Dr Renata Borovica-Gajic
David Eccles

INFO90002 Database Systems

Lecture 6
Normalization

Learning Objectives

- By the end of this lecture, you should be able to:
  - Define normalization
  - Explain and identify database anomalies
  - Define and identify functional dependencies
  - Normalize relations to:
    - 1st Normal Form (1NF)
    - 2nd Normal Form (2NF)
    - 3rd Normal Form (3NF)
    - Boyce-Codd Normal Form (BCNF)

Motivation for normalization

- What happens if we don't normalize?

What's wrong with the *organization* of data in this table?

Student ID#	Student Name	Campus Address	Degree	Phone	Subject ID	Subject Title	Lecturer Name	Lecturer Office	Lecturer Phone	Sem.	Grade
A121	Joy Egbert	166 Grattan Street	B.Com.	555-7771	ACC101	Accounting	Davern	T240C	8344-1846	1-11	H1
A121	Joy Egbert	166 Grattan Street	B.Com.	555-7771	ECO101	Economics	Smyth	T240F	8344-1868	1-11	H2B
A121	Joy Egbert	166 Grattan Street	B.Com.	555-7771	ECO104	Quant. M.	Collier	T240D	8344-5716	1-11	H2B
A121	Joy Egbert	166 Grattan Street	B.Com.	555-7771	FIN101	Finance.	James	T240D	8344-5275	1-11	H2A
A121	Joy Egbert	166 Grattan Street	B.Com.	555-7771	ACC103	Processes	Wise	T240E	8344-5309	1-11	H3
A123	Larry Mueller	302 Royal Parade	B.Com.	555-1235	ACC101	Accounting	Davern	T240C	8344-1846	1-11	H1
A123	Larry Mueller	302 Royal Parade	B.Com.	555-1235	ECO101	Economics	Smyth	T240F	8344-1868	1-11	H2B
A123	Larry Mueller	302 Royal Parade	B.Com.	555-1235	ECO104	Quant. M.	Collier	T240D	8344-5716	1-11	H2A
A123	Larry Mueller	302 Royal Parade	B.Com.	555-1235	FIN101	Finance.	James	T240D	8344-5275	1-11	H3
A124	Mike Guon	224 Swanston St.	B.Eco.	555-2214	ACC101	Accounting	Davern	T240C	8344-1846	1-11	H2A
A124	Mike Guon	224 Swanston St.	B.Eco.	555-2214	ECO101	Economics	Smyth	T240F	8344-1868	1-11	H2A
A124	Mike Guon	224 Swanston St.	B.Eco.	555-2214	ECO104	Quant. M.	Collier	T240D	8344-5716	1-11	H2B
A124	Mike Guon	224 Swanston St.	B.Eco.	555-2214	ACC103	Processes	Wise	T240E	8344-5309	1-11	H2B
A126	Jackie Judson	85 Barry Street	B.Eco.	555-1245	ACC101	Accounting	Davern	T240C	8344-1846	1-11	H1
A126	Jackie Judson	85 Barry Street	B.Eco.	555-1245	ECO101	Economics	Smyth	T240F	8344-1868	1-11	H2B
A126	Jackie Judson	85 Barry Street	B.Eco.	555-1245	ECO104	Quant. M.	Collier	T240D	8344-5716	1-11	H2B
A126	Jackie Judson	85 Barry Street	B.Eco.	555-1245	ACC103	Processes	Wise	T240E	8344-5309	1-11	H2A
...	...	...	...	...	...	...	...	...	...	...	...

Anomalies in Denormalized Data:

- Consider the following denormalized table (relation) :

Student-ID	Course-ID	Fee
130	C200	75
200	C300	100
250	C200	75
425	C400	150
500	C300	100
575	C500	50
…	…	…

- ***Insertion Anomaly****:* A new course cannot be added until at least one student has enrolled (which comes first student or course?)
- ***Deletion Anomaly****:* If student 425 withdraws, we lose all record of course C400 and its fee!
- ***Update Anomaly****:* If the fee for course C200 changes, we have to change it in multiple records (rows), else the data will be inconsistent.

