DBMS [8-10 marks]

Syllabus:-

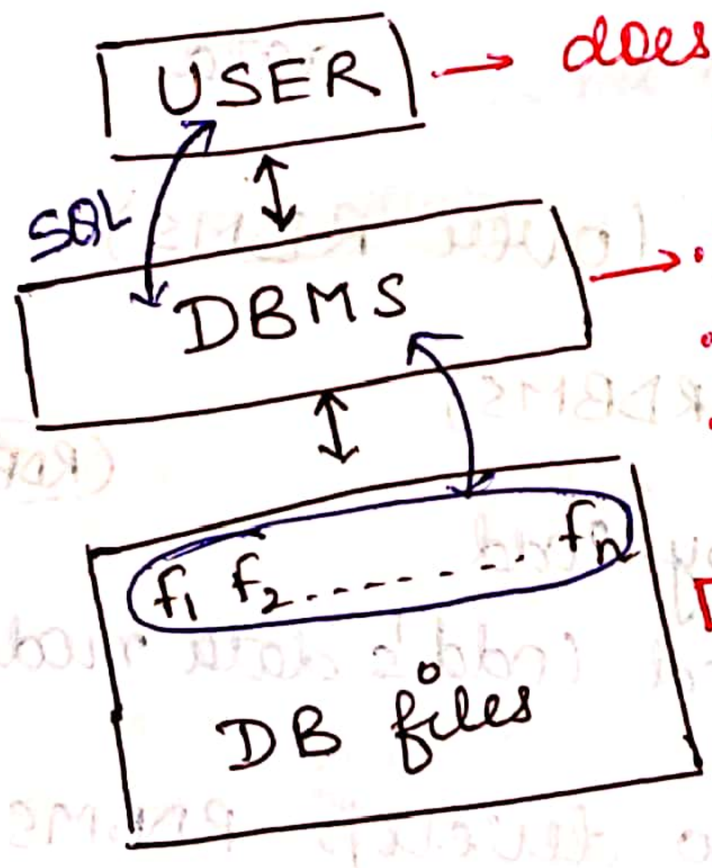
1. Integrity Constraints $$ ER Model 2 marks
2. Normalization 2-4 marks
3. Query (RA, SQL, RC) 4 marks
4. File org and Indexing 2-4 marks
5. Transactions and concurrency Control 2-4 marks

- Notes
- WB|GATE
- Text Book exercise Problems
  - → DBMS (Raghuram krishna)
  - → DBMS (Navathe)

Introduction:

Data Base — Collection of related data
ex:- Set of student's info.

DBMS — Software which is used to manage data base files.



→ does not know how the files are actually stored.

→ acts as an interface
- it controls all files
- it is responsible for storing files
- it contains all info about how the data is stored.

data independency:
USER can be able to retrive the data without knowing how it is actually stored.

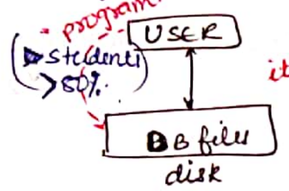
Flat file system (OS files)
DB files manages by user without DBMS.

It is good for small database.
but for huge DB then it fails to manage the DB

User should know compute structure

user is responsible about how data is stored, i.e, File structure & data format is user responsibility.

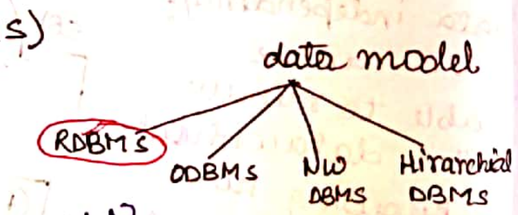
Flat file system can be used to manage small DB. if DB is too huge, flat file system fails to manage DB

Limitation of Flat file	Advantage of DBMS file system
⇒ Too complex to manage application programs and development of application programs	⇒ Because of data independency development of application programs becomes simple.
eg:-  it is complex writing program.	Data Independency: Hiding storage info to the user.
⇒ Requires more I/O cost to access data from DB file	⇒ Because of Indexing DBMS file system access cost is too less
⇒ Provides less degree of concurrency. Degree of concurrency: no. of users can use DB simultaneously.	⇒ Because of concurrency control of DBMS, can possible more degree of concurrency.
⇒ Maintaining non redundant data is too complex almost impossible.	⇒ Uses normalization or schema refinement used to maintain non redundant data.

Integrity Constraints (over RDMS)

Relational DBMS (RDBMS)

- ~~produc~~ Proposed by Codd [also called Codd's data model]



- Codd 12 Rules to develop RDBMS S/W (software) (RDBMS guidelines)

RDBMS Guidelines

- data in DB file must be in tabular format. [Set of rows & columns]
- No two rows of DB files (tables) is same

eg:- Student

Sid	Sname	DOB
S1	A	1995
S2	A.	1993
S3	C	1993
S4	B	1994

(RDMS file)

record/tuple

Columns are called attribute/field.

Relational Instance (snapshot) ⇓ Set of records of DB table

eg:-

S1, A, 1995 # S2,
— — — — — —
— — — — — —
— — — — — —

flat file system

Relational schema. Structure or definition of DB Table

eg:- Student (Sid, Sname, DOB)

Arity : # of attributes of DB Table

Cardinality : # of records of DB Table

Candidate Key : Minimal set of attributes which can differentiate records of Relational scheme uniquely.

[minimal attribute + field values are unique]

eg:- Student (Sid, Sname, DOB)

Sid is Cand Key.

