# Normalization is a Good Idea

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# Steps for a New Application

Requirements

what are you going to build?

Conceptual Database Design

pen-and-pencil description

Logical Design

formal database schema

Schema Refinement:

fix potential problems, normalization

Normalization

Physical Database Design

use sample of queries to optimize for speed/storage

App/Security Design

prevent security problems

# A Relational Model of Data for Large Shared Data Banks

E. F. Codd
*IBM Research Laboratory, San Jose, California*

Future users of large data banks must be protected from having to know how the data is organized in the machine (the internal representation). A prompting service which supplies such information is not a satisfactory solution. Activities of users at terminals and most application programs should remain unaffected when the internal representation of data is changed and even when some aspects of the external representation are changed. Changes in data representation will often be needed as a result of changes in query, update, and report

# Redundancy = Bad

What was our solution?

- Break database into small relations
- Perform good ER modeling and SQL translation
- Kind of ... adhoc

Is there a systematic approach??

# Redundancy = Bad

| sid | name | address | hobby | cost |
|---|---|---|---|---|
| 1 | Eugene | amsterdam | trucks | $$ |
| 1 | Eugene | amsterdam | cheese | $ |
| 2 | Bob | 40th | paint | $$$ |
| 3 | Bob | 40th | cheese | $ |
| 4 | Shaq | florida | swimming | $ |

people have names and addrs

hobbies have costs

people many-to-many with hobbies

What's primary key?  sid?  sid + hobby?

Update/insert/delete anomalies. Wastes space

## Anomalies (Inconsistencies)

Update Anomaly

change one address, need to change all

Insert Anomaly

add person without hobby?

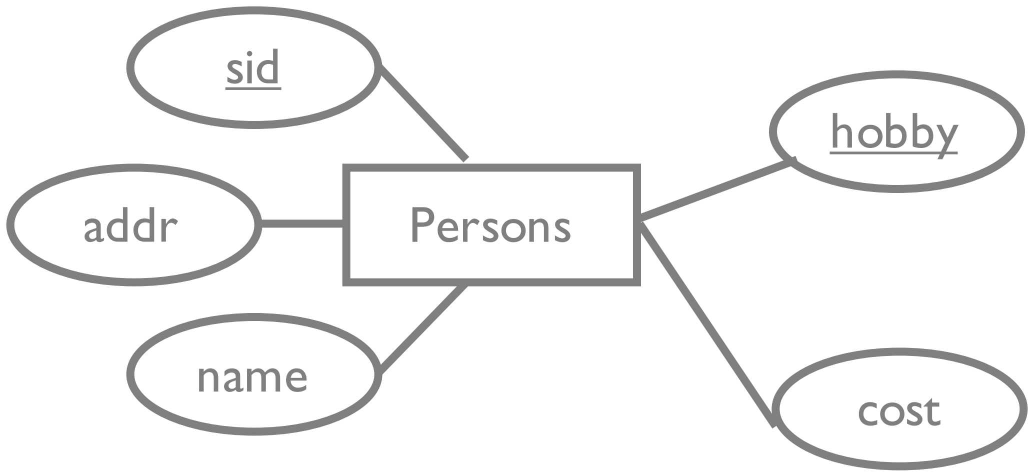
not allowed? dummy hobby?

Delete Anomaly

if delete a hobby. Delete the person?

