

(De/)Normalization



On tap

Learning Objectives

- In this chapter, students will learn:
 - What normalization is and what role it plays in the database design process
 - About the normal forms 1NF, 2NF, 3NF, BCNF, and 4NF
 - How normal forms can be transformed from lower normal forms to higher normal forms
 - That normalization and ER modeling are used concurrently to produce a good database design
 - That some situations require denormalization to generate information efficiently

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The goal of normalization

Loosely speaking:



[<http://rovingcrafters.com/>]

Goal: reduce redundancies, anomalies

Normalization

- Evaluating and correcting table structures to minimize data redundancies
- Reduces data anomalies
- Assigns attributes to tables based on determination
- Normal forms
 - First normal form (1NF)
 - Second normal form (2NF)
 - Third normal form (3NF)

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Higher normal forms → cleaner designs

Normalization

- Structural point of view of normal forms
 - Higher normal forms are better than lower normal forms
- Properly designed 3NF structures meet the requirement of fourth normal form (4NF)
- **Denormalization:** Produces a lower normal form
 - Results in increased performance and greater data redundancy

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Normalization is a design step

Need for Normalization

- Used while designing a new database structure
 - Analyzes the relationship among the attributes within each entity
 - Determines if the structure can be improved
- Improves the existing data structure and creates an appropriate database design

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A construction company db

Employees of the construction company work on projects. Each employee has an ID, name, job title and corresponding hourly rate.

Each project has a number, name and assigned employees. An employee can be assigned to more than one project.

The company bills clients for projects, based on hours worked by employees.

PROJ_NUM	PROJ_NAME	EMP_NUM	EMP_NAME	JOB_CLASS	CHG_HOUR	HOURS
15	Evergreen	103	June E. Alborough	Elect. Engineer	84.50	23.8
		101	John G. News	Database Designer	105.00	19.4
		105	Alice K. Johnson *	Database Designer	105.00	35.7
		106	William Smithfield	Programmer	35.75	12.6
		102	David H. Senior	Systems Analyst	96.75	23.8
18	Amber Wave	114	Annelise Jones	Applications Designer	48.10	24.6
		118	James J. Frommer	General Support	18.36	45.3
		104	Anne K. Ramoras *	Systems Analyst	96.75	32.4
		112	Darlene M. Smithson	DSS Analyst	45.95	44.0
		105	Alice K. Johnson	Database Designer	105.00	64.7
22	Rolling Tide	104	Anne K. Ramoras	Systems Analyst	96.75	48.4
		113	Delbert K. Joenbrood *	Applications Designer	48.10	23.6
		111	Geoff B. Wabash	Clerical Support	26.87	22.0
		106	William Smithfield	Programmer	35.75	12.8
		107	Maria D. Alonso	Programmer	35.75	24.6
26	Starlight	115	Travis B. Bawangi	Systems Analyst	96.75	46.9
		101	John G. News *	Database Designer	105.00	56.3
		114	Annelise Jones	Applications Designer	48.10	33.1
		108	Ralph E. Washington	Systems Analyst	96.75	23.6
		118	James J. Frommer	General Support	18.36	30.5
		112	Darlene M. Smithson	DSS Analyst	45.95	41.4

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Report

The construction company periodically generates a report like so:

