Normalization

Knowledge objectives

1. Distinguish cartesian product, relation and function terms in set theory terminology
2. Explain the goal of the relational normalization and how to reach it
3. Give the definition of NF^2, 1NF, 2NF, 3NF, BCNF and 4NF
4. Explain the inclusion dependencies between different normal forms

Understanding objectives

1. Explain whether a functional dependency is true or not, given the extension of the relation and the semantics of the attributes
2. Explain whether a functional dependency is full or not, given the extension of the relation and the semantics of the attributes
3. Explain through an example the insertion, update and deletion anomalies that may appear in a relation
4. Justify in which normal form a relation is, given its candidate keys, an explanation of its contents and possibly an extension
5. Normalize a relation up to BCNF, given its functional dependencies and using the analysis algorithm
6. Explain through an example why sometimes it may be better to denormalize a relational schema

Application objectives

- Find all functional dependencies in a relation, given its schema and an explanation of its contents

Anomalies

Updating

Deleting

Inserting

Update anomaly

Supplying			
prov	item	quant	city
1	a1	100	~~BCN~~
1	a2	150	~~BCN~~
2	a1	200	MDR
2	a2	300	MDR
3	a2	100	MDR

Athens

Athens

Several tuples need to be updated because of only one change!

Deletion anomaly

Supplying			
prov	item	quant	city
1	a1	100	BCN
1	a2	150	BCN
2	a1	200	MDR
2	a2	300	MDR
~~3~~	~~a2~~	~~100~~	~~MDR~~

Data may be lost unintentionally!

Insertion anomaly

Supplying			
prov	Item	Quant	city
1	a1	100	BCN
1	a2	150	BCN
2	a1	200	MDR
2	a2	300	MDR
3	a2	100	MDR
~~4~~	~~NULL~~	~~NULL~~	~~Athens~~

Data cannot be inserted independently!

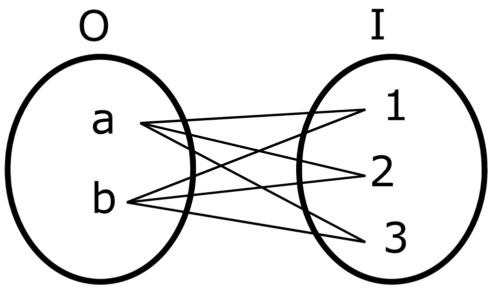
Motivation

- Objective:
  - Formalize a set of simple ideas that guide a good database design

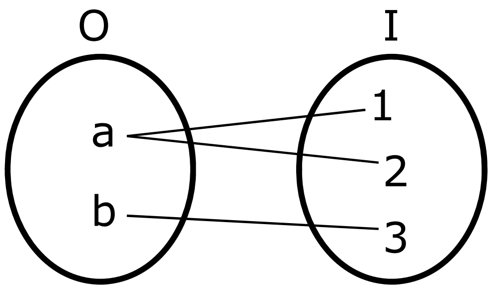
- Foundations:
  - Every relation (SQL table) must correspond to one semantic concept
    - Normalization theory allows us to recognize when this principle is not fulfilled

Functional dependencies

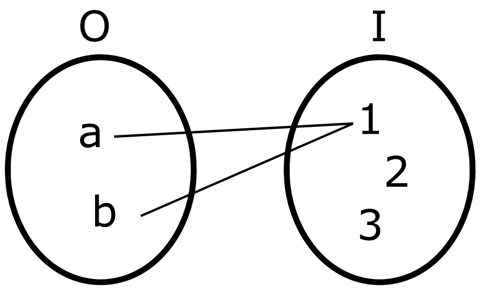
Set theory (I)



Cartesian product

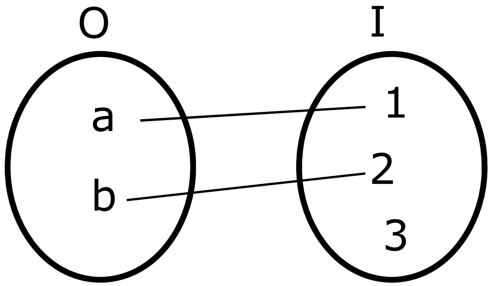


Relation
(subset of the cartesian product)



