CS 145 Midterm Review

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

High-Level: Lecture 2

- 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

```sql
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

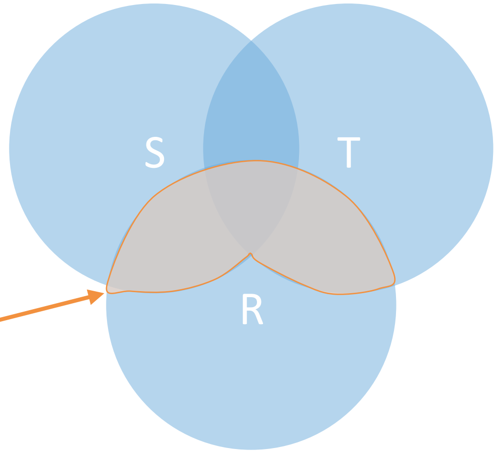
A
3
3

High-Level: Lecture 3

- 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
```



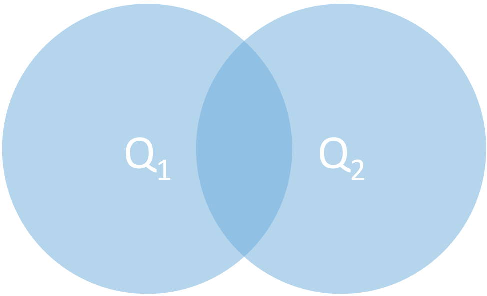
Computes R ∩ (S ∪ T)

But what if S = ϕ?

Go back to the semantics!

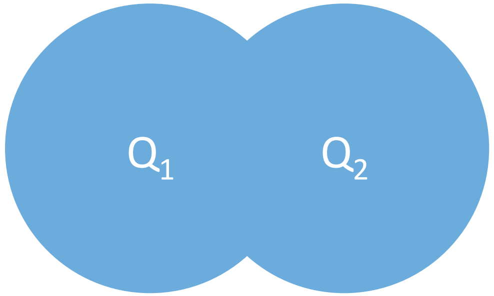
INTERSECT

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



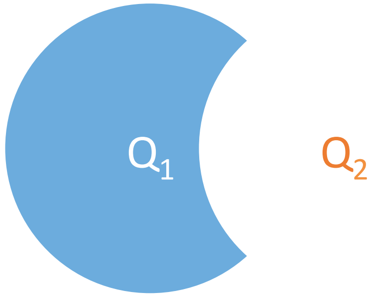
UNION

```
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(name, city)
Product(name, maker)
Purchase(id, 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

```sql
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

```sql
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

