# 08. Relational Database Design

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## Normal Forms

Normal forms are used as a measure of the "goodness" of a relation. The higher the normal form, fewer the redundancies, and fewer anomalies it has; and the better the relation is. The process of deriving "good relations" in a relational database design is called *Normalization*. Normalized relations have minimized data redundancies and hence minimized anomalies.

Initially, Edgar (Ted) F. Codd proposed three normal forms, which he called the First, Second, and Third normal forms. A stronger definition of 3NF, called the Boyce-Codd Norm Form (BCNF) was proposed later by Boyce and Codd. All these normal forms are based on the functional dependencies among the attributes of a relation.

Later Fourth normal form (4NF) and the Fifth normal form (5NF) were proposed based on multi-value dependencies and join dependencies respectively.

Each normal form defines its own set of requirements, and if a relation meets those requirements, then it is in that normal form. Requirement rules are designed such that if a relation is in higher norm form, it is guaranteed to be in its lower normal form.

## First Normal Form (1NF):

A relation is in the First normal form if it qualifies to following-

- All attributes are "Atomic", that is
    - No composite
    - No Multiple values

With the given definition, the following relation is not in 1NF-

Room_HOR(RoomNo, Wing, Floor, Resident_Set)

And suppose it has the following two tuples -
<C115, C, 1, {201001023, 201001111}>
<H211, H, 2, {201111011}>

It is not in 1NF, because the attribute "Resident_Set" is not atomic.

Alternatively, the following scheme is also not in 1NF-

**Room_HOR(RoomNo, Wing, Floor, Resident1, Resident2)**,

and suppose it has the following two tuples -
<C115, C, 1, 201001023, 201001111>
<H211, H, 2, 201111011, null>

It just fooling around of the previous one. The *Resident* is a multi-value attribute. Creating multiple attributes for a multi-value attribute is wrong; by doing so we lose out the fact that these are multiple values of the same attribute.

*What is the problem with such a design?*

Attempt to answer the following queries from the above scheme of ROOM_HOR relation:

1. "Give us the wing-wise count of residents"
2. Find out room for a given student-id

With the above understanding, the following relation schema is also not in 1NF-

**Department(DNO, DName, MGR_ENO, DLOCATIONS)**
[A sample tuple: <4,'Marketing',101, {Delhi,Mumbai,Pune}>]

Composite attributes are also not atomic therefore the following relation is also not in 1NF-

**Student(ID, Name(Fname, Minit, Lname), Batch, CPI)**
[Sample tuple: <200701001,<Charu,K,Chawla>, 2007, 6.8>]

"Contradiction": is DOB not a composite in the following STUDENT relation?

Student(ID, FName, MInit, LName, DOB, Batch, CPI)
[Sample tuple: <200701001, Charu, K, Chawla, <1988,11,21>, 2007, 6.8>]

It is indeed composite, but we treat it as a single value of "Date" as the data type. With the acceptance of user-defined object types as an attribute type, CJ Date says that an attribute is atomic if it has a single value of "appropriate type".

Modern Object RDBMS allows having Object Types, Arrays, and even Relations as data types for an attribute. Such attribute type is not atomic in the original sense; however, with the object-oriented understanding of types, where types take care of manipulating data within an object through operator overloading or so, usage of such data type can come nearer to "atomic values".

Again to repeat that Normal Form is a measure of the goodness of a relation; each normal form defines its own sets of requirements, and if a relation meets those requirements, then it is in that normal form. It should also be noted that rules are designed such that if a relation is in higher norm form, it is implied to be in lower normal form.

There are two ways in which these forms are studies in the literature -

1. Begin with BCNF (most stricter form), and come down to 2NF, or
2. Reverse, i.e. start with 2NF, and go up to BCNF

In most modern text, first approach is preferred; we will also follow this route. Probably with following reasons -

- Most relations that you design using your common sense, or by mapping ER to Relations; are likely to be in BCNF..
- Second, 2NF and 3NF are discussed more for historical reasons.

## Determination of Normal Form

Each normal form allows certain redundancies. Redundancies are measured through Functional Dependencies. Therefore, each normal form (except first normal form) defines what functional dependencies are acceptable and what not.

If we consider determination of normal form of a relation is a task, we have following input

1. Relation Schema (R)
2. Projected Function Dependency set, or simply a Function Dependency set (F)

The determination process is applied iteratively. Either we begin from the lowest normal form (1NF) and move towards 2NF, 3NF, and so. And stop wherever the relation fails to meet the requirements of a normal form. However, normally we begin from BCNF, go toward the lower side, and stop when we find the relation complying with the requirement of the normal form.

## Projected FDs

Consider the FD set for the XIT database.

Now suppose we want to find out what FDs apply to the "STUDENT" relation, we compute projected FD on Student; let us say referred as Fs. The figure below depicts projected FDs for STUDENT (Fs) and for PROGRAM (Fp).

| F | Fs | Fp |
|---|---|---|
| **studid → name**<br>**studid → progid**<br>**studid → cpi**<br>**studid → progid**<br>**studid → pname**<br>**studid → intake**<br>**studid → did**<br>**progid → pname**<br>**progid → intake**<br>**progid → did**<br>**progid → dname**<br>**did → dname** | **studid → name**<br>**studid → progid**<br>**studid → cpi**<br>**studid → progid** | **progid → pname**<br>**progid → intake**<br>**progid → did** |

Computation of Projected FDs goes as follows:

Suppose you have a relation R and FD set F on R; let us say R is split into R1 and R2, FDs on R1 and R2 also need to be projected. Done as follows-

- For every FD X → Y on R, of X U R is a subset of R1 then X → Y is projected on decomposed relation R1
- This is repeated for every FD in F for every decomposed relation
- At the end we have sets of projected FDs on every decomposed relation.

