1	20.0	English,Joyce A.	ProductX	Bellaire
453453453	2	20.0	English,Joyce A.	ProductY	Sugarland
333445555	2	10.0	Wong,Franklin T.	ProductY	Sugarland
333445555	3	10.0	Wong,Franklin T.	ProductZ	Houston
333445555	10	10.0	Wong,Franklin T.	Computerization	Stafford
333445555	20	10.0	Wong,Franklin T.	Reorganization	Houston
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999887777	10	10.0	Zelaya,Alicia J.	Computerization	Stafford
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987987987	30	5.0	Jabbar,Ahmad V.	Newbenefits	Stafford
987654321	30	20.0	Wallace,Jennifer S.	Newbenefits	Stafford
987654321	20	15.0	Wallace,Jennifer S.	Reorganization	Houston
888665555	20	null	Borg,James E.	Reorganization	Houston

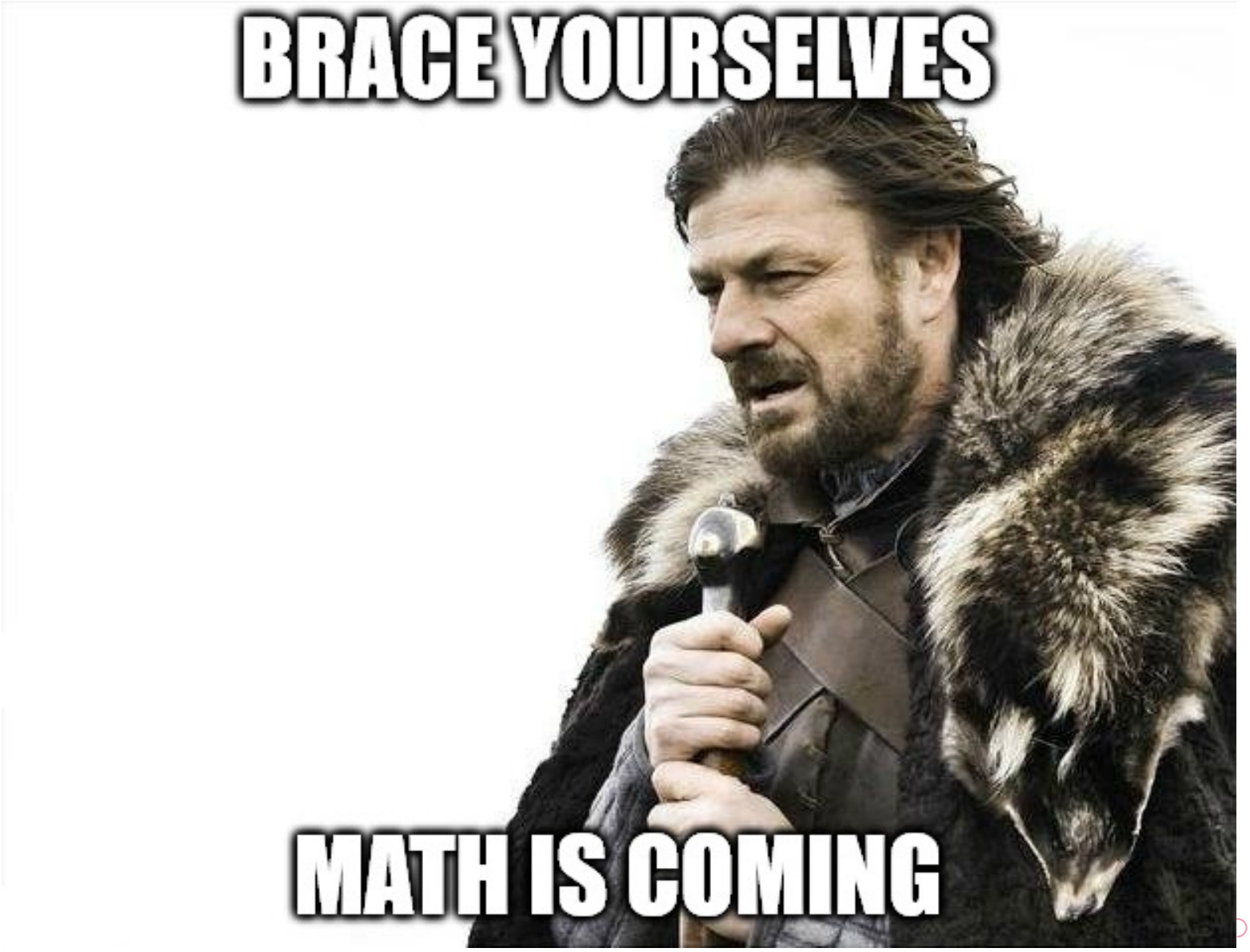
Introduction
Spurious tuples

- Normalization uses decomposition to eliminate anomalies and remove redundancy.
- The two tables above in the previous slide are a decomposition of the bottom one.
- If we join the two tables, we get more tuples than those that were in the original table
- Those below the dotted line are extra tuples called spurious tuples.
- Normalization must ensure that the decomposition does not create spurious tuples after a join.

Normal forms

- Normalization is the process of converting the relations (tables) of a database into other relations in some normal form.
- Normal forms are properties that a relation must satisfy.
- There are two different kinds of definitions of normal forms:
- Historical definitions: The original definitions defined by Codd, taking into account only the primary key.
- Refined definitions: A refinement of the normal forms that takes into account also the candidate keys.

Normal forms
Functional dependencies



- Both kinds of definitions of normal forms rely on the concept of functional dependency.
- In what follows we write t_i[X] to indicate the values of the row i of a table for a set of attributes X
- **Example**: t_3[SSN,HOURS,NAME] in the table below is the combination of values: t_3[SSN,HOURS,NAME] $= \{$ 666884444,40.0,Narayan, Ramesh K. $\}$

redundancy redundancy

EMP_PROJ

SSN	PNUMBER	HOURS	ENAME	PNAME	PLOCATION
123456789	1	32.5	Smith,John B.	ProductX	Bellaire