Sid Sname : Not Cand Key (because it is not minimal)

eg:- Enroll (Sid Cid fee)

Student can enroll many courses

Course can be enrolled by many students

Sid	Cid	fee
S1	C1	–
S2	C2	–
S3	C2	–
S1	C2	–

Sid Cid : Cand key.

eg:- emp (Eid, Ename, DOB PanID, Adharno, Ifsc, Ano)

SB101	101
CAN101	101
SB102	102
CAN02	102

4 cand key exist

we are assuming only Ano is not unique

Candidate Keys {eid, PanID, Adhar no, Ifsc Acno}

eid → primary key

PanID, Adhar no, Ifsc Acno → Alternative Keys

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NULL: Unknown/unexisted value

eid	Ename	DOB	PanID	Adhar no	Ifsc	Ano
e1	A	1995	X5		SB101	101
e2	A	NULL	NULL		CAN01	101
e3	B		X2		SB102	102
e4	B		NULL		CAN02	102

Not NULL: Attribute not allowed NULL's

Primary Key: Any one Cand Key of relational Schema whose feild values always NOT NULL

Constraint:
- must be one of C_K
- feild values not allowed NULL's
- Almost one PK allowed for any Relational Schema

Alternative Keys: All C_K of relational Schema except ~~accept~~ P_K

Constraint:
- must be one of C_K
- field value allow NULL
- many AK's are allowed.

eg:-
```
CREATE TABLE Emp
( eid      Varchar (10)   Primary Key,
  ename    Varchar (30)   NOT NULL,
  PanID    Varchar (9)    UNIQUE,
  AdharNO  integer (12)   UNIQUE NOT NULL,
  Ifsc     Varchar (6),
  ano      integer (10),
  UNIQUE (ifsc, ano)
);
```

Simple Candidate Key:
Candidate Key with only one attribute
eg:- eid, panID, Adharno

Compound Candidate Key:
Candidate Key with at least two attributes
eg:- Ifsc Ano

Prime Attribute (KEY attribute)
Attribute which belongs to some candidate Key of relational scheme.
eg:- eid, panid, Adharno, Ifsc, Ano

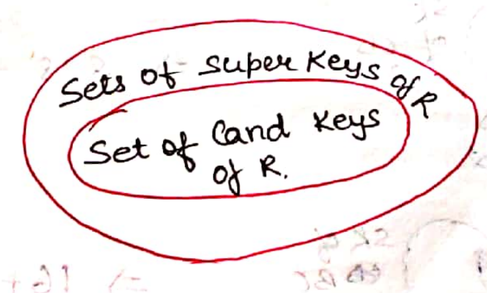
Prime Attribute set of Emp {eid, panID, Adharno, Ifsc, Ano}

Non-Prime Attribute set of Emp {ename, DOB}

Super Key (used for DB design)
Set of attributes which can differentiate records of relational schema uniquely.
(may not minimal attribute set)
Constraint: field values unique for all the records.

eg:- Student (Sid, Sname DOB)
Cand Key: {Sid}
Super Keys: { Sid ← minimal S.K
Sid Sname
Sid DOB
Sid Sname DOB
}

Candidate Key:
minimal Super Key



Q- R(ABCD)

How many SK's in R if {A} cand Key ?

SK <=> [C_K] · [any subset of other attributes]

A · { Any subset of (BCD) } → 2^3

{ A, AB, AC, AD, ABC, ABD, ACD, ABCD }

8 super keys

Q- R(ABCDE)

How many S_K in R if

(i) { AB, BC } C_K

(ii) { AB, CD } Cand Key.

(iii) { A, BC } Ca K

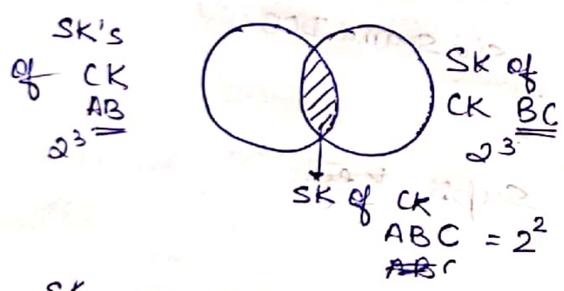
(i) AB = { CDE } = 2^3
BC = { DE } = 2^2
12

(ii) AB = { CDE } = 2^3
CD = { E } = 2^1
10 ✗

(iii) A = { BCDE } = 2^4
BC = { DE } = 2^2
20

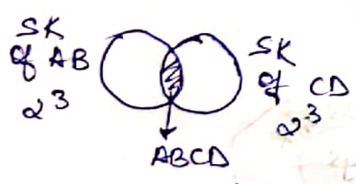
(OR)

(i)



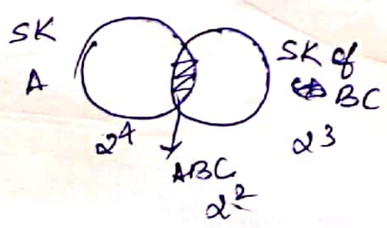
$n(X \cup Y) = n(X) + n(Y) - n(X \cap Y)$
⇒ 8+8 −4
= 16−4 = 12

(ii)



⇒ 8+8 −2 = 14

(iii)



⇒ 16+8−4
= 20

Q- R(ABCDEF)