Normalisation

- A technique used to remove undesired redundancy from databases (Break one large table into several smaller tables).

A relation is normalized if all determinants are candidate keys

How do we normalise?

Invoice example

Bill To

John
Synex Inc
128 AA Juanita Ave
Glendora
CA 91740 US

Ship To

John
Synex Inc
128 AA Juanita Ave
Glendora
CA 91740 US

Date	14-Aug-2009	Order No		Sales Person	Charles Wooten
Shipping Date	13-Aug-2009	Shipping Terms		Terms	COD

ID	SKU / Description	Unit Price (USD)	Qty	Amount (USD)
PS.V880.005	AMD Athlon X2DC-7450, 2.4GHz/1GB/160GB/SMP-DVD/VB	580.00	6.00	3,480.00
PS.V880.037	PDC-E5300 - 2.6GHz/1GB/320GB/SMP-DVD/FDD/VB	645.00	4.00	2,580.00
LC.V890.002	LG 18.5" WLCD	230.00	10.00	2,300.00
HP.Q754.071	HP LaserJet 5200	1,103.00	1.00	1,103.00

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	Sales Person	Terms	Product ID	Product Name	Unit Price	Quantity	Amount	Sub Total
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	Charles Wooten	COD	PSV880.006	AMD Athlon X2DC	580	6	3480	9463
						PSV880.037	PDC E5300	645	4	2580	
						LC.V890.002	LG 8.5" LCD	230	10	2300	
						HPQ754.071	HP LaserJet 5200	1103	1	1103	
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	Charles Wooten	COD	HP Q754.071	HP LaserJet 5200	1103	2	2206	3356
						LCV890.002	LG 8.5" LCD	230	5	1150	

This is not relational model

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	Sales Person	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	Charles Wooten	COD	9463	0	780.70	0
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	Charles Wooten	COD	3356	0	100	0

Product ID	Product Name	Unit Price	Quantity	Amount
PSV880.006	AMD Athlon X2DC	580	6	3480
PSV880.037	PDC E5300	645	4	2580
LC.V890.002	LG 8.5” LCD	230	10	2300
HPQ754.071	HP LaserJet 5200	1103	1	1103
HPQ754.071	HP LaserJet 5200	1103	2	2206
LCV890.002	LG 8.5” LCD	230	5	1150

Break into two
But…
How do we connect?

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	Sales Person	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	Charles Wooten	COD	9463	0	780.70	0
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	Charles Wooten	COD	3356	0	100	0

Product ID	Product Name	Unit Price	Quantity	Amount	*Invoice Number*
PSV880.006	AMD Athlon X2DC	580	6	3480	INV0012
PSV880.037	PDC E5300	645	4	2580	INV0012
LC.V890.002	LG 8.5" LCD	230	10	2300	INV0012
HPQ754.071	HP LaserJet 5200	1103	1	1103	INV0012
HPQ754.071	HP LaserJet 5200	1103	2	2206	INV0013
LCV890.002	LG 8.5" LCD	230	5	1150	INV0013

Add FK

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	Sales Person	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	Charles Wooten	COD	9463	0	780.70	0
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	Charles Wooten	COD	3356	0	100	0

This is about product

Product ID	Product Name	Unit Price	Quantity	Amount	*Invoice Number*
PSV880.006	AMD Athlon X2DC	580	6	3480	INV0012
PSV880.037	PDC E5300	645	4	2580	INV0012
LC.V890.002	LG 8.5” LCD	230	10	2300	INV0012
HPQ754.071	HP LaserJet 5200	1103	1	1103	INV0012
HPQ754.071	HP LaserJet 5200	1103	2	2206	INV0013
LCV890.002	LG 8.5” LCD	230	5	1150	INV0013

This is about Order (invoice)

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	Sales Person	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	Charles Wooten	COD	9463	0	780.70	0
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	Charles Wooten	COD	3356	0	100	0

Product ID	Quantity	Amount	*Invoice Number*
PSV880.006	6	3480	INV0012
PSV880.037	4	2580	INV0012
LC.V890.002	10	2300	INV0012
HPQ754.071	1	1103	INV0012
HPQ754.071	2	2206	INV0013
LCV890.00	5	1150	INV0013

