CS 564 Midterm Review

The Best Of Collection (Master Tracks), Vol. 1

Announcements

- Midterm next Wednesday

- In class: roughly 70 minutes
  - **Come in 10 minutes earlier!**

Midterm

- Format:
  - Regular questions. **No** multiple-choice.
  - This implies fewer questions ☺
  - A couple bonus questions
  - Closed book and no aids! We will provide a cheat sheet

- Material: Everything including buffer management
  - External sort is not fair game!

- High-lights:
  - Simple SQL and Schema Definitions
  - Join Semantics
  - Function Dependencies and Closures
  - Decompositions (BCNF and Properties)
  - Buffer Pool and Replacement Policies

High-Level: SQL

- Basic terminology:
  - relation / table (+ “instance of”), row / tuple, column / attribute, multiset

- Table schemas in SQL

- Single-table queries:
  - SFW (selection + projection)
  - Basic SQL operators: LIKE, DISTINCT, ORDER BY

- Multi-table queries:
  - Foreign keys
  - JOINS:
    - Basic SQL syntax & semantics of

Tables in SQL

Product

PName	Price	Manufacturer
Gizmo	$19.99	GizmoWorks
Powergizmo	$29.99	GizmoWorks
SingleTouch	$149.99	Canon
MultiTouch	$203.99	Hitachi

A **relation** or **table** is a multiset of tuples having the attributes specified by the schema

A **multiset** is an unordered list (or: a set with multiple duplicate instances allowed)

A **tuple** or **row** is a single entry in the table having the attributes specified by the schema

An **attribute** (or **column**) is a typed data entry present in each tuple in the relation

Table Schemas

- The **schema** of a table is the table name, its attributes, and their types:

Product(Pname: *string*, Price: *float*, Category: *string*, Manufacturer: *string*)

- A **key** is an attribute whose values are unique; we underline a key

Product(<u>Pname</u>: *string*, Price: *float*, Category: *string*, <u>Manufacturer</u>: *string*)

SQL Query

- Basic form (there are many many more bells and whistles)

```
SELECT <attributes>
FROM   <one or more relations>
WHERE  <conditions>
```

Call this a **SFW** query.

LIKE: Simple String Pattern Matching

```
SELECT *
FROM   Products
WHERE  PName LIKE '%gizmo%'
```

DISTINCT: Eliminating Duplicates

```
SELECT DISTINCT Category
FROM   Product
```

ORDER BY: Sorting the Results

```
SELECT   PName, Price
FROM     Product
WHERE    Category='gizmo'
ORDER BY Price, PName
```

Joins

Product

PName	Price	Category	Manuf
Gizmo	$19	Gadgets	GWorks
Powergizmo	$29	Gadgets	GWorks
SingleTouch	$149	Photography	Canon
MultiTouch	$203	Household	Hitachi

Company

Cname	Stock	Country
GWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

```
SELECT PName, Price
FROM   Product, Company
WHERE  Manufacturer = CName
           AND Country='Japan'
     AND Price <= 200
```

PName	Price
SingleTouch	$149.99

An example of SQL semantics

```
SELECT R.A
FROM   R, S
WHERE  R.A = S.B
```

A
1
3

B	C
2	3
3	4
3	5

Cross Product

A	B	C
1	2	3
1	3	4
1	3	5
3	2	3
3	3	4
3	3	5

Apply Selections / Conditions

A	B	C
3	3	4
3	3	5

Apply Projection

Output

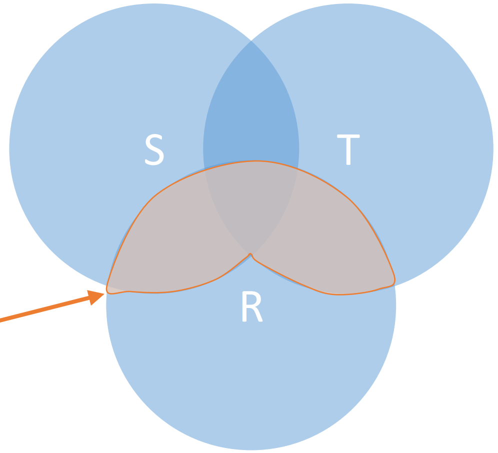
A
3
3

High-Level: Advanced SQL

- Set operators
  - INTERSECT, UNION, EXCEPT, [ALL]
  - Subtleties of multiset operations
- Nested queries
  - IN, ANY, ALL, EXISTS
  - Correlated queries
- Aggregation
  - AVG, SUM, COUNT, MIN, MAX, …
- GROUP BY
- NULLs & Outer Joins

An Unintuitive Query

```
SELECT DISTINCT R.A
FROM   R, S, T
WHERE  R.A=S.A OR R.A=T.A
```



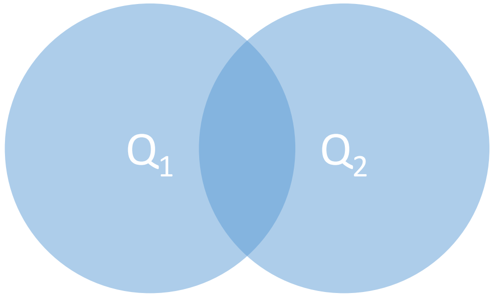
Computes $R \cap (S \cup T)$

But what if $S = \phi$?

Go back to the semantics!

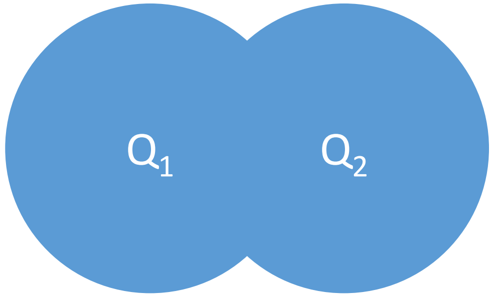
INTERSECT

```
SELECT R.A
FROM   R, S
WHERE  R.A=S.A
INTERSECT
SELECT R.A
FROM   R, T
WHERE  R.A=T.A
```



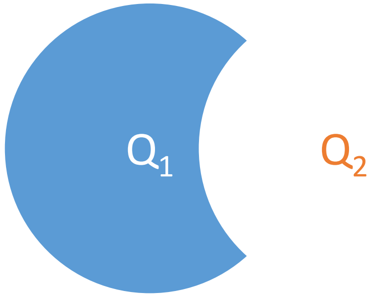
UNION

```
SELECT R.A
FROM   R, S
WHERE  R.A=S.A
UNION
SELECT R.A
FROM   R, T
WHERE  R.A=T.A
```