## Boyce-Codd Normal Form (BCNF)

A relation R is in Boyce-Codd Normal Form, when determinant of every FD that holds on R, is super-key# of R. In other words, For every FD **A** → **B** that holds on relation R, A is its super-key. This requirement is to be checked for all FDs on R, if any FDs fail to meet this criteria, the relation is not in BCNF.

> # In most places in literature; there is usage of super-key; but when we work on minimal set; where we have all left sides irreducible, we can read super-key as Key.

Exercise ##: Given R(ABCDEF), and following FDs on R, determine if R is in BCNF?

A→ B

A→ C

A→ D

B → E

B → F

NO

Exercise ##: Given R(ABCDEF), and following FDs on R, determine if R is in BCNF?

A→ B

A→ C

A→ D

AB → E

AB → F

YES

Exercise ##: Are relations Student, Program, and Department in XIT database are in BCNF?

| | |
|---|---|
| Student(StudID, Name, dob, cpi, prog_id)<br>`Studid → name`<br>`studid → dob`<br>`studid → cpi`<br>`studid → pid` | Key?<br>Is BCNF? Y |
| Program(pid, pname, intake, did)<br>`pid → pname`<br>`pid → did`<br>`pid → intake` | Key?<br>Is BCNF? Y |
| Department(did, dname)<br>`did → dname` | Key?<br>Is BCNF? Y |

Exercise ##: Are relations in alternate relational schema for XIT database are in BCNF?

| | |
|---|---|
| Student(StudID, Name, dob, cpi, prog_id)<br>`Studid → name`<br>`studid → dob`<br>`studid → cpi`<br>`studid → pid` | Key?<br>Is BCNF? Y |

| | |
|---|---|
| PD(pid, pname, intake, did, dname)<br>pid → pname<br>pid → did<br>pid → intake<br>did → dname | Key?<br>Is BCNF? N |

## Company Database:

- Employee(<u>ENO</u>, name, salary, DoB, SUPER_ENO, dno)
- Department(<u>dno</u>, dname, MGR_ENO)
- dept_locations(<u>dno, dlocation</u>)
- Project(<u>pno</u>, pname, plocation, dno)
- works_on(<u>ENO</u>, <u>pno</u>, hours)
- dependent(<u>ENO</u>, <u>dep_name</u>, dep_bdate, relationship)

ENO → {ename, salary, dob, dno, super_eno, dname, mgr_eno }

dno → {dname, mgr_eno}

pno → {pname, plocation, dno, dname, mgr_eno}

{eno, pno} → hours

{eno, dep_name} → {dep_gender,  dep_bdate, relationship}

Y

## DA-ACAD Database:

- Student(StudetID, StdName, ProgID, Batch, CPI)
- Term(AcadYear, Semester)
- Course(CourseNo, CourseName, Credit)
- Faculty(FacultyID, FacultyName)
- Offers(AcadYear, Semester, CourseNo, FacultyID)
- Registers(StudetID, AcadYear, Semester, CourseNo, course_grade)
- Result(StudetID, AcadYear, Semester, Semester_SPI, Semester_CPI)

StudetID → {StdName, ProgID, Batch, CPI}

CourseNo → {CourseName, Credit}

FacultyID → FacultyName

{StudetID,AcadYear,Semester} → Semester_SPI

{StudetID,AcadYear,Semester} → Semester_CPI

{StudetID,CourseNo,AcadYear,Semester} → course_grade

{CourseNo,AcadYear,Semester} → FacultyID

Y

## TGMC database

- Member(<u>MembID</u>, MembName, MembEmail, TeamID)
- Team(<u>TeamID</u>, TeamPWD, MentorID)
- Mentor(<u>MentorID</u>, MentorName, MentorEmail, InstID)
- Institute(<u>InstID</u>, InstName, City, PIN, State)

All Attributes:

MembID , MembName, MembEmail, TeamID, TeamPWD, MentorID, MentorName, MentorEmail, InstID, InstName, City, PIN, State

**Given FDs:**

- MembID →{MembName, MembEmail, TeamID, TeamPWD, MentorID, MentorName, MentorEmail, InstID, InstName, City, PIN, State}
- TeamID → {TeamPWD, MentorID, MentorName, MentorEmail, InstID, InstName, City, PIN, State}
- MentorID → {MentorName, MentorEmail, InstID}
- InstID → {InstName, City, PIN, State}
- PIN → {City, State}

N

## 3rd Normal Form (3NF)

Third Normal Form is less restrictive than BCNF; it relaxes BCNF condition for *prime attributes* (attribute that are part of some candidate key).

A relation is in 3NF, if, for every FD **A → B** that holds on relation R,

- A is its super-key, or
- B is a prime attribute.

An attribute is prime if it is part of some [candidate] key.

<u>Exercise #10</u>: A relation R(A,B,C} having following FDs: {A,B} → C, C→A

{A, B} is key.

Relation is not in BCNF but in 3NF?

Note that 3NF definition is relaxed with respect to BCNF. Therefore if a relation is BCNF, it is automatically in 3NF?

<u>Exercise #11</u>: Suppose we have WORKS_ON as following:

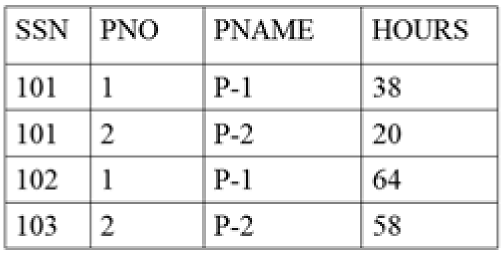
WORKS_ON(ENO, PNo, PName, Hours)

FDs (suppose):

- PNO → Pname
- PName → PNo
- {ENO, PNo} → Hours
- {ENO, PName} → Hours

Keys: ?