Break into two

Product ID	Product Name	Unit Price
PSV880.006	AMD Athlon X2DC	580
PSV880.037	PDC E5300	645
LC.V890.002	LG 8.5” LCD	230
HPQ754.071	HP LaserJet 5200	1103

Invoice example – Spreadsheet Format

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Product ID	Quantity	Amount	*Invoice Number*
PSV880.006	6	3480	INV0012
PSV880.037	4	2580	INV0012
LC.V890.002	10	2300	INV0012
HPQ754.071	1	1103	INV0012
HPQ754.071	2	2206	INV0013
LCV890.00	5	1150	INV0013

What about amount?

Product ID	Product Name	Unit Price
PSV880.006	AMD Athlon X2DC	580
PSV880.037	PDC E5300	645
LC.V890.002	LG 8.5” LCD	230
HPQ754.071	HP LaserJet 5200	1103

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	Sales Person	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	Charles Wooten	COD	9463	0	780.70	0
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	Charles Wooten	COD	3356	0	100	0

Product ID	Quantity	*Invoice Number*
PSV880.006	6	INV0012
PSV880.037	4	INV0012
LC.V890.002	10	INV0012
HPQ754.071	1	INV0012
HPQ754.071	2	INV0013
LCV890.00	5	INV0013

What about sales person?

Could be derived

Product ID	Product Name	Unit Price
PSV880.006	AMD Athlon X2DC	580
PSV880.037	PDC E5300	645
LC.V890.002	LG 8.5” LCD	230
HPQ754.071	HP LaserJet 5200	1103

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer Name	Customer Address	*Sales Person ID*	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	John / Synex	128 Juanita Ave...	1	COD	9463	0	780.70	0
INV0013	15-Aug-09	Mary / ThisCo	123 Smith Street...	1	COD	3356	0	100	0

What about customer?

Product ID	Quantity	*Invoice Number*
PSV880.006	6	INV0012
PSV880.037	4	INV0012
LC.V890.002	10	INV0012
HPQ754.071	1	INV0012
HPQ754.071	2	INV0013
LCV890.00	5	INV0013

Sales Person ID	Sales Person
1	Charles Wooten

Product ID	Product Name	Unit Price
PSV880.006	AMD Athlon X2DC	580
PSV880.037	PDC E5300	645
LC.V890.002	LG 8.5” LCD	230
HPQ754.071	HP LaserJet 5200	1103

Invoice example – Spreadsheet Format

Invoice Number	Date	Customer ID	*Sales Person ID*	Terms	Sub Total	Discount	Sales Tax	Shipping
INV0012	14-Aug-09	1	1	COD	9463	0	780.70	0
INV0013	15-Aug-09	2	1	COD	3356	0	100	0

Product ID	Quantity	*Invoice Number*
PSV880.006	6	INV0012
PSV880.037	4	INV0012
LC.V890.002	10	INV0012
HPQ754.071	1	INV0012
HPQ754.071	2	INV0013
LCV890.00	5	INV0013