123456789	2	7.5	Smith,John B.	ProductY	Sugarland
666884444	3	40.0	Narayan,Ramesh K.	ProductZ	Houston
453453453	1	20.0	English,Joyce A.	ProductX	Bellaire
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999887777	10	10.0	Zelaya,Alicia J.	Computerization	Stafford
987987987	10	35.0	Jabbar,Ahmad V.	Computerization	Stafford
987987987	30	5.0	Jabbar,Ahmad V.	Newbenefits	Stafford
987654321	30	20.0	Wallace,Jennifer S.	Newbenefits	Stafford
987654321	20	15.0	Wallace,Jennifer S.	Reorganization	Houston
888665555	20	null	Borg,James E.	Reorganization	Houston

Definition:

Given a subset of attributes X and Y in a relation, we say that Y depends on X, and we write X $\rightarrow$ Y, if for any pair of rows where we have t_i[X] $= t_j$[X] we also have t_i[Y] $= t_j$[Y].

Example: In the table below we have, if we assume that there is a dependency PNAME $\rightarrow$ PLOCATION, then when t_i[PNAME] $= t_j$[PNAME] we also have t_i[PLOCATION] $= t_j$[PLOCATION]. For instance every time we have the value 'ProductY' in the column PNAME, we also have 'Sugarland' in the column PLOCATION. It is not possible that a row has 'ProductY' in the column PNAME and 'Belaire' in the column PLOCATION.

EMP_PROJ

SSN	PNUMBER	HOURS	ENAME	PNAME	PLOCATION
123456789	1	32.5	Smith,John B.	ProductX	Bellaire
123456789	2	7.5	Smith,John B.	ProductY	Sugarland
666884444	3	40.0	Narayan,Ramesh K.	ProductZ	Houston
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987987987	30	5.0	Jabbar,Ahmad V.	Newbenefits	Stafford
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987654321	20	15.0	Wallace,Jennifer S.	Reorganization	Houston
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Functional dependencies
Important observations

- Functional dependencies are defined by the database designer.
- It is not possible to infer functional dependencies by reading the data from the table.
- Functional dependencies should be read in the documentation of the database or asked to the designer.
- If you need to normalize a database and there is no documentation or the designer is unavailable, **as last resort**, you can try to infer functional dependencies from the data.