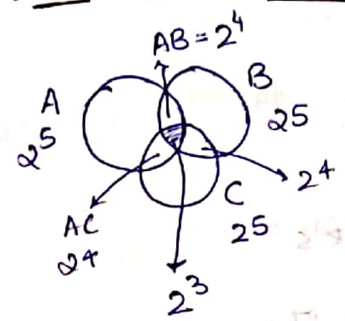
How many S_K in R if

(i) { A, B, C } Cand Keys

(ii) { A, BC, CD } C_K
GATE

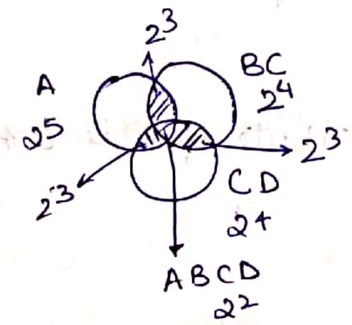
(iii) { AB, BCD, CDE } C-K

(i)



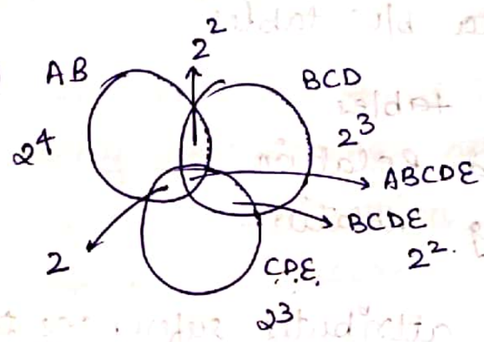
⇒ 32+32+32 −16−16−16+8
= 96 − 48 + 8
= 56

(ii)



⇒ 32+16+16−8−8−8+4
= 64 − 24 + 4
= 44

(iii)



= 16 +8 +8 − 2 −4 −4 +2
= 32 − 8
= 24

⇒ (+) → Individual, 3 sets, 5 sets
(−) → 2 sets, 4 sets

Q- R(ABCDE)

{ AB, BC, CD, DE } cand keys

Super key { AB, ABC, ABCD, ABCDE, ABD, ABE, ABCE, ABDE, BC, BCD, BCDE, BCE, CD, ACD, CDE, ACDE, DE, BDE, ADE }

19 SK's

Q- R (A_1 A_2 A_3 .... A_n)

How many S-K in R?

(a) $n!$ (c) $2^n - 1$

(b) 2^n (d) 2^{2^n}

R ($\underline{A_1}$ $\underline{A_2}$ $\underline{A_3}$)

A1	A1A2	A1A2A3	max SK's
A2	A1A3		$2^3 - 1 = 7$
A3	A2A3		

$2^n - 1$ max ~~of~~ S-K's if each attribute of R is C-K
(c)

Foreign Key (Refrencial Key)

⇒ used to relate data b/w tables

⇒ defined over two tables
Referenced Relation
Referencing Relation

⇒ def: FK is set of attributes references to primary key / Alternative key of same relation / some other relation

eg: Stud (Sid, Sname, DOB) Enroll (Sid, Cid, fee)

Referenced Relation

Referencing relation

Stud (Sid)	Sname	DOB	Enroll (Sid)	Cid	fee
S1	A	1995	S1	C1	5000
~~S2~~ S20	A	1995	S1	C2	6000
S3	B	1994	S2	C2	4000
S4	B	1994	S4	C1	4000
~~S5~~	~~C~~	~~1994~~	~~S10~~	~~C1~~	~~5000~~
S6	D	1996			

D, I, D, U

(1 to many)

restricted because it is not in stud relation data is inconsistent

eg: Emp (eid, ename, SupID) — also must be emp

Emp (eid)	ename	SupID
e1	A	NULL
e2	B	e1
e3	B	e1
e4	C	e2
e5	A	NULL
e6	D	e5 ~~e8~~

del

#Cascading delete = 3

Total delete = 4

it ON delete Cascade

→ it is not an emp

eg: R (A, B, C) S (D, E)

PK AK FK

R (A)	B	C	S (D)	E
a1	2	c1	2	e1
~~a2~~	~~4~~	~~c2~~	2	e2
a3	null	c2	null	e3
a4	6	c3	~~null~~ 4	e4
a5	null	c1	6 ~~10~~	e5

non-relation is allowed in both the sides

D can be NULL or values of B

→ it is not related to any referenced record.

not allowed

Foreign Key allows NULL value ~~and~~ are referencing record whose foreign key value is null, not related to any referenced record (out of referential integrity constraint)

each record of Referenced Relation can related many referencing record and each record of referencing relation can relate atmost one referenced record.

Referential Key Integrity Constraint (FK IC):
(IC)

(1) Referenced Rel (Stud)

(a) Insertion: NO voilation

(b) Deletion: may cause voilation

default (i) ON DELETE NO ACTION

Deletion of Referenced Record is not allowed if FK voilation occurs

(ii) ON DELETE CASCADE

Deletion of Referenced Record is allowed and DBMS deletes all related referencing records.

(iii) ON DELETE SET NULL

If FK field allowed to set NULL, set NULL in FK values and allowed delete referenced record.