Is it in BCNF?



| SSN | PNO | PNAME | HOURS |
|---|---|---|---|
| 101 | 1 | P-1 | 38 |
| 101 | 2 | P-2 | 20 |
| 102 | 1 | P-1 | 64 |
| 103 | 2 | P-2 | 58 |

Is it in 3NF?

> Key: Two keys. {ENO, PNO}, and {ENO, PName}
>
> Is it in BCNF? No. First two FDs violate the requirement.
>
> Is it in 3NF? Yes. Right Attributes are Prime Attributes.

<u>Exercises #12</u>: find out if following relations are in 3NF?

Given relation R(ENO, FName, PNO, PName, HOURS), and FD set-

{ENO, PNO} → HOURS

ENO → FNAME

PNO → PNAME

Compute key?

Is R in BCNF?

Is R in 3NF?

| SSN | FNAME | PNO | PNAME | HOURS |
|---|---|---|---|---|
| 101 | Sumit | 1 | P-1 | 38 |
| 101 | Sumit | 2 | P-2 | 20 |
| 102 | Vipul | 1 | P-1 | 64 |
| 103 | Ajay | 2 | P-2 | 58 |

> Key: {ENO, PNO}
>
> BCNF? No. Last two FDs violate the requirement!
>
> 3NF? No. Again last two FDs violate the requirement!

<u>Exercise #13</u>: is our SP (student-program combined) in BCNF? is it in 3NF?

SP(StudID, Name, dob, cpi, prog_id, pname, intake, did)

```
Studid → name
studid → dob
studid → cpi
studid → pid
pid → pname
pid → did
pid → intake
```

Key?

Is BCNF?

NN

## Second Normal Form (2NF)

It is classic definition and defined in terms of Key. Second Normal form requires that all non-prime attributes are irreducibly (fully) dependent on key; that is no non-prime attribute should be partially dependent on key.

> Note: These dependencies are also checked using FDs.

With this definition does our SP in 2NF?

Yes. It is.

Below is example that is not in 2NF?

AB → C, A → D; Key is AB. C and D are non-prime attributes. C is dependent on Key, while D is partially dependent on Key, as there is FD A → D

Note that this definition of 2NF is relaxed with respect to 3NF. Therefore, if a relation is 3NF, it is automatically in 2NF

Exercise #14: Does R of our exercise #12 in 2NF? No

Exercise #15: A → B, A → C, C → D; is this in 2NF?

Yes.

Key is A; and non-prime attributes are B, C, and D.

B is dependent on Key; FD A → B.

C is dependent on Key; FD A → C.

D is dependent on Key; A → D. (transitively inferred from A → C and C → D

## Alternate Definition of 3NF from second normal form side

3NF definition: all non-prime attributes are irreducibly and directly dependent on key, transitively dependency is not allowed.

Note that both 3NF (i.e. earlier and this) mean same?

## Summary Normal Forms:

| Normal Form | Requirement |
|---|---|
| BCNF | For every FD $X \rightarrow Y \in F_R$ on relation R, X is Key<br>*In other worlds*: **Every attribute is dependent only and only on "Key"** |
| 3NF | We allow FD $X \rightarrow Y$<br>Either X is Key OR Y is Prime Attribute<br>*In other worlds*: **Every non-prime attribute is dependent only and only on "Key" (transitively dependency is not acceptable)** |
| 2NF | **Every non-prime attribute is dependent only and only on "Key" (transitively dependency is acceptable)** |
| 1NF | All attributes are "Atomic" |

## Does every relation that is in 3NF, also in 2NF?

Yes.

Had we have an A → D instead of C → D exercise #15, and then it would have been in 3NF, and BCNF as well. In fact, 3NF require every non-prime attributes to be dependent on Key (and every Key) and directly – not transitively.

BCNF also essentially requires that every attribute including prime attributes should be dependent on every key.

Exercise #16: Compute Normal Form for
R(CourseNo, Sem, AcadYear, InstructorID, StudentID, Grade)

Some Normal Form theorems

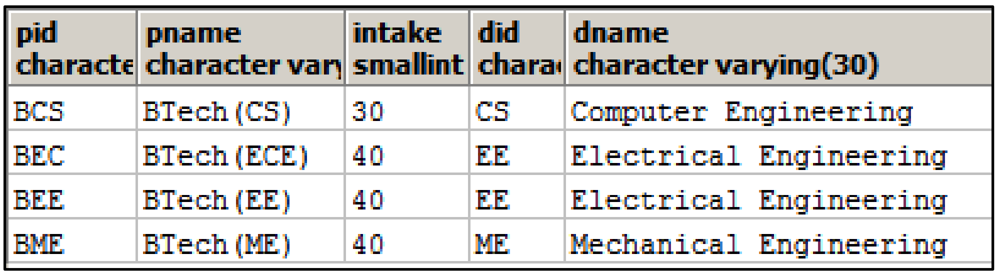
- All attribute Key Relation is always in BCNF
  - If a relation has no FD than key is all attributes, and such relations are always in BCNF
- Also, a relations with only two attribute is always in BCNF