EXCEPT

```
SELECT R.A
FROM   R, S
WHERE  R.A=S.A
EXCEPT
SELECT R.A
FROM   R, T
WHERE  R.A=T.A
```



Nested queries: Sub-queries Returning Relations

Company(<u>name</u>, city)
Product(<u>name</u>, maker)
Purchase(<u>id</u>, product, buyer)

```
SELECT c.city
FROM   Company c
WHERE  c.name IN (
         SELECT pr.maker
    FROM   Purchase p, Product pr
    WHERE  p.product = pr.name
           AND  p.buyer = 'Joe Blow')
```

"Cities where one can find companies that manufacture products bought by Joe Blow"

Nested Queries: Operator Semantics

Product(name, price, category, maker)

ALL

```
SELECT name
FROM   Product
WHERE  price > ALL(
  SELECT price
  FROM   Product
  WHERE  maker = 'G')
```

Find products that are more expensive than *all products* produced by "G"

ANY

```
SELECT name
FROM   Product
WHERE  price > ANY(
  SELECT price
  FROM   Product
  WHERE  maker = 'G')
```

Find products that are more expensive than *any one product* produced by "G"

EXISTS

```
SELECT name
FROM   Product p1
WHERE  EXISTS (
  SELECT *
  FROM   Product p2
  WHERE  p2.maker = 'G'
   AND  p1.price =
            p2.price)
```

Find products where *there exists some* product with the same price produced by "G"

Nested Queries: Operator Semantics

Product(name, price, category, maker)

ALL

```
SELECT name
FROM   Product
WHERE  price > ALL(X)
```

Price must be > *all* entries in multiset X

ANY

```
SELECT name
FROM   Product
WHERE  price > ANY(X)
```

Price must be > *at least one* entry in multiset X

EXISTS

```
SELECT name
FROM   Product p1
WHERE  EXISTS (X)
```

X must be non-empty

**Note that p1 can be referenced in X (correlated query!)*

Correlated Queries

Movie(title, year, director, length)

```
SELECT DISTINCT title
FROM   Movie AS m
WHERE  year <> ANY(
             SELECT  year
       FROM    Movie
       WHERE   title =  m.title)
```

Find movies whose title appears more than once.

Note the scoping of the variables!

Note also: this can still be expressed as single SFW query…

Simple Aggregations

Purchase

Product	Date	Price	Quantity
bagel	10/21	1	20
banana	10/3	0.5	10
banana	10/10	1	10
bagel	10/25	1.50	20

```
SELECT SUM(price * quantity)
FROM   Purchase
WHERE  product = 'bagel'
```

→ 50 (= 1*20 + 1.50*20)

Grouping & Aggregations: GROUP BY

```
SELECT   product, SUM(price*quantity)
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
HAVING   SUM(quantity) > 10
```

Find total sales after 10/1/2005, only for products that have more than
10 total units sold

HAVING clauses contains conditions on **aggregates**

*Whereas WHERE clauses condition on **individual tuples…***

GROUP BY: (1) Compute FROM-WHERE

```
SELECT   product, SUM(price*quantity) AS TotalSales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
HAVING SUM(quantity) > 10
```

FROM
WHERE

Product	Date	Price	Quantity
Bagel	10/21	1	20
Bagel	10/25	1.50	20
Banana	10/3	0.5	10
Banana	10/10	1	10
Craisins	11/1	2	5
Craisins	11/3	2.5	3

GROUP BY: (2) Aggregate by the GROUP BY

```
SELECT   product, SUM(price*quantity) AS TotalSales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
HAVING SUM(quantity) > 10
```

Product	Date	Price	Quantity
Bagel	10/21	1	20
Bagel	10/25	1.50	20
Banana	10/3	0.5	10
Banana	10/10	1	10
Craisins	11/1	2	5
Craisins	11/3	2.5	3

GROUP BY

Product	Date	Price	Quantity
Bagel	10/21	1	20
	10/25	1.50	20
Banana	10/3	0.5	10
	10/10	1	10
Craisins	11/1	2	5
	11/3	2.5	3

GROUP BY: (3) Filter by the HAVING clause

```
SELECT   product, SUM(price*quantity) AS TotalSales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
HAVING SUM(quantity) > 30
```

Product	Date	Price	Quantity
Bagel	10/21	1	20
	10/25	1.50	20
Banana	10/3	0.5	10
	10/10	1	10
Craisins	11/1	2	5
	11/3	2.5	3

HAVING

Product	Date	Price	Quantity
Bagel	10/21	1	20
	10/25	1.50	20
Banana	10/3	0.5	10
	10/10	1	10

GROUP BY: (3) SELECT clause

```
SELECT   product, SUM(price*quantity) AS TotalSales
FROM     Purchase
WHERE    date > '10/1/2005'
GROUP BY product
HAVING SUM(quantity) > 100
```

Product	Date	Price	Quantity
Bagel	10/21	1	20
	10/25	1.50	20
Banana	10/3	0.5	10
	10/10	1	10

SELECT →

Product	TotalSales
Bagel	50
Banana	15

General form of Grouping and Aggregation

```
SELECT    S
FROM      R1,…,Rn
WHERE     C1
GROUP BY  a1,…,ak
HAVING    C2
```

Evaluation steps:

1. Evaluate FROM-WHERE: apply condition C_1 on the attributes in $R_1,\ldots,R_n$
2. GROUP BY the attributes $a_1,\ldots,a_k$
3. Apply HAVING condition C_2 to each group (may have aggregates)
4. Compute aggregates in SELECT, S, and return the result

Null Values

- *For numerical operations,* NULL -> NULL:
  - If x = NULL then 4*(3-x)/7 is still NULL

- *For boolean operations,* in SQL there are three values:

FALSE	**=**	**0**
UNKNOWN	**=**	**0.5**
TRUE	**=**	**1**

  - If x= NULL then x=“Joe” is UNKNOWN

Null Values

- C1 AND C2 = min(C1, C2)
- C1 OR C2 = max(C1, C2)
- NOT C1 = 1 – C1

```
SELECT *
FROM   Person
WHERE (age < 25)
  AND (height > 6 AND weight > 190)
```

Won’t return e.g.
(age=20
height=NULL
weight=200)!

Rule in SQL: include only tuples that yield TRUE / 1.0

Null Values

Unexpected behavior:

```
SELECT *
FROM   Person
WHERE  age < 25
   OR  age >= 25
```

Some Persons are not included !

```
SELECT *
FROM   Person
WHERE  age < 25
   OR  age >= 25
   OR  age IS NULL
```

Now it includes all Persons!

Can test for NULL explicitly:

- x IS NULL
- x IS NOT NULL

RECAP: Inner Joins

By default, joins in SQL are **"inner joins"**:

Product(name, category)
Purchase(prodName, store)

```
SELECT Product.name, Purchase.store
FROM   Product
  JOIN Purchase ON Product.name = Purchase.prodName
```

```
SELECT Product.name, Purchase.store
FROM   Product, Purchase
WHERE  Product.name = Purchase.prodName
```

Both equivalent:
Both INNER JOINS!