Functional dependencies

Bad practice - An example

ssn	name	salary
299260	John Smith	25000
993693	Walter White	3000
388528	John Smith	2500
396926	James Garnett	1800

By looking at the data in the table I could infer that name $\rightarrow$ salary because two employees with the name John Smith earn 2500 euros per month. If later I add the tuple (395935,John Smith,2000) (another employee with the same name but different salary) the dependency is gone! This because clearly the salary of an employee should not depend on a person's name, but this is what we could infer just by looking at the data.

Normal forms
1st Normal form

- The first normal form is automatically granted by the relational model.
- If you designed the conceptual model properly and translated correctly the ERD into the relational model, then all your relations should be in 1NF.

Definition:
A table is in 1st normal form (1NF) if no row has multiple values for an attribute.

Example:
The table to the right violates the 1NF since some rows have multiple values for PNUMBER and HOURS.

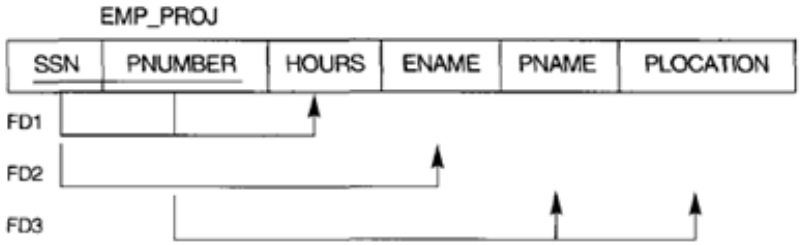
EMP_PROJ

SSN	ENAME	PNUMBER	HOURS
123456789	Smith,John B.	1	32.5
		2	7.5
666884444	Narayan,Ramesh K.	3	40.0
453453453	English,Joyce A.	1	20.0
		2	20.0
333445555	Wong,Franklin T.	2	10.0
		3	10.0
		10	10.0
		20	10.0
999887777	Zelaya,Alicia J.	30	30.0
		10	10.0
987987987	Jabbar,Ahmad V.	10	35.0
		30	5.0
987654321	Wallace,Jennifer S.	30	20.0
		20	15.0
888665555	Borg,James E.	20	null

Normal forms
2nd Normal form

Definition: A table is in 2nd normal form (2NF) if it is in 1NF and every attribute that is not part of a key depends on the whole primary key.

Example:
The table to the right is not in 2NF because PNAME depends only on PNUMBER and not on the whole key.
The same for PLOCATION



Useful trick: If you have a table where the primary key is made of only one attribute, the table is always in 2NF. You can say this without any additional check

Why?

Normal forms

2nd Normal Form

Useful trick: If you have a table where the primary key is made of only one attribute, the table is always in 2NF. You can say this without any additional check

Why? Because to break the 2NF there must exist a functional dependency where the left side is a part of the primary key, but this is impossible if you have only one attribute.

Normal forms

2nd Normal Form - Reson

redundancy redundancy

EMP_PROJ

SSN	PNUMBER	HOURS	ENAME	PNAME	PLOCATION
123456789	1	32.5	Smith,John B.	ProductX	Bellaire
123456789	2	7.5	Smith,John B.	ProductY	Sugarland
666884444	3	40.0	Narayan,Ramesh K.	ProductZ	Houston
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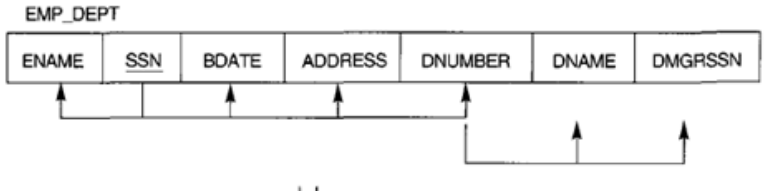
If I want to assign an employee to an existing project, I have to manually repeat the data in PNAME and PLOCATION for the new tuple even if they already exist in other tuples.

For example if I add the employee 394394343 to project 1, I have to repeat the values ProductX and Bellaire in the new tuple manually.