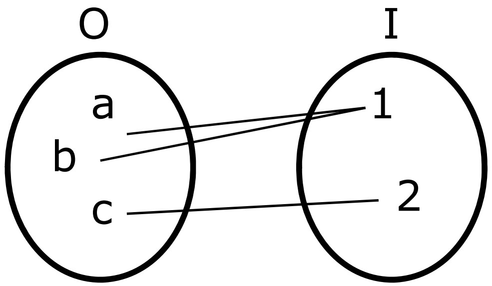
Function
(every origin at most one image)

Set theory (II)

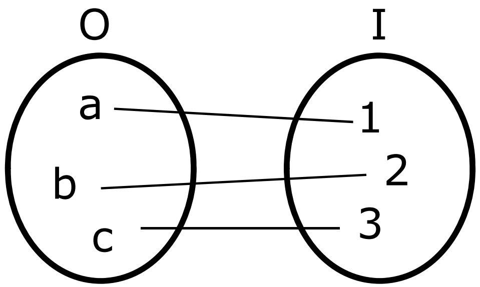


Injective function
(every image at most one origin)

PK are injective functions

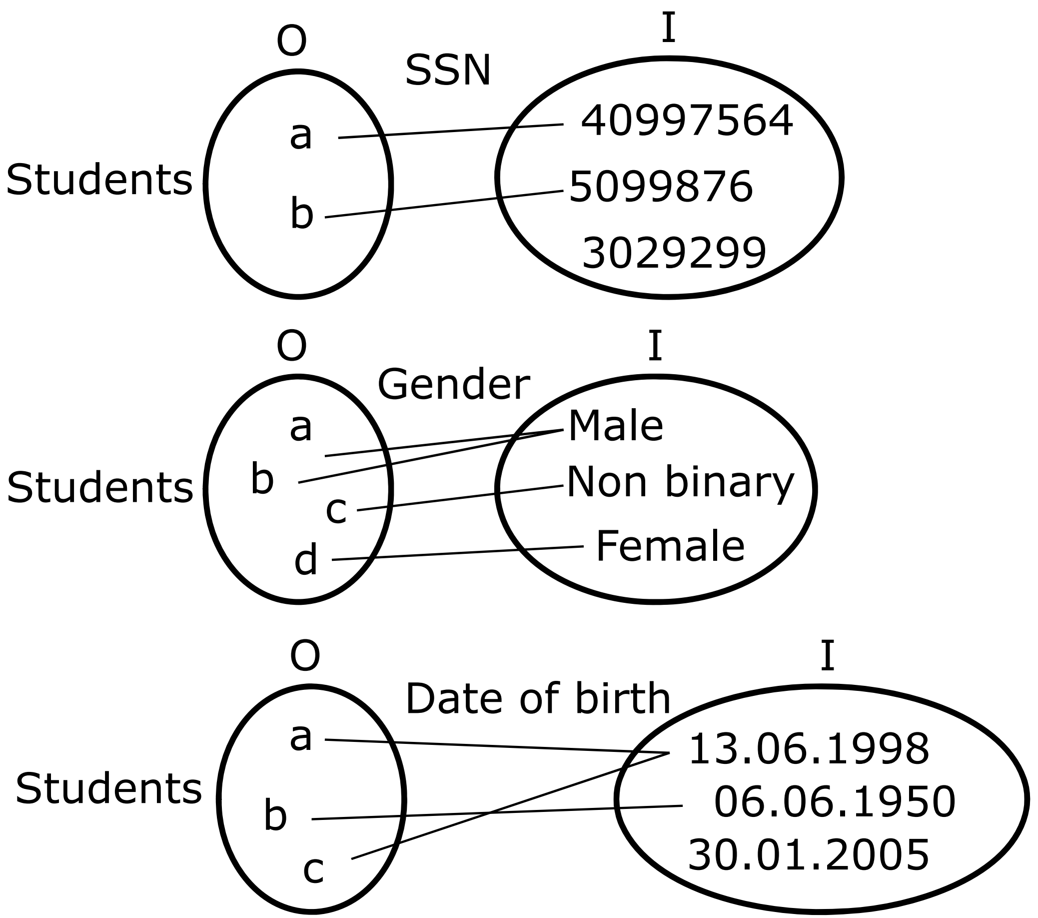


Exhaustive function
(every image at least one origin)