INNER JOIN:

Product

name	category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

prodName	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

```
SELECT Product.name, Purchase.store
FROM   Product
  INNER JOIN Purchase
             ON Product.name = Purchase.prodName
```

→

name	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Note: another equivalent way to write an INNER JOIN!

LEFT OUTER JOIN:

Product

name	category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

prodName	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

```
SELECT Product.name, Purchase.store
FROM   Product
  LEFT OUTER JOIN Purchase
          ON Product.name = Purchase.prodName
```

name	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz
OneClick	NULL

General clarification: Sets vs. Multisets

- In theory, and in any more formal material, **by definition** all relations are ***sets of tuples***

- In SQL, relations (i.e. tables) are **multisets**, meaning you can have duplicate tuples
  - We need this because intermediate results in SQL don't eliminate duplicates

- If you get confused: just state your assumptions & we'll be forgiving!

High-Level: ER Diagrams

- ER diagrams!
  - Entities (vs. Entity Sets)
  - Relationships
  - Multiplicity
  - Constraints: Keys, single-value, referential, participation, etc…

Entities vs. Entity Sets

Example:

Entities are **not** explicitly represented in E/R diagrams!

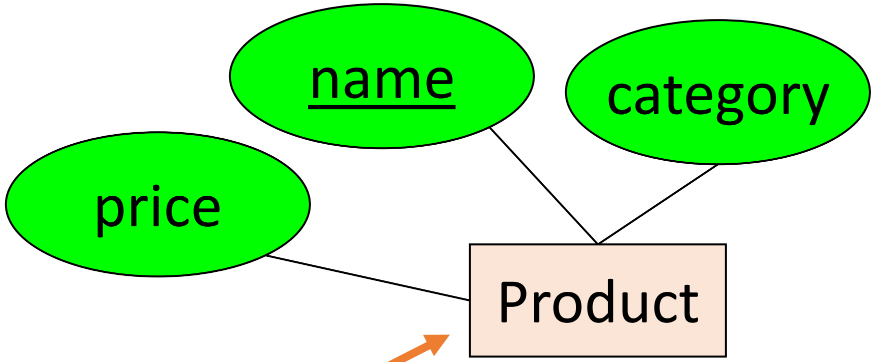
Entity

Name: Xbox
Category: Total Multimedia System
Price: $250

Name: My Little Pony Doll
Category: Toy
Price: $25

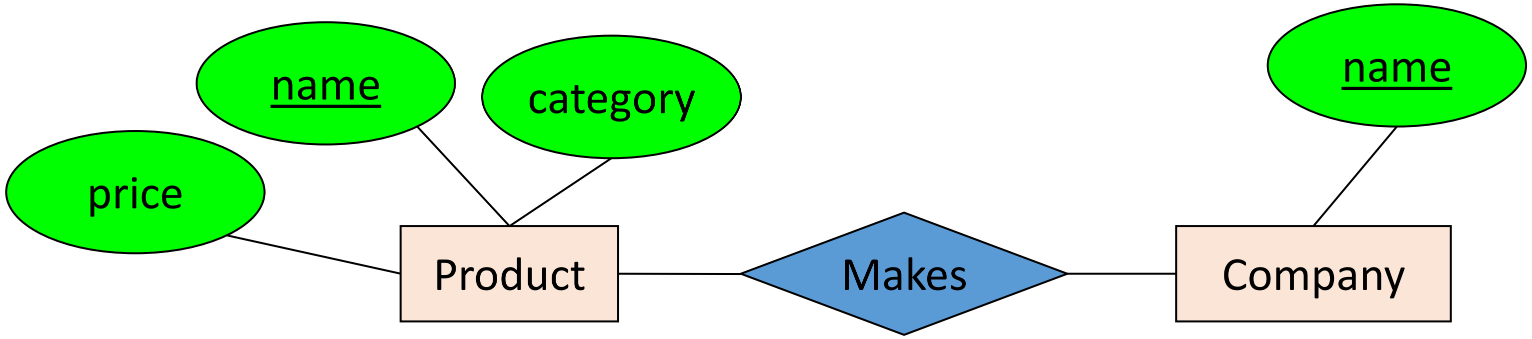
Product

Entity Attribute



Entity Set

What is a Relationship?



A <u>**relationship**</u> between **entity sets P and C** is a ***subset of all possible pairs of entities in P and C***, with tuples uniquely identified by ***P and C's keys***

What is a Relationship?

Company

name
GizmoWorks
GadgetCorp

Product

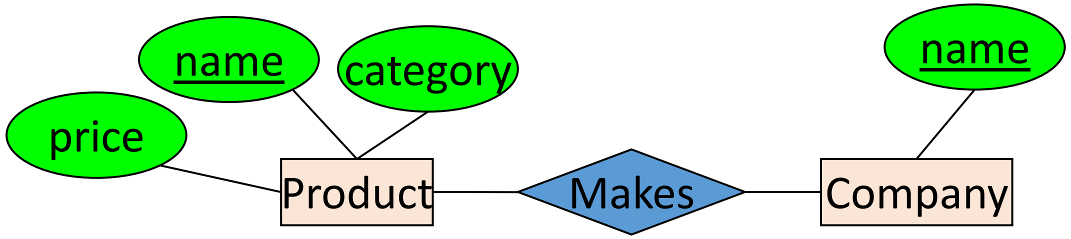
name	category	price
Gizmo	Electronics	$9.99
GizmoLite	Electronics	$7.50
Gadget	Toys	$5.50

Company C × Product P

C.name	P.name	P.category	P.price
GizmoWorks	Gizmo	Electronics	$9.99
GizmoWorks	GizmoLite	Electronics	$7.50
GizmoWorks	Gadget	Toys	$5.50
GadgetCorp	Gizmo	Electronics	$9.99
GadgetCorp	GizmoLite	Electronics	$7.50
GadgetCorp	Gadget	Toys	$5.50

Makes

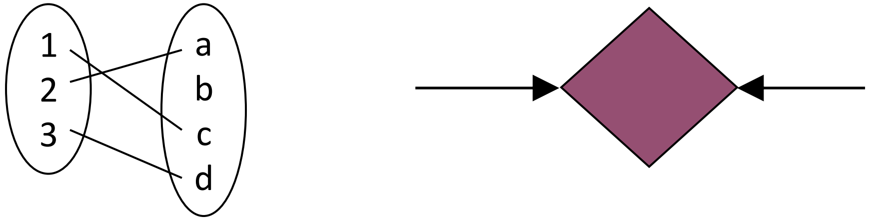
C.name	P.name
GizmoWorks	Gizmo
GizmoWorks	GizmoLite
GadgetCorp	Gadget