```sql
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

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

Price must be > *all* entries in multiset X

ANY

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

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

EXISTS

```sql
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!

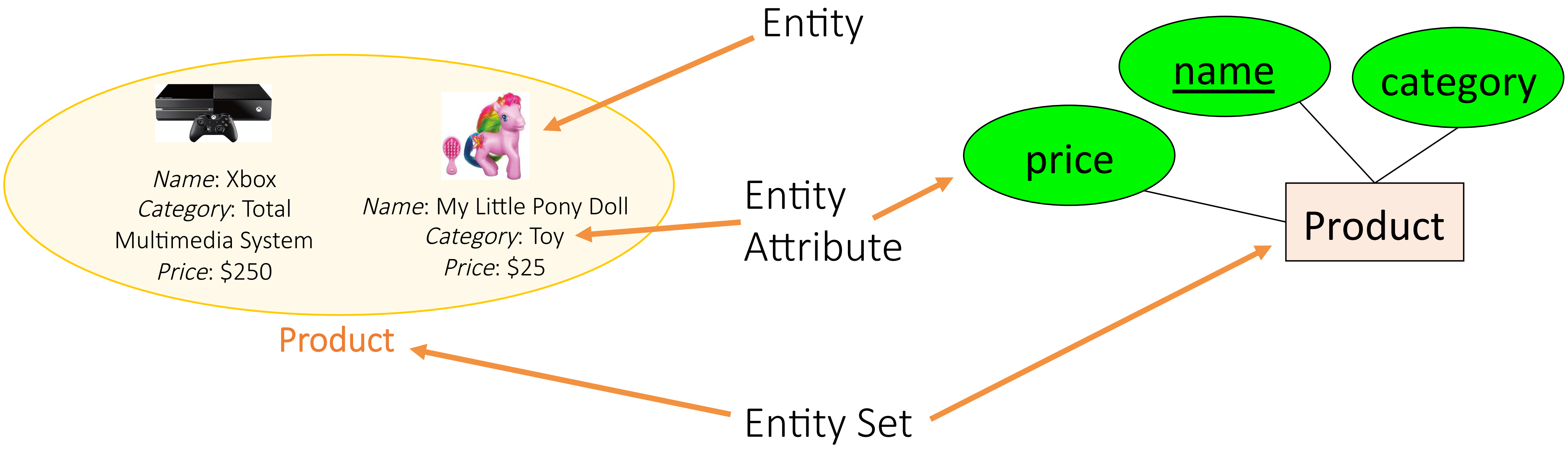
High-Level: Lecture 4

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

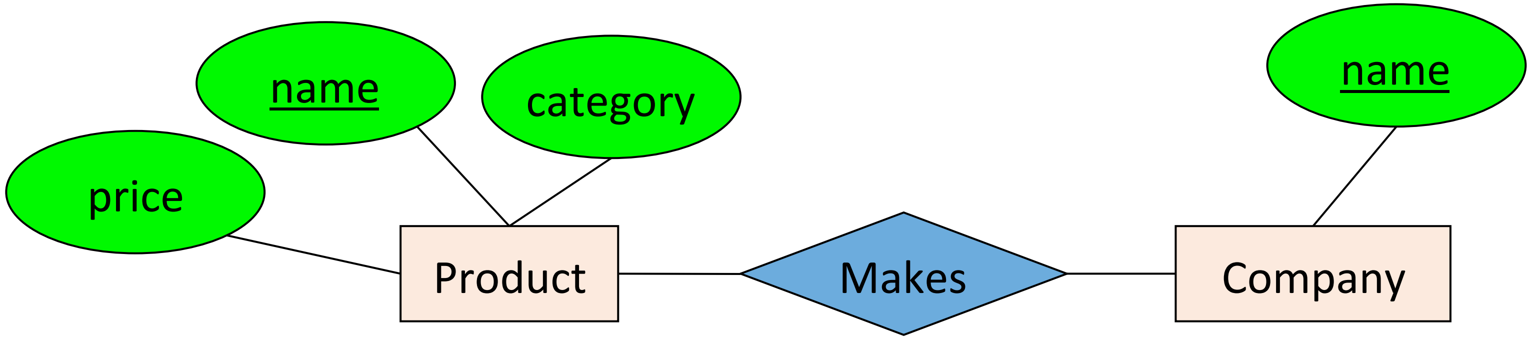
Entities vs. Entity Sets

Example:

Entities are <u>not</u> explicitly represented in E/R diagrams!



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

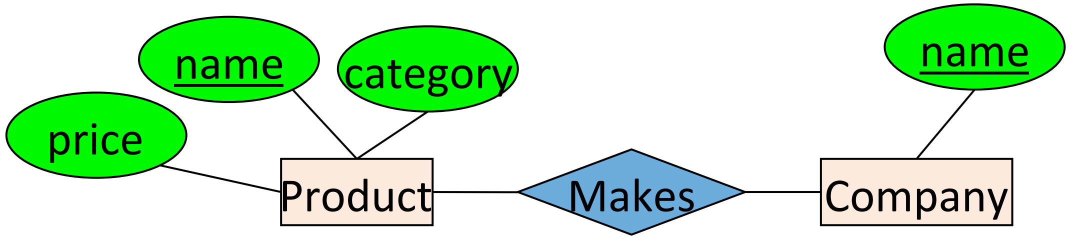
name	category	price
Gizmo	Electronics	$9.99
GizmoLite	Electronics	$7.50
Gadget	Toys	$5.50

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

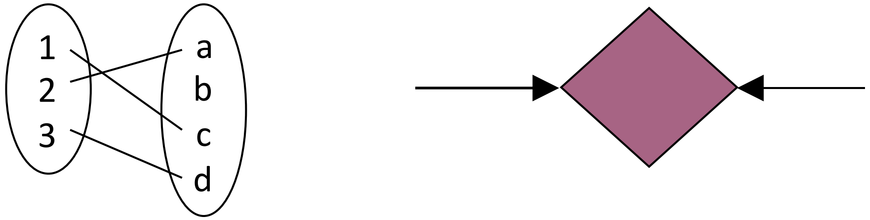
C.name	P.name
GizmoWorks	Gizmo
GizmoWorks	GizmoLite
GadgetCorp	Gadget



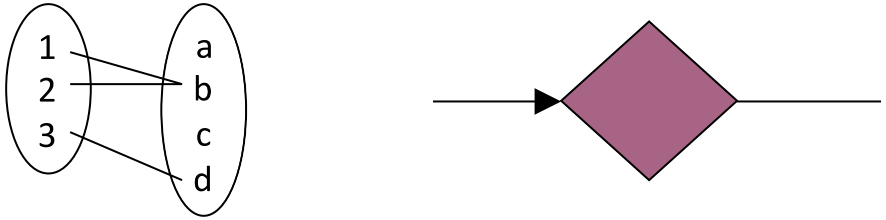
A <u>relationship</u> between **entity sets P and C** is a ***subset of all possible pairs of entities in P and C,*** with tuples uniquely identified by ***P and C's keys***

Multiplicity of E/R Relationships

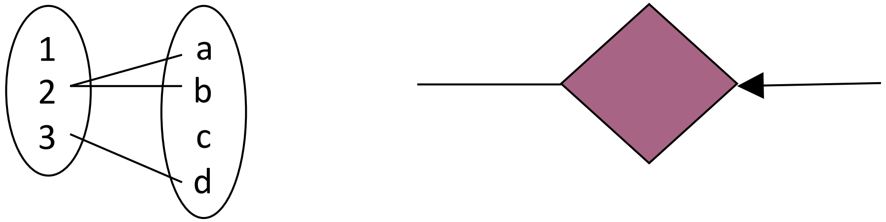
One-to-one:



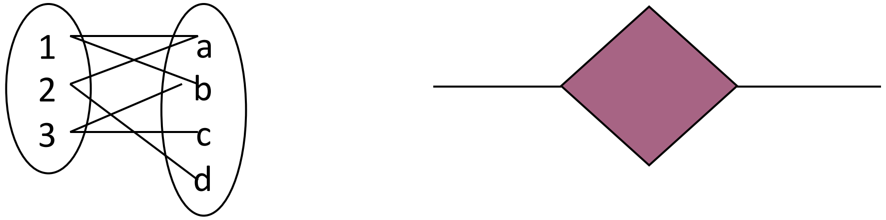
Many-to-one:



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:

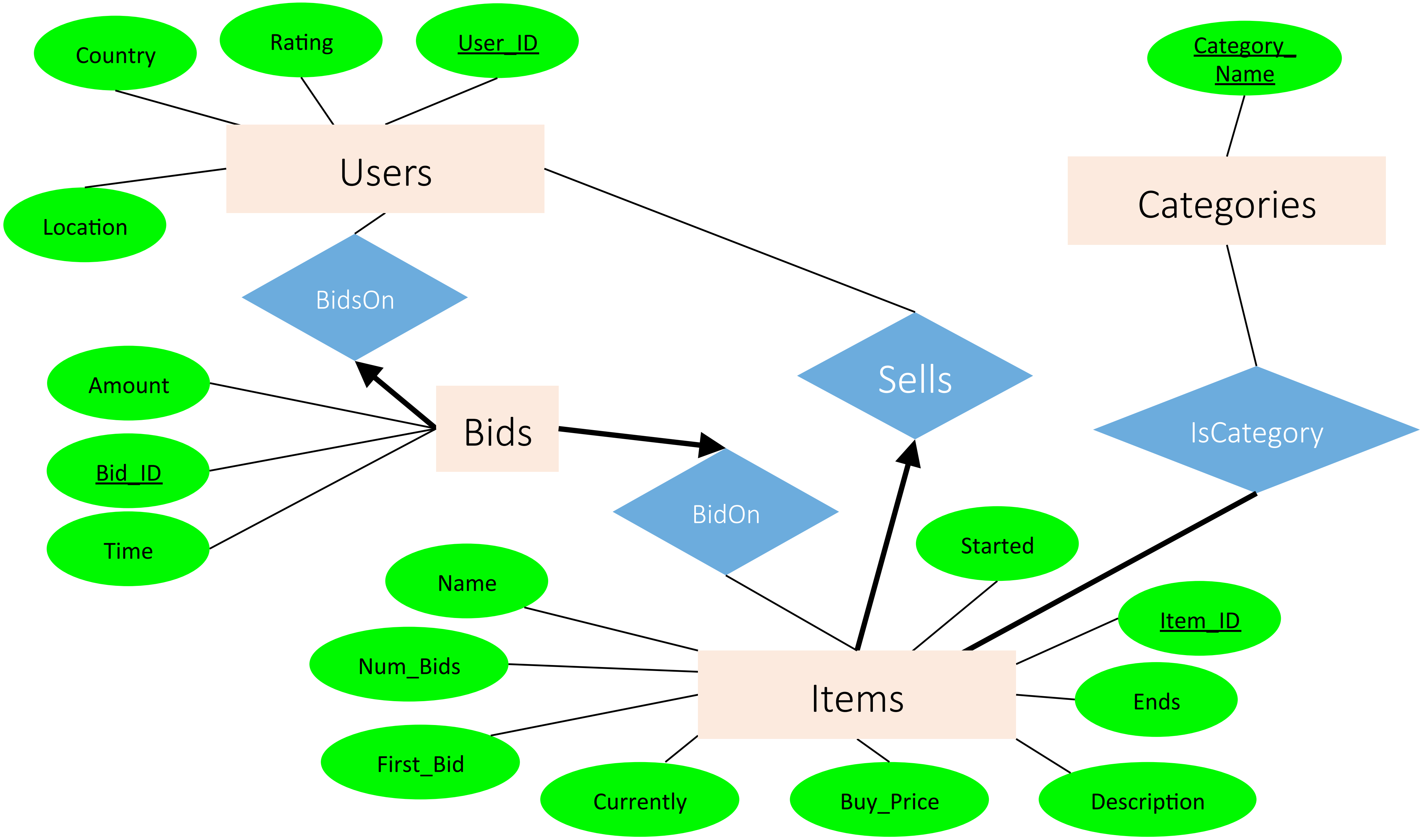
  - Keys: Implicit constraints on uniqueness of entities
    - *Ex: An SSN uniquely identifies a person*

  - 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*

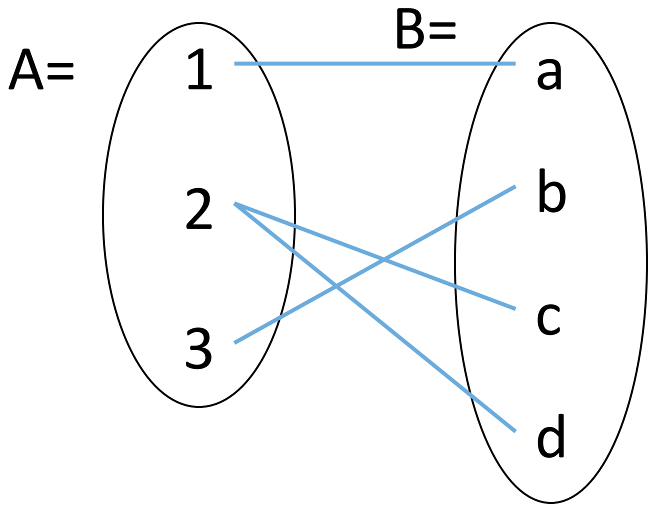
  - Other constraints:
    - *Ex: peoples' ages are between 0 and 150*

Recall FOREIGN KEYs!


Country
