Academic Honesty Policy

- Collaboration is strongly encouraged, but…
- Each student must write down his/her own solutions independently in his or her own words.
- Each student must submit a list of anyone with whom the assignment was discussed.
- All sources (internet included) must be cited and credited.
- Solution sets from this course or any other course may not be used under any circumstances.

Mid-term Evaluation

- Participation
- Assignments
- Project Phase I

Mid-term Exam

- Lecture time on Nov 16th, 2015

Course Feedback and Discussion

- One representative from each seminar group
- Office 403, 11:00-12:00 Sep 25

Again, what if you have questions/problems?

- Slides, Textbooks, and Google
- Your classmates
- Piazza
- Your seminar instructors
- I am always available on Monday for your questions (403, 415, or around)

Again, how to succeed in the course?

- Read Slides, Textbooks, and use Google
- Work with your classmates
- Ask questions and help others on Piazza
- Discuss with your seminar instructors
- Participate lectures/seminars, handin assignments, handin projects

Functional Dependencies

Relational Design Theory

- How to assess the quality of a schema

  redundancy

  integrity constraints

  (Formal properties of a schema)Quality seal: normal forms

- How to improve the quality of a schema

  synthesis algorithm

  decomposition algorithm

- How to construct a (high-quality) schema

  start with universal relation

  apply synthesis or decomposition algorithms

Why not redundancy?

- Waste of storage space

  importance is diminishing as storage gets cheaper

  (disk density will even increase in the future)

- Additional work to keep multiple copies of data consistent

  multiple updates in order to accomodate one event

- Additional code to keep multiple copies of data consistent

  Somebody needs to implement the logic

but..

- Sometimes redundency is necessary.
- possible to improve data locality
- Space (memory, disk) is no longer the problem it used to be => tradeoff space/performance
- Fault tolerance
- We will discuss this later. Now we will focus on avoiding redundancy in a schema

Functional Dependencies

- *X* -> *A* is an assertion about a relation *R* that whenever two tuples of *R* agree on all the attributes of *X*, then they must also agree on the attribute *A*.
  - Say "*X* -> *A* holds in *R*."
  - Convention: …, *X*, *Y*, *Z* represent sets of attributes; *A*, *B*, *C*,… represent single attributes.
  - Convention: no set formers in sets of attributes, just *ABC*, rather than {*A*,*B*,*C* }.

Example

Drinkers(name, addr, beersLiked, manf, favBeer)

- Reasonable FD's to assert:

1. name -> addr
2. name -> favBeer
3. beersLiked -> manf

Example Data

name	addr	beersLiked	manf	favBeer
Janeway	Voyager	Bud	A.B.	WickedAle
Janeway	Voyager	WickedAle	Pete's	WickedAle
Spock	Enterprise	Bud	A.B.	Bud

Because name -> addr

Because name -> favBeer

Because beersLiked -> manf

FD's With Multiple Attributes

- No need for FD's with > 1 attribute on right.

  But sometimes convenient to combine FD’s as a shorthand.

  Example: name -> addr and name -> favBeer become name -> addr favBeer

- > 1 attribute on left may be essential.

  Example: bar beer -> price

Keys of Relations

- K is a *superkey* for relation R if K functionally determines all of R.
- K is a *key* for R if K is a superkey, but no proper subset of K is a superkey.

Example

Drinkers(name, addr, beersLiked, manf, favBeer)

- {name, beersLiked} is a superkey because together these attributes determine all the other attributes.

```
name -> addr favBeer

beersLiked -> manf
```

Example, Cont.

- {name, beersLiked} is a key because neither {name} nor {beersLiked} is a superkey.
  - name doesn’t -> manf; beersLiked doesn’t -> addr.
- There are no other keys, but lots of superkeys.
  - Any superset of {name, beersLiked}.

E/R and Relational Keys

- Keys in E/R concern entities.
- Keys in relations concern tuples.
- Usually, one tuple corresponds to one entity, so the ideas are the same.
- But --- in poor relational designs, one entity can become several tuples, so E/R keys and Relational keys are different.