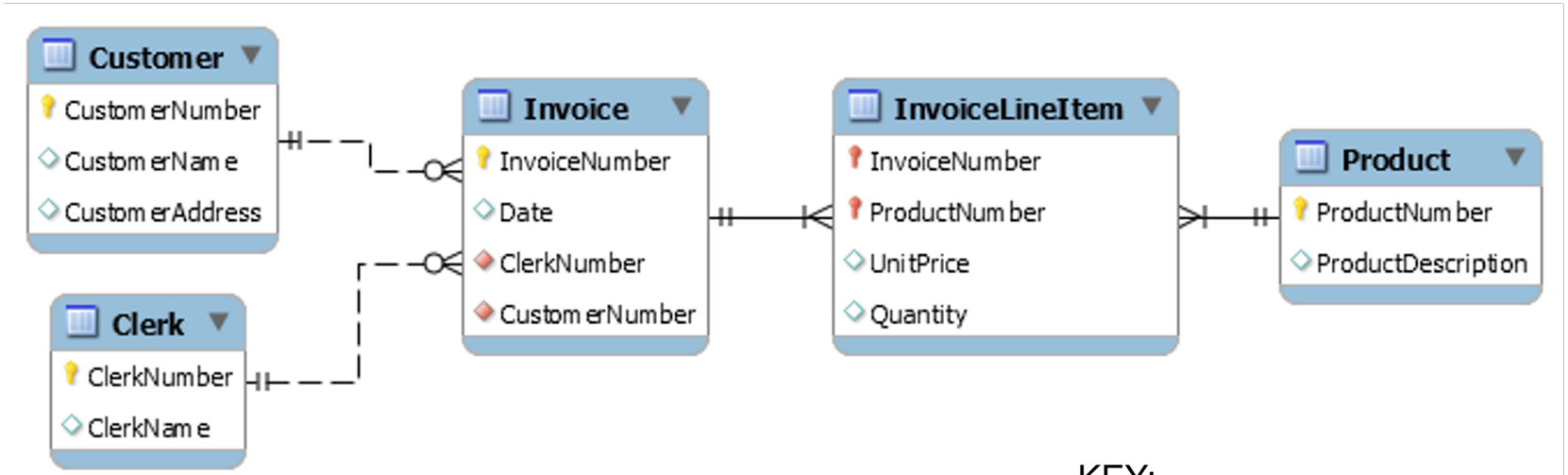
Sales Person ID	Sales Person
1	Charles Wooten

Customer ID	Customer Name	Customer Address
1	John / Synex	128 Juanita Ave...
2	Mary / ThisCo	123 Smith Street...

Product ID	Product Name	Unit Price
PSV880.006	AMD Athlon X2DC	580
PSV880.037	PDC E5300	645
LC.V890.002	LG 8.5” LCD	230
HPQ754.071	HP LaserJet 5200	1103

Normalized Relations and ER Diagram

- We can name the relations now
  - Customer (CustomerNumber, CustomerName, CustomerAddress)
  - Clerk (ClerkNumber, ClerkName)
  - Product (ProductNumber, ProductDescription)
  - Invoice (InvoiceNumber, Date, *CustomerNumber*, *ClerkNumber*)
  - InvoiceLineItem (*InvoiceNumber*, *ProductNumber*, UniPrice, Quantity)



KEY:
PK = Underline
FK = Italic
PFK Underline + Italic

- Now let's go back to theoretical concepts…

Functional Dependency

- A functional dependency concerns values of attributes in a relation
- A set of attributes X **determines** another set of attributes Y if each value of X is associated with only one value of Y
  - Written X → Y
  - X determines Y (If I know X then I also know Y)

- Emp# → Emp-name
- Emp# → Salary

Functional Dependency: Definitions

- Determinants $(X, Y \rightarrow Z)$ $A(\underline{X}, \underline{Y}, Z, D)$
  - the attribute(s) on the left hand side of the arrow
- Key and Non-Key attributes
  - each attribute is either part of the primary key or it is not
- Partial functional dependency $(Y \rightarrow Z)$
  - a functional dependency of one or more non-key attributes upon part (but not all) of the primary key
- Transitive dependency $(Z \rightarrow D)$
  - a functional dependency between 2 (or more) non-key attributes

Armstrong's Axioms

Functional dependencies can be identified using Armstrong's Axioms

$A = (X1, X2, \ldots, Xn)\ and\ B = (Y1, Y2, \ldots, Yn)$

1. Reflexivity: $B \subseteq A \Longrightarrow A \rightarrow B$

   Example: Student_ID, name -> name

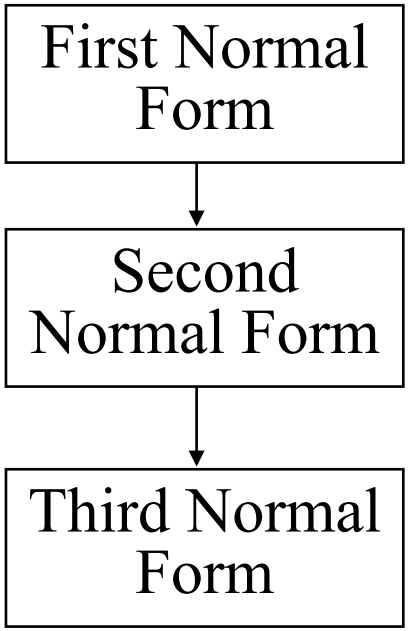
2. Augmentation: $A \rightarrow B \Longrightarrow \mathrm{AC} \rightarrow BC$