Bijective function
(every image exactly one origin)

Set theory and databases



Injective function

Exhaustive function

It is not:
- injective,
- exhaustive,
- bijective

Functional Dependencies

$$R\ (A_1, A_2, \ldots, A_n)$$

- An FD {X} → {Y} (e.g., {SSN} → {birthDate}, {provider} → {city}) guarantees that given a value of {X}, this univocally determines the value of {Y}

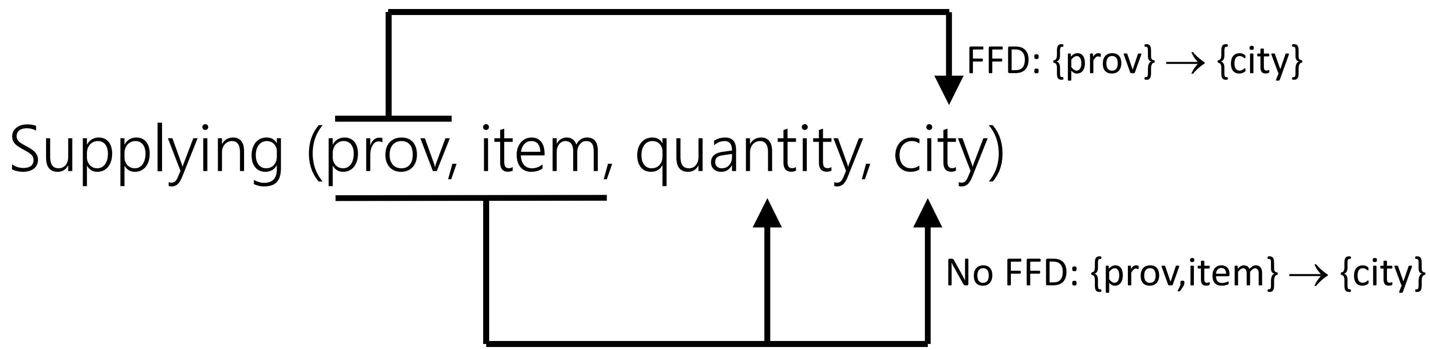
$$\forall s,t \in R,\ s[X]=t[X] \Rightarrow s[Y]=t[Y]$$

{X} functionally determines {Y}

{Y} functionally depends on {X}

Fully Functional Dependencies

- An FD {X} → {Y} is fully (FFD) iff there is no proper subset of {X} which determines {Y}