## Determine Normal Form of a Relation (the method)

```
Input: Relation R, set of FDs F
Output: Highest Normal Form of a relation
Method:
    Compute all keys from F
    //Check for BCNF
    If there is any* FD f that violates BCNF requirement THEN
        State "relation is not in BCNF, FD f violates"
        Also output other FDs that are violating BCNF requirement.
        //Check for 3NF
        If there is any* FD that violates 3NF requirement THEN
            State "relation is not in 3NF, FD f violates"
            Also output other FDs that are violating 3NF requirement.
            //Check for 2NF
            If there is any* FD that violates 2NF requirement THEN
                State "relation is not in 2NF, FD f violates"
                Also output other FDs that are violating 2NF requirement.
            Else
                Relation is in 2NF
        Else
            Relation is in 3NF
    Else
        Relation is in BCNF
*Needs to be checked for every FD
```

## Decomposition

How do you make the relations in higher normal form?
Our following relation PD is in 2 NF; how do you make it in 3NF?



| pid characte | pname character vary | intake smallint | did chara | dname character varying(30) |
|---|---|---|---|---|
| BCS | BTech(CS) | 30 | CS | Computer Engineering |
| BEC | BTech(ECE) | 40 | EE | Electrical Engineering |
| BEE | BTech(EE) | 40 | EE | Electrical Engineering |
| BME | BTech(ME) | 40 | ME | Mechanical Engineering |

Probably, you already know the answer?

P(PID,PName,Intake,DID) and D(DID,DName)?

Note the presence of DID in both relations? Why?

Question could be little harder when semantics of attributes is not known to you as in case of following relation?

R(ABCD), {AB → C, A → D}

Requires us to have some systematic methodology for split; the process of splitting a relation into multiple relations is called "decomposition".

Here, first we study decomposition requirements that is when we split a relation R into multiple relations, what should be ensured so that "decomposition" is correct. Then we lean some algorithms that can be used for "decomposition".

### Decomposition Requirements

Decomposition of a relation R into R1, R2, R3, … Rm implies, attributes of R spread in said m relation schemas. Any arbitrary decomposition does not serve any purpose rather adds noice to the data. A decomposition needs to comply following requirements-

- Loss-less: JOIN of decomposed relation gives back original relation; suppose r1, r2, r3, …. rm are instances of decomposed relation schemas, then r1 * r2 * r3 …. * rm should yield r of R. [discussed below]
- Attribute Preserving: Union of attributes of all decomposed relation should be equal to attributes of R
- FD Preserving: A FD is said to be lost if its attributes are split into multiple relations. It is desirable that we should not be losing any FD from minimal set; it is ok loosing inferred FD.

### Lossless Decomposition:

As already stated, decomposition should guarantee r = r1 * r2 . When it does, then it is "loss-less join decomposition" or simply "loss-less decomposition".

Let us say R(A1,A2,A3,A4,A5,A6) getting decomposed into R1(A1,A2,A3,A4) and R2(A4,A5,A6); that if r is relation instance of R, then instances of R1 and R2 will be computed as following-

**r1** $\leftarrow \pi_{a1,a2,a3,a4}(r)$**, and**

**r2** $\leftarrow \pi_{a4,a5,a6}(r)$

And lossless decomposition should guarantee **r = r1 * r2**

Consider SPD example, and see if they meet out on above requirements?

See if

- Loss-less : spd = s * p * d
- Attribute Preserving : SPD = S ∪ P ∪ D
- FD preserving: F = Fs ∪ Fp ∪ Fd

---

**studid → name**

**studid → prog_id**

**studid → cpi**

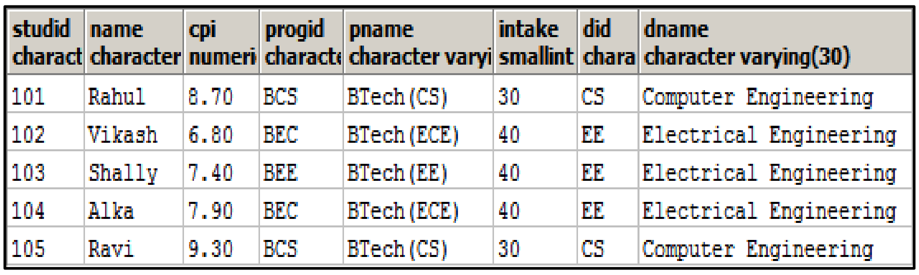
**studid → pid**

**pid → pname**

**pid → intake**

**pid → did**

**did → dname**



| studid charact | name character | cpi numeri | progid characte | pname character varyi | intake smallint | did chara | dname character varying(30) |
|---|---|---|---|---|---|---|---|
| 101 | Rahul | 8.70 | BCS | BTech(CS) | 30 | CS | Computer Engineering |
| 102 | Vikash | 6.80 | BEC | BTech(ECE) | 40 | EE | Electrical Engineering |
| 103 | Shally | 7.40 | BEE | BTech(EE) | 40 | EE | Electrical Engineering |
| 104 | Alka | 7.90 | BEC | BTech(ECE) | 40 | EE | Electrical Engineering |
| 105 | Ravi | 9.30 | BCS | BTech(CS) | 30 | CS | Computer Engineering |

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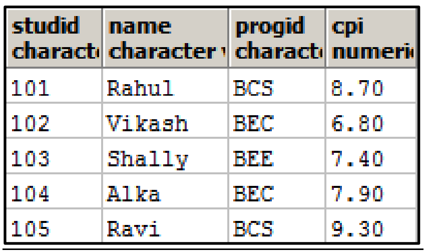
$\pi_{studid,name,progid,cpi}(rxit)$



| studid charact | name character | progid charact | cpi numeri |
|---|---|---|---|
| 101 | Rahul | BCS | 8.70 |
| 102 | Vikash | BEC | 6.80 |
| 103 | Shally | BEE | 7.40 |
| 104 | Alka | BEC | 7.90 |
| 105 | Ravi | BCS | 9.30 |