   Example: Student_ID -> name => Student_ID, surname ->name, surname

3. Transitivity: $A \rightarrow B \text{ and } \mathrm{B} \rightarrow C \Longrightarrow A \rightarrow C$

   Example: ID -> birthdate and birthdate -> age then ID ->age

Steps in Normalisation



Keep atomic data/Remove repeating groups

Remove partial dependencies

Remove transitive dependencies

First Normal Form

Remove Repeating Groups/Keep Atomic Data

- repeating groups of attributes cannot be represented in a flat, two dimensional table
- removing cells with multiple values (keep atomic data)

Set of values

Example: Order-Item (Order#, Customer#, (Item#, Desc, Qty))

- Order-Item (Order#, Customer#, (Item#, Desc, Qty))

↓

- Order-Item (Order#, Item#, Desc, Qty)
- Order (Order#, Customer#)

Break them into two
Use PK/FK to connect

Second Normal Form

Remove Partial Dependencies

a non-key attribute cannot be identified

by part of a composite key

Example: Order-Item (Order#, Item#, Desc, Qty)

- Order-Item (Order#, Item#, Desc, Qty)

Partial dependency

Item (Item#, Desc)

Order-Item (Order#, Item#, Qty)

Partial Dependency Anomalies

Order-Item (Order#, Item#, Desc, Qty)

Order#	Item#	Desc	Qty
27	873	nut	2
28	402	bolt	1
28	873	nut	10
30	495	washer	50

- *UPDATE* change item desc in many places
- *DELETE* data for last item lost when last order for that item is deleted
- *INSERT* cannot add new item until it is ordered

Solution to these Anomalies

Order-Item

Order#	Item#	Qty
27	873	2
28	402	1
28	873	10
30	495	50

delete last order for item, but item remains

add new item at any time

Item

Item#	Desc
873	nut
402	bolt
495	washer

change item description in one place

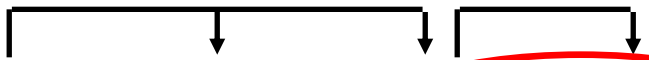
Third Normal Form

Remove Transitive Dependencies

a non-key attribute **cannot be identified**

by another non-key attribute

Example: Employee (Emp#, Ename, Dept#, Dname)



- Employee (Emp#, Ename, Dept#, Dname)

Transitive dependency

- Employee (Emp#, Ename, Dept#)
- Department(Dept#, Dname)

Transitive Dependency Anomalies

Example: Employee (Emp#, Ename, Dept#, Dname)

Emp#	Ename	Dept#	Dname
10	Smith	D5	MIS
20	Jones	D7	Finance
25	Smith	D7	Finance
30	Black	D8	Sales

- *UPDATE* change dept name in many places
- *DELETE* data for dept lost when last employee for that dept is deleted
- *INSERT* cannot add new dept until an employee is allocated to it