Rating
User_ID
Users
Location
Category_Name
Categories
BidsOn
Sells
IsCategory
Amount
Bid_ID
Time
Bids
BidOn
Started
Name
Item_ID
Num_Bids
Items
Ends
First_Bid
Currently
Buy_Price
Description

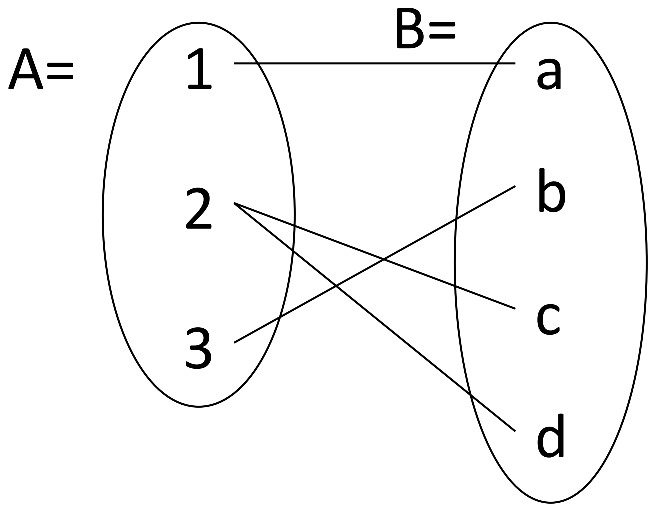
RECALL: Mathematical def. of Relationship

- ***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 × 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)}*

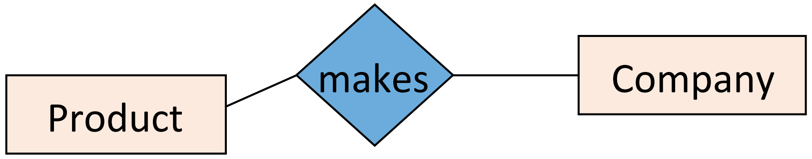


RECALL: Mathematical def. of Relationship

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



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



RECALL: Mathematical def. of Relationship

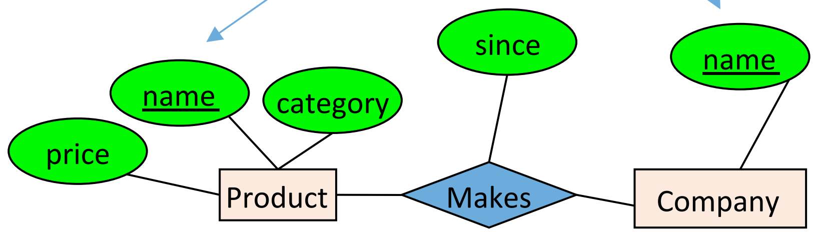
- There can only be **one relationship for every unique combination of entities**

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**

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

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



Why does this make sense?

High-Level: Lecture 5

- 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**

…	CS229	C12

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

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

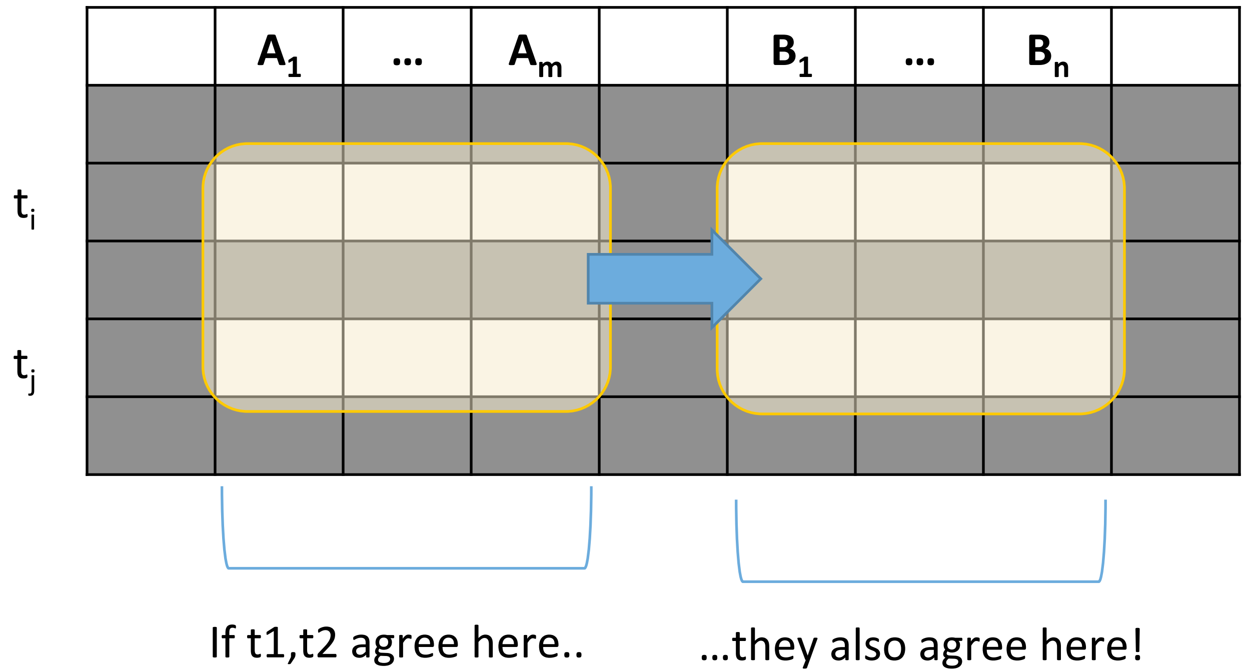
Student	Course
Mary	CS145
Joe	CS145
Sam	CS145
..	..

Course	Room
CS145	B01
CS229	C12

Is this form better?

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

A Picture Of FDs



Defn (again):

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

The *functional dependency* A→ 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 **closure**, $\{A_1, \ldots, A_n\}^+$ is the set of attributes B s.t. $\{A_1, \ldots, A_n\} \rightarrow B$

Example: F =

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

Example Closures:

```
{name}+ = {name, color}
{name, category}+ =
{name, category, color, dept, price}
{color}+ = {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^+

F =

```
{name} → {color}

{category} → {dept}

{color, category} → {price}
```

```
{name, category}+ =
{name, category}
```

```
{name, category}+ =
{name, category, color}
```

```
{name, category}+ =
{name, category, color, dept}
```

```
{name, category}+ =
{name, category, color, dept, price}
```

Keys and Superkeys

A <u>superkey</u> 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 <u>key</u> 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!*

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
```

Also see Lecture-5.ipynb!!!

High-Level: Lecture 7

- Conceptual design

- Boyce-Codd Normal Form (BCNF)
  - Definition
  - Algorithm

- Decompositions
  - Lossless vs. Lossy
  - A problem with BCNF

- MVDs
  - *In slightly greater depth since we skipped in lecture…*

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 <u>in BCNF</u> 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

$\Rightarrow$ **Not** in BCNF

What is the key?
{SSN, PhoneNumber}

Example

Name	<u>SSN</u>	City
Fred	123-45-6789	Seattle
Joe	987-65-4321	Madison

<u>SSN</u>	<u>PhoneNumber</u>
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***

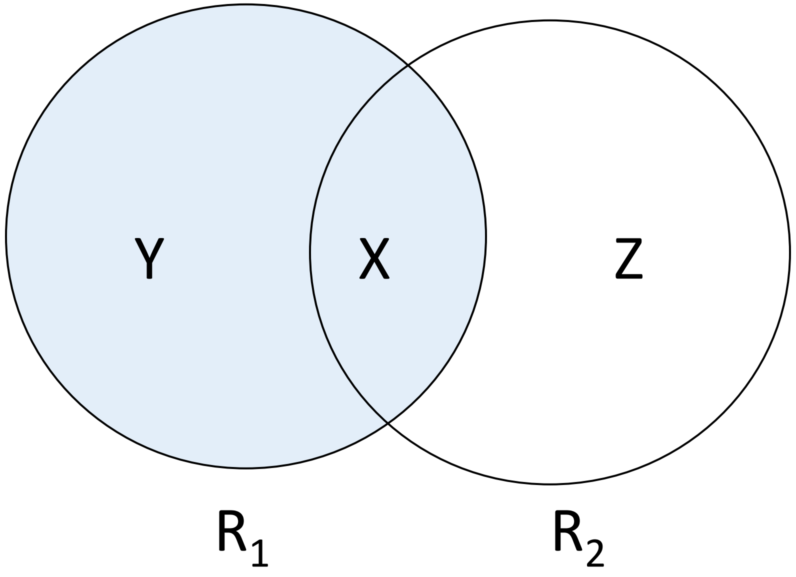
BCNF Decomposition Algorithm

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

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

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

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



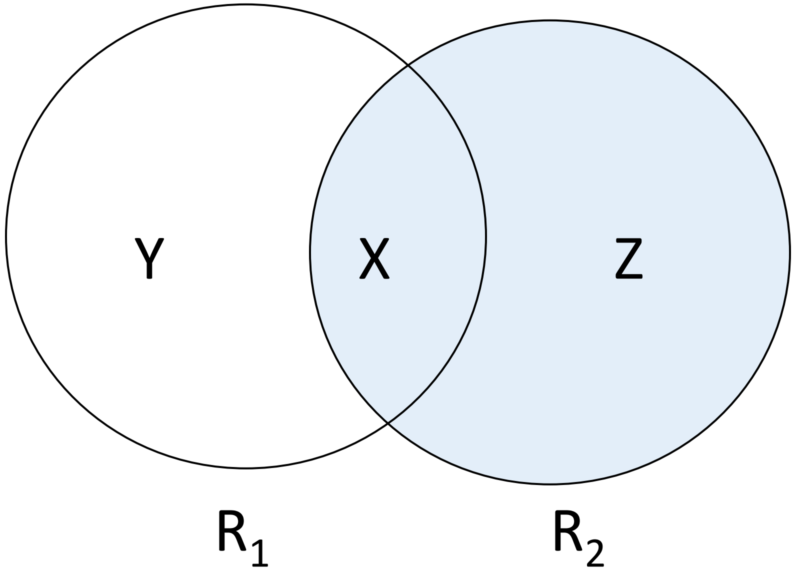
BCNF Decomposition Algorithm

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 $R_1(X \cup Y)$ and $R_2(X \cup Z)$

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]

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

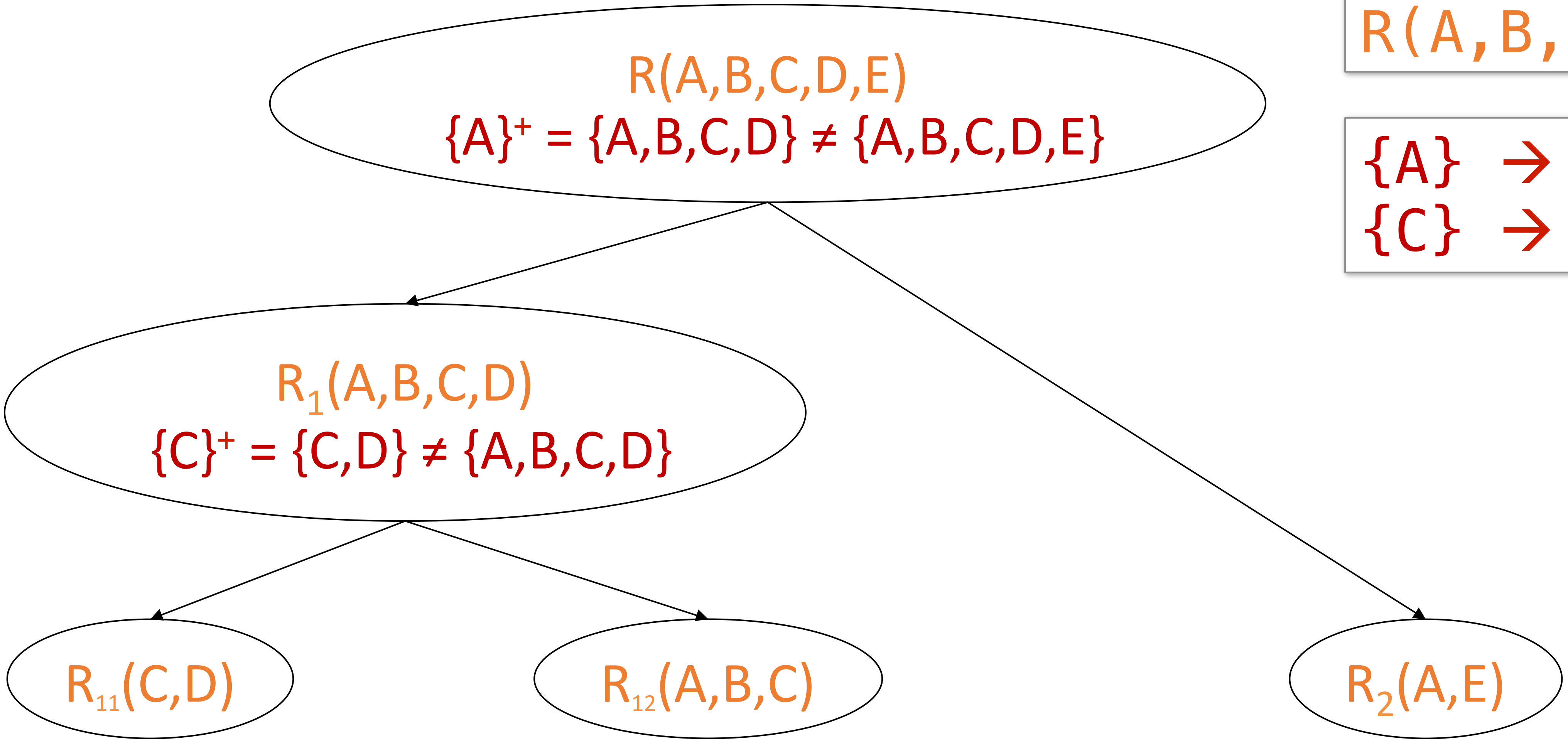
  <u>let</u> $Y = X^+ - X$, $Z = (X^+)^C$
  decompose R into $R_1(X \cup Y)$ and $R_2(X \cup Z)$

  Return BCNFDecomp(R_1), BCNFDecomp(R_2)

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

`{A} → {B,C}`
`{C} → {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

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}
{Company,Product} → {Unit}

Unit	Company
…	…

Unit	Product
…	…

{Unit} → {Company}

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

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

Multiple Value Dependencies (MVDs)

Many of you asked, “what do these mean in real life?”

Grad student CA thinks:
“Hmm… what is real life?? Watching a movie over the weekend?”

MVDs: Movie Theatre Example

Movie_theater	film_name	snack
Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
Rains 216	Star Trek: The Wrath of Kahn	Burrito
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
Rains 218	Star Wars: The Boba Fett Prequel	Ramen
Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

Are there any functional dependencies that might hold here?

No…

And yet it seems like there is some pattern / dependency…

MVDs: Movie Theatre Example

Movie_theater	film_name	snack
Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
Rains 216	Star Trek: The Wrath of Kahn	Burrito
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
Rains 218	Star Wars: The Boba Fett Prequel	Ramen
Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

For a given movie theatre…

MVDs: Movie Theatre Example

Movie_theater	film_name	snack
Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
Rains 216	Star Trek: The Wrath of Kahn	Burrito
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
Rains 218	Star Wars: The Boba Fett Prequel	Ramen
Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

For a given movie theatre…

Given a set of movies and snacks…

MVDs: Movie Theatre Example

Movie_theater	film_name	snack
Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
Rains 216	Star Trek: The Wrath of Kahn	Burrito
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
Rains 218	Star Wars: The Boba Fett Prequel	Ramen
Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

For a given movie theatre…

Given a set of movies and snacks…

Any movie / snack combination is possible!

MVDs: Movie Theatre Example

	Movie_theater (A)	film_name (B)	Snack (C)
t_1	Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
	Rains 216	Star Trek: The Wrath of Kahn	Burrito
	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
t_2	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
	Rains 218	Star Wars: The Boba Fett Prequel	Ramen
	Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

More formally, we write $\{A\} \twoheadrightarrow \{B\}$ if for any tuples t_1,t_2 s.t. $t_1[A] = t_2[A]$

MVDs: Movie Theatre Example

	Movie_theater (A)	film_name (B)	Snack (C)
t_1	Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
t_3	Rains 216	Star Trek: The Wrath of Kahn	Burrito
	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
t_2	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
	Rains 218	Star Wars: The Boba Fett Prequel	Ramen
	Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

More formally, we write $\{A\} \twoheadrightarrow \{B\}$ if for any tuples t_1, t_2 s.t. $t_1[A] = t_2[A]$ there is a tuple t_3 s.t.

- $T_3[A] = t_1[A]$

MVDs: Movie Theatre Example

	Movie_theater (A)	film_name (B)	Snack (C)
t_1	Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
t_3	Rains 216	Star Trek: The Wrath of Kahn	Burrito
	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
t_2	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
	Rains 218	Star Wars: The Boba Fett Prequel	Ramen
	Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

More formally, we write $\{A\} \twoheadrightarrow \{B\}$ if for any tuples t_1,t_2 s.t. $t_1[A] = t_2[A]$ there is a tuple t_3 s.t.

- $t_3[A] = t_1[A]$
- $t_3[B] = t_1[B]$

MVDs: Movie Theatre Example

	Movie_theater (A)	film_name (B)	Snack (C)
t_1	Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
t_3	Rains 216	Star Trek: The Wrath of Kahn	Burrito
	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
t_2	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
	Rains 218	Star Wars: The Boba Fett Prequel	Ramen
	Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

More formally, we write $\{A\} \twoheadrightarrow \{B\}$ if for any tuples t_1,t_2 s.t. $t_1[A] = t_2[A]$ there is a tuple t_3 s.t.

- $t_3[A] = t_1[A]$
- $t_3[B] = t_1[B]$
- and $t_3[R\backslash B] = t_2[R\backslash B]$

Where $R\backslash B$ is "R minus B" i.e. the attributes of R not in B

MVDs: Movie Theatre Example

	Movie_theater (A)	film_name (B)	Snack (C)
t_2	Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
	Rains 216	Star Trek: The Wrath of Kahn	Burrito
t_3	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
t_1	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
	Rains 218	Star Wars: The Boba Fett Prequel	Ramen
	Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

Note this also works!

Remember, an MVD holds over *a relation or an instance*, so defn. must hold for every applicable pair...

MVDs: Movie Theatre Example

	Movie_theater (A)	film_name (B)	Snack (C)
t_2	Rains 216	Star Trek: The Wrath of Kahn	Kale Chips
	Rains 216	Star Trek: The Wrath of Kahn	Burrito
t_3	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Kale Chips
t_1	Rains 216	Lord of the Rings: Concatenated & Extended Edition	Burrito
	Rains 218	Star Wars: The Boba Fett Prequel	Ramen
	Rains 218	Star Wars: The Boba Fett Prequel	Plain Pasta

This expresses a sort of dependency (= data redundancy) that we *can't* express with FDs

* *Actually, it expresses* ***conditional independence*** *(between film and snack given movie theatre)!*

MVDs…

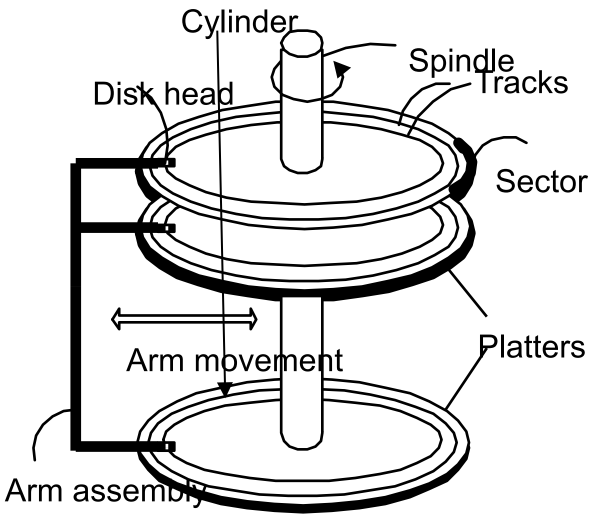
Think you can't understand them?

YES YOU

High-Level: Lecture 8

- Our model of the computer: Disk vs. RAM, local vs. global
- Transactions (TXNs)
- ACID
- Logging for Atomicity & Durability
  - Write-ahead logging (WAL)

High-level: Disk vs. Main Memory



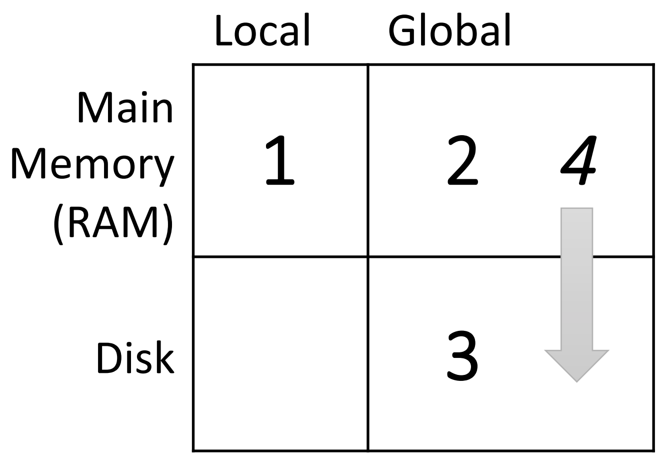
Disk:

- ***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!

Our model: Three Types of Regions of Memory



1. **Local:** In our model each process in a DBMS has its own local memory, where it stores values that only it "sees"

2. **Global:** Each process can read from / write to shared data in main memory

3. **Disk:** Global memory can read from / flush to disk

4. ***Log:*** *Assume on stable disk storage- spans both main memory and disk…*

Log is a *sequence* from main memory -> disk

"<u>Flushing</u> to disk" = writing to disk + erasing ("evicting") from main memory

Transactions: Basic Definition

A <u>**transaction ("TXN")**</u> is a sequence of one or more ***operations*** (reads or writes) which reflects ***a single real-world transition***.

In the real world, a TXN either happened completely or not at all