PROJECT NUMBER	PROJECT NAME	EMPLOYEE NUMBER	EMPLOYEE NAME	JOB CLASS	CHARGE/HOUR	HOURS BILLED	TOTAL CHARGE
15	Evergreen	103 101 105 106 102	John E. Atchough John C. News Alice K. Johnson * William Smithfield David H. Senior	Elec. Engineer Database Designer Database Designer Programmer Systems Analyst	\$ 105.00 \$105.00 \$105.00 \$ 35.75 \$ 96.75	23.8 19.4 35.7 12.6 23.8	\$ 2,207.10 \$ 2,037.00 \$ 3,748.50 \$ 450.45 \$ 2,302.65
				Subtotal			\$10,549.70
18	Amber Wave	114 118 104 112	Annelise Jones James J. Frommer Anne K. Ramerias * Darlene M. Smithson	Applications Designer General Support Systems Analyst DSS Analyst	\$ 48.10 \$ 18.36 \$ 96.75 \$ 45.95	24.6 45.3 32.4 44.0	\$ 183.26 \$ 831.71 \$ 3,134.70 \$ 2,021.80
				Subtotal			\$ 7,171.47
22	Rolling Tide	105 104 113 111 106	Alice K. Johnson Anne K. Ramerias Delbert K. Joenbrood * Geof B. Wabash William Smithfield	Database Designer Systems Analyst Applications Designer Clerical Support Programmer	\$105.00 \$ 96.75 \$ 48.10 \$ 26.67 \$ 35.75	64.7 48.4 23.6 22.0 12.8	\$ 6,793.50 \$ 4,682.70 \$ 1,153.16 \$ 591.14 \$ 457.60
				Subtotal			\$13,660.10
25	Starlight	107 115 101 114 108 118 112	Maria D. Alonso Troy B. Bowangi John G. News * Annelise Jones Ralph B. Washington James J. Frommer Darlene M. Smithson	Programmer Systems Analyst Database Designer Applications Designer Systems Analyst General Support DSS Analyst	\$ 35.75 \$ 96.75 \$105.00 \$ 48.10 \$ 96.75 \$ 18.36 \$ 45.95	24.6 45.8 56.3 33.1 23.6 30.5 41.4	\$ 979.45 \$ 4,431.15 \$ 5,911.50 \$ 1,592.11 \$ 2,283.30 \$ 559.98 \$ 1,902.33
				Subtotal			\$17,559.82
				Total			\$48,941.09

Note: A * indicates the project leader.

Issues with our db

Here is our table again:

PROJ_NUM	PROJ_NAME	EMP_NUM	EMP_NAME	JOB_CLASS	CHG_HOUR	HOURS
15	Evergreen	103	June E. Arbough	Elect. Engineer	84.50	23.8
		101	John G. News	Database Designer	105.00	19.4
		105	Alice K. Johnson *	Database Designer	105.00	35.7
		106	William Smithfield	Programmer	35.75	12.6
		102	David H. Senior	Systems Analyst	96.75	23.8
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		118	James J. Frommer	General Support	18.36	45.3
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		105	Alice K. Johnson	Database Designer	105.00	64.7
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		114	Annelise Jones	Applications Designer	48.10	33.1
		108	Ralph E. Washington	Systems Analyst	96.75	23.6
		118	James J. Frommer	General Support	18.36	30.5
		112	Darlene M. Smithson	DSS Analyst	45.95	41.4

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There are numerous issues:

- the PROJ_NUM attr could be used as a PK (or part of a PK, along with PROJ_NAME) but it contains nulls
- possibilities for data inconsistencies exist, eg. if someone's name or title is misspelled
- the redundancies that exist, could lead to insertion anomalies (eg. a new employee needs to be assigned to some project, even a fake one), update anomalies (eg. if an employee's JOB_CLASS changes, it has to be modified multiple times), deletion anomalies (eg. if a project has just one employee and that employee leaves, deleting the lone employee record would lead to the project itself getting deleted!)
- data redundancy leads to wasted storage space

We have 'repeating groups' (for each project, we list all details about each employee) - our table is un-normalized, ie. is in

'ONF':)

So, we need to clean up the design!

Objectives: what do we want?

Normalization Process

- Objective is to ensure that each table conforms to the concept of well-formed relations
 - Each table represents a single subject
 - No data item will be unnecessarily stored in more than one table **wholly; nothing but**
 - All nonprime attributes in a table are dependent **on** the primary key
 - Each table is void of insertion, update, and deletion anomalies

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Normal forms

Normalization is a systematic process that yields progressively higher 'normal forms' (NFs) for each entity (table) in our db. We want **at least** 3NF for each table; in RL, we stop **at** 3NF.