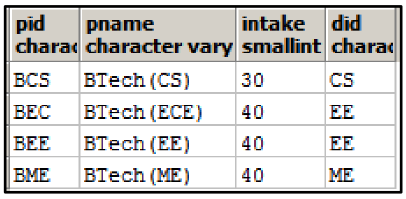
**studid → name**

**studid → prog_id**

**studid → cpi**

**studid → pid**

$\pi_{progid,pname,intake,did}(rxit)$



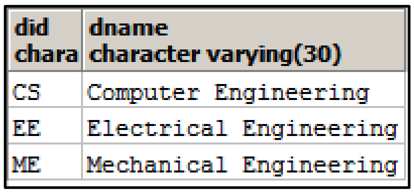
| pid charac | pname character vary | intake smallint | did charac |
|---|---|---|---|
| BCS | BTech(CS) | 30 | CS |
| BEC | BTech(ECE) | 40 | EE |
| BEE | BTech(EE) | 40 | EE |
| BME | BTech(ME) | 40 | ME |

**pid → pname**

**pid → intake**

**pid → did**

$\pi_{did,dname}(rxit)$



| did chara | dname character varying(30) |
|---|---|
| CS | Computer Engineering |
| EE | Electrical Engineering |
| ME | Mechanical Engineering |

**did → dname**

It is called "loss-less" because natural join of decomposed relation results into original relation, that is, there is no loss of "information".

Lossy decomposition normally results into additional tuples (also referred as spurious tuples) on having natural join of decomposed relations.

## Example A lossy decomposition

R(PNO, PNAME, ENO, HOURS)

PNO → PNAME

PNAME → PNO

{PNO, ENO} → HOURS

{PNAME, ENO} → HOURS

Keys:

{PNO, ENO},

{PNAME, ENO}

| ENO | PNO | PNAME | HOURS |
|---|---|---|---|
| 101 | 1 | PATR | 38 |
| 101 | 2 | XURT | 20 |
| 102 | 1 | PATR | 64 |
| 103 | 2 | XURT | 58 |

| ENO | PNO | HOURS |
|---|---|---|
| 101 | 1 | 38 |
| 101 | 2 | 20 |
| 102 | 1 | 64 |
| 103 | 2 | 58 |

| PNO | PNAME |
|---|---|
| 1 | PATR |
| 2 | XURT |

| ENO | PNAME | HOURS |
|---|---|---|
| 101 | PATR | 38 |
| 101 | XURT | 20 |
| 102 | PATR | 64 |
| 103 | XURT | 58 |

| PNO | PNAME |
|---|---|
| 1 | PATR |
| 2 | XURT |

**Correct Decompositions are:**
R1(PNO, PNAME), R2(PNO, ENO, HOURS) OR

R1(PNO, PNAME), R2(PNAME, ENO, HOURS)

PNO → PNAME

~~PNAME → PNO~~

{PNO, ENO} → HOURS

~~{PNAME, ENO} → HOURS~~

Keys:

{PNO, ENO},

~~{PNAME, ENO}~~

| ENO | PNO | PNAME | HOURS |
|---|---|---|---|
| 101 | 1 | PATR | 38 |
| 101 | 2 | XURT | 20 |
| 102 | 1 | PATR | 64 |
| 103 | 3 | XURT | 58 |

| ENO | PNO | HOURS |
|---|---|---|
| 101 | 1 | 38 |
| 101 | 2 | 20 |
| 102 | 1 | 64 |
| 103 | 3 | 58 |

| PNO | PNAME |
|---|---|
| 1 | PATR |
| 2 | XURT |
| 3 | XURT |

| ENO | PNAME | HOURS |
|---|---|---|
| 101 | PATR | 38 |
| 101 | XURT | 20 |
| 102 | PATR | 64 |
| 103 | XURT | 58 |

| PNO | PNAME |
|---|---|
| 1 | PATR |
| 2 | XURT |
| 3 | XURT |

ON JOIN we do not get back original relation

| ENO | PNAME | HOURS | PNO |
|---|---|---|---|
| 101 | PATR | 38 | 1 |
| 101 | XURT | 20 | 2 |
| 101 | XURT | 20 | 3 |
| 102 | PATR | 64 | 1 |
| 103 | XURT | 58 | 2 |
| 103 | XURT | 58 | 3 |

**Correct Decompositions is:**
R1(PNO, PNAME), R2(PNO, ENO, HOURS)

~~R1(PNO, PNAME), R2(PNAME, ENO, HOURS)~~

**Check for Loss-less-ness**

A test for binary decomposition: Let us say R is decomposed into if R1 and R2, then it is lossless, when we have one of following FD-

- (R1 intersection R2) → (R1-R2), or
- (R1 intersection R2) → (R2-R1), or

Or in other words, common attribute(s) are key of one of the decomposed relation.

## Decomposition Algorithms

- BCNF decomposition algorithm
- 3NF synthesis algorithm

### BCNF decomposition algorithm

- //Source: Ullman et al
- Input: A relation **R** with set (minimal) of FD's **F**.
- Output: A decomposition of R into a collection of relations, all of which are in BCNF.

```
NR ← {(R,F)}
Repeat till each relation S in NR is in BCNF.
    If there is a FD X → Y over relation S that violates BCNF condition.
        Compute X+, and choose X+ as one relation as S1, and another S2 as {(S - X+) U X}
        Map FD set Fs on S1 and S2 and compute Fs1 and Fs2
        Replace <S, Fs> in NR with <S1,Fs1> and <S2,Fs2>
Recursively repeat the algorithm on S1 and S2
```

Exercise ##:

Apply this alogirthm to RXIT and see if we get all there relations
**RXIT(studid, name, progid, cpi, pname, intake, did, dname)**

| F [RXIT] |
|---|
| **studid → name** |
| **studid → progid** |
| **studid → cpi** |
| **studid → progid** |
| **studid → pname** |
| **studid → intake** |
| **studid → did** |
| **progid → pname** |
| **progid → intake** |
| **progid → did** |
| **progid → dname** |
| **did → dname** |

Exercise #17: Apply BCNF Decomposition Algo

1. Given relation R(ENO, FName, PNO, PName, HOURS), and FD set-
   {ENO, PNO} → HOURS --FD1
   ENO → FNAME --FD2
   PNO → PNAME --FD3

   Key: {ENO, PNO}

   FD violates ENO → FNAME violates BCNF requirement

   Compute $ENO^+$ = {ENO, FName}

   Have R1(ENO, FName) and R2(ENO, PNO, PName, HOURS), and projected FDs are F1={ENO → FNAME} and F2 = {{ENO, PNO} → HOURS , PNO → PNAME }

   We can prove that R1 is now in BCNF. But R2 is not; therefore we further apply the algorithm on this, FD that violates the requirement is PNO → PNAME; compute closure of PNO, we get {PNO, PName), so we decompose R2 into

   R21(PNO, PName) and R22(ENO, PNO, HOURS)

   Projected FDs are F21 = {PNO → PNAME } and F22 = {{ENO, PNO} → HOURS }

   And, can prove that now R21 and R22 both are in BCNF?

Exercise #18: Decompose following relation using BCNF decomposition Algorithm

R(ABCDE), {AB → C, A → D, A → E }
R1(ADE) and R2(ABC); and FDs are F1={A → D, A → E} and F2={AB → C}
And both are in BCNF!

Decompose following relation using BCNF decomposition Algorithm-

1. R(ABCD), {A → B, B → C, C → D }
2. **Medicine**(TradeName, GenericName, BatchNo, Stock, MRP, TaxRate, Manufacturer)
   TradeName → GenericName
   TradeName → Manufacturer
   BatchNo → TradeName
   BatchNo → Stock
   BatchNo → MRP
   GenericName → TaxRate
3. Book(ISBN, Title, Author, Publisher, Price, AccessonNo);
   AccessonNo → ISBN
   ISBN → {Title, Publisher, Price}

BCNF decomposition algorithm guarantees lossless decomposition but does not guarantee FD preservation. For example, consider relation

R(A,B,C), and FDs
$AB \rightarrow C$
$C \rightarrow B$

Key: AB, AC

FD $C \rightarrow B$ violates BCNF requirement, and we have following decomposition

$C^+$=BC; R1(BC); R2(AC); F1{$C \rightarrow B$}; F2{}.

Though both relations are in BCNF, we lose FD $AB \rightarrow C$

Other example can be our WH(PNO, PNAME, ENO, HOURS) with FDs

PNO $\rightarrow$ PNAME
PNAME $\rightarrow$ PNO
{PNO, ENO} $\rightarrow$ HOURS
{PNAME, ENO} $\rightarrow$ HOURS

Note that there can be two BCNF decompositions based on which FD we begin with, and also note that we will be losing one of the FD3 or FD4. Of course both relations will be lossless and leading to relations in BCNF!

## 3NF Synthesis Algorithm

3-NF Synthesis algorithm guarantees lossless and preserves FDs, however its resultant relations "may not" (but quiet likely to) be in BCNF, but surely in 3NF.

Here is how it goes-

- Find a minimal FD set on R.
- For each set of FDs where X is determinant; say $X \rightarrow A1$, $X \rightarrow A2$, … $X \rightarrow An$; create a relation schema R'(X U A1 U A2 U … U An).
- If none of the relation created in above step that contains key of R; then create one more relation schema for key of R.

Example #19: Given relation R(ABCDEF), and FDs, and using 3NF synthesis algo, we get following decomposition

| | | |
|---|---|---|
| $A \rightarrow B$ | | R1(ABC) |
| $A \rightarrow C$ | Key: AF | R2(CDE) |
| $C \rightarrow D$ | | R(AF) |
| $C \rightarrow E$ | | |

In 3NF synthesis algorithm, sometimes we may get a relation that is subset of another. In such a case subset relation can be dropped. For example, we have a relation

Example #20: Given relation R(A,B,C,D,E), and FDs, and using 3NF synthesis algo, we have following decomposition

| | | |
|---|---|---|
| {A,B} → C<br>C → B<br>A → D | Key: ABE | R1(ABC)<br>~~R2(CB)~~<br>R3(AD)<br>R4(ABE) |

R2 is subset of R1, and can be dropped.

Which relation of this decomposition is not in BCNF?

==> Attempt decomposing it using BCNF decomposition algorithm?

Exercises: Decompose given following relations decompose them using 3NF synthesis algorithms.

1. R(ABCDEF), and FDs
   [A → B
   [B → CDE
   [E → F

2. Book(ISBN,Title,Author,Publisher,Price, AccessonNo), and FDs
   [ AccessonNo → ISBN
   [ ISBN → {Title, Publisher, Price}

3. R(CourseNo, Sem, AcadYear, InstructorID, StudentID, Grade)
   [{CourseNo, Sem, AcadYear} → InstructorID
   [{CourseNo, Sem, AcadYear, StudentID} → Grade

4. LibMember(ID, Name,Type, NoOfBooksCanBeIssued,IssueDuration)

5. R (StudentID, SPI, CPI_UptoDate, CPI_UptoASem, AcadYr, Sem, ProgCode, CourseNo, Grade)

6. IssueLog( IssueDate, MemberID, AccessonNo, DueDate, ReturnDate)

## Multi Value Dependencies or MVDs

Suppose you have following attributes of a person in citizen's database of India.