```
START TRANSACTION
     UPDATE Product
     SET Price = Price – 1.99
     WHERE pname = 'Gizmo'
COMMIT
```

Transaction Properties: ACID

- Atomic
  - State shows either all the effects of txn, or none of them
- Consistent
  - Txn moves from a state where integrity holds, to another where integrity holds
- Isolated
  - Effect of txns is the same as txns running one after another (ie looks like batch mode)
- Durable
  - Once a txn has committed, its effects remain in the database

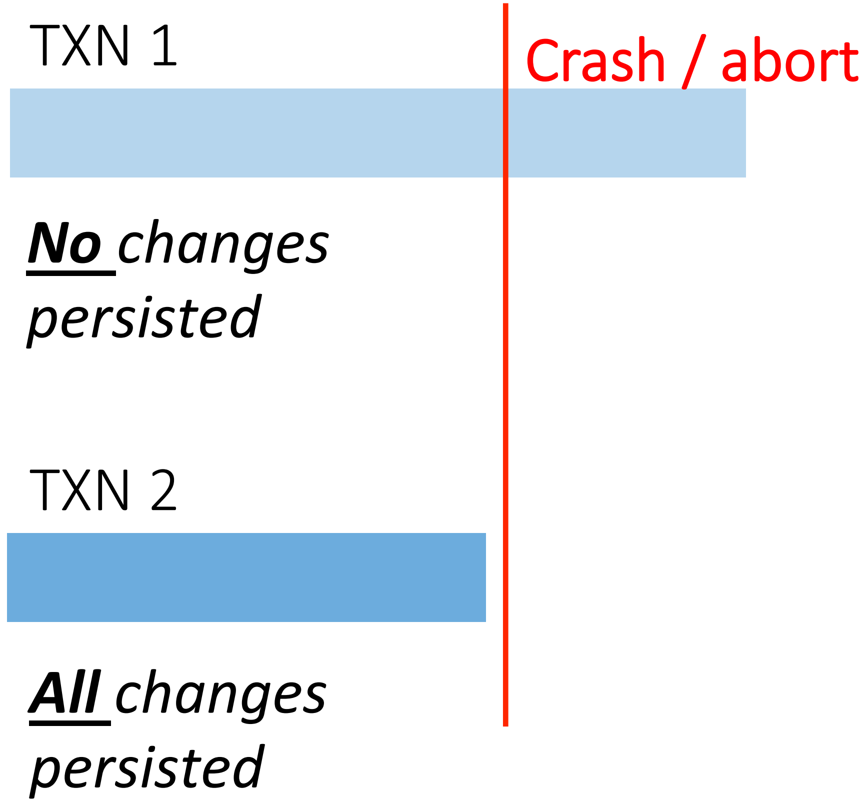
ACID is/was source of great debate!

Goal of LOGGING: Ensuring Atomicity & Durability

ACID

- **Atomicity:**
  - TXNs should either happen completely or not at all
  - If abort / crash during TXN, *no* effects should be seen

- **Durability:**
  - If DBMS stops running, changes due to completed TXNs should all persist
  - *Just store on stable disk*



Basic Idea: (Physical) Logging

- Record UNDO information for every update!
  - Sequential writes to log
  - Minimal info (diff) written to log

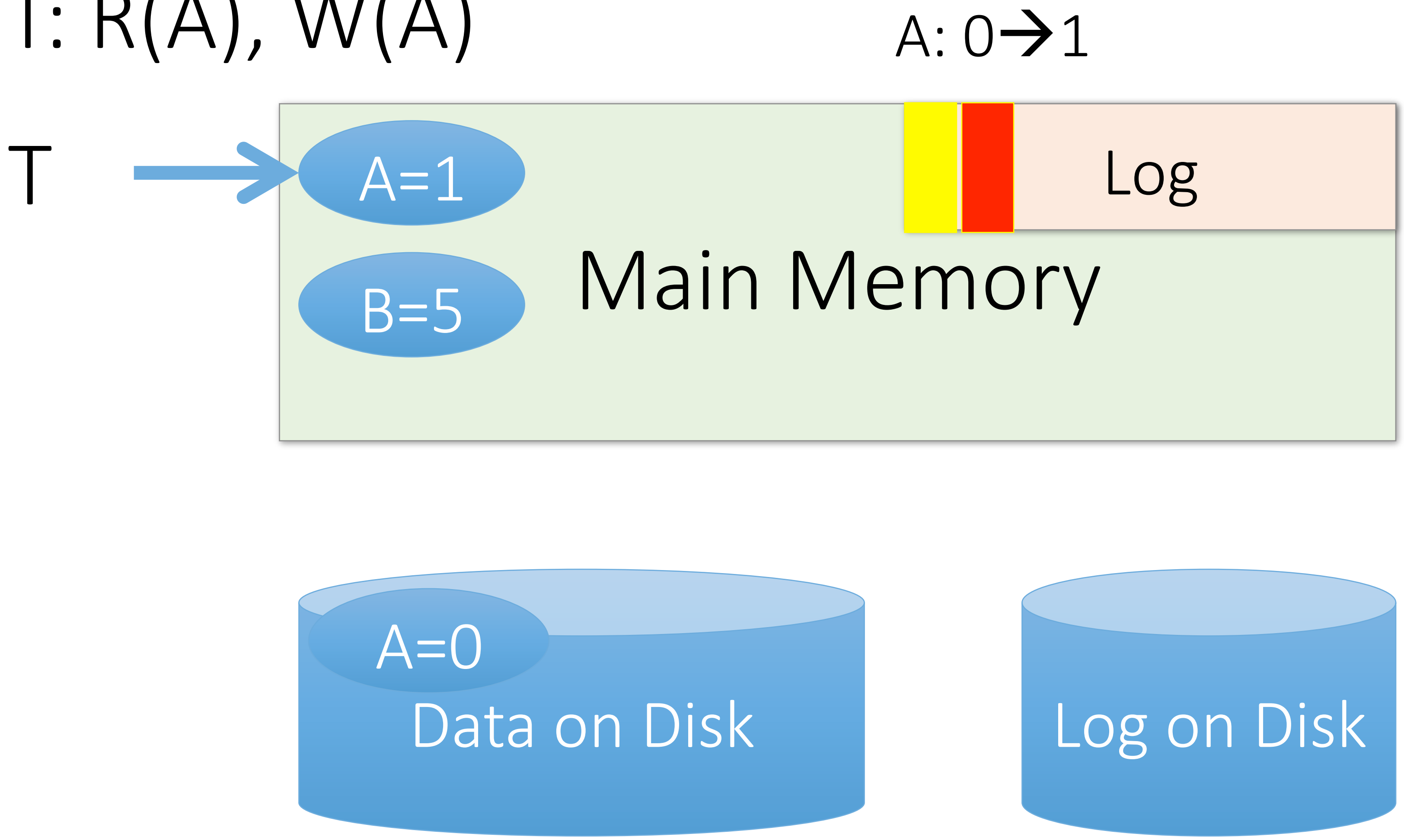
- The **log** consists of **an ordered list of actions**
  - Log record contains:

    <XID, location, old data, new data>

This is sufficient to UNDO any transaction!

Write-ahead Logging (WAL) Commit Protocol

T: R(A), W(A)



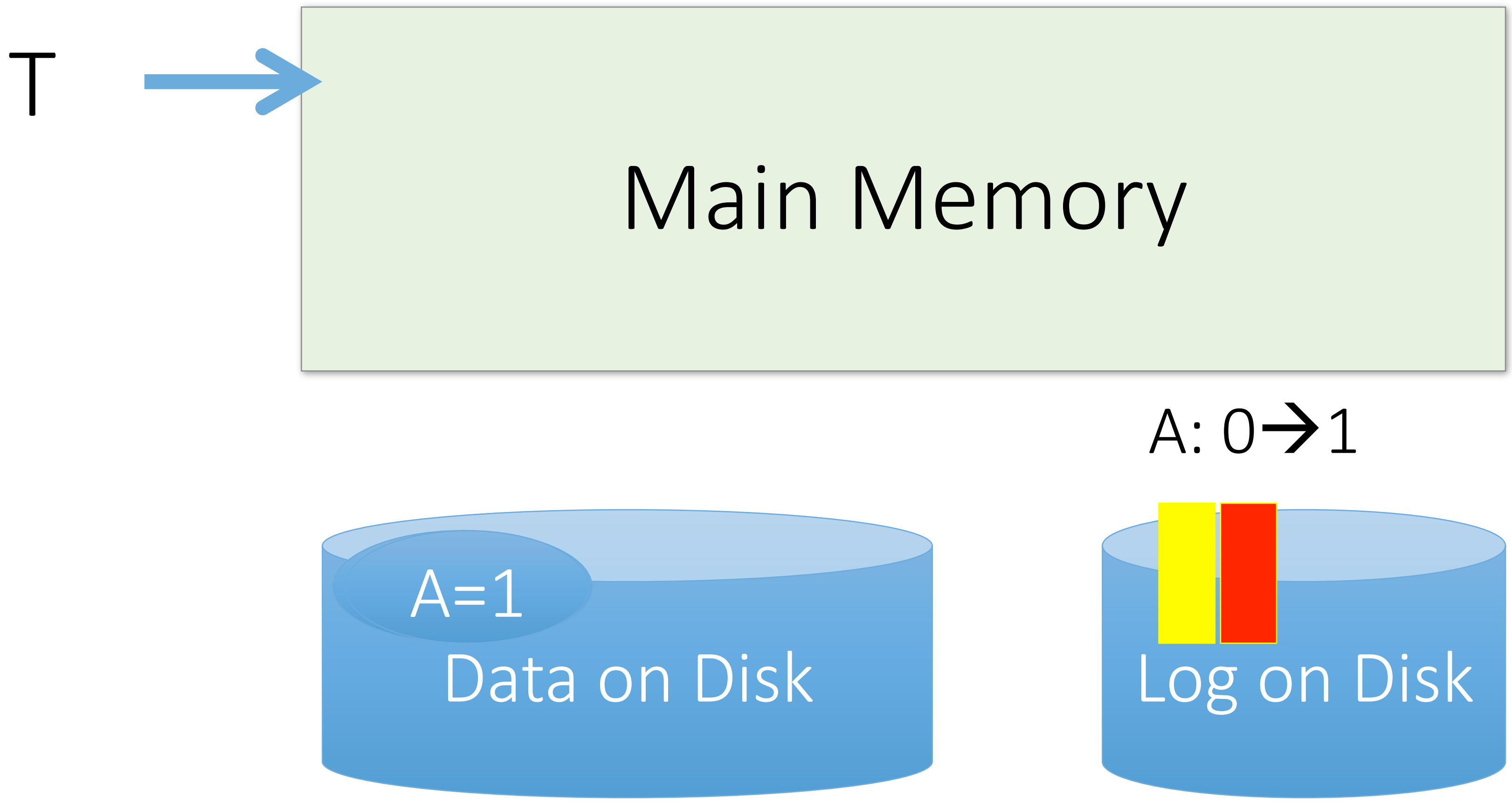
This time, let's try committing ***after*** **we've written log to disk but** ***before*** **we've written data to disk**… this is WAL!

OK, Commit!

If we crash now, is T durable?

Write-ahead Logging (WAL) Commit Protocol

T: R(A), W(A)



This time, let's try committing ***after* we've written log to disk but** ***before* we've written data to disk**… this is WAL!

OK, Commit!

If we crash now, is T durable?

USE THE LOG!

Write-Ahead Logging (WAL)

- DB uses **Write-Ahead Logging (WAL)** Protocol:

Each update is logged! Why not reads?

commit log

1. Must *force log record* for an update *before* the corresponding data page goes to storage

→ Atomicity

action log

2. Must *write all log records* for a TX *before commit*

→ Durability

High-Level: Lecture 9

- Motivation: Concurrency with Isolation & consistency
  - Using TXNs…
- Scheduling
- Serializability
- Conflict types & classic anomalies

Concurrency: Isolation & Consistency

- The DBMS must handle concurrency such that…

1. **Isolation** is maintained: Users must be able to execute each TXN **as if they were the only user**
   - DBMS handles the details of *interleaving* various TXNs

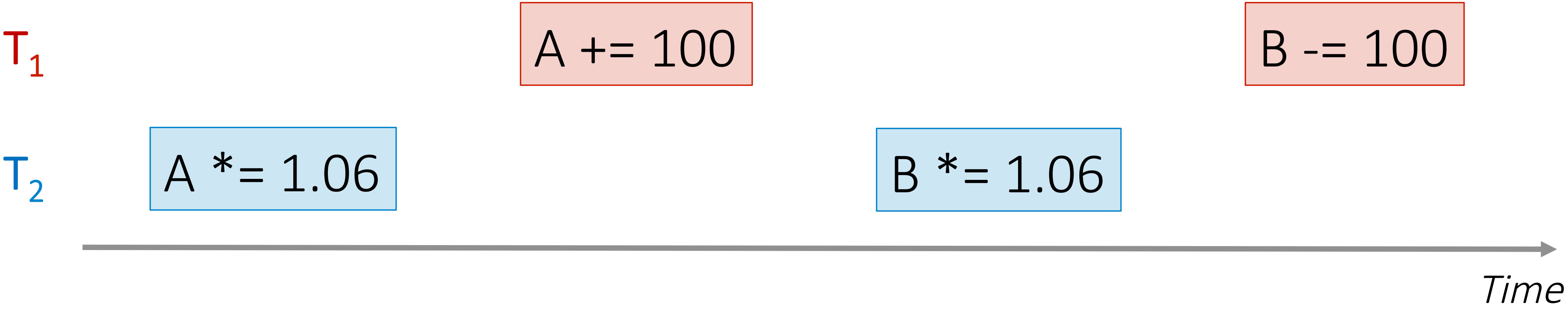
ACID

2. **Consistency** is maintained: TXNs must leave the DB in a **consistent state**
   - DBMS handles the details of enforcing integrity constraints