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(c) Updation : may cause Voilation

default (i) ON UPDATE no Action

(ii) ON UPDATE CASCADE

(iii) ON UPDATE SET NULL

(II) Referencing Rel (Enroll)

(a) Insertion : may cause Voilation

Restricted Oper^n

(b) Deletion : NO Voilation

(c) Updating : may cause voilation

Insertion, Updation of referencing Rel is restricted if F.K voilation occurs.

eg:- Stud (Sid Sname DOB)

Enroll (Sid Cid fee)

```
CREATE TABLE ENROLL
{   Sid     varchar(10),
    Cid     varchar(10),
    fee     integer,
    primary key (sid,cid),
    FOREIGN KEY (sid)
    REFERENCES Stud (Sid)
    ON DELETE CASCADE
    ON UPDATE CASCADE
};
```

it is present where foreign key is present

← if not mentioned then references to its own table

↓ it act W.R.T stud relation

NORMALIZATION (Schema Refinement)

normalization used to reduce or eliminate redundancy in relational schema.

If two or more independent relations stored in single relation which can cause redundancy

eg:- Sid → Sname DOB (Stud info)

Cid → Cname Instructor (Course info)

Sid Cid → fee (mapping)

R

Sid	Sname	DOB	Cid	Cname	Ins^n	fee
S1	A	1995	C1	DB	Koath	–
S2	A	1995	C1	DB	Koath	–
S3	B	1995 1994	C1	DB	Koath	–
S3	B	1994	C2	OS	Galwin	–
S3	B	1994	C3	Algo	Coreman	–
			C4			

Problems because of Redundancy

[DB Anamalies]

(a) Insertion Anamaly

to insert some data there must be other independent data.

eg:- to insert course, there must be some student enroll for course.

(b) Deletion Anamaly

Deletion of some data may lost some other independent data

eg:- because of deletion of student may lost course info.

(c) Updation Anamaly

If some redundant copy may updates, other redundant copies failed to update, it cause inconsistency

Normalization of DB :

decompose relation into two or more sub relation to reduce / eliminate redundancy and DB anamalies.

eg: R_1 (Sid Sname DOB)

Sid
S1
S2
~~S3~~

R_2 (Sid Cid fee)

Sid	Cid	fee
S1	C1	–
S2	C1	–
~~S3~~	~~C1~~	~~–~~
~~S3~~	~~C2~~	~~–~~
~~S3~~	~~C3~~	~~–~~

R_3 (Cid Cname In

Cid	Cname	In
C1		
C2	OS	G
C3	Algo	Co
C4	CO	Hay

NO Redundancy
NO DB Anamalies
} Goals of Normalized DB design

Functional Dependency (FD)

X, Y are some set of Attributes over R

eg: R (X Y) $X \rightarrow Y$

$t_1 \rightarrow$	x_1	y_5
t	x_2	y_2
	x_3	y_2
	x_4	y_4
	x_1	y_5
$t_2 \rightarrow$	x_1	y_5

[Y determines by X]

$X \rightarrow Y$ FD implied in R

if $t_1 \cdot X = t_2 \cdot X$ then $t_1 \cdot Y = t_2 \cdot Y$

eg: R (Sid Sname Cid)

S1	A	C1
S1	A	C2
S2	B	C2
S3	B	C3
S4	C	C3

{ Sid $\rightarrow$ Sname
sidcid $\rightarrow$ Sname }

eg:- R (X Y) $X \rightarrow Y$ not implied in R.

$t_1 \rightarrow x_1$ y_1
$t_2 \rightarrow x_1$ y_2

$\because$ $t_1 \cdot X = t_2 \cdot X$ but $t_1 \cdot Y \neq t_2 \cdot Y$.

Trivial FD (Reflexive FD)

$X \rightarrow Y$ FD is trivial iff $X \supseteq Y$

attribute determines themselves

eg:
Sid $\rightarrow$ Sid
Sname $\rightarrow$ Sname
Cid $\rightarrow$ ~~Sname~~ Cid
Sid Sname $\rightarrow$ Sname
Sid sname $\rightarrow$ Sid Sname
} trivial FD

Non Trivial FD

$X \rightarrow Y$ non trivial FD if no common attribute in X, Y attribute sets.

attribute determine some other attribute

eg:
Sid $\rightarrow$ Sname
Sid Cid $\rightarrow$ Sname

Semi Non Trivial FD

Combination of trivial & non trivial FD

eg:-
Sid $\rightarrow$ Sid Sname
SidCid $\rightarrow$ Cid Sname
Sid $\rightarrow$ Sid
Sid $\rightarrow$ Sname
SidCid $\rightarrow$ Cid
Sid Cid $\rightarrow$ Sname.

(if $X \rightarrow YZ$ then $X \rightarrow Y$, $X \rightarrow Z$)

Every possible trivial FD over attributes of relation R is always implied on relation R

Armstrong Rules Over FD's

1. Reflexivity: $X \rightarrow X$ always in relation R (trivial FD)
2. Transitivity: if $X \rightarrow Y$, $Y \rightarrow Z$ then $X \rightarrow Z$
3. Augumentation: if $X \rightarrow Y$ then $XZ \rightarrow YZ$ always true

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eg:- Sid → Sname

⇒ SidCid → SnameCid.

eg: $A \to B \Rightarrow AC \to BC$

$AC \to BC \not\Rightarrow A \to B$

4. <u>Split Rule</u>:

if $X \to YZ$ then,

$X \to Y$

$X \to Z$

5. <u>Merge Rule</u>:

if $X \to Y$, $X \to Z$ then,

$X \to YZ$

eg:- $\{A \to B\} \Rightarrow AC \to B$ (split rule)

⇓

$AC \to BC$ (aug)

Attribute Closure (x^+)