Example Data

name	addr	beersLiked	manf	favBeer
Janeway	Voyager	Bud	A.B.	WickedAle
Janeway	Voyager	WickedAle	Pete's	WickedAle
Spock	Enterprise	Bud	A.B.	Bud

Relational key = {name beersLiked}

But in E/R, name is a key for Drinkers, and beersLiked is a key for Beers.

Note: 2 tuples for Janeway entity and 2 tuples for Bud entity.

Where Do Keys Come From?

1. Just assert a key *K*.
   - The only FD's are $K \rightarrow A$ for all attributes *A*.
2. Assert FD's and deduce the keys by systematic exploration.
   - E/R model gives us FD's from entity-set keys and from many-one relationships.

More FD's From "Physics"

- Example: " no two courses can meet in the same room at the same time" tells us: hour room -> course.

Inferring FD's

- We are given FD's X_1 -> A_1, X_2 -> A_2,…, X_n -> A_n , and we want to know whether an FD Y -> B must hold in any relation that satisfies the given FD's.

  Example: If A -> B and B -> C hold, A -> C holds. (Transitivity)

- Important for design of good relation schemas.

Inference Test

- To test if *Y* -> *B*, start by assuming two tuples agree in all attributes of *Y*.

← *Y* →

0000000. . . 0

00000?? . . . ?

Inference Test – (2)

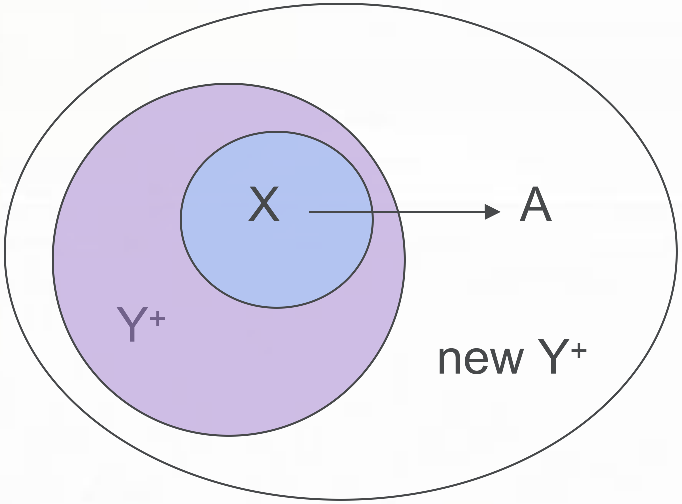
- Use the given FD's to infer that these tuples must also agree in certain other attributes.

  If B is one of these attributes, then $Y \rightarrow B$ is true.

  Otherwise, the two tuples, with any forced equalities, form a two-tuple relation that proves $Y \rightarrow B$ does not follow from the given FD's.

Closure Test

- An easier way to test is to compute the *closure* of Y, denoted Y^+.
- Basis: $Y^+ = Y$.
- Induction: Look for an FD left side X that is a subset of the current Y^+. If the FD is $X \rightarrow A$, add A to Y^+.



X
A
Y+
new Y+

Example

- A relation with attributes ABCDEF
- FD's: A,B -> C, BC-> AD, D->E
- AB+

Finding All Implied FD's

- Motivation: "normalize" the process where we break a relation schema into two or more schemas.

- Example: *ABCD* with FD's *AB* ->*C*, *C* ->*D*, and *D* ->*A*.

  Decompose into *ABC*, *AD*. What FD's hold in *ABC* ?

  Not only *AB* ->*C*, but also *C* ->*A* !

Why?

ABCD $a_1b_1cd_1$ $a_2b_2cd_2$

comes from

ABC a_1b_1c a_2b_2c

$d_1=d_2$ because $C \rightarrow D$

$a_1=a_2$ because $D \rightarrow A$

Thus, tuples in the projection with equal C's have equal A's; $C \rightarrow A$.

Basic Idea

1. Start with given FD's and find all *nontrivial* FD's that follow from the given FD's.

   Nontrivial = left and right sides disjoint.