ACID

Example- consider two TXNs:

The DBMS can also **interleave** the TXNs



What goes / could go wrong here??

Scheduling examples

Starting Balance

A	B
\$50	\$200

<u>Serial schedule $T_1 \rightarrow T_2$:</u>

T_1: A += 100 | B -= 100

T_2: A *= 1.06 | B *= 1.06

A	B
\$159	\$106

<u>*Interleaved* schedule B:</u>

T_1: A += 100 | B -= 100

T_2: A *= 1.06 | B *= 1.06

A	B
\$159	**\$112**

Different result than serial $T_1 \rightarrow T_2$!

Scheduling Definitions

- A **serial schedule** is one that does not interleave the actions of different transactions
- A and B are **equivalent schedules** if, ***for any database state***, the effect on DB of executing A **is identical to** the effect of executing B
- *A* **serializable schedule** is a schedule that is equivalent to ***some*** serial execution of the transactions.

The word "**some**" makes this def powerful and tricky!

Serializable?

T_1: A += 100, B -= 100

T_2: A *= 1.06, B *= 1.06

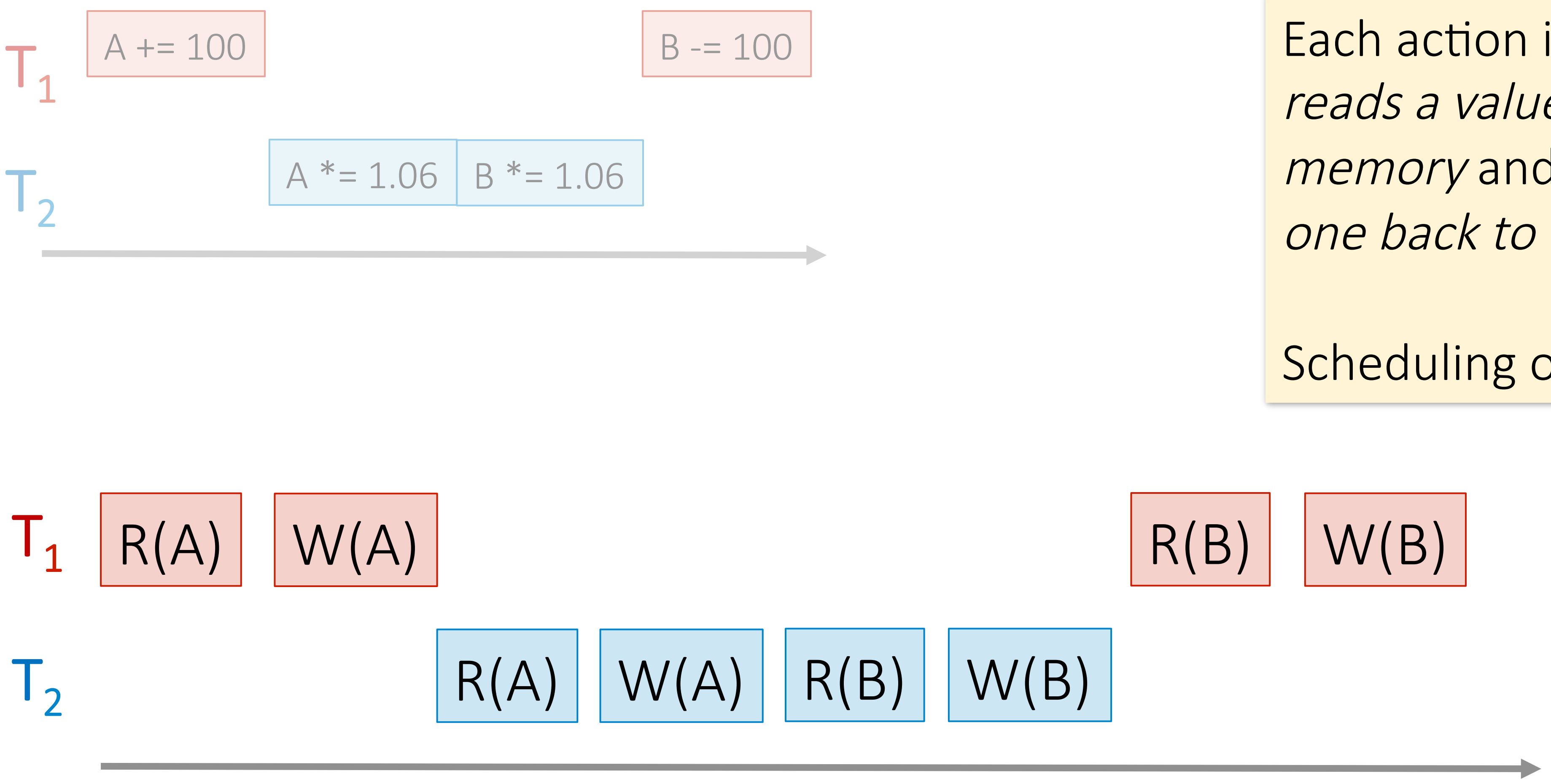
Serial schedules:

	A	B
$T_1 \rightarrow T_2$	1.06*(A+100)	1.06*(B-100)
$T_2 \rightarrow T_1$	1.06*A + 100	1.06*B - 100

A	B
1.06*(A+100)	1.06*(B-100)

Same as a serial schedule *for all possible values of A, B* = serializable

The DBMS's view of the schedule



Each action in the TXNs *reads a value from global memory* and then *writes one back to it*

Scheduling order matters!

Conflict Types

Two actions <u>conflict</u> if they are part of different TXNs, involve the same variable, and at least one of them is a write

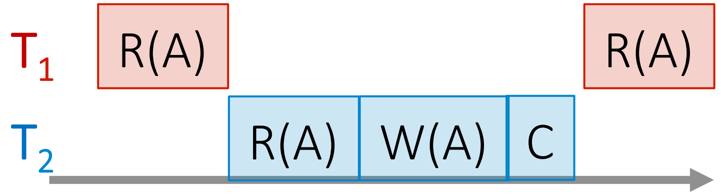
- Thus, there are three types of conflicts:
  - Read-Write conflicts (RW)
  - Write-Read conflicts (WR)
  - Write-Write conflicts (WW)

Why no "RR Conflict"?

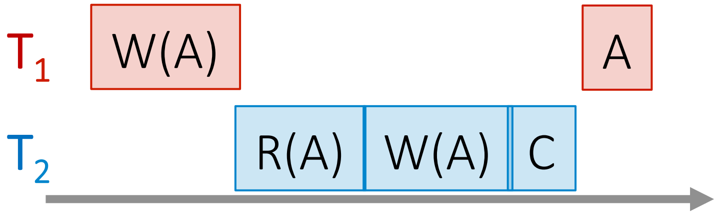
Interleaving anomalies occur with / because of these conflicts between TXNs *(but these conflicts can occur without causing anomalies!)*

Classic Anomalies with Interleaved Execution

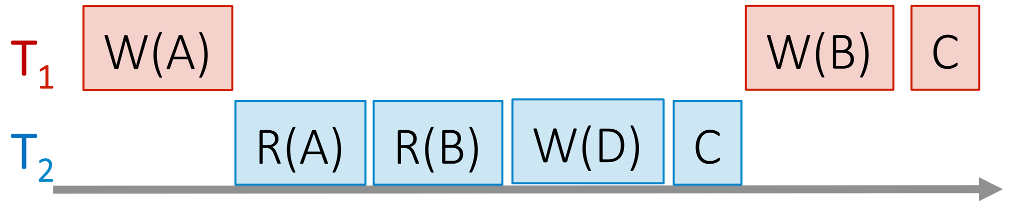
"Unrepeatable read":



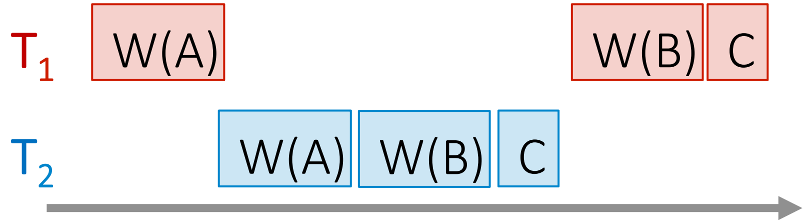
"Dirty read" / Reading uncommitted data:



"Inconsistent read" / Reading partial commits:



Partially-lost update:



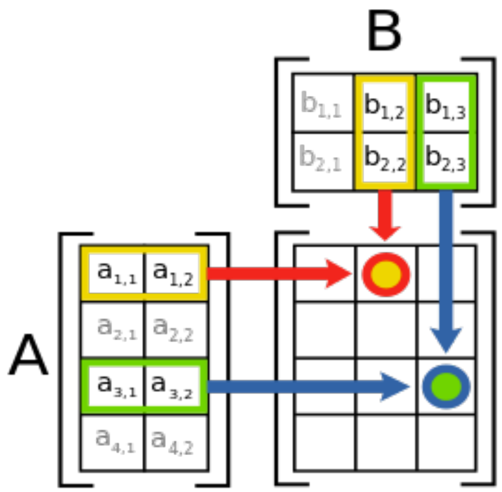
Notes

- Locking & etc. (all content in lecture 9 after activity 9-1) will **not** be covered

- PS1 review slides included as appendix (after this…)

- PS2 & additional content covered in extra review session on **Sunday, in Gates 104**

Linear Algebra, Declaratively



- Matrix multiplication & other operations = just **joins**!
- The shift from **procedural** to **declarative** programming

$C_{ij} = \sum_{k=1}^{m} A_{ik} B$