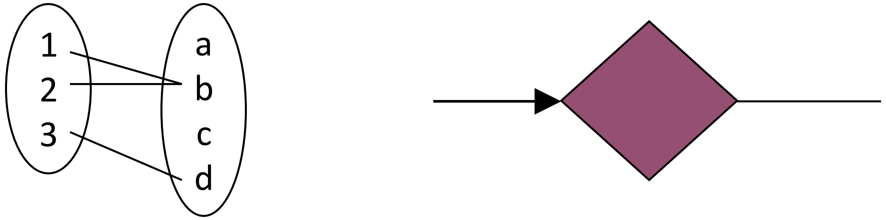
A <u>relationship</u> between **entity sets P and C** is a ***subset of all possible pairs of entities in P and C***, with tuples uniquely identified by ***P and C's keys***

Multiplicity of E/R Relationships

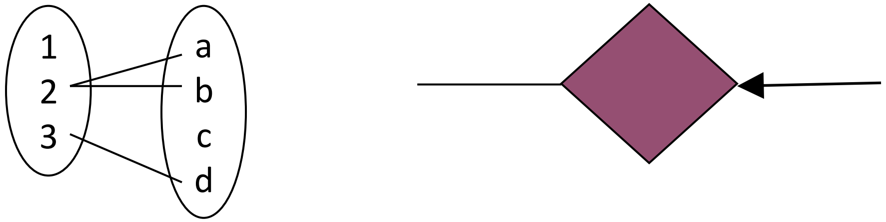
One-to-one:



Many-to-one:



One-to-many:



Many-to-many:

Indicated using arrows

X -> Y means <u>there exists a function mapping from X to Y</u> (*recall the definition of a function)*

Constraints in E/R Diagrams

- Finding constraints is part of the E/R modeling process. Commonly used constraints are:

  - Keys: Implicit constraints on uniqueness of entities
    - *Ex: An SSN uniquely identifies a person*

  - Single-value constraints:
    - *Ex: a person can have only one father*

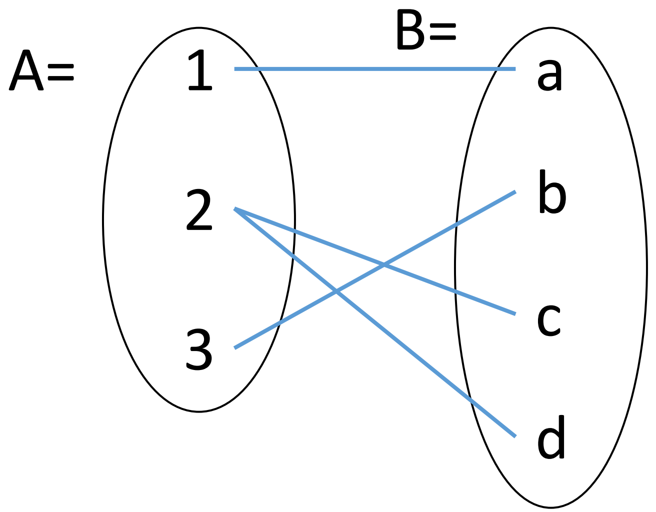
  - Referential integrity constraints: Referenced entities must exist
    - *Ex: if you work for a company, it must exist in the database*

  - Other constraints:
    - *Ex: peoples' ages are between 0 and 150*

Recall FOREIGN KEYs!

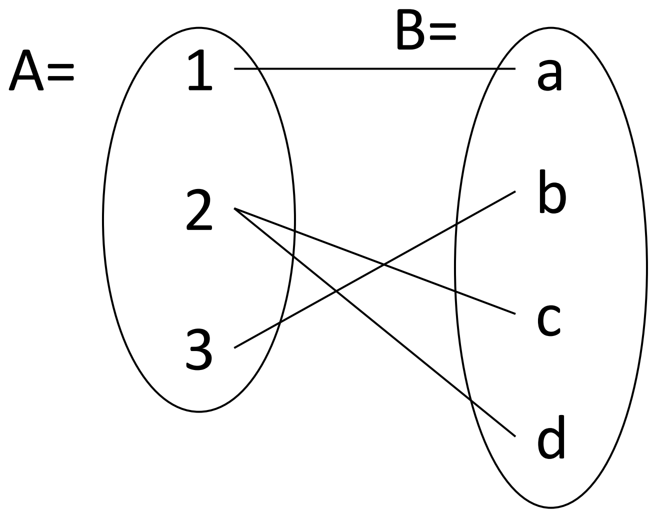
RECALL: Mathematical def. of Relationship

- ***A mathematical definition:***
  - Let A, B be sets
    - *A={1,2,3}, B={a,b,c,d},*
  - A x B (the ***cross-product***) is the set of all pairs (a,b)
    - $A \times B = \{(1,a), (1,b), (1,c), (1,d), (2,a), (2,b), (2,c), (2,d), (3,a), (3,b), (3,c), (3,d)\}$
  - **We define a <u>relationship</u> to be a subset of A x B**
    - $R = \{(1,a), (2,c), (2,d), (3,b)\}$

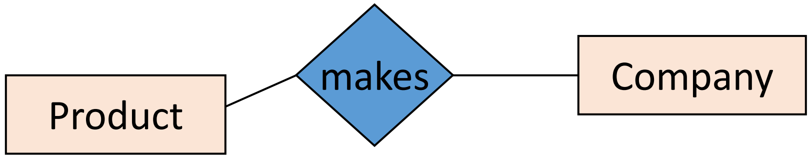


RECALL: Mathematical def. of Relationship

- ***A mathematical definition:***
  - Let A, B be sets
  - A x B (the ***cross-product***) is the set of all pairs
  - A <u>relationship</u> is a subset of A x B



- **Makes** is relationship- it is a ***subset*** of **Product** × **Company**:



RECALL: Mathematical def. of Relationship

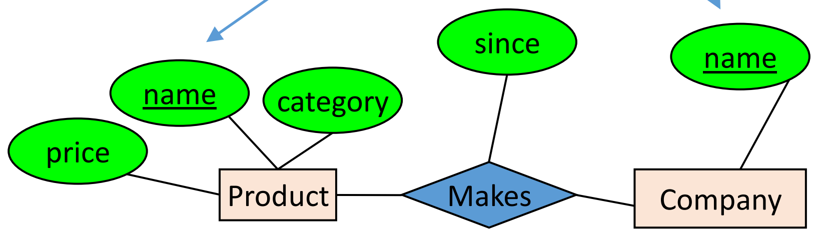
- There can only be **one relationship for every unique combination of entities**

This follows from our mathematical definition of a relationship- it's a SET!

- This also means that **the relationship is uniquely determined by the keys of its entities**

$Key_{Makes} = Key_{Product} \cup Key_{Company}$

- *Example: the key for Makes (to right) is {Product.name, Company.name}*



Why does this make sense?