UUID, name, dob, email, phone?

Apply BCNF decomposition algorithm and get following

R1(UUID, name, dob), R2(UUID, email, phone)

Both are in BCNF?

Do you understand meaning of each tuple?

How values are stored?

| UUID | email | Phone |
|---|---|---|
| 101 | 101@gm.com | 91011 |
| 101 | 101@ym.com | 91015 |
| | | |
| | | |

If so,

- How do you delete a phone number?
  - Do we set null for the attribute in corresponding tuple? We cannot because the attribute is part of key!
- How do you add a new number?
  - Do we update any of existing tuple (if some value null)?
- How do you add a person not having email?

The problem is partially solved by making attributes independent, and has following tuples for recording same facts-

| UUID | email | Phone |
|---|---|---|
| 101 | 101@gm.com | 91011 |
| 101 | 101@ym.com | 91011 |
| 101 | 101@gm.com | 91015 |
| 101 | 101@ym.com | 91015 |
| | | |
| | | |

Now to delete a phone number –
"DELETE FROM CITIZEN WHERE UUID = 101 AND Phone = '91011'"

For adding a phone number, we add phone number tuple for all emails of the user, and updated relation becomes as following-

| UUID | email | Phone |
|---|---|---|
| 101 | 101@gm.com | 91011 |
| 101 | 101@ym.com | 91011 |
| 101 | 101@gm.com | 91015 |
| 101 | 101@ym.com | 91015 |
| 101 | 101@gm.com | 92015 |
| 101 | 101@ym.com | 92015 |
| | | |
| | | |

Moreover, you cannot add a person who does not have an email or phone?

There are still problem.

Hopefully you see redundancies here and hence anomalies.

This motivates us for higher normal form!

Basically the problem is due to a phenomenon called multi-value dependencies? Here you have

A person (given UUID), has multiple phone numbers?

A person (given UUID), has multiple emails?

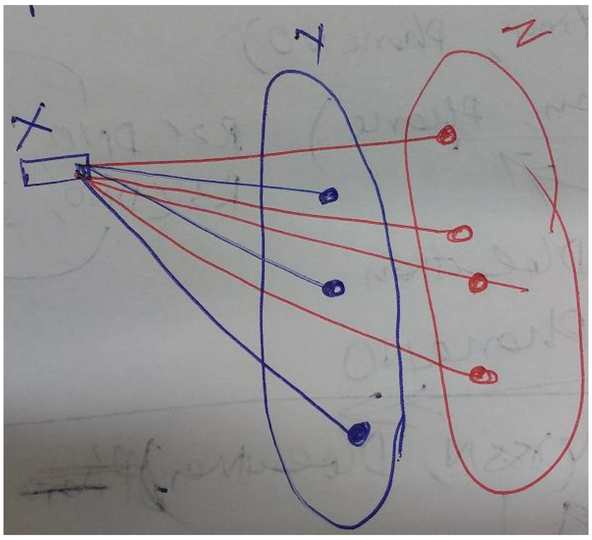
You should be able to correlate this with functional dependencies; if for a given value of attribute X, if we have a single value of Y retrieved from database then we say it is FD "X $\rightarrow$ Y"; if we get a set of values of Y, then it is Multi-Value Dependency or MVD and represented as

X -->> Y

and read as "**X multi-determines Y**"

In our example here, we have following MVDs

UUID -->> email
UUID -->> phone



Notice that this MVD would not have been a problem, originally if we had relation R(UUID, name, dob, phone)

And by BCNF decomposition algorithm, we would have got following relations

R1(UUID, name, dob)

R2(UUID, phone)

Now R2 does not have any of above mentioned problems?

Actually this problem comes only when we have more than one MVD in a relation.

Trivial MVD

- A MVD A -->> B is called trivial, when either of following is true -
  A U B = R, or
  B is subset of A

MVD in R2 above is trivial?

Note that FD is a special case of MVD, when set of values of Y, for a given value of X, is singleton then it is FD.

Inference rules that we learned for FDs may not be true for MVDs.

We do not plan to look into inference rules for MVDs.

## 4NF based on MVDs

- A relation is in 4NF if and only if, when for every non-trivial FD or MVD, key is the determinant.
- In other words, relation is in 4NF, only if it is in BCNF and all MVDs are in fact "FDs out of keys". [Note: Key is defined only in terms of FDs]
- Definition of 4NF definition covers BCNF.

## 4NF Decomposition Algorithm

BCNF decomposition algorithm can be extended for BCNF

Input: Relation R and FD set F

Assumption: F in minimal, and in "canonical form".

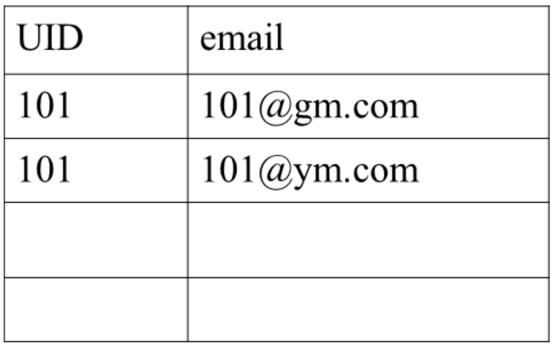
```
NR ← {(R,F)}
Repeat till each relation S in NR is in 4NF.
    If there is a FD X → Y or X -->> Y over relation S that violates 4NF requirement.
```

```
        Decompose S into S1(X U Y) and S2 as (S - Y)
        Map FD set Fs on S1 and S2 and compute Fs1 and Fs2
        Replace <S, Fs> in NR with <S1,Fs1>, <S2,Fs2>
Recursively repeat the algorithm on S1 and S2
```