```
C = [[0]*p for i in range(n)]

for i in range(n):
  for j in range(p):
    for k in range(m):
      C[i][j] += A[i][k] * B[k][j]
```

Proceed through a series of instructions

```
SELECT A.i, B.j, SUM(A.x * B.x)
FROM A, B
WHERE A.j = B.i
GROUP BY A.i, B.j;
```

Declare a desired output set

Common SQL Query Paradigms

GROUP BY / HAVING + Aggregators + Nested queries

```
SELECT station_id,
       COUNT(day) AS nbd
FROM precipitation,
    (SELECT day, MAX(precip)
     FROM precipitation
     GROUP BY day) AS m
WHERE day = m.day AND precip = m.precip
GROUP BY station_id
HAVING COUNT(day) > 1
ORDER BY nbd DESC;
```

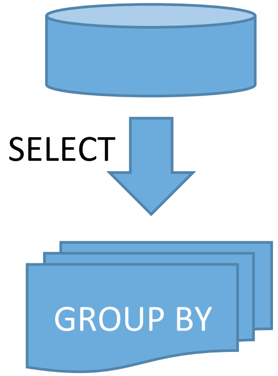
Think about **order***!

**of the semantics, not the actual execution*

Common SQL Query Paradigms

GROUP BY / HAVING + Aggregators + Nested queries

```
SELECT station_id,
       COUNT(day) AS nbd
FROM precipitation,
     (SELECT day, MAX(precip)
      FROM precipitation
      GROUP BY day) AS m
WHERE day = m.day AND precip = m.precip
GROUP BY station_id
HAVING COUNT(day) > 1
ORDER BY nbd DESC;
```

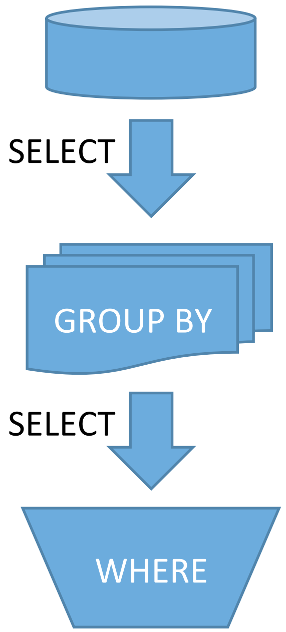


Get the max precipitation **by day**

Common SQL Query Paradigms

GROUP BY / HAVING + Aggregators + Nested queries

```
SELECT station_id,
       COUNT(day) AS nbd
FROM precipitation,
    (SELECT day, MAX(precip)
     FROM precipitation
     GROUP BY day) AS m
WHERE day = m.day AND precip = m.precip
GROUP BY station_id
HAVING COUNT(day) > 1
ORDER BY nbd DESC;
```



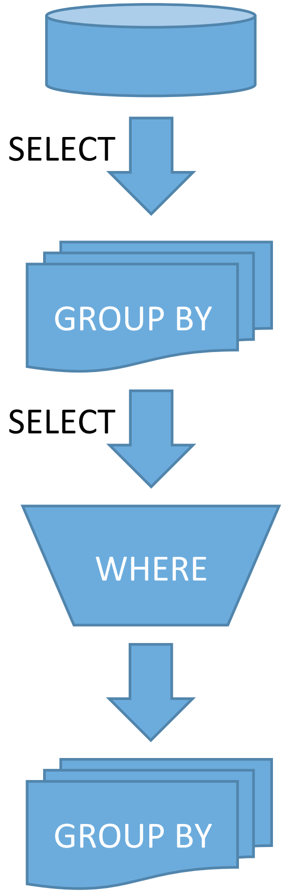
Get the max precipitation **by day**

Get the station, day pairs where / when this happened

Common SQL Query Paradigms

GROUP BY / HAVING + Aggregators + Nested queries

```
SELECT station_id,
       COUNT(day) AS nbd
FROM precipitation,
    (SELECT day, MAX(precip)
     FROM precipitation
     GROUP BY day) AS m
WHERE day = m.day AND precip = m.precip
GROUP BY station_id
HAVING COUNT(day) > 1
ORDER BY nbd DESC;
```



Get the max precipitation **by day**

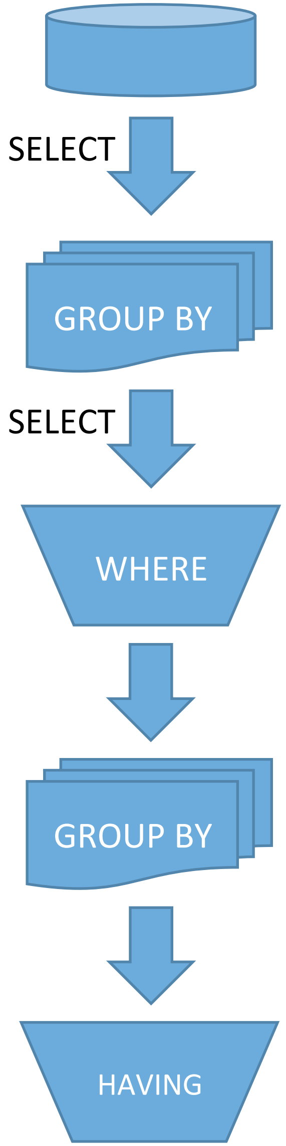
Get the station, day pairs where / when this happened

Group by stations

Common SQL Query Paradigms

GROUP BY / HAVING + Aggregators + Nested queries

```
SELECT station_id,
       COUNT(day) AS nbd
FROM precipitation,
    (SELECT day, MAX(precip)
     FROM precipitation
     GROUP BY day) AS m
WHERE day = m.day AND precip = m.precip
GROUP BY station_id
HAVING COUNT(day) > 1
ORDER BY nbd DESC;
```



Get the max precipitation **by day**

Get the station, day pairs where / when this happened

Group by stations

Having > 1 such day

Common SQL Query Paradigms

Complex correlated queries