Normal forms

NF^2

1NF

2NF

3NF

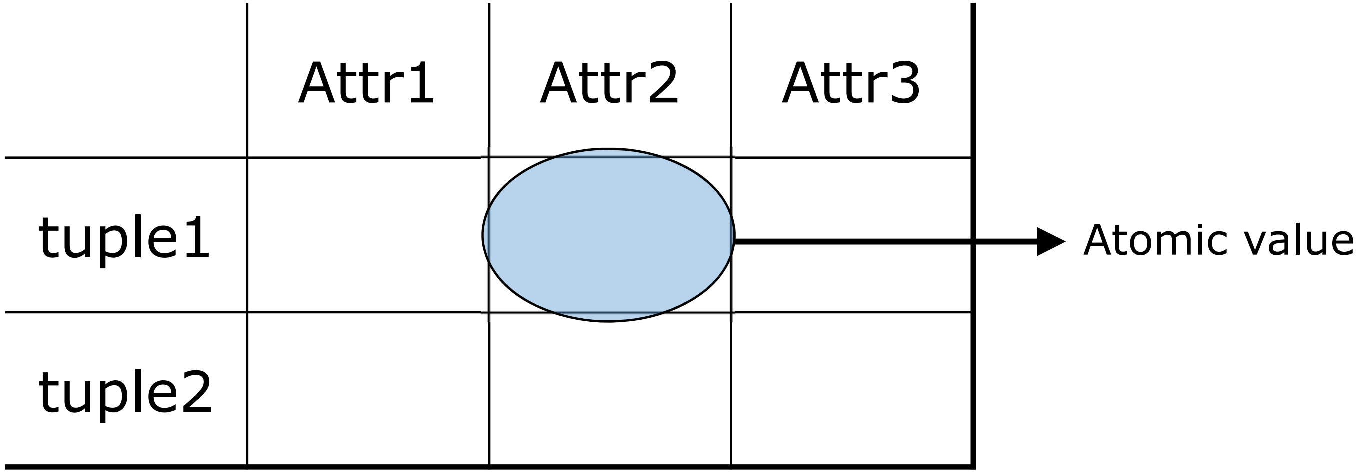
BCNF

Overall ideas

- The main purpose is to eliminate redundancies and update anomalies
- A normal form restricts the set of dependencies in a relation
- Schemas in normal form are “good” schemas

First Normal Form - 1NF (I)

- A relation (SQL table) is in 1NF iff no attribute is itself a table; that is, every attribute value is atomic (non-breakable, non-aggregate and non-group)



First Normal Form - 1NF (II)

Pieces (<u>#piece</u>, description, proj_quantity)

100	{name: "screw", size: 0.5}	1 12 2 24
101	{name: "chair", size: 75}	1 4 3 22

Normalize (flatten)

Pieces (<u>#piece</u>, name, size, proj, quantity)

PK?

100	screw	0.5	1	12
100	screw	0.5	2	24
101	chair	75	1	4
101	chair	75	3	22

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Second Normal Form – 2NF (I)

- A relation (SQL table) is in 2NF iff:
  - It is in 1NF

    &
  - Every non-key attribute depends FFD on each of the candidate keys

- Exception: an attribute may functionally depend on a part of a candidate key if this attribute is part of another candidate key

Second Normal Form – 2NF (II)

(prov, item, quantity, provider_city)

Normalize (split)

(prov, item, quantity)

FK

(prov, provider_city)

2 semantic concepts

2 tables

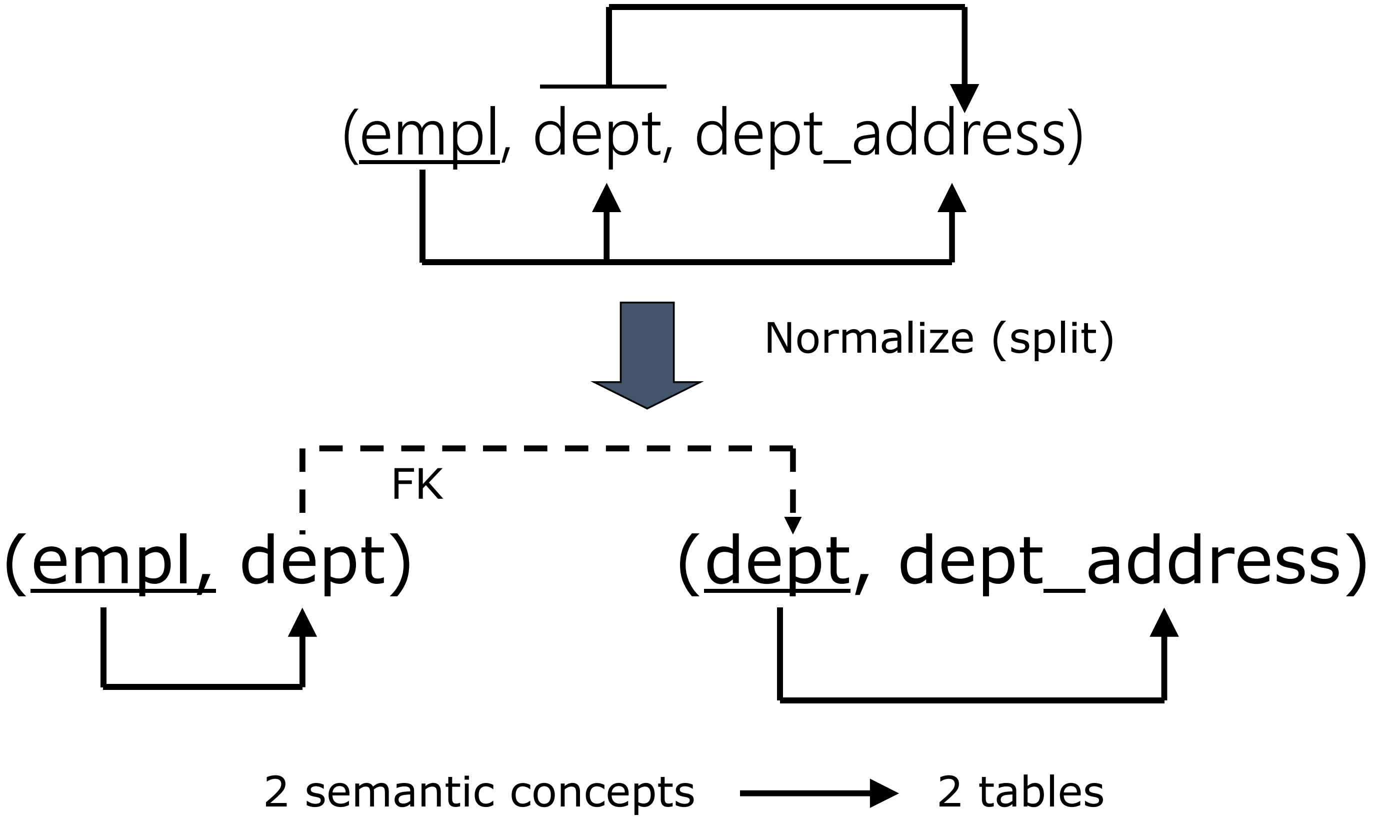
Third Normal Form - 3FN (I)