Table 6.2 - Normal Forms

NORMAL FORM	CHARACTERISTIC	SECTION
First normal form (1NF)	Table format, no repeating groups, and PK identified	6.3.1
Second normal form (2NF)	1NF and no partial dependencies	6.3.2
Third normal form (3NF)	2NF and no transitive dependencies	6.3.3
Boyce-Codd normal form (BCNF)	Every determinant is a candidate key (special case of 3NF)	6.6.1
Fourth normal form (4NF)	3NF and no independent multivalued dependencies	6.6.2

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The process

Normalization Process

- Ensures that all tables are in at least 3NF
- Higher forms are not likely to be encountered in business environment
- Works one relation at a time
- Starts by:
 - Identifying the dependencies of a relation (table)
 - Progressively breaking the relation into new set of relations

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Normalization how-to, in one sentence: **work on one relation (table) at a time: identify dependencies, then 'normalize' - progressively break it down into smaller relations (tables), based on the dependencies we identify in the original relation so that "only the PK, the whole PK and nothing but the PK" acts as a determinant!** But how?? Details follow..

Functional dependence, determination

Functional Dependence Concepts

Concept	Definition
Functional dependence	The attribute B is fully functionally dependent on the attribute A if each value of A determines one and only one value of B.
Functional dependence (Generalized definition)	Attribute A determines attribute B if all of the rows in the table that agree in value for attribute A also agree in value for attribute B.
Fully functional dependence (composite key)	If attribute B is functionally dependent on a composite key A but not on any subset of that composite key, the attribute B is fully functionally dependent on A.

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Partial dependency, transitive dependency

Types of Functional Dependencies

- **Partial dependency:** Functional dependence in which the determinant is only part of the primary key
 - Assumption - One candidate key
 - Straight forward
 - Easy to identify
- **Transitive dependency:** An attribute functionally depends on another nonkey attribute

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If (A,B) is a primary key, we have **partial** dependence if $(A,B) \rightarrow (C,D)$ and $B \rightarrow C$ [C is only partially dependent on the PK, ie. we only need B to determine C]. In other words, a part of an existing PK is acting like a PK on its own.

If X is a primary key, we have a **transitive** dependency if $X \rightarrow Y$ and $Y \rightarrow Z$ [Z is transitively dependent on X , not directly so]. In other words, a non-PK (regular attr) is acting like a PK.

0NF->1NF: eliminate repeating groups

Conversion to First Normal Form

- **Repeating group:** Group of multiple entries of same type can exist for any single key attribute occurrence
 - Existence proves the presence of data redundancies
- Enable reducing data redundancies
- Steps
 - Eliminate the repeating groups
 - Identify the primary key
 - Identify all dependencies

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In other words, "fill in the blanks" so that there are no nulls. Now we have a relation (table), with a value in each cell.

Further, identify the PK! In our example, it is (PROJ_NUM,EMP_NUM).

0NF->1NF [cont'd]

Conversion to First Normal Form

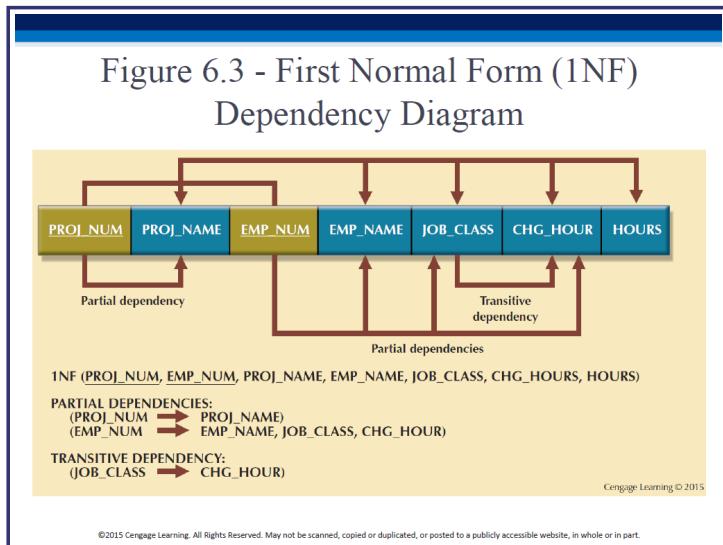
- **Dependency diagram:** Depicts all dependencies found within given table structure
 - Helps to get an overview of all relationships among table's attributes
 - Makes it less likely that an important dependency will be overlooked

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Create a **dependency diagram**, showing relationships (dependencies) between the attributes - this will help us systematically normalize the table.