High-Level: DB Design

- Redundancy & data anomalies

- Functional dependencies
  - For database schema design
  - Given set of FDs, find others implied- using Armstrong's rules

- Closures
  - Basic algorithm
  - To find all FDs

- Keys & Superkeys

Constraints Prevent (some) Anomalies in the Data

A poorly designed database causes ***anomalies***:

Similarly, we can't reserve a room without students = an ***insert* anomaly**

Student	Course	Room
Mary	CS145	B01
Joe	CS145	B01
Sam	CS145	B01
..	..	..

...	CS229	C12

If every course is in only one room, contains ***redundant*** information!

If we update the room number for one tuple, we get inconsistent data = an ***update* anomaly**

If everyone drops the class, we lose what room the class is in! = a ***delete* anomaly**

Constraints Prevent (some) Anomalies in the Data

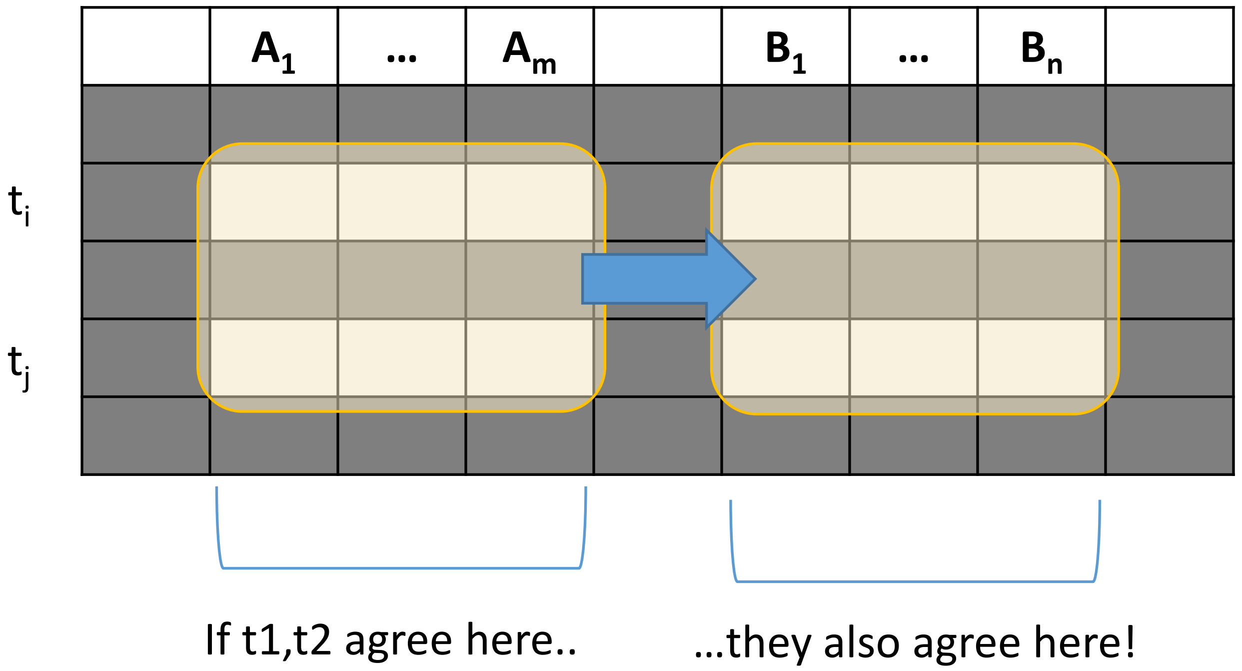
Student	Course
Mary	CS145
Joe	CS145
Sam	CS145
..	..

Course	Room
CS145	B01
CS229	C12

Is this form better?

- Redundancy?
- Update anomaly?
- Delete anomaly?
- Insert anomaly?

A Picture Of FDs



<u>Defn (again):</u>

Given attribute sets **$A=\{A_1,\ldots,A_m\}$** and **$B = \{B_1,\ldots B_n\}$** in **R**,

The ***functional dependency*** **$A \rightarrow B$ on R** holds if for ***any*** t_i,t_j in R:

<u>if</u> $t_i[A_1] = t_j[A_1]$ AND $t_i[A_2]=t_j[A_2]$ AND ... AND $t_i[A_m] = t_j[A_m]$

<u>then</u> $t_i[B_1] = t_j[B_1]$ AND $t_i[B_2]=t_j[B_2]$ AND ... AND $t_i[B_n] = t_j[B_n]$

FDs for Relational Schema Design

- High-level idea: **why do we care about FDs?**

1. Start with some relational *schema*
2. Find out its *functional dependencies (FDs)*
3. Use these to *design a better schema*
    1. One which minimizes possibility of anomalies

This part can be tricky!

Finding Functional Dependencies

Equivalent to asking: Given a set of FDs, $F = \{f_1,\ldots f_n\}$, does an FD g hold?

Inference problem: How do we decide?

Answer: Three simple rules called **Armstrong's Rules.**

1. **Split/Combine,**
2. **Reduction, and**
3. **Transitivity…** *ideas by picture*

Closure of a set of Attributes

Given a set of attributes $A_1, \ldots, A_n$ and a set of FDs **F:**
Then the <u>**closure**</u>, $\{A_1, \ldots, A_n\}^+$ is the set of attributes **B** s.t. $\{A_1, \ldots, A_n\} \rightarrow B$

<u>Example:</u> F =

{name} → {color}
{category} → {department}
{color, category} → {price}

Example Closures:

$\{\text{name}\}^+ = \{\text{name, color}\}$
$\{\text{name, category}\}^+ =$
$\{\text{name, category, color, dept, price}\}$
$\{\text{color}\}^+ = \{\text{color}\}$

Closure Algorithm

Start with $X = \{A_1, \ldots, A_n\}$, FDs F.
Repeat until X doesn't change; **do**:
if $\{B_1, \ldots, B_n\} \rightarrow C$ is in F **and** $\{B_1, \ldots, B_n\} \subseteq X$:
then add C to X.
Return X as X^+

$\{\text{name, category}\}^+ =$
$\{\text{name, category}\}$

$\{\text{name, category}\}^+ =$
$\{\text{name, category, color}\}$

$\{\text{name, category}\}^+ =$
$\{\text{name, category, color, dept}\}$

$\{\text{name, category}\}^+ =$
$\{\text{name, category, color, dept, price}\}$

F =

$\{\text{name}\} \rightarrow \{\text{color}\}$

$\{\text{category}\} \rightarrow \{\text{dept}\}$

$\{\text{color, category}\} \rightarrow \{\text{price}\}$

Keys and Superkeys

A **superkey** is a set of attributes $A_1, \ldots, A_n$ s.t. for *any other* attribute **B** in R, we have $\{A_1, \ldots, A_n\} \rightarrow B$

I.e. all attributes are *functionally determined* by a superkey

A **key** is a *minimal* superkey

Meaning that no subset of a key is also a superkey

CALCULATING Keys and Superkeys

- **Superkey?**
  - Compute the closure of A
  - See if it = the full set of attributes

- **Key?**
  - Confirm that A is superkey
  - Make sure that no subset of A is a superkey
    - *Only need to check one 'level' down!*

Also see Lecture-5.ipynb!!!