- A relation (SQL table) is in 3NF iff:
  - It is in 2NF

    &
  - There is no non-key attribute functionally depending on something that is not a candidate key

- Exception: propagates that of 2NF

Third Normal Form - 3FN (II)



Boyce-Codd Normal Form – BCNF (I)

(ssn, subj, #enrolment, mark)

16	DBD	~~215~~ 220	MH
16	AS	~~215~~ 220	9
16	IES	~~215~~ 220	8

Modification anomaly

Repetitions ⇒ Redundancy?

- ✓ 1NF?
- ✓ 2NF?
- ✓ 3NF?

Still, if #enrolment changes from 215 to 220, we have to modify three rows

Boyce-Codd Normal Form – BCNF (II)

- A relation (SQL table) is in BCNF (a.k.a. Strong 3NF) iff:
  - It is in 1NF

    &
  - Each and every determinant (arrow tail) is a candidate key (either primary or alternative). That is, every determinant determines by itself all attributes in the relation (either directly or not)

Boyce-Codd Normal Form – BCNF (III)

(ssn, subj, #enrolment, mark)

Determinant	Is it candidate key?
ssn, subj	Yes
#enrolment, subj	Yes
ssn	No
#enrolment	No

Normalize (split)

(ssn, subj, mark) (ssn, #enrolment)	(#enrolment, subj, mark) (ssn, #enrolment)
(ssn, subj, mark) (#enrolment, ssn)	(#enrolment, subj, mark) (#enrolment, ssn)

Automatic normalization

Analysis

~~Synthesis~~

Armstrong rules

- Reflexivity

For all x, $x \rightarrow x$

- Augmentation

If $x \rightarrow y$ then $xz \rightarrow y$

- Projectability or Decomposition

If $x \rightarrow yz$ then $x \rightarrow y$ and $x \rightarrow z$

- Addition

If $x \rightarrow y$ and $x \rightarrow w$ then $x \rightarrow yw$

- Transitivity

If $x \rightarrow y$ and $y \rightarrow z$ then $x \rightarrow z$

- Pseudo-transitivity

If $x \rightarrow y$ and $yz \rightarrow w$ then $xz \rightarrow w$

Closure of dependencies

$$\mathrm{L} = \{\mathrm{FD}\}$$ ---> Explicit functional dependencies

Armstrong rules $\Downarrow$

$$\mathrm{L}^{+} = \{\mathrm{FD}\}$$ ---> Explicit **and implicit** functional dependencies