$x^+ = \left\{ \begin{array}{l} \text{Set of all attributes} \\ \text{that can determines} \\ \text{by attribute } X \end{array} \right\}$

eg:- Given FD Set

$\{A \to B, C \to D, AB \to E, BE \to C, EF \to G\}$

$A^+ = \{A, B, E, C, D\}$, $A \to ABCDE$

reflexivity

$(AF)^+ = \{ABCDEFG\}$, $AF \to ABCDEFG$

Super Key

eg: R(A B C D) {.....} FD

2

3

4

5 7

5 8

$A^+ = \{ABCD\}$

if $A^+ = \{ABC\}$ then A is not S.K

X is some attribute set over R

X is super key of R

iff X^+ must determine all attribute of Rel R

Candidate Key. (minimal S.K)

X is candidate key of R

iff ① X must be S.K of R

$X^+ = \{$All attribute of R$\}$

|| (and)

② No Proper subset of X is S.K of R

$\forall Y \subset X$ such that

Y^+ : not determines all attributes of R

eg:- R(ABCDE)

$\{AB \to C, C \to D, B \to E\}$

$(AB)^+ = \{A\ B\ C\ D\ E\}$ ∴ AB is S.K

$A^+ = \{A\}$

$B^+ = \{B\ E\}$ → not S.K.

∴ AB is C.K of relational schema.

** Q- Find C.K of given Rel R with FD set:

1. R(ABCDEF) $\{F \to A, D \to E, C \to F\}$

$(BCD)^+ = \{A\ B\ C\ D\ E\ F\}$

min S.K

∴ BCD is C.K

$X \to Y$

$\begin{pmatrix} F \\ D \\ C \end{pmatrix}$ $\begin{pmatrix} A \\ E \\ F \end{pmatrix}$

$F^+ = __$

$__ = F$

$C^+ = C$

$D^+ = D$

2. R(ABCDEF) $\{B \to D, C \to A, E \to B\}$

$(CEF)^+ = \{CEFABD\}$

min SK ∴ CEF is C.K.

3. R(ABCDEF) $\{AB, AC, AEF, AED\}$

$\{AB \to C, C \to D, CD \to E, DE \to F, EF \to B\}$

$(AB)^+ = ABCDEF$

$(AC)^+ = ACDEFB$

$(AEF)^+ = AEFBCD$ // $AE^+ = AE$, $AF^+ = AF$

$(AED)^+ = ABCDEF$

$(\cancel{ACD})^+$ $(\cancel{AE})^+$

4. R(ABCDE) $\{AB \to C, C \to D, CD \to E, DE \to B\}$ (C: Prime, D: Prime, E: Prime, B: Prime)

∴ more than 1 C-K exist

must belong to all C-K

$(AB)^+ = \{ABCDE\}$ // find one C-K

$(AD)^+ = \{ACDEB\}$

{Non trivial FD $X \to Y$, Prime} $\Longleftrightarrow$ {Rel atleast two candidate in R}

$(ADE)^+ = \{ADEBC\}$ // $AD^+ = AD$, $AE^+ = AE$

$(ACD)^+ = \{ACDEB\}$ // $AC^+ = \{ACDEB\}$

(not minimal S-K)

$\{AB, ADE, AC\}$

5. R(ABCDEF)

$\{AB \to C, C \to DE, E \to F, F \to B\}$ (C: Prime, F: Prime, B: Prime)

$\{AB, AF, AE, AC\}$

$(AB)^+ = \{ABCDEF\}$

$(AF)^+ = \{AFBCDE\}$

$(AE)^+ = \{AEFBCD\}$

$(AC)^+ = \{ACDEFB\}$

6. R(ABCD)

$\{AB \to CD, C \to A, D \to B\}$

$\{CD, AB, AD, CB\}$

$(CD)^+ = \{CDAB\}$

$(AB)^+ = \{ABCD\}$

$(AD)^+ = \{ADBC\}$

$(\cancel{AC})^+ = \{A\}$

$(CB)^+ = \{CBAD\}$

7. R(ABCDEFGH) $\{DA, DE, DF, DB\}$

$\{CH \to G, A \to BC, B \to CFH, E \to A, F \to EG\}$

$(DA)^+ = DABCFHEG$

$(DE)^+ = DEABCFGH$

$(DF)^+ = DFEGABCH$

$(DB)^+ = DBCFHAGE$

$(\cancel{DCH})^+ = DCHG$

$(\cancel{DG})^+ = DG$

(4)

Finding C-K of Relational Schema with n attribute is NP complete problem (exponential TC)

$O(2^n)$

Membership Test

$X \to Y$, FD member of FD set (F)

iff X^+ must determine Y in FD set (F)

$F = \{\ldots\}$ $X \to Y$ member of F

$X^+ = \{\ldots Y \ldots\}$

ex: $\{AB \to C, BC \to D, CD \to E, E \to F\}$

(i) $AB \to F$ (ii) $ABG \to E$ (iii) $BC \to A$

$(AB)^+ = \{ABCDEF\}$ Yes | $(ABG)^+ = \{ABGCDEF\}$ Yes | $(BC)^+ = \{BCDEF\}$ Not member of FD set

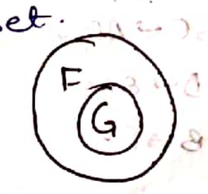
Equality Test for FD set :

$F = \{\ldots\}$ $X \to Y$ $A^+ = \{\ldots B \ldots\}$ $G = \{\ldots\}$ $A \to B$ $X^+ = \{\ldots Y \ldots\}$

Given FD sets F and G logically equal

iff (i) F cover G : Every FD of G set must member of F set.