Let A be a set of attributes, R set of all attributes, F set of FDs:

```
IsSuperkey(A, R, F):
A+ = ComputeClosure(A, F)
Return (A+==R)?
```

```
IsKey(A, R, F):
If not IsSuperkey(A, R, F):
        return False
For B in SubsetsOf(A, size=len(A)-1):
        if IsSuperkey(B, R, F):
                return False
return True
```

High-Level: Decompositions

- Conceptual design
- Boyce-Codd Normal Form (BCNF)
  - Definition
  - Algorithm
- Decompositions
  - Lossless vs. Lossy
  - A problem with BCNF

Back to Conceptual Design

Now that we know how to find FDs, it’s a straight-forward process:

1. Search for “bad” FDs

2. If there are any, then *keep decomposing the table into sub-tables* until no more bad FDs

3. When done, the database schema is *normalized*

Recall: there are several normal forms…

Boyce-Codd Normal Form

BCNF is a simple condition for removing anomalies from relations:

A relation R is **in BCNF** if:

if $\{A_1, \ldots, A_n\} \rightarrow B$ is a *non-trivial* FD in R

then $\{A_1, \ldots, A_n\}$ **is a superkey** for R

Equivalently: $\forall$ sets of attributes X, either ($X^+ = X$) or ($X^+ =$ all attributes)

In other words: there are no "bad" FDs

Example

Name	SSN	PhoneNumber	City
Fred	123-45-6789	206-555-1234	Seattle
Fred	123-45-6789	206-555-6543	Seattle
Joe	987-65-4321	908-555-2121	Westfield
Joe	987-65-4321	908-555-1234	Westfield

{SSN} → {Name,City}

This FD is *bad* because it is **not** a superkey

$\Longrightarrow$ Not in BCNF

What is the key?
{SSN, PhoneNumber}

Example

Name	SSN	City
Fred	123-45-6789	Seattle
Joe	987-65-4321	Madison

SSN	PhoneNumber
123-45-6789	206-555-1234
123-45-6789	206-555-6543
987-65-4321	908-555-2121
987-65-4321	908-555-1234

{SSN} → {Name,City}

This FD is now *good* because it is the key

Let's check anomalies:

- Redundancy ?
- Update ?
- Delete ?

Now in BCNF!

BCNF Decomposition Algorithm

BCNFDecomp(R):

BCNF Decomposition Algorithm

BCNFDecomp(R):

Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

Find a set of attributes X which has non-trivial "bad" FDs, i.e. is not a superkey, using closures

BCNF Decomposition Algorithm

BCNFDecomp(R):
  Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

  if (not found) **then** **Return** R

If no "bad" FDs found, in BCNF!

BCNF Decomposition Algorithm

BCNFDecomp(R):
Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

<u>if</u> (not found) <u>**then**</u> **Return** R

<u>**let**</u> $Y = X^+ - X$, $Z = (X^+)^C$

Let Y be the attributes that ***X functionally determines*** (+ that are not in X)

And let Z be **the other attributes that it *doesn't***

BCNF Decomposition Algorithm

BCNFDecomp(R):

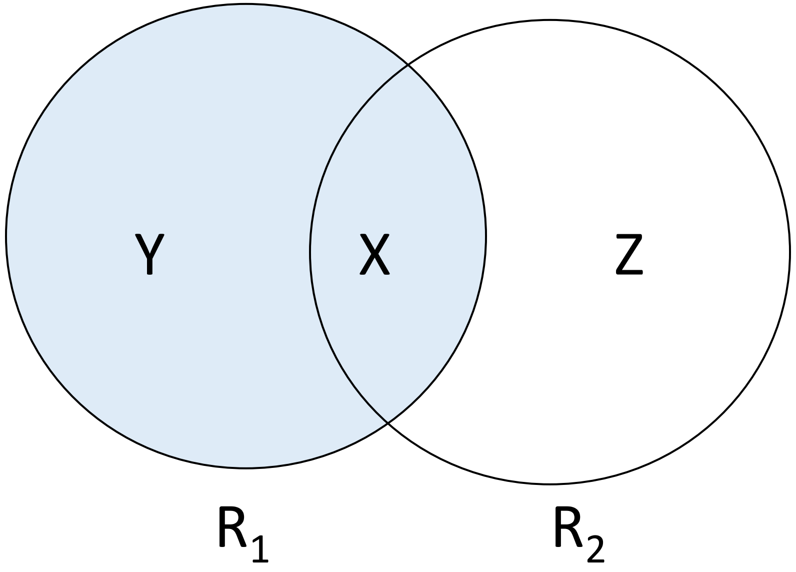
Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

if (not found) **then Return** R

let $Y = X^+ - X$, $Z = (X^+)^C$

decompose R into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

Split into one relation (table) with X plus the attributes that X determines (Y)…



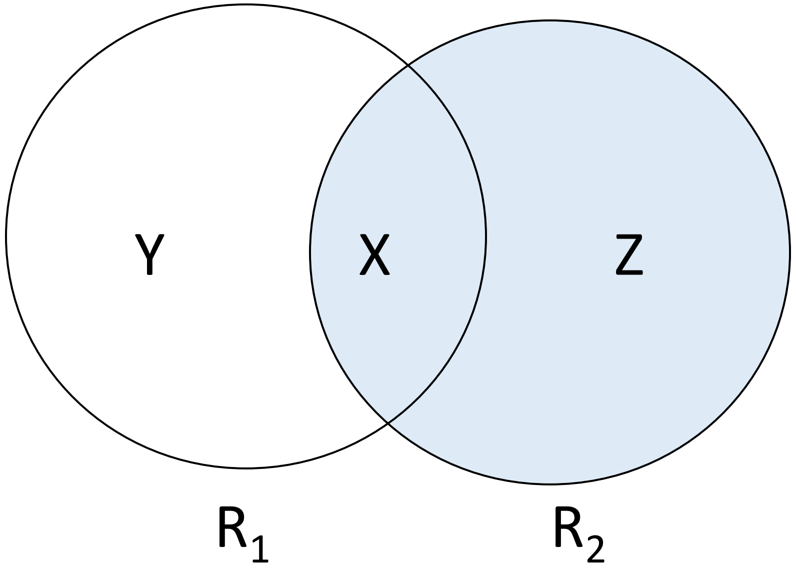
BCNF Decomposition Algorithm

BCNFDecomp(R):
  Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

  if (not found) **then** **Return** R

  let $Y = X^+ - X$, $Z = (X^+)^C$
  decompose R into $R_1(X \cup Y)$ and $R_2(X \cup Z)$

And one relation with X plus the attributes it *does not* determine (Z)



BCNF Decomposition Algorithm

BCNFDecomp(R):
  Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

  if (not found) **then** **Return** R

  let $Y = X^+ - X$, $Z = (X^+)^C$
  decompose **R** into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

  Return BCNFDecomp(R_1), BCNFDecomp(R_2)

Proceed recursively until no more "bad" FDs!