- What can be inferred from the closure?
  - Whether a functional dependency is true or not
  - Whether two relational schemas are equivalent or not
  - The whole set of determinants

Analysis

- Input:
  - The "universal relation" containing all attributes in the database
  - The closure of functional dependencies ($\mathbf{L}^+$)
    - This contains all the existing determinants in the database
- Algorithm:
  1. If relation R with attributes A is not in BCNF (i.e., exists a determinant that is not candidate key)
     1. Take $A_L \rightarrow A_R$ belonging to $\mathbf{L}^+$, with A_L and A_R being subsets of A, violating BCNF for R
     2. Split R into two relations with attribute sets: $A_L U A_R$ and $A\text{-}A_R$, respectively
  2. If either $A_L U A_R$ or $A\text{-}A_R$ is not in BCNF, go back to 1

- Considerations:
  I. Some dependencies may be lost

R(<u>Professor, Hour</u>, Course)
L={C → P, PH → C}

⇒

R1(<u>C</u>, P)
R2(<u>C, H</u>)

  II. Decomposition may not be unique

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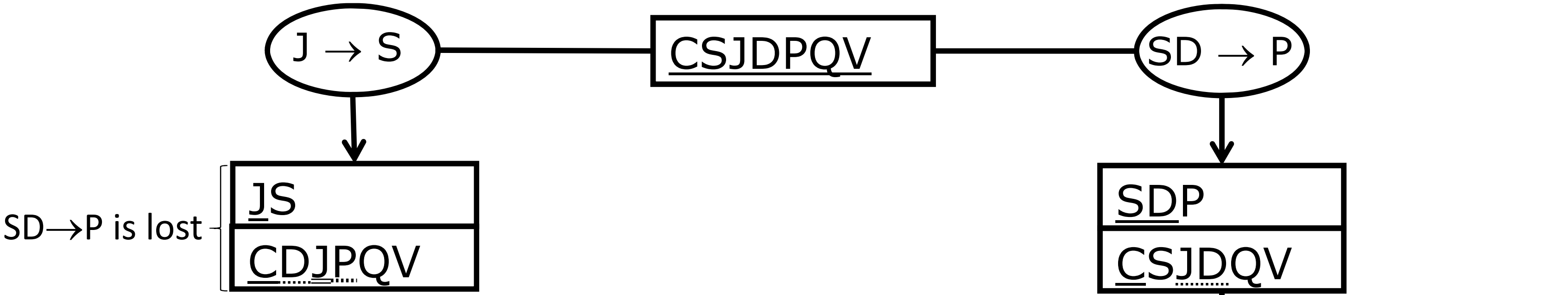
S. Abiteboul, R. Hull and V. Vianu. *Foundations of Databases*. Addison-Wesley, 1995

Example of analysis

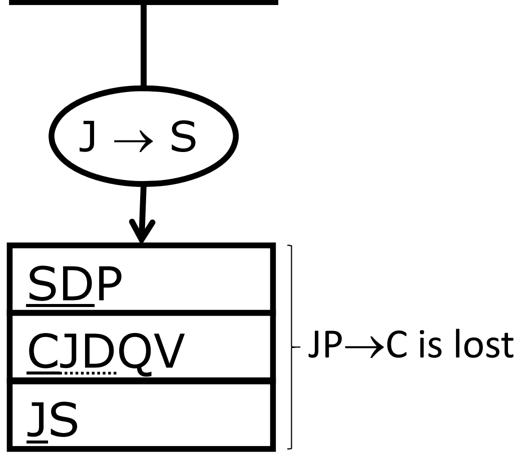
R (C, S, J, D, P, Q, V) L = {J→S, SD→P, JP→C, C→SJDPQV}



Pseudo-transitivity

$$\left.\begin{array}{c} SD \to P \\ \text{and} \\ J \to S \end{array}\right\} \Rightarrow JD \to P$$

But then, JD → JP → C,
hence JD is candidadate key



Examining normalization

Conclusions up to BCNF (strong 3NF)

- Any schema can always be normalized up to BCNF
  - Normalization is not unique

- Normalization can be fully automated (given a set of functional dependencies)
  - The normalized schema (in 3NF) is equivalent to that at the beginning (may not be true in BCNF)

- A normalized schema is better than a denormalized one because
  a) Eliminates redundancies and, hence, anomalies
  b) Separates semantically different concepts
     - It may be necessary to join them back to answer some queries!!!