$F \supseteq G$



and (ii) G Covers F : Every FD of F set must member of G set.

$F \subseteq G$

eg:- F Covers G G Covers F

F Covers G	G Covers F	
T	T	$\Rightarrow F \equiv G$
T	F	$\Rightarrow F \supset G$
F	T	$\Rightarrow F \subset G$
F	F	$\Rightarrow F \$ G$ not Comparable

$\boxed{F \bigcirc G}$ disjoint

eg:- $F = \{A \to B, B \to C, C \to A\}$

$G = \{A \to BC, B \to AC, AB \to C, BC \to A\}$

which is true?

(a) $F \subset G$ (b) $F \supset G$ (c) $F \equiv G$ (d) None

$F \subset G$ $G \subset F$

$A^+ = \{ABC\}$ $A \to B$ ✓

$B^+ = \{BAC\}$ $B \to C$ ✓

$C^+ = \{C\}$ $C \to A$ ✗

G covers F ND

G: $A \to BC$, $B \to AC$, $AB \to C$, $BC \to A$

F: $A \to B$ ✓, $B \to C$ ✓, $C \to A$ ✗

$F \subset G$

$A^+ = \{ABC\}$ $A \to BC$ ✓

$B^+ = \{BCA\}$ $B \to AC$ ✓

$C^+ = \{CAB\}$

(b)

F covers G Yes

F: $A \to B$, $B \to C$, $C \to A$

$A \to BC$ ✓, $B \to AC$ ✓, $AB \to C$ ✓, $BC \to A$ ✓

eg:- $F = \{A \to BCDEF, BC \to ADEF, AC \to E, D \to E, B \to F, AB \to F\}$

$G = \{A \to BC, BC \to AD, D \to E, B \to F\}$

F covers G Yes

$A \to BCDEF$ ✓
$BC \to ADEF$ ✓
$AC \to E$ ✓
$D \to E$ ✓
$B \to F$ ✓
$AB \to F$ ✓

$A \to BC$ ✓
$BC \to AD$ ✓
$D \to E$ ✓
$B \to F$ ✓

G covers F Yes

(C) $F \equiv G$

Properties Of Decomposition :

1. Lossless Join Decomposition
2. Dependency Preserving Decomposition

→ Lossless Join Decomposition

⋈ : Natural Join

Relational Schema R with instance (r) decomposed into R1, R2, ... sub relations

In General,

$(R_1 \bowtie R_2 \bowtie R_3 \ldots \bowtie R_n) \supseteq r$

if $(R_1 \bowtie R_2 \bowtie \ldots \bowtie R_n) = r$ then decomposition is lossless join

if $(R_1 \bowtie R_2 \bowtie \ldots \bowtie R_n) \supset r$ then lossy join decomposition

R with instance r

R_1 R_2

1. $(R_1 \bowtie R_2) = r$ LLJ
2. $(R_1 \bowtie R_2) \supset r$ lossy Join
3. $(R_1 \bowtie R_2) \subset r$ Not possible

eg: R (Sid Sname Cid) $\{Sid \to Sname\}$

C_K : Sid Cid

r

Sid	Sname	Cid
S1	A	C1
S1	A	C2
S2	B	C2
S3	B	C3

① decomposed into

R_1 (Sid Sname) R_2 (Sid Cid)

Sid	Sname
S1	A
S2	B
S3	B

Sid	Cid
S1	C1
S1	C2
S2	C2
S3	C3

$R_1 \bowtie R_2 = r$

Sid	Sname	Cid
S1	A	C1
S1	A	C2
S2	B	C2
S3	B	C3

Lossless Join decomposition

② decomposed into

$R_1 \bowtie R_2 \supset r$

Sid	Sname	Cid.
S1	A	C1
S1	A	C2
S2	B	C2
S2	B	C3
S3	B	C2
S3	B	C3

R_1 (Sid Sname) R_2 (Sname Cid)

Sid	Sname
S1	A
S2	B
S3	B

Sname	Cid
A	C1
A	C2
B	C2
B	C3

∴ it is lossy join

Spurious records (records which are not present in original instances) so originality of original data is lost.

NOTE: Because of Spurious Records, data access using SQL Querry causes inconsistency. (result of SQL Querries is incorrect)

R(A B C) {A→B, B→C}

A : C_K

r	2	4	7
	3	4	7
	4	5	9
	5	5	9
	6	6	9

ⓐ R_1 (A B) R_2 (B C)

A	B
2	4
3	4
4	5
5	5
6	6

B	C
4	7
5	9
6	9

lossless

ⓑ R_1 (A C) R_2 (B C)

A	C
2	7
3	7
4	9
5	9
6	9

B	C
4	7
5	9
6	9

lossy

Lossless : Common attribute of any of the sub relation is CK or S_K (Unique)

Lossy : Common attribute is not S_K for atleast one subrelation (not Unique)

Relational schema R with FD set (F) decomposed into R1, R2 sub relations

Decomposition is loss less Join iff ① $R_1 \cup R_2 = R$

② $(R_1 \cap R_2) \rightarrow R_1$ or $(R_1 \cap R_2) \rightarrow R_2$

common attribute S_K for either R_1 or R_2

eg:- R(ABCDE) → R_1(ABC), R_2(CD) lossy

Q- R(ABCDE) {AB→C, C→D, B→E} test given decomposition is LLJ or not?