**Theory Can Fix This!**

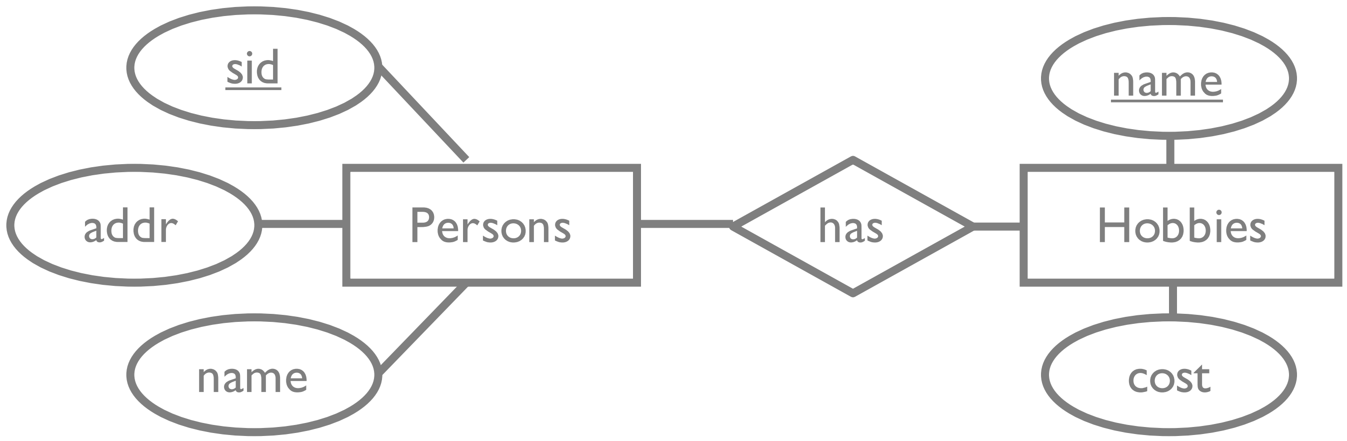
# A Possible Approach



```
data(sid, addr, name, hobby, cost)
```

# A Possible Approach

ER diagram was a heuristic



We have decomposed example table into:

```
person(sid, addr, name)
hobby(name, cost)
personhobby(hobbyname, sid)
```

WHY is this a good decomposition??

# A Possible Approach

What if decompose into:

```
    person(sid, name, addr, cost)
    personhobby(sid, hobbyname)
```

| sid | name | addr | cost |
|---|---|---|---|
| 1 | Eugene | amsterdam | $$ |
| 1 | Eugene | amsterdam | $ |
| 2 | Bob | 40th | $$$ |
| 3 | Bob | 40th | $ |
| 4 | Shaq | florida | $ |

| sid | hobby |
|---|---|
| 1 | trucks |
| 1 | cheese |
| 2 | paint |
| 3 | cheese |
| 4 | swimming |

but… which cost goes with which hobby?

lost information: *lossy decomposition*

## Decomposition

Replace schema R with 2+ smaller schemas that

1. each contain subset of attrs in R
2. together include all attrs in R

ABCD replaced with AB, BCD or AB, BC, CD

Not free – may introduce problems!

1. lossy-join: able to recover R from smaller relations
2. non-dependency-preserving: constraints on R hold by only enforcing constraints on smaller schemas
3. performance: additional joins, may affect performance

Can we systematically decompose our relation to

prevent decomposition problems & remove redundancy?

# Functional Dependencies (FD)

| sid | name | address | hobby | cost |
|---|---|---|---|---|
| 1 | Eugene | amsterdam | trucks | $$ |
| 1 | Eugene | amsterdam | cheese | $ |
| 2 | Bob | 40th | paint | $$$ |
| 3 | Bob | 40th | cheese | $ |
| 4 | Shaq | florida | swimming | $ |

sid sufficient to identify name and addr, but not hobby

e.g., exists a function f(sid) → name, addr

sid → name, addr is a functional dependency

"sid determines name, addr"

"name, addr are functionally dependent on sid"

"if 2 records have the same sid, their name and addr are the same"

# Functional Dependencies (FD)

$X \rightarrow Y$

holds on R

if $t_1.X = t_2.X$ then $t_1.Y = t_2.Y$

where X,Y are subsets of attrs in R

Examples of FDs in person-hobbies table

- sid, hobby → name, address cost
- hobby → cost
- sid → name, address

## Fun Facts

Functional Dependency is an integrity constraint

- statement about all instances of relation
- Generalizes key constraints
  - if K is candidate key of R, then K → R

Given FDs, simple definition of redundancy

- when left side of FD is not table key

Where do FDs come from?

- thinking really hard aka application semantics
- can’t stare at database to derive (like ICs)