Denormalizing

People (id, name, address, telephone, city, province)

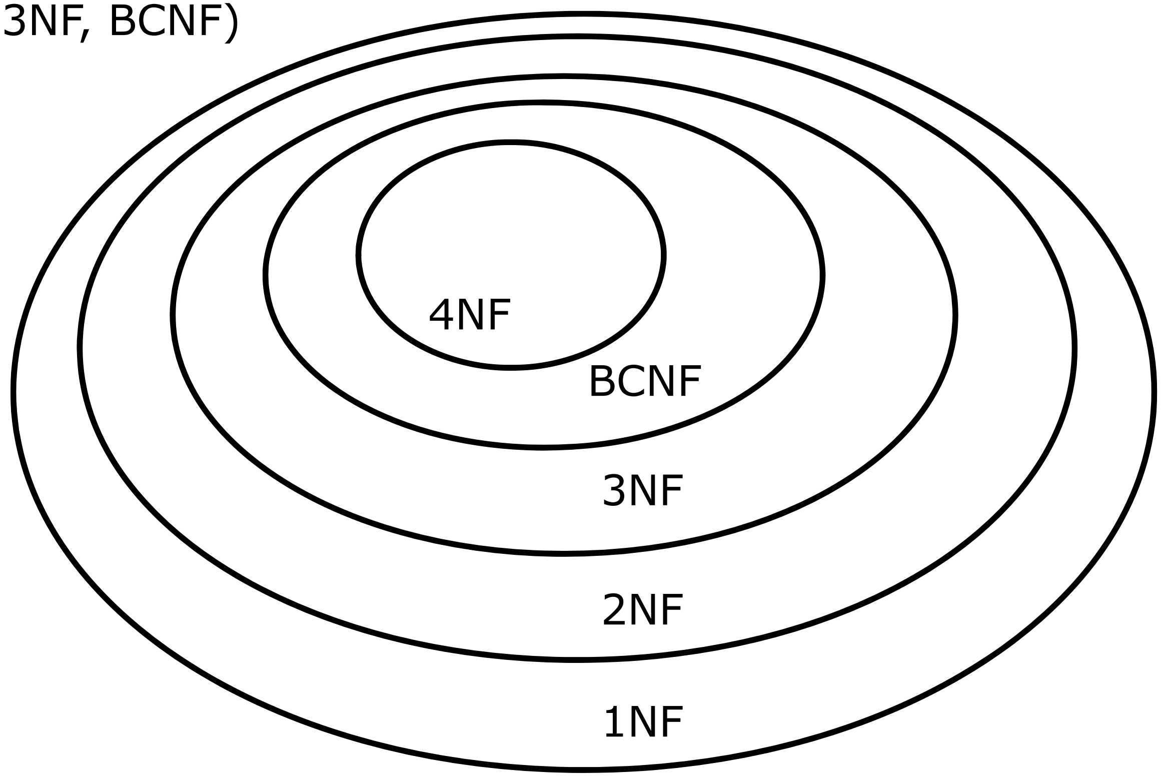
BCNF

People(id, name, address, telephone, city)
Cities(city, province)

- We can denormalize …
  - … when otherwise the join would be performed too often
  - … when changes are not expected or rare
  - … when consistency is guaranteed by other means

Normal Forms Structure

Dependencies:
- Functional (1NF, 2NF, 3NF, BCNF)
- Multivalued (4NF)



Non-First Normal Form (NF^2)

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4NF

Multivalued Dependencies

Multivalued Dependencies

$$R\ (A_1, A_2, \ldots, A_n)$$

- An MVD $\{X\} \twoheadrightarrow \{Y\}$ (e.g., $\{SSN\} \twoheadrightarrow \{spoken\text{-}language\}$, $\{team\} \twoheadrightarrow \{players\}$) guarantees that given a value of {X}, this determines a set of values of {Y}

$$R = R[X \cup Y] \bowtie R[\{A_1,\ldots,A_n\}\text{-}Y]$$

Fourth Normal Form - 4NF (I)

employee(<u>id</u>, knows-prog-lang, works-in-project)

id	knows-prog-lang	works-in-project
16	Java Python	HumanRecources StockManagement Marketing
17	C++ Python	HumanRecources Marketing