(i) {ABC, CD}

NO $R_1 \cup R_2 \neq R$ Lossy

(ii) {ABC, DE}

NO $R_1 \cap R_2 \neq \phi$ Lossy

(iii) {ABC, CDE}

~~Yes~~ NO

$(AB)^+ = ABCDE$ Lossy

$R_1 \cup R_2 = R$ ✓

$(R_1 \cap R_2) = C^+ = \{CD\}$ ↓ not S_K for any sub relation

(iv) {ABCD, BE}

~~No~~ ~~Yes~~ Yes

$R_1 \cap R_2 = B^+ = \{BE\}$ ⇑ SK for R_2 lossless

Q- R(ABCDEFGHIJ)

{AB→C, A→DE, B→F, F→GH, D→IJ}

(I) { DIJ (R1), ADE (R2), FGH (R3), BF (R4), ABC (R5) }

(II) {FGH, DIJ, ADEBF, ABC}

(I) if $R_i \cap R_j \rightarrow R_i | R_j$ then $R_i \bowtie R_j$ not causes spurious tuples if we join all these relation into single table without voilating above relation then lossless.

$(R_1 \cup R_2 \cup R_3 \cup R_4 \cup R_5) = R$

$R_4 \cap R_5 = (B^+) = \{BFGH\}$ ⇓ S_K for R_4

∴ $R_4 \bowtie R_5 = ABCF$

Scanned by CamScanner

$R_1 \cap R_2 = (D^+) = \{DIJ\}$

$\Downarrow$

S-K for R1

$R_1 \bowtie R_2 = ADEIJ$

$\therefore (\overset{R_1}{ADEIJ}, \overset{R_2}{FGH}, \overset{R_3}{ABCF})$

~~R3 AR~~ $R_2 \cap R_3 = \{F\}^+ = \{FGH\}$

$\Downarrow$

S-K for R_2

$(\overset{R_1}{ADEIJ}, \overset{R_2}{ABCFGH})$

$R_1 \cap R_2 = A^+ = \{ADEIJ\}$

$\Downarrow$

S-K for R1

$(ABCDEFGHIJ) = R$

Lossless

(ii) $\{\overset{R_1}{FGH}, \overset{R_2}{DIJ}, \overset{R_3}{ADEBF}, \overset{R_4}{ABC}\}$

$R_2 \cap R_3 = D^+ = \{DIJ\}$

$\Downarrow$

S-K for R_2

$\{\overset{R_1}{FGH}, \overset{R_2}{ABDEFIJ}, \overset{R_3}{ABC}\}$

$R_2 \cap R_3 = (AB)^+ = \{ABC\}$

$\Downarrow$

S-K for R_3

$\{FGH, ABCDEFIJ\}$

$R_1 \cap R_2 = F^+ = \{FGH\}$

$\Downarrow$

S-K for R_1

$\therefore$ Lossless.

Dependency Preserving Decomposition

Relational schema R with FD set (F) decomposed into R1, R2, ..., Rn sub relations with $F_1 F_2 \ldots F_n$ FD sets.

in General,

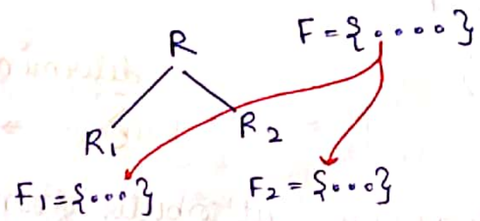
$\{F_1 \cup F_2 \cup \ldots \cup F_n\} \subseteq F$

if $\{F_1 \cup F_2 \cup \ldots \cup F_n\} = F$

then DP decomposition

if $\{F_1 \cup F_2 \cup \ldots \cup F_n\} \subset F$

then not DP decomposition



1. $\{F_1 \cup F_2\} = F$ — DP decomp
2. $\{F_1 \cup F_2\} \subset F$ — Not DP decomp

$\{F_1 \cup F_2\} \supset F$ — Not possible.

eg: R (ABCDE) with FD set

$\{A \to B, B \to C, \overbrace{C \to D, D \to BE}^{C \to B}\}$

decomposed into $\{AB, BC, CD, DE\}$

R_1 (A B)	R_2 (B C)	R_3 (C D)	R_4 (D E)
$A \to B$	$B \to C$, $C \to B$	$C \to D$, $D \to C$	$D \to E$
F_1	F_2	F_3	F_4

$A \to B$ ✓

$B \to C$ ✓

$C \to D$ ✓

$D \to BE$ ✓

$\{F_1 \cup F_2 \cup F_3 \cup F_4\} = F$

$\therefore$ DP decomposition

Q- R(ABCD) $\{AB \to CD, D \to A\}$ decomposed into $\{ABC, AD, BCD\}$

R_1 (A B C)	R_2 (A D)	R_3 (B C D)
$AB \to C$	$D \to A$	$BD \to C$

$(BD)^+ = \{BDAC\}$

$AB \to CD$ ✗

$\therefore$ Not DP decomposition.

Scanned by CamScanner

Q- R(ABCDEF) {AB→C , C→D , D→E }

{ BCD , AB, DE , EF}

R_1(BCD)	R_2(AB)	R_3 (DE)	R_4(EF)
BC → D		D → E	E → F
BD → C			
C → D			

AB → C ×
F → A ×

Not DP decomp.