Solution to these Anomalies

Employee

Emp#	Ename	Dept#
10	Smith	D5
20	Jones	D7
25	Smith	D7
30	Black	D8

delete last emp in dept, but dept remains

add new dept at any time

Dept#	Dname
D5	MIS
D7	Finance
D8	Sales

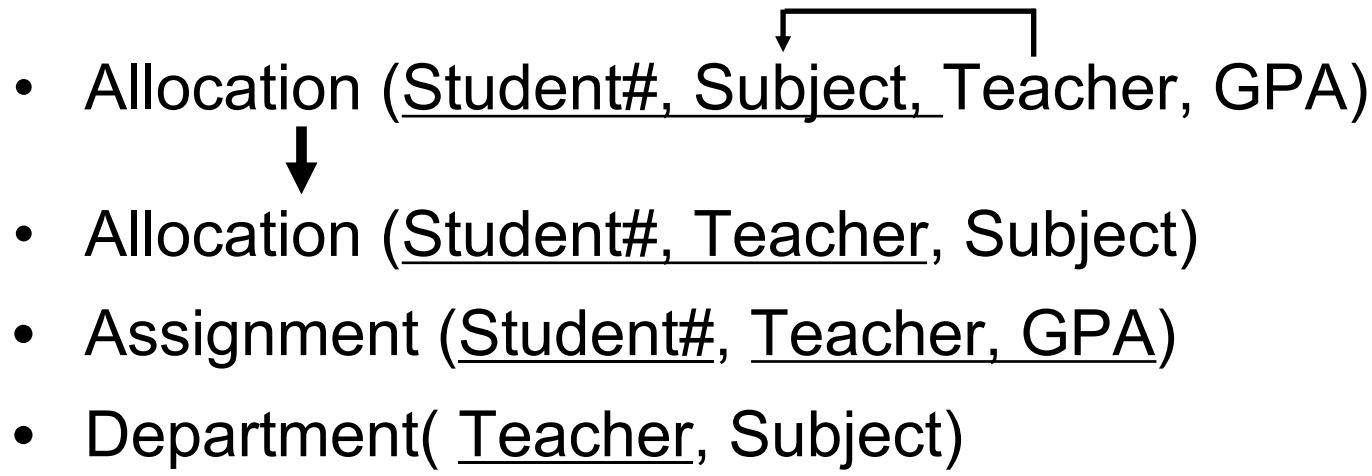
change dept name in one place

Boyce-Codd Normal Form

Every determinant must be a candidate key

"Every non-key attribute must provide a fact about the key, the whole key, and nothing but the key. (So help me Codd)"

Example: Allocation (Student#, Subject, Teacher)



Boyce-Codd Anomalies

Allocation

Stud#	Subject	Teacher
123	Physics	Einstein
123	Music	Mozart
456	Biology	Darwin
789	Physics	Bohr
999	Physics	Einstein

- *UPDATE* student changing subject may lose teacher for that subject
- *DELETE* deleting student may lose teacher for that subject
- *CREATE* cannot assign a teacher to a subject until a student takes it

Solution to these Anomolies

Stud#	Teacher
123	Einstein
123	Mozart
456	Darwin
789	Bohr
999	Einstein

delete student but subject remains

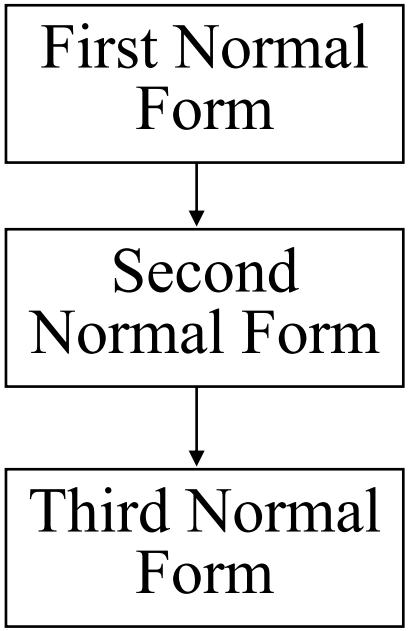
Change enrolment without losing teacher/subject

Teacher	Subject
Einstein	Physics
Mozart	Music
Darwin	Biology
Bohr	Physics

assign teacher to subject

Boyce-Codd is taught for completeness but is not examinable

Summary of Normalisation



Atomic cells and remove repeating groups

Remove partial dependencies

Remove transitive dependencies

Normalisation vs Denormalization

Normalisation:

- Normalised relations contains a minimum amount of redundancy and allow users to insert, modify, and delete rows in tables without errors or inconsistencies (anomalies)

Denormalization:

- The pay-off: query speed.
- The price: extra work on updates to keep redundant data consistent.

- Denormalization may be used to improve performance of time-critical operations.
  - Essential for Data Analytics! (Data Warehouse lecture)

What's Examinable?

- Normalisation Process (1NF -> 2NF -> 3NF)
- Anomalies
- Functional dependencies
- Denormalisation

Next Lecture

- ER Modelling LIVE!
- Make sure you have read the Medicare Case Study
- Please attempt a conceptual model