# Fun Facts

Functional Dependency is an integrity constraint

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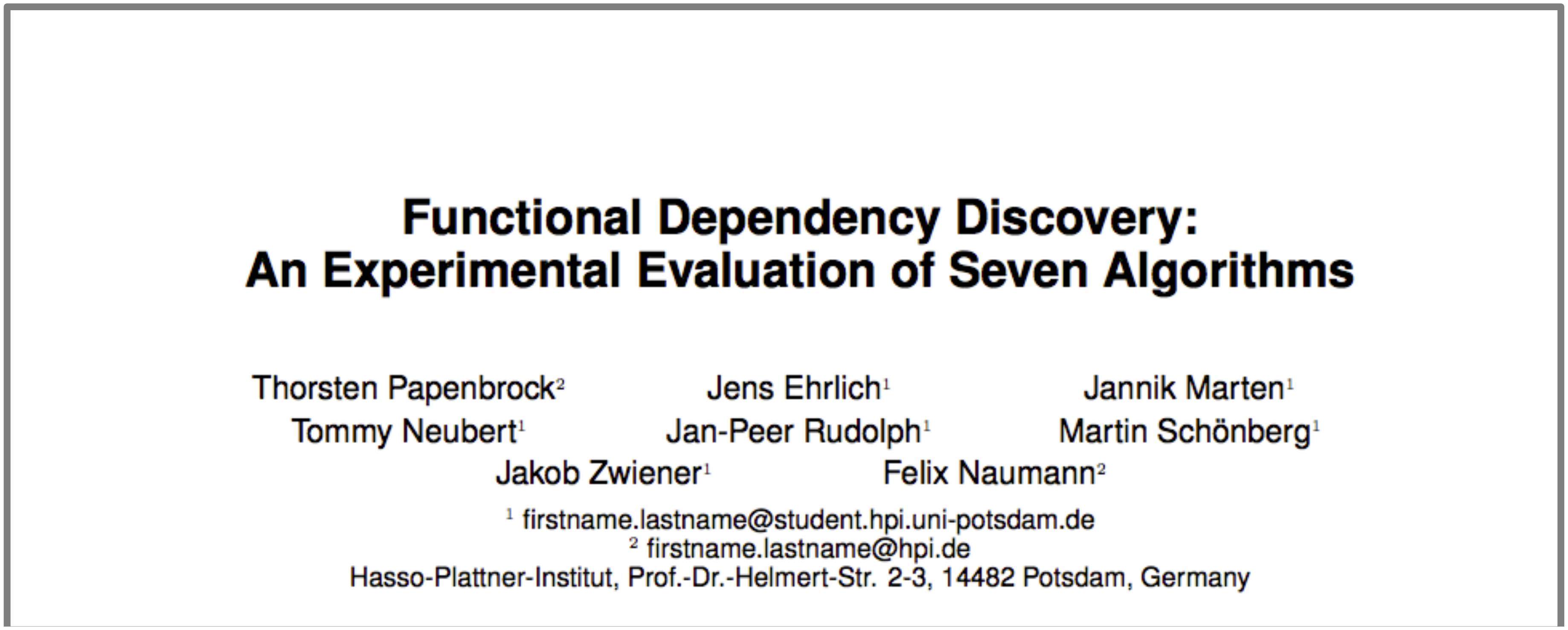

**Functional Dependency Discovery:
An Experimental Evaluation of Seven Algorithms**

Thorsten Papenbrock[2] Jens Ehrlich[1] Jannik Marten[1]
Tommy Neubert[1] Jan-Peer Rudolph[1] Martin Schönberg[1]
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## Normal Forms

Two different criterias for decomposing a relation

Boyce Codd Normal Form (BCNF)

No redundancy, may lose dependencies

Third Normal Form (3NF)

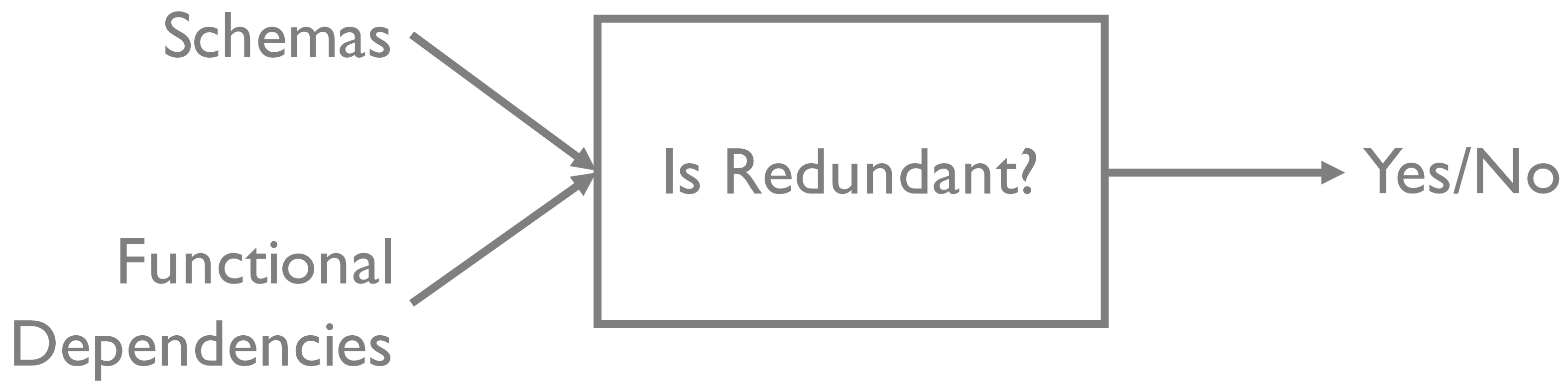
May have redundancy, no decomposition problems