Normal forms
Transitive dependency

The 3rd normal form requires to define a *transitive dependency*

Definition: A functional dependency X $\rightarrow$ Y is transitive if there is a set of attributes Z, which is neither a candidate key nor a subset of any key, and both X $\rightarrow$ Z and Z $\rightarrow$ Y are valid functional dependency



Example: In the table above the functional dependency SSN $\rightarrow$ { DNAME,DMGRSSN } is transitive because also SSN $\rightarrow$ DNUMBER and DNUMBER $\rightarrow$ { DNAME,DMGRSSN } are valid functional dependencies.

Normal forms

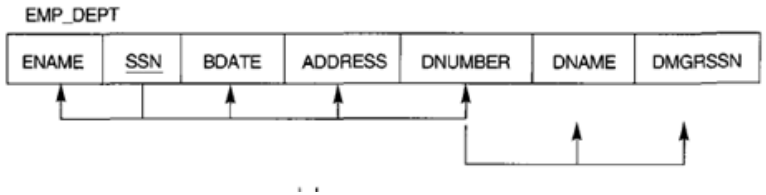
Decomposition rule

Another useful trick: We do not give the proof of this, but remember that you can always decompose a functional dependency, with a right side containing more than one attribute, into two smaller functional dependencies. This procedure is recursive, so you can apply it again to the two functional dependencies created at the previous step.

Example: DNUMBER $\rightarrow$ { DNAME,DMGRSSN } can be decomposed into the two functional dependencies DNUMBER $\rightarrow$ DNAME and DNUMBER $\rightarrow$ DMGRSSN

Definition (3NF): A table is in 3rd normal form (3NF) if it is in 2NF and no attribute that is not part of a key is transitively dependent on the primary key.

Example: The table below is in 2NF but not in 3NF because of the transitive dependency SSN $\rightarrow$ { DNAME,DMGRSSN }



Normal forms

3rd normal form - Reason

redundancy

EMP_DEPT

ENAME	SSN	BDATE	ADDRESS	DNUMBER	DNAME	DMGRSSN
Smith,John B.	123456789	1965-01-09	731 Fondren,Houston,TX	5	Research	333445555
Wong,Franklin T.	333445555	1955-12-08	638 Voss,Houston,TX	5	Research	333445555
Zelaya, Alicia J.	999887777	1968-07-19	3321 Castle,Spring,TX	4	Administration	987654321
Wallace,Jennifer S.	987654321	1941-06-20	291 Berry,Bellaire,TX	4	Administration	987654321
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Borg,James E.	888665555	1937-11-10	450 Stone,Houston,TX	1	Headquarters	888665555

If I add a new employee to a department I have to repeat DNAME and DMGRSSN for that department because of the transitive dependency.

If I add employee 394394343 to department number 5 I have to repeat the value Research and 333445555 for that department manually.

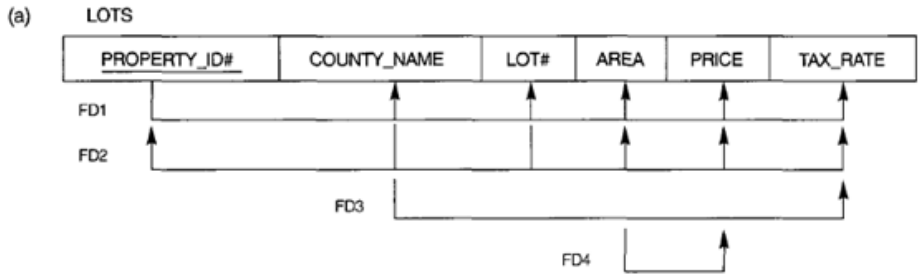
Normalization on candidate keys

- All the normal forms defined so far are defined for the primary key only.
- Anomalies might aries also with depndencies on the candidate key.
- We give more general definitions of normal forms that take into account also the candidate keys.
- The definition of 1NF is not affected since it only requires that each tuple has a single value for all the attributes (not based on a property on the primary key).