2. Restrict to those FD's that involve only attributes of the projected schema.

Simple, Exponential Algorithm

1. For each set of attributes X, compute X^+.
2. Add $X \rightarrow A$ for all A in $X^+ - X$.
3. However, drop $XY \rightarrow A$ whenever we discover $X \rightarrow A$.
   - Because $XY \rightarrow A$ follows from $X \rightarrow A$ in any projection.
4. Finally, use only FD's involving projected attributes.

A Few Tricks

- No need to compute the closure of the empty set or of the set of all attributes.
- If we find X^+ = all attributes, so is the closure of any superset of X.

Example

- ABC with FD's $A \to B$ and $B \to C$. Project onto AC.

  $A^+ = ABC$; yields $A \to B$, $A \to C$.

  - We do not need to compute AB^+ or AC^+.

  $B^+ = BC$; yields $B \to C$.

  $C^+ = C$; yields nothing.

  $BC^+ = BC$; yields nothing.

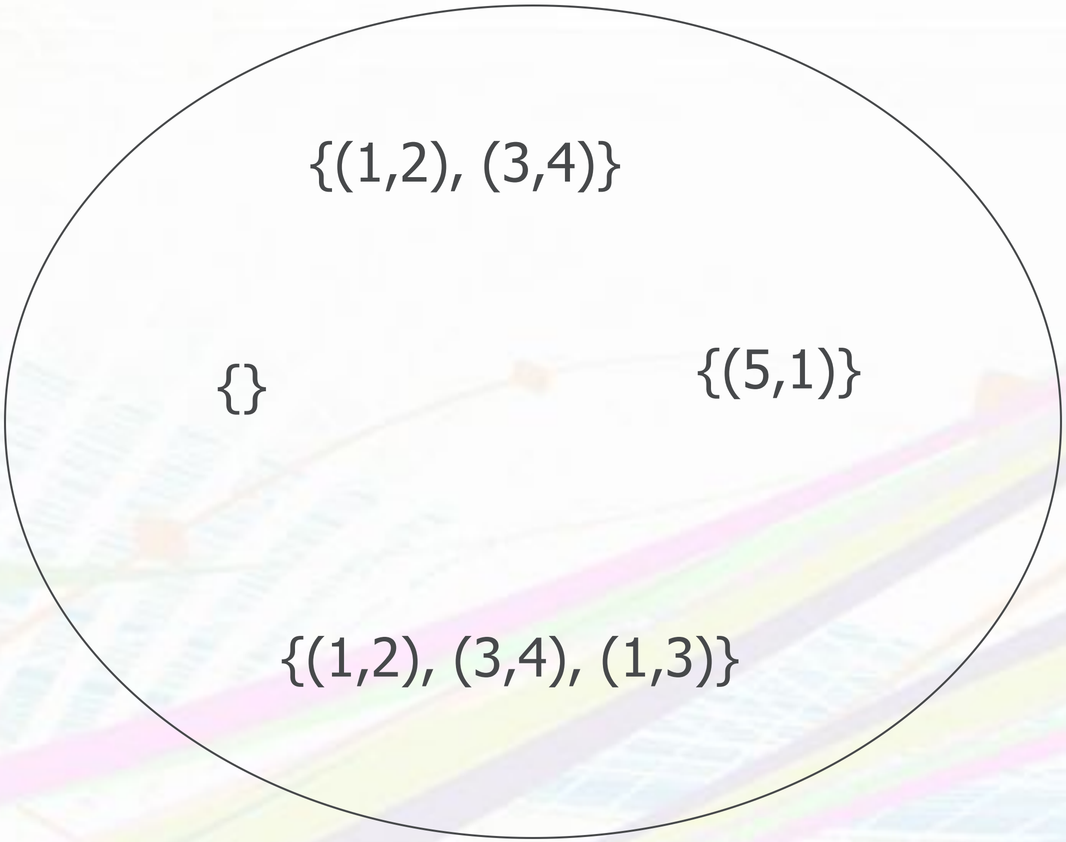
Example --- Continued

- Resulting FD's: $A \rightarrow B$, $A \rightarrow C$, and $B \rightarrow C$.
- Projection onto AC : $A \rightarrow C$.
  - Only FD that involves a subset of $\{A, C\}$.