## Redundancy depends on FDs

consider R(ABC)

no FDs: no redundancy

if A→B: tuples with same A value means B is duplicated!



# BCNF

Relation R in BCNF has *no redundancy* wrt FDs

(only FDs are key constraints)

```
F: set of functional dependencies over relation R

for (X→Y) in F
    Y is in X or
    X is a superkey of R
```

Is this in BCNF?

sid → name

| sid | hobby | name |
|---|---|---|
| x | $y_1$ | z |
| x | $y_2$ | ? |

## BCNF

Relation R in BCNF has *no redundancy* wrt FDs

(only FDs are key constraints)

```
F: set of functional dependencies over relation R

for (X→Y) in F
   Y is in X or
   X is a superkey of R
```

Functional Dependencies

SH → NAC (sid, hobby → name, addr, cost)
H → C
S → NA

What's in BCNF?

| | |
|---|---|
| SHNAC | NO |
| SNA, SHC | NO |
| SNA, HC, SH | YES |

# BCNF

Suppose we have

Client, Office → Account

Account → Office

What's in BCNF?

R(Account, Client, Office)

R(Account, Office)   R(Client, Account)

Where did CO→A go? *Lost a Functional Dependency*

Can we preserve FDs *and* remove most redundancy?

# 3rd Normal Form (3NF)

Relax BCNF (e.g., BCNF⊆3NF)

```
F: set of functional dependencies over relation R

for (X→Y) in F
   Y is in X or
   X is a superkey of R or
```

# $3^{rd}$ Normal Form (3NF)

Relax BCNF (e.g., BCNF⊆3NF)

```
F: set of functional dependencies over relation R

for (X→Y) in F
   Y is in X or
   X is a superkey of R or
   Y is part of a key in R
```

Is new condition trivial? NO! key is minimal

Nice properties

lossless join ^ dependency preserving decomposition to 3NF always possible

## $3^{rd}$ Normal Form (3NF)

Relax BCNF (e.g., BCNF$\subseteq$3NF)

```
F: set of functional dependencies over relation R

for (X→Y) in F
    Y is in X or
    X is a superkey of R or
    Y is part of a key in R
```

FDs

CO → A

A → O

(AO), (CA) splits up key in CO→A

COA is in 3NF!

# $3^{rd}$ Normal Form (3NF)

Relax BCNF (e.g., BCNF⊆3NF)

```
F: set of functional dependencies over relation R

for (X→Y) in F
    Y is in X or
    X is a superkey of R or
    Y is part of a key in R
```

Schema: SBDC

SBD→C, S→C  Not in 3NF

SBD→C, S→C, C→S  In 3NF (Hint: CBD is a key)

In both cases, SC is stored redundantly

## We’re going to need some theory

Closure of FDs

- armstrong’s axioms

Minimal FD Set

Principled Decomposition

BCNF & 3NF

# Closure of FDs

If I know

Name → Bday and Bday → age

Then it implies

Name → age

f' is implied by set F if f' is true when F is true

$F^+$ closure of F is all FDs implied by F

Can we construct this closure automatically? YES

# Closure of FDs

*Inference rules* called Armstrong's Axioms

| | |
|---|---|
| Reflexivity | if $Y \subseteq X$ then $X \rightarrow Y$ |
| Augmentation | if $X \rightarrow Y$ then $XZ \rightarrow YZ$ for any $Z$ |
| Transitivity | if $X \rightarrow Y$ & $Y \rightarrow Z$ then $X \rightarrow Z$ |

These are sound and complete rules

| | |
|---|---|
| sound | doesn't produce FDs not in the closure |
| complete | doesn't miss any FDs in the closure |

# Closure of FDs

Can we compute the closure?     YES. slowly

expensive. exponential in # attributes

Can we *check* if $X \rightarrow Y$ is in the closure of F?