```
SELECT x1.p AS median
FROM x AS x1
WHERE
      (SELECT COUNT(*)
       FROM X AS x2
       WHERE x2.p > x1.p)
      =
      (SELECT COUNT(*)
       FROM X AS x2
       WHERE x2.p < x1.p);
```

This was a tricky problem- but good practice in thinking about things declaratively

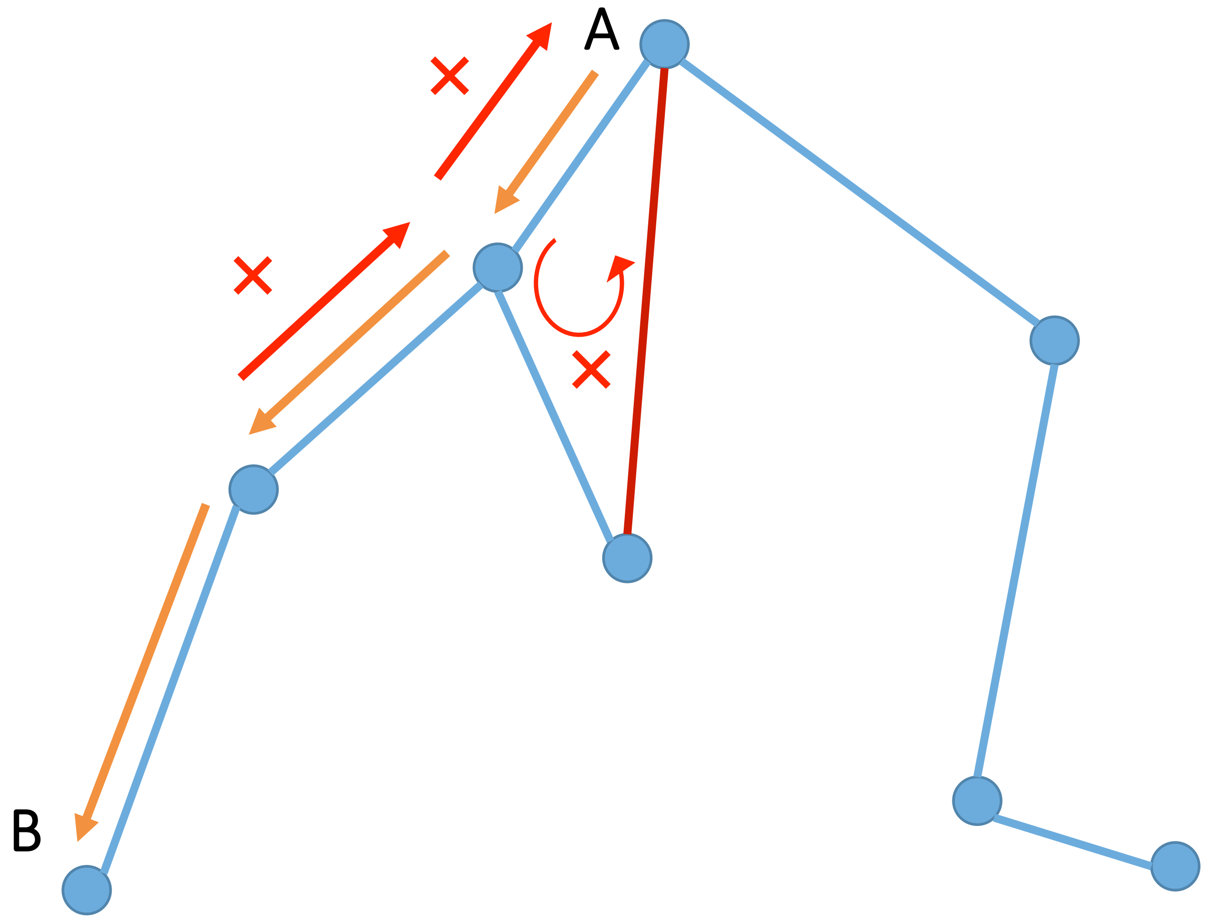
Common SQL Query Paradigms

Nesting + EXISTS / ANY / ALL

```
SELECT sid, p3.precip
FROM (
      SELECT sid, precip
      FROM precipitation AS p1
      WHERE precip > 0 AND NOT EXISTS (
            SELECT p2.precip
            FROM precipitation AS p2
            WHERE p2.sid = p1.sid
              AND p2.precip > 0
              AND p2.precip < p1.precip)) AS p3
WHERE NOT EXISTS (
      SELECT p4.precip
      FROM precipitation AS p4
      WHERE p4.precip – 400 > p3.precip);
```

More complex, but again just think about **order!**

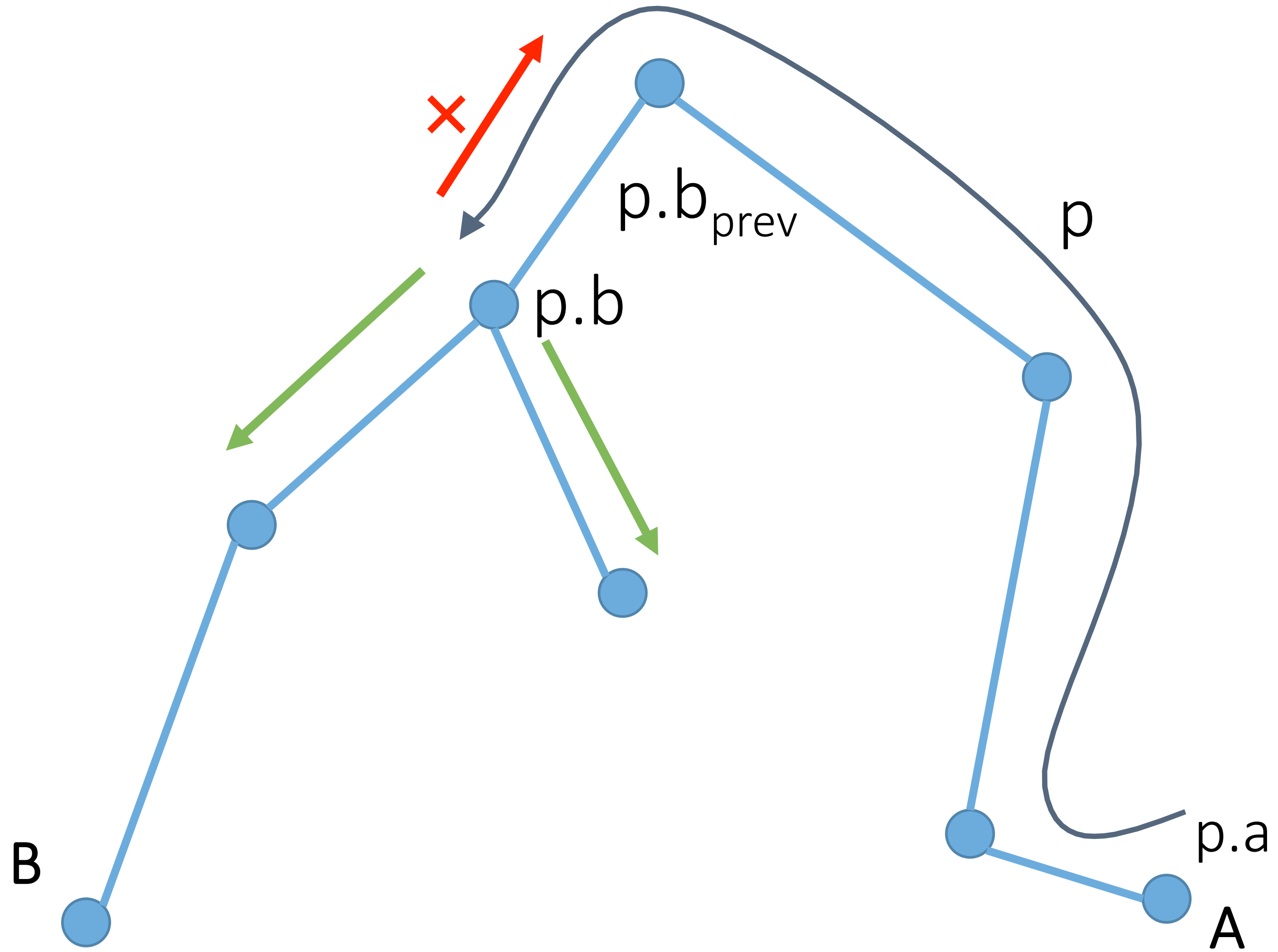
Graph traversal & recursion



For fixed-length paths

```
SELECT A, B, d
FROM edges
UNION
SELECT e1.A, e2.B,
       e1.d + e2.d AS d
FROM edges e1, edges e2
WHERE e1.B = e2.A
  AND e2.B <> e1.A
UNION
SELECT e1.A, e3.B,
       e1.d + e2.d + e3.d AS d
FROM edges e1, edges e2, edges e3
WHERE e1.B = e2.A
  AND e2.B = e3.A
  AND e2.B <> e1.A
  AND e3.B <> e2.A
  AMD e3.B <> e1.A
```

Graph traversal & recursion



For variable-length paths on trees

```
WITH RECURSIVE
paths(a, b, b_prev, d) AS (
      SELECT A, B, A
      FROM edges
      UNION
      SELECT p.a, e.B, e.A,
             p.d + e.d
      FROM paths p, edges e
      WHERE p.b = e.A
        AND e.B <> p.b_prev)
SELECT a, b, MAX(d)
FROM paths;
```