Example

BCNFDecomp(R):
  Find a *set of attributes* X s.t.: $X^+ \neq X$ and $X^+ \neq$ [all attributes]

  if (not found) **then Return** R

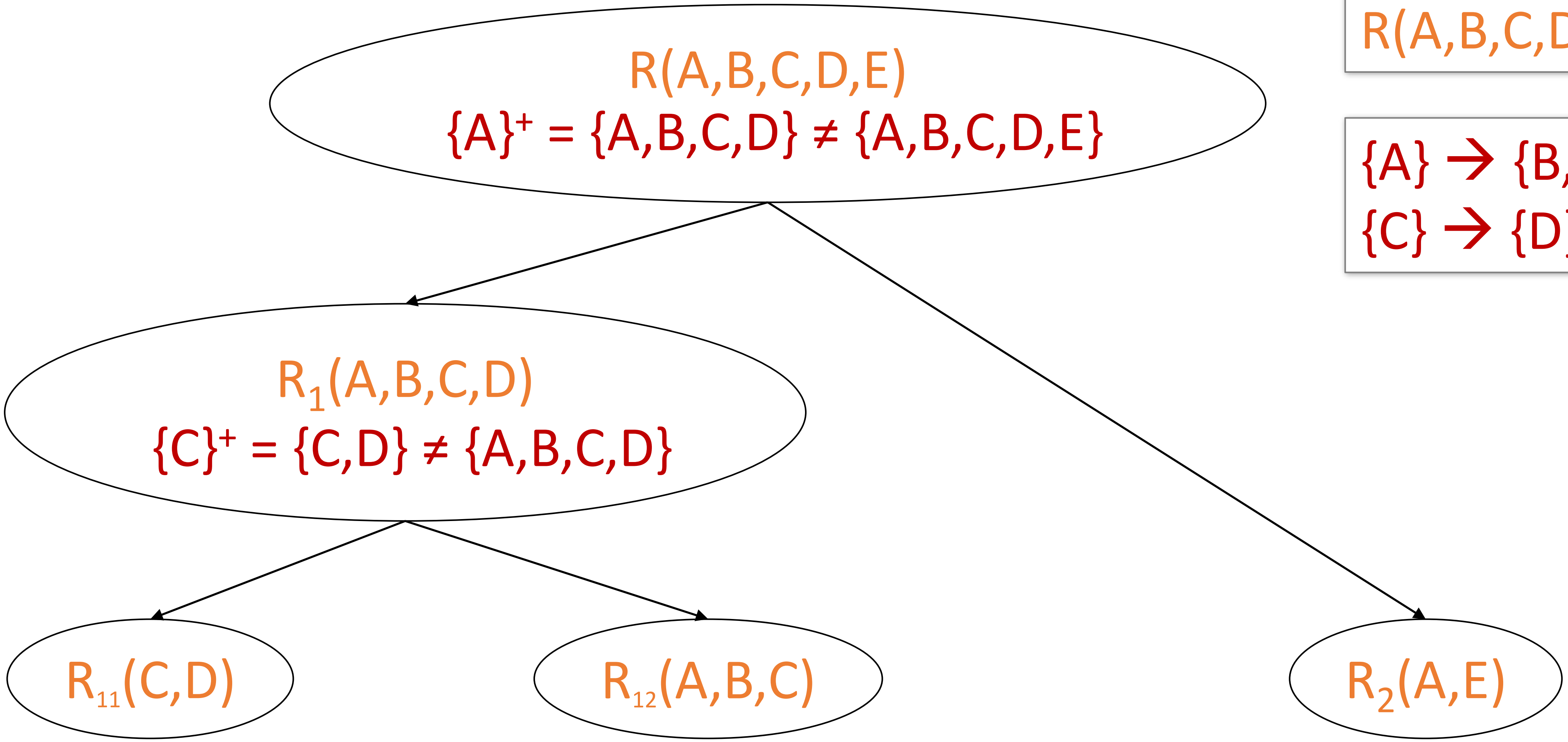
  let $Y = X^+ - X$, $Z = (X^+)^C$
  decompose R into $\mathbf{R_1(X \cup Y)}$ and $\mathbf{R_2(X \cup Z)}$

  Return BCNFDecomp(R_1), BCNFDecomp(R_2)

R(A,B,C,D,E)

$\{A\} \rightarrow \{B,C\}$
$\{C\} \rightarrow \{D\}$

Example



R(A,B,C,D,E)

$\{A\} \rightarrow \{B,C\}$
$\{C\} \rightarrow \{D\}$

Lossless Decompositions

$R(A_1,\ldots,A_n,B_1,\ldots,B_m,C_1,\ldots,C_p)$

$R_1(A_1,\ldots,A_n,B_1,\ldots,B_m)$

$R_2(A_1,\ldots,A_n,C_1,\ldots,C_p)$

If $\{A_1, \ldots, A_n\} \rightarrow \{B_1, \ldots, B_m\}$

Then the decomposition is lossless.

$\{A_1, \ldots, A_n\}$ is a key for one of R1 or R2

Note: don't need

$\{A_1, \ldots, A_n\} \rightarrow \{C_1, \ldots, C_p\}$

BCNF decomposition is always lossless. Why?

A Problem with BCNF

Unit	Company	Product
…	…	…

Unit	Company
…	…

Unit	Product
…	…

{Unit} → {Company}

{Unit} → {Company}
{Company,Product} → {Unit}

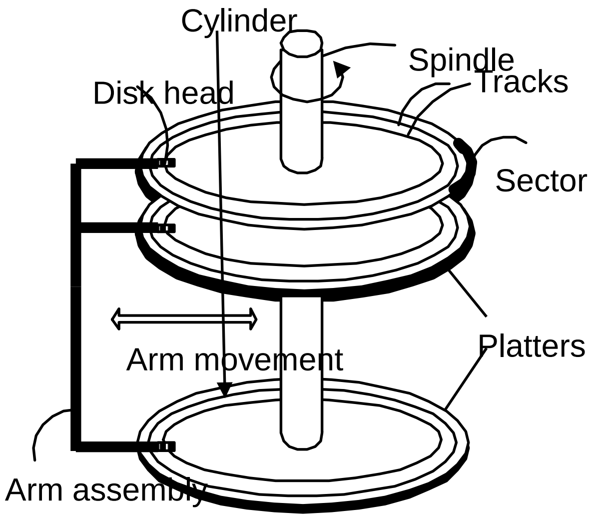
We do a BCNF decomposition on a "bad" FD:
$\{Unit\}^+ = \{Unit, Company\}$

We lose the FD {Company,Product} → {Unit}!!