$X^+$ = *attribute closure* of X (expand X using axioms)

check if Y is implied in the attribute closure

# Closure of FDs

$F = \{A \rightarrow B, B \rightarrow C, CB \rightarrow E\}$

Is $A \rightarrow E$ in the closure?

| | |
|---|---|
| $A \rightarrow B$ | given |
| $A \rightarrow AB$ | augmentation A |
| $A \rightarrow BB$ | apply $A \rightarrow B$ (transitivity) |
| $A \rightarrow BC$ | apply $B \rightarrow C$ (transitivity) |
| $A \rightarrow E$ | apply $BC \rightarrow E$ (transitivity) |

## We’re going to need some theory

Closure of FDs

- armstrong’s axioms

Minimal FD Set

Principled Decomposition

BCNF & 3NF

## Minimum Cover of FDs

Closures let us compare sets of FDs meaningfully

$F1 = \{A \rightarrow B, A \rightarrow C, A \rightarrow BC\}$

$F2 = \{A \rightarrow B, A \rightarrow C\}$

F1 equivalent to F2

If there's a closure (a maximally expanded FD), there's a *minimal* FD. Let's find it

# Minimum Cover of FDs

1. Turn FDs into *standard form*
   decompose each FD so single attr on the right side

2. Minimize left side of each FD
   for each FD, check if can delete left attr w/out changing closure
   given ABC → D, B→C   can reduce to AB→D, B→C

3. Delete redundant FDs
   check each remaining FD and see if it can be deleted
   e.g., in closure of the other FDs

2 must happen before 3!

# Minimum Cover of FDs

A→B, ABC→E, EF→G, ACF→EG

Standard form

A→B, ABC→E, EF→G, ACF→E, ACF→G

Minimize left side

A→B, AC→E, EF→G, ACF→E, ACF→G

reason: AC→E + A→B implies ABC→E

Delete Redundant FDs

A→B, AC→E, EF→G, ~~ACF→E, ACF→G~~

reason: ACF→E implied by AC→E, EF→G

## We’re going to need some theory

Closure of FDs

- armstrong’s axioms

Minimal FD Set

Principled Decomposition

BCNF & 3NF

## Decomposition

Eventually want to decompose R into $R_1 \ldots R_n$ wrt F

We've seen issues with decomposition.

- Lost Joins: Can't recover R from $R_1 \ldots R_n$
- Lost dependencies

Principled way of avoiding these?

# Lossless Join Decomposition

Let's say relation R is decomposed into relations X, Y

Join the decomposed tables to get *exactly the* original

$\pi_X(R) \bowtie \pi_Y(R) = R$

Lossless wrt F if and only if $F^+$ contains

$X \cap Y \rightarrow X$ or $Y \cap X \rightarrow Y$

intersection of X, Y is a key for one of them

# Lossless Join Decomposition

Lossless wrt F if and only if $F^+$ contains

$X \cap Y \rightarrow X$ or $Y \cap X \rightarrow Y$

intersection of X, Y is a key for one of them

FDs: $A \rightarrow C, A \rightarrow B$

| A | B | C |
|---|---|---|
| 1 | 2 | 1 |
| 5 | 3 | 4 |
| 9 | 2 | 6 |

→

| A | B |
|---|---|
| 1 | 2 |
| 5 | 3 |
| 9 | 2 |

| B | C |
|---|---|
| 2 | 1 |
| 3 | 4 |
| 2 | 6 |

→

| A | B | C |
|---|---|---|
| 1 | 2 | 1 |
| 5 | 3 | 4 |
| 9 | 2 | 6 |
| 1 | 2 | 6 |
| 9 | 2 | 1 |

Lossy! $AB \cap BC = B$ doesn't determine anything

# Lossless Join Decomposition

Lossless wrt F if and only if $F^+$ contains

$X \cap Y \rightarrow X$ or $Y \cap X \rightarrow Y$

intersection of X, Y is a key for one of them

FDs: $A \rightarrow C, A \rightarrow B$

| A | B | C |
|---|---|---|
| 1 | 2 | 1 |
| 5 | 3 | 4 |
| 9 | 2 | 6 |

$\rightarrow$

| A | B |
|---|---|
| 1 | 2 |
| 5 | 3 |
| 9 | 2 |

| A | C |
|---|---|
| 1 | 1 |
| 5 | 4 |
| 9 | 6 |

$\rightarrow$

| A | B | C |
|---|---|---|
| 1 | 2 | 1 |
| 5 | 3 | 4 |
| 9 | 2 | 6 |

OK

# Dependency-preserving Decomposition

$F_R$ = Projection of F onto R

Subset of F that are "valid" for R

FDs $X \rightarrow Y$ in $F^+$ s.t. X and Y attrs are in R

If R decompose to X, Y.