Flatten

employee(<u>id, prog-lang, works-in-project</u>)

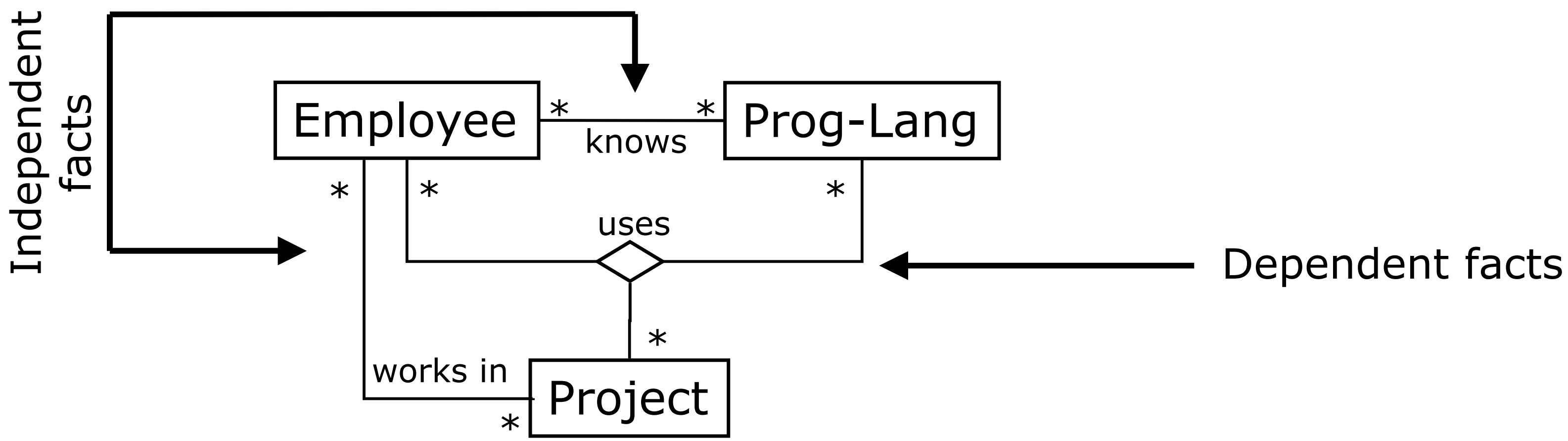
16	Java	HumanResources
16	Java	StockManagement
16	Java	Marketing
16	Python	HumanResources
16	Python	StockManagement
...		

- ✓ 1NF?
- ✓ 2NF?
- ✓ 3NF?
- ✓ BCNF?

Fourth Normal Form - 4NF (II)

- A relation (SQL table) is in 4NF iff:
  - It is in BCNF

    &
  - There are not **independent** multivalued dependencies



Fourth Normal Form - 4NF (III)

Employee(<u>id, knows-prog-lang, works-in-project</u>)

$id \twoheadrightarrow knows\text{-}prog\text{-}lang$, $id \twoheadrightarrow works\text{-}in\text{-}project$

Normalize (split)

Knows(<u>id, prog-lang</u>) Works(<u>id, in-project</u>)

Independent facts → Avoidable repetition → Redundancy

One value depends on the other

Uses(<u>id, prog-lang, in-project</u>)

16	Java	HumanResources
16	Python	StockManagement
17	C++	HumanResources

Dependent facts → Unavoidable repetition

Closing

Summary

- Functional Dependencies
- Multivalued Dependencies
- Anomalies
  - Update
  - Delete
  - Insert
- Normal Forms:
  - 1NF (Codd '70)
  - 2NF (Codd '70)
  - 3NF (Codd '70)
  - BCNF (Boyce-Codd '74)
  - 4FN (Fagin '77)
- Automatic normalization using analysis algorithm
- Denormalization

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