High-Level: Storage and Buffers

- Our model of the computer: Disk vs. RAM
- Buffer Pool
- Replacement Policies

High-level: Disk vs. Main Memory



Disk:

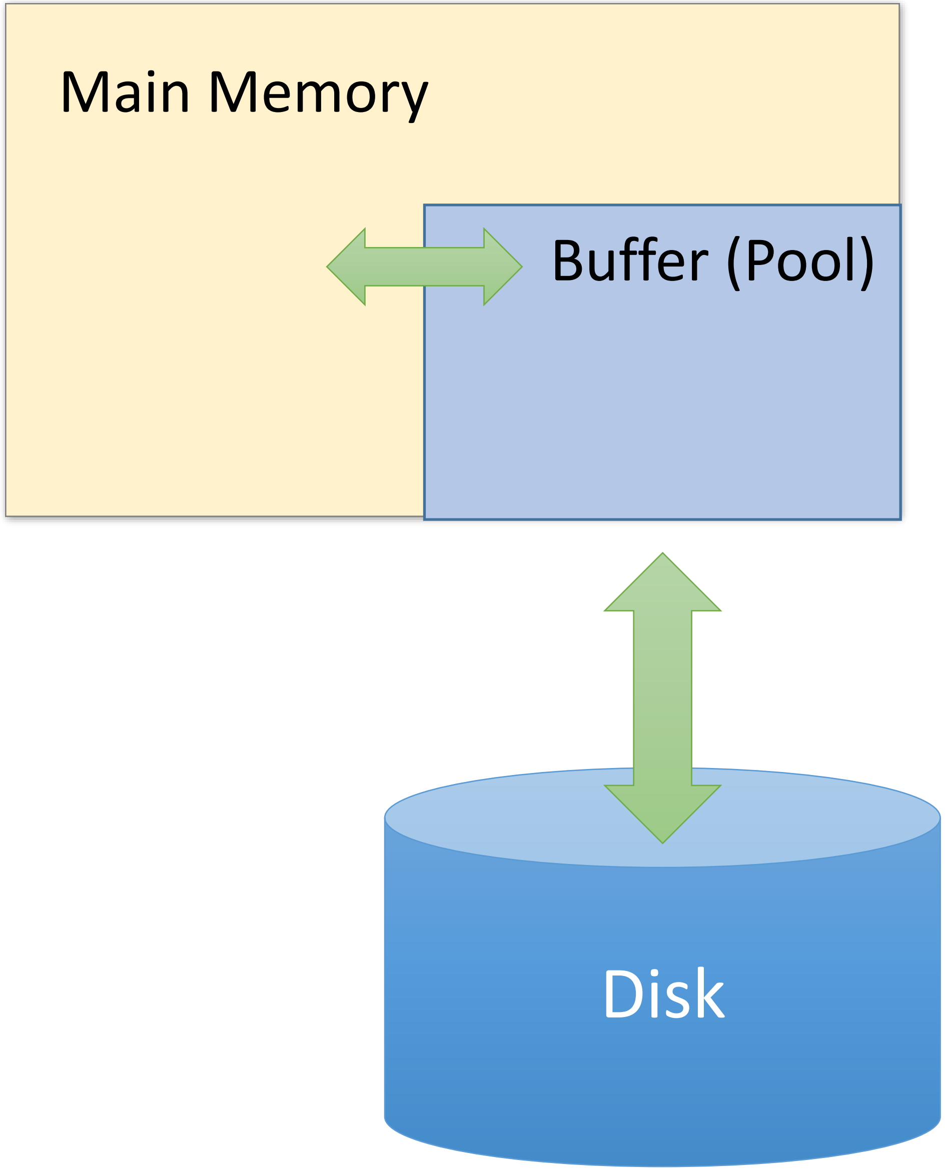
- ***Slow:*** Sequential access
  - (although fast sequential reads)
- ***Durable:*** We will assume that once on disk, data is safe!
- ***Cheap***

Random Access Memory (RAM) or Main Memory:

- ***Fast:*** Random access, byte addressable
  - ~10x faster for sequential access
  - ~100,000x faster for random access!
- ***Volatile:*** Data can be lost if e.g. crash occurs, power goes out, etc!
- ***Expensive:*** For $100, get 16GB of RAM vs. 2TB of disk!

The Buffer (Pool)

- A **buffer** is a region of physical memory used to store *temporary data*
  - *In this lecture:* a region in main memory used to store **intermediate data between disk and processes**
- *Key idea:* Reading / writing to disk is slow-need to cache data!



Buffer Manager

- Memory divided into buffer frames: slots for holding disk pages
- Bookkeeping per frame:
  - ***Pin count*** : # users of the page in the frame
    - *Pinning* : Indicate that the page is in use
    - *Unpinning* : Release the page, and also indicate if the page is *dirtied*
  - ***Dirty bit*** : Indicates if changes must be propagated to disk

Buffer Manager

- When a Page is requested:
  - In buffer pool -> return a handle to the frame. Done!
    - Increment the pin count
  - Not in the buffer pool:
    - Choose a frame for *replacement*

      (Only replace pages with pin count == 0)
    - If frame is dirty, write it to disk
    - Read requested page into chosen frame
    - Pin the page and return its address

Buffer Manager

- When a Page is requested:
  - In buffer pool -> return a handle to the frame. Done!
    - Increment the pin count
  - Not in the buffer pool:
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      (Only replace pages with pin count == 0)
    - If frame is dirty, write it to disk
    - Read requested page into chosen frame
    - Pin the page and return its address

Buffer replacement policy

- How do we choose a frame for replacement?
  - LRU (**L**east **R**ecently **U**sed)
  - Clock
  - MRU (**M**ost **R**ecently **U**sed)
  - FIFO, random, …

- The replacement policy has big impact on # of I/O’s (depends on the access pattern)

LRU

- uses a **queue** of pointers to frames that have pin count = 0
- a page request uses frames only from the *head* of the queue
- when a the pin count of a frame goes to 0, it is added to the *end* of the queue

MRU

- uses a **stack** of pointers to frames that have pin count = 0
- a page request uses frames only from the *top* of the stack
- when a the pin count of a frame goes to 0, it is added to the *top* of the stack