Dependency diagram

Indicate full dependencies on the top, and partial and transitive dependencies on the bottom. "Top good, bottom bad". Also, color the PK components in a different color (and underline them). Result:



PROJ_NAME has only a partial dependency on the PK (since it is only dependent on PROJ_NUM, which is just a part of the PK).

CHG_HOUR is dependent on JOB_CLASS, which is a non-prime attribute that is itself dependent on EMP_NUM. So $\text{JOB_CLASS} \rightarrow \text{CHG_HOUR}$ is a signaling dependency, indicating a $\text{EMP_NUM} \rightarrow \text{CHG_HOUR}$ transitive dependency.

0NF->1NF [cont'd]

Conversion to First Normal Form

- 1NF describes tabular format in which:
 - All key attributes are defined
 - There are no repeating groups in the table
 - All attributes are dependent on the primary key
- All relational tables satisfy 1NF requirements
- Some tables contain partial dependencies
 - Subject to data redundancies and various anomalies

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1NF->2NF: remove partial dependencies

Conversion to Second Normal Form

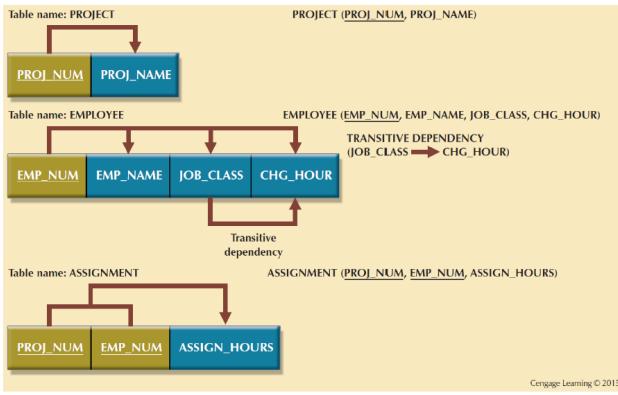
- Steps
 - Make new tables to eliminate partial dependencies
 - Reassign corresponding dependent attributes
- Table is in 2NF when it:
 - Is in 1NF
 - Includes no partial dependencies

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1NF->2NF [cont'd]

We eliminate partial dependencies by creating separate tables of such dependencies, and removing the dependent attributes from the starter table.

Figure 6.4 - Second Normal Form (2NF)
Conversion Results



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2NF->3NF: remove transitive dependencies

We promote the non-prime keys that masquerade as PKs, into actual PKs (give them their own tables).

Whether we eliminate partial dependencies (to create 2NF) or transitive ones (to create 3NF), we follow the same process: create a new relation for each 'problem' dependency!

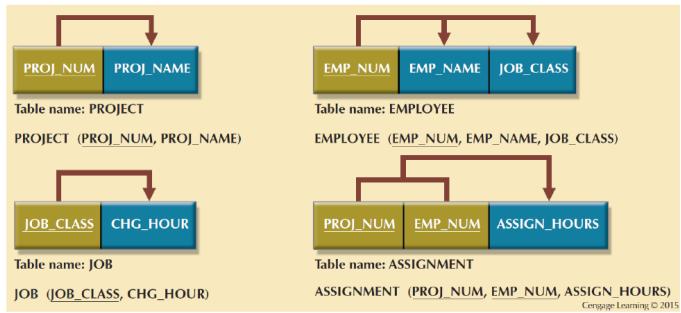
Conversion to Third Normal Form

- Steps
 - Make new tables to eliminate transitive dependencies
 - **Determinant:** Any attribute whose value determines other values within a row
 - Reassign corresponding dependent attributes
 - Table is in 3NF when it:
 - Is in 2NF
 - Contains no transitive dependencies

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2NF->3NF [cont'd]

Figure 6.5 - Third Normal Form (3NF)
Conversion Results



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'Good' tables

We can create a better DB by doing the following augmentations, to the 3NF model we just created:

- evaluate PKs - create a JOB_CODE
- evaluate naming conventions - eg. JOB_CHG_HOUR
- refine attr atomicity, eg. EMP_NAME
- identify new attrs, eg. EMP_HIREDATE
- identify new relationships, PROJECT can have EMP_NUM as FK [to be able to record a project's (always sole) manager]
- refine PKs for data granularity, eg. ASSIGN_NUM
- maintain historical accuracy [duplicate data], eg. store JOB_CHG_HOUR in ASSIGNMENT
- evaluate derived attrs, eg. ASSIGN_CHARGE

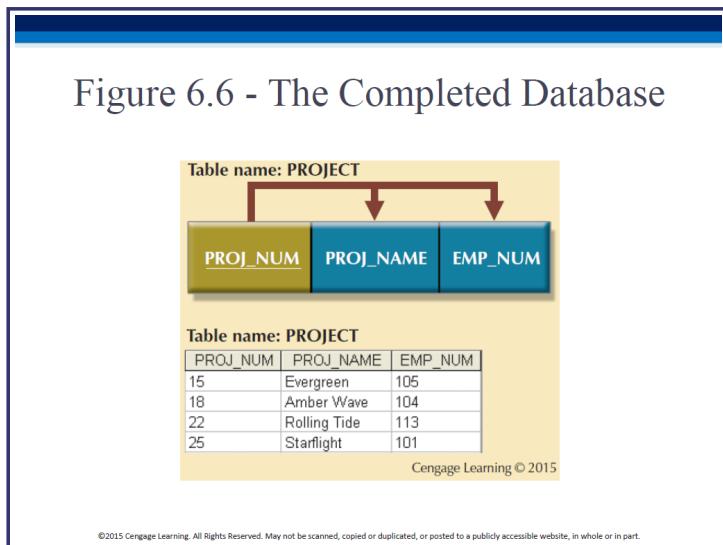
Requirements for Good Normalized Set of Tables

- Evaluate PK assignments and naming conventions
- Refine attribute atomicity
 - **Atomic attribute:** Cannot be further subdivided
 - **Atomicity:** Characteristic of an atomic attribute
- Identify new attributes and new relationships
- Refine primary keys as required for data granularity
 - **Granularity:** Level of detail represented by the values stored in a table's row
- Maintain historical accuracy and evaluate using derived attributes

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Final result

Here is the result of making the "extra" changes to our 3NF form:



Final result [cont'd]

Figure 6.6 - The Completed Database

Table name: JOB		
Database name: Ch06_ConstructCo		
JOB_CODE	JOB_DESCRIPTION	JOB_CHG_HOUR
500	Programmer	35.75
501	Systems Analyst	96.75
502	Database Designer	105.00
503	Electrical Engineer	84.50
504	Mechanical Engineer	67.90
505	CML Engineer	55.78
506	Clerical Support	26.87
507	DSS Analyst	45.95
508	Applications Designer	48.10
509	Bio Technician	34.55
510	General Support	18.36

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Final result [cont'd]

Figure 6.6 - The Completed Database

Table name: ASSIGNMENT

ASSIGN_NUM	ASSIGN_DATE	PROJ_NUM	EMP_NUM	ASSIGN_HOURS	ASSIGN_CHG_HOUR	ASSIGN_CHARGE
1001	04-Mar-14 15			2.5	95.50	238.75
1002	04-Mar-14 18	118	114	18.36	25.70	
1003	05-Mar-14 15	101		3.6	105.00	378.00
1004	05-Mar-14 22	113		2.5	48.10	120.25
1005	05-Mar-14 15	103		1.9	84.50	160.55
1006	05-Mar-14 25	115		4.2	105.00	405.00
1007	05-Mar-14 22	105		5.2	105.00	540.00
1008	05-Mar-14 25	101		1.7	105.00	178.50
1009	05-Mar-14 15	102		2.0	105.00	210.00
1010	06-Mar-14 15	102		3.8	86.75	327.50
1011	06-Mar-14 22	104		2.6	86.75	291.50
1012	06-Mar-14 15	101		2.3	105.00	241.50
1013	06-Mar-14 25	114		1.8	48.10	88.58
1014	06-Mar-14 22	111		4.0	26.87	107.49
1015	06-Mar-14 25	114		3.4	48.10	183.54
1016	06-Mar-14 18	112		1.2	45.95	55.14
1017	06-Mar-14 18	118		2.0	18.36	36.72
1018	06-Mar-14 18	104		2.6	86.75	251.55
1019	06-Mar-14 15	103		3.0	86.75	260.50
1020	07-Mar-14 22	105		2.7	105.00	283.50
1021	06-Mar-14 25	108		4.2	86.75	406.55
1022	07-Mar-14 25	114		5.8	48.10	278.98
1023	07-Mar-14 22	106		2.4	35.75	85.00