A Geometric View of FD's

- Imagine the set of all *instances* of a particular relation.
- That is, all finite sets of tuples that have the proper number of components.
- Each instance is a point in this space.

Example: R(A,B)

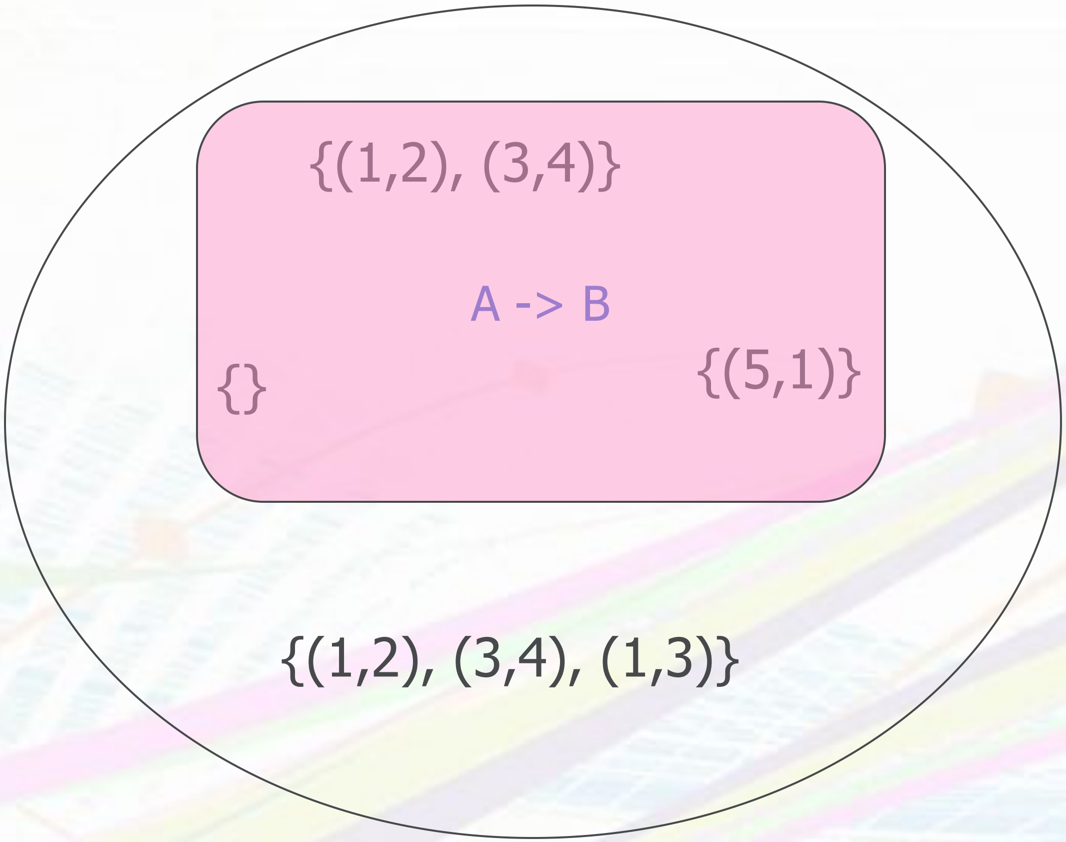


An FD is a Subset of Instances

- For each FD *X -> A* there is a subset of all instances that satisfy the FD.
- We can represent an FD by a region in the space.
- Trivial FD = an FD that is represented by the entire space.

  Example: *A -> A*.