Normalization on candidate keys

General 2nd normal form

Definition: A table is in 2NF if every attribute that is not part of a key is not partially dependent on any key of the table (primary or candidate)



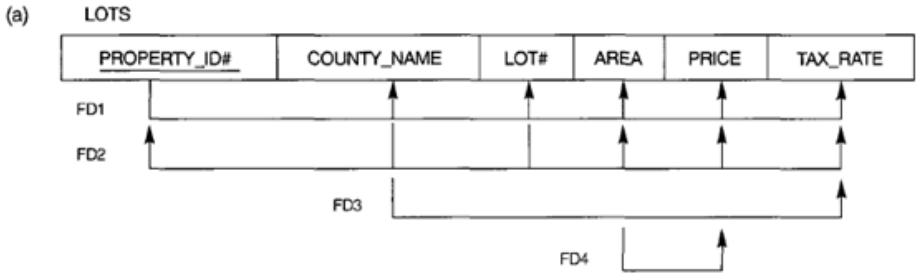
Example: The table is not in 2NF because a candidate key is

{ COUNTY_LOT,LOT# }

and the attribute AREA depends on LOT#.

Normalization on candidate keys

General 2nd normal form - Reason



If I want to add a new property in an existing lot, I have to manually repeat the data about AREA, PRICE, and TAX_RATE.

Normalization on candidate keys

General 3rd normal form

Trivial functional dependency: A functional dependency

$X \rightarrow Y$

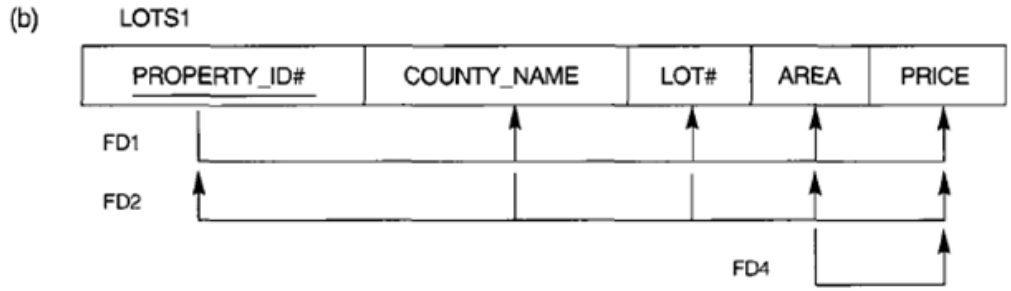
is trivial if Y is part of X.

Definition: A table is in 3rd normal form if it is in 2NF and for any non-trivial functional dependency $X \rightarrow A$ one of the two conditions is satisfied:

1. X is a superkey.
2. A is part of a key.

Normalization on candidate keys

General 3rd normal form - Reason



If I want to add a new property in a lot with the same area of another one, I have to manually repeat the data about the PRICE for that AREA.

It can be seen as a generalization of the previous 3NF where there must not be a transitive dependency also on a candidate key of the table

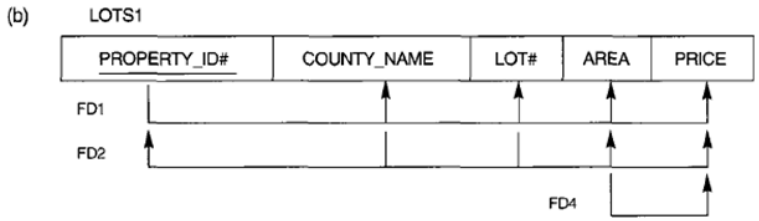
Normalization on candidate keys

Boyce-Codd normal form

Definition: A table is in Boyce-Codd normal form (BCNF) if for all non-trivial dependencies $X \rightarrow A$ then X is a superkey of the table.

NOTE: If a table is in BCNF then it is also in 3NF. Indeed to esnure the 3NF it is enough that only one between the BCNF condition and the other one (see the previous slide) is met.

Example:
The table to the right is in 3NF but not in BCNF because AREA depends on COUNTY_NAME, which is not a superkey.



Summary

- Unnormalized tables might contain data redundancy and cause anomalies.
- Normal form are a way to solve these problems.
- There are normal form definitions for tables with just one key (the primary key and no candidate keys).
- There are normal form definitions for tables with candidate keys.