In our example, the relation R(UID, email, phone) with following MVDs: UID -->> email and UID -->> phone; is not in 4NF because

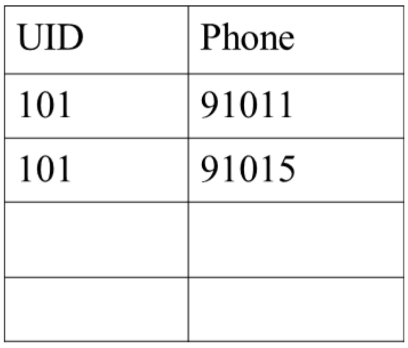
- MVDs are not trivial,
- MVDs are not FDs and UID is not the key

Using above Algorithm can be decomposed as following-



| UID | email |
|---|---|
| 101 | 101@gm.com |
| 101 | 101@ym.com |
| | |
| | |

**UID -->> email**



| UID | Phone |
|---|---|
| 101 | 91011 |
| 101 | 91015 |
| | |
| | |

**UID -->> Phone**

==> Now MVDs are trivial in their respective relations.

Note following-

- MVD should not be a problem in real cases, as most likely be get addressed by other FDs.
- Consider example DNO, DNAME, DLocation, MGR_ENO; you have following FDs and MVDs here-
  DNO → {DNAME, MGR_ENO}
  DNO -->> DLocation
- Being ignorant about MVD, if we decompose the relation using BCNF decomposition algorithm, what we have is following-
  R1(DNO, DNAME, MGR_ENO); FDs: {DNO → DNAME, DNO → MGR_ENO}
  R2(DNO, DLocation}; FDs: None; MVD: DNO -->> DLocation
  - Now we look at MVD; projected on R2; we find that it is trivial and has already been taken care of.
  - Both the relations are in 4NF.
- Consider a relation R(ENO, PNO, HOUR) do you see MVDs
  ENO -->> {PNO, HOUR}?

  Is the relation in BCNF? Yes. We have only FD {ENO, PNO} → {HOUR}.

  Is the relation in 4NF? Yes; the MVD is trivial.

- Now let us consider a situation, where we have more than one MVD in a relation. Consider R(ENO, PNO, HOUR, DEP_NAME, DEP_RELATION)

  MVDs
  ENO -->> {PNO, HOUR}
  ENO -->> {DEP_NAME, DEP_RELATION}

  FDs
  {ENO, PNO} → {HOUR}
  {ENO, DEP_NAME} → DEP_RELATION

  Key: {ENO, PNO, DEP_NAME}

  Is it in BCNF? NO

  If we decompose it using BCNF decomposition algo, we get following relations
  R1(ENO, PNO, HOUR)
  R2(ENO, DEP_NAME, DEP_RELATION)

  R1 and R2 are in 4NF as well?
  MVDs are trivial in their respective relations.

==> Do not consider MVDs that are reverse consequence of a FD; for example DNO -->> ENO? you may find many such MVDs otherwise.

## 5th and higher normal forms [OPTIONAL]

Theoretically, yes there are higher normal forms. Higher normal forms are based on "join dependencies".

If a relation R can be losslessly decomposed into R1, R2 (or more) then R is said to have a join dependency. It is expressed as

*{R1, R2}

It is also said that you can have lossless decomposition of a relation into R1 and R2 only when you have join dependency *{R1,R2}.

Join dependency are hard to detect otherwise but can be expressed in terms of FDs and MVDs.

If a relation R(ABCDE) has FDs A → BC and C → DE then the relation has a join dependency, and is expressed as *{ABC, CDE}.

> You can decompose (lossless) relation EMP_PROJ(ENO, ENAME, PNO, HOURS) into EMP(ENO,ENAME) and PROJ(ENO,PNO,HOURS), because it has a join dependency *{EMP(ENO,ENAME), PROJ(ENO,PNO,HOURS)}

If a relation R(ABCD) has MVDs A -->> {BC} then the relation has a join dependency, and is expressed as *(ABC, AD).

You also have a join dependency when you have FDs A → B and A → C as *(AB, AC) but such join dependency is called as trivial join dependency. JDs implied by candidate key, that means each of decomposed relation is super-key of original relation

| A relation is in 5th Normal form if there is no non-trivial join dependency. |
|---|

Below is a peculiar example (from CJ Date's book) having a join dependency that is not visible through FD and MVD?

Suppose we have following three facts drawn from tuples in relation SPJ

(1) Supplier s1 supplies part p1
(2) Project j1 uses part p1
(3) Supplier s1 supplies some part to j1

**SPJ**

| *S#* | *P#* | *J#* |
|---|---|---|
| S1 | P1 | J2 |
| S1 | P2 | J1 |
| S2 | P1 | J1 |
| S1 | P1 | J1 |

From these three observations if we can infer that <u>s1 supplies p1 to project j1</u>, then an additional tuple should also exist in relation SPJ? Is not it strange derivation?

**SP**

| *S#* | *P#* |
|---|---|
| S1 | P1 |
| S1 | P2 |
| S2 | P1 |

**PJ**

| *P#* | *J#* |
|---|---|
| P1 | J2 |
| P2 | J1 |
| P1 | J1 |

**SJ**

| *S#* | *J#* |
|---|---|
| S1 | J2 |
| S1 | J1 |
| S2 | J1 |

If so, then there is an insertion anomaly in the relation SPJ. It can be shown that relation SPJ with given constraint, has a 3-way join dependency. It should be easy to establish that drawn above three fact from relations SP, PJ, and SJ respectively, and JOIN of SP, PJ and SJ will give a tuple that expresses that <u>s1 supplies p1 to project j1.</u>