Example: A -> B for R(A,B)



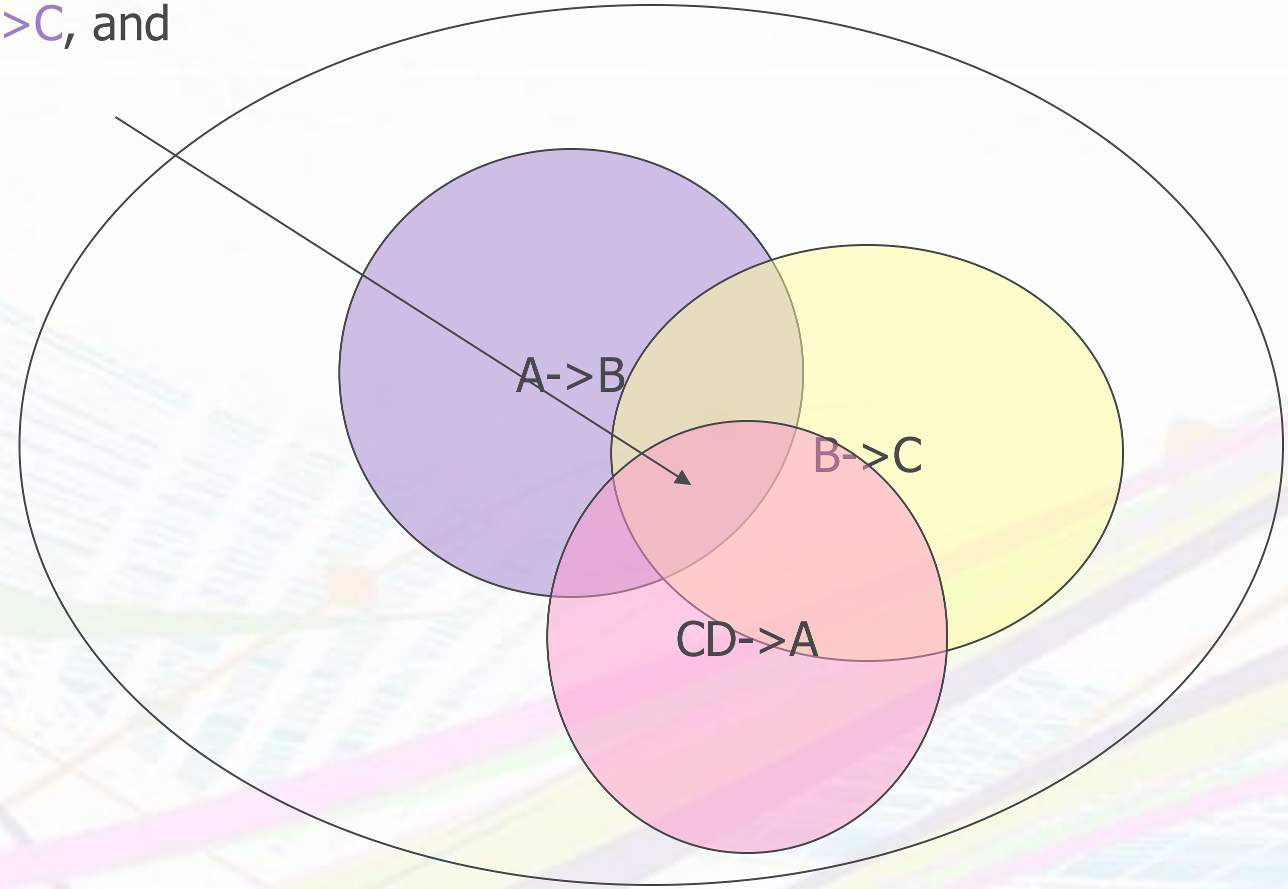
Representing Sets of FD's

- If each FD is a set of relation instances, then a collection of FD's corresponds to the intersection of those sets.

  Intersection = all instances that satisfy all of the FD’s.

Example

Instances satisfying
A->B, B->C, and
CD->A



Implication of FD's

- If an FD $Y \to B$ follows from FD's $X_1 \to A_1, \ldots, X_n \to A_n$, then the region in the space of instances for $Y \to B$ must include the intersection of the regions for the FD's $X_i \to A_i$.

That is, every instance satisfying all the FD's $X_i \to A_i$ surely satisfies $Y \to B$.

But an instance could satisfy $Y \to B$, yet not be in this intersection.

Example