Table name: ASSIGNMENT

ASSIGN_NUM	ASSIGN_DATE	PROJ_NUM	EMP_NUM	ASSIGN_HOURS	ASSIGN_CHG_HOUR	ASSIGN_CHARGE
1001	04-Mar-14 15			2.5	95.50	238.75
1002	04-Mar-14 18	118	114	18.36	25.70	
1003	05-Mar-14 15	101		3.6	105.00	378.00
1004	05-Mar-14 22	113		2.5	48.10	120.25
1005	05-Mar-14 15	103		1.9	84.50	160.55
1006	05-Mar-14 25	115		4.2	105.00	405.00
1007	05-Mar-14 22	105		5.2	105.00	540.00
1008	05-Mar-14 25	101		1.7	105.00	178.50
1009	05-Mar-14 15	102		2.0	105.00	210.00
1010	06-Mar-14 15	102		3.8	86.75	327.50
1011	06-Mar-14 22	104		2.6	86.75	291.50
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1015	06-Mar-14 25	114		3.4	48.10	183.54
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1022	07-Mar-14 25	114		5.8	48.10	278.98
1023	07-Mar-14 22	106		2.4	35.75	85.00

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Final result [cont'd]

Figure 6.6 - The Completed Database

Table name: EMPLOYEE

Database name: Ch06_ConstructCo

EMP_NUM	EMP_LNAME	EMP_FNAME	EMP_INITIAL	EMP_HIREDATE	JOB_CODE
101	News	John	G	08-Nov-00	502
102	Senior	David	H	12-Jul-89	501
103	Arbough	June	E	01-Dec-97	503
104	Ramoras	Anne	K	15-Nov-94	504
105	Johnson	Alice	K	11-Feb-94	512
106	Smithfield	William	I	22-Jun-05	500
107	Alonzo	Maria	D	10-Oct-94	500
108	Washington	Ralph	B	22-Aug-89	501
109	Smith	Larry	W	16-Jul-99	501
110	Olenko	Gerald	A	11-Dec-96	506
111	Wabash	Geoff	B	04-Apr-89	506
112	Smithson	Darlene	M	23-Oct-95	507
113	Joenbrood	Delbert	K	15-Nov-94	508
114	Jones	Annelise		20-Aug-91	508
115	Bawangit	Travis	B	25-Jan-90	501
116	Priat	Gerald	L	05-Mar-95	510
117	Williamson	Angie	H	19-Jun-94	509
118	Frommer	James	J	04-Jan-06	510

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Normalization: summary

- * 1NF: eliminate repeating groups (partial:y, transitive:y)
 - * 2NF: eliminate redundant data (partial:n, transitive:y)
 - * 3NF: eliminate fields not dependent on key fields (partial:n, transitive:n)
-

Here is more, on normalization.

Denormalization

Denormalization

- Design goals
 - Creation of normalized relations
 - Processing requirements and speed
- Number of database tables expands when tables are decomposed to conform to normalization requirements
- Joining a larger number of tables:
 - Takes additional input/output (I/O) operations and processing logic
 - Reduces system speed

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Denormalization [cont'd]

Denormalization

- Defects in unnormalized tables
 - Data updates are less efficient because tables are larger
 - Indexing is more cumbersome
 - No simple strategies for creating virtual tables known as views

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