FDs that hold on X, Y equivalent to all FDs on R

$(F_X \cup F_Y)^+ = F^+$

Consider ABCD, C is key, $AB \rightarrow C$, $D \rightarrow A$

BCNF decomposition: BCD, DA

$AB \rightarrow C$ doesn't apply to either table!

## We’re going to need some theory

- Closure of FDs
    - armstrong’s axioms
- Minimal FD Set
- Principled Decomposition
- BCNF & 3NF

# BCNF

```
while BCNF is violated
   R with FDs $F_R$
   if X→Y violates BCNF
      turn R into R-Y & XY
```

ABCDE    key A, BC→A, D→B, C→D

DB, ACDE    using D→B

DB, CD, ACE    using C→D

uh oh, lost BC→A

note: we just blindly apply decomposition

# 3NF

```
$F^{min}$ = minimal cover of F
Run BCNF using $F^{min}$
for $X \rightarrow Y$ in $F^{min}$ not in projection onto $R_1 \ldots R_N$
    create relation XY
```

ABCDE key A, $BC \rightarrow A$, $D \rightarrow B$, $C \rightarrow D$

# 3NF

$F^{min}$ = minimal cover of F

Run BCNF using $F^{min}$

```
for X→Y in F^min not in projection onto R_1…R_N
    create relation XY
```

ABCDE $A \rightarrow B$, $A \rightarrow C$, $A \rightarrow D$, $A \rightarrow E$,

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

Expand $A \rightarrow BCDE$

Due to $C \rightarrow D$ and $D \rightarrow B$, we know that $C \rightarrow B$

# 3NF

$F^{min}$ = minimal cover of F

Run BCNF using $F^{min}$

```
for X→Y in F^min not in projection onto R_1…R_N
    create relation XY
```

ABCDE  A→B, A→C, A→ D, A→E,
C→A, D→B~~, C→D~~

C→A and A→D implies C→D

# 3NF

```
$F^{min}$ = minimal cover of F
Run BCNF using $F^{min}$
for $X \rightarrow Y$ in $F^{min}$ not in projection onto $R_1 \ldots R_N$
    create relation XY
```

ABCDE    $A \rightarrow B$, $A \rightarrow C$, $A \rightarrow D$, $A \rightarrow E$,
$C \rightarrow A$, $D \rightarrow B$

| | |
|---|---|
| DB, ACDE | using $D \rightarrow B$ |
| DB, AC, ADE | using $A \rightarrow C$ |
| DB, CD, AE, AD | using $A \rightarrow E$ |

# 3NF

$F^{min}$ = minimal cover of F

Run BCNF using $F^{min}$

```
for $X \rightarrow Y$ in $F^{min}$ not in projection onto $R_1 \ldots R_N$
    create relation XY
```

ABCDE $\quad A \rightarrow B,\ A \rightarrow C,\ A \rightarrow D,\ A \rightarrow E,$
$C \rightarrow A,\ D \rightarrow B$

| | |
|---|---|
| DB, ACDE | using $D \rightarrow B$ |
| DB, AC, ADE | using $A \rightarrow C$ |
| DB, AC, AE, AD | using $A \rightarrow E$ |
| DB, AC, AE, AD, AB | to recover lost dependency $A \rightarrow B$ |

## Summary

Normal Forms: BCNF and 3NF

FD closures: Armstrong's axioms

Proper Decomposition

## Summary

Accidental redundancy is really really bad

Adding lots of joins can hurt performance

Can be at odds with each other

Normalization good starting point, relax as needed

People usually think in terms of entities and keys, usually ends up reasonable

## What you should know

- Purpose of normalization
  - Anomalies
  - Decomposition problems
  - Functional dependencies & axioms
- 3NF & BCNF
  - properties
  - algorithm