Canonical Cover [Minimal cover]

minimal set of FD's which are logically equal to given FD set F

Given FD set (F),

determinant
(X) → Y

Procedure :

1. Remove extraneous attributes from determinate of each FD
   ↓ unnecessary.

eg: { XYZ → W , X^+ = {... Y ...}}
extraneous X → Y

Q- find the extraneous attribute

(I) {ABCD → E , A → F , F → D}
D A → D ⇒ {ABC → E , A → F, F → D}

(II) {AB → C , A → B}
⇒ {A → C , A → B} B

2. Remove redundant FD's from step ① result

X → Y FD of FD set (F) is redundant iff X → Y must member of {F − (X → Y)}

eg: {A → B , B → C , A → C}
×
Redudant because it can be derived from other FD

Q- {AB → C , AB → D , BC → D }
×
~~AB → CD~~ , ~~BC → D~~

$(AB)^+$ = ABCD

eg:- {ABCD → E , BC → D , A → F , F → C , AB → F}

① [ABC → E , BC → D A → F , F → C , AB → F ×]
Redundant

Removal of Extraneous
ABCD → E
BC → D
A → F
F → C
AB → F

Redundant
AB → E
BC → D
A → F
F → C
AB → F ×

AB^+ = ABEFCD

∴ minimal cover = { AB → E, BC → D, A → F, F → C}

Q- { A → BC ×
CD → E ×
E → C
D → AEH
ABH → BD
DH → BC
}

D → A ✓
D → E ✓
D → H ✓
ABH → B ×
ABH → D ✓
DH → B
DH → C ×

A → BC ✓
D → E ×
E → C ✓
D → A ✓
E ✓
H ✓
AH → B ×
→ D ✓
D → B ✓
→ C ×

Result:
D → AEH ✓
AH → D ✓
E → C ✓
A → BC

Minimal set of FD cover F may not unique but all minimal cover are logically equal which is also equal to the FD set F

eg:- F = { AB → C
A → B
B → A
}

AB → C
A → C
A → B
B → A
⇓
F_1 (A → BC
B → A)

A → B
B → C
A → B
B → A
⇓
F_2 (A → B
B → AC)

$F_1 = F_2 = F$

Normal Forms

used to identify degree of redundancy.

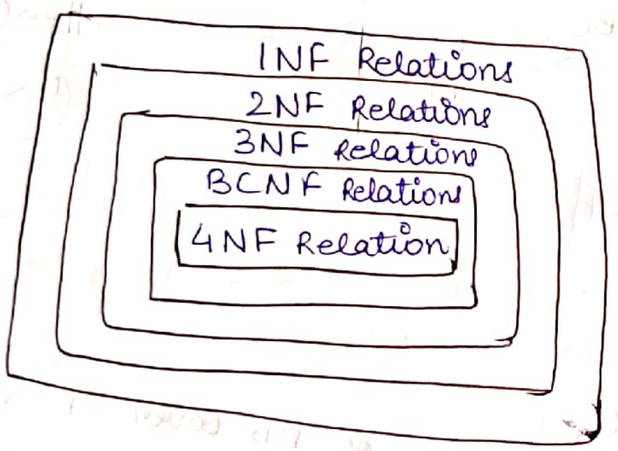
Over FD ($X \to Y$):
- 1NF
- 2NF
- 3NF
- BCNF — 0% redundancy over FD's

Over MVD ($X \to\to Y$):
- 4NF — 0% redundancy over MVD's

Redundancy:
- Over non trivial FD $X \to Y$ [Single valued Dependency]
- Over non trivial MVD $X \to\to Y$ [multi Valued DP]

⇒ To eliminate redundancy over FD's relation should decomposed into BCNF

⇒ relation should decomposed into 4NF



First Normal Form (1NF)

⇒ Default normal form of RDBMS rel.

⇒ Relational schema are in 1NF iff No multivalued attribute in R [every attribute of R must be atomic / single valued]

⇒ eg: R

Sid	Sname	Cid
S1	A	C1|C2
S2	B	C2|C3
S3	B	C3

MVA (multi valued attribute)

{Sid → Sname}

Not in 1NF

Not in RDBMS

1NF design <=> design C_K

R

Sid	Sname	Cid
S1	A	C1
S1	A	C2
S2	B	C2
S2	B	C3
S3	B	C3

SidCid : C_K

{Sid → Sname}

not S_K

R is in 1NF

eg: R(Sid Sname DOB Cid Phno email)

Sid	Sname	DOB	Cid	Phno	email
S1	A	1995	C1|C2 (2)	P1|P2|P3 (3)	e1|e2|e3|e4 (4)
S2	B	1994	C2|C3 (2)	P3|P4 (2)	e4|e5 (2)

not in 1NF

C_K: SidCidPhnoemail

Sid → Sname DOB

not S_K

Sid	Sname	DOB	Cid	Phno	email
S1	A	1995	C1	P1	e1
S1	A	1995			
⋮					
S1	A	1995	C2	P3	e4
S2	B	1994	C2	P3	e4
⋮					
S2	B	1994	C3	P4	e5

24 tuples required

8 tuples required

it is in 1NF

**Degree of redundancy is very high in 1NF

1NF — default NF of RDBMS

2NF 3NF BCNF — reduce/eliminate redundancy over FD's.

$X \to Y$ FD of R forms redundancy iff
1] Non Trivial FD
&&
2] X is not S_K.

$X \rightarrow Y$ FD of R not forms redundancy

iff ① Trivial FD ($X \supseteq Y$)

(OR)

② X is S_K

eg: Emp (eid ename rating hourlywage)

eid	ename	rating	hourlywage
e1		10	500
e2		10	500
e3		10	500
e4		12	800
e5		12	800

eid → ename rating (eid: S_K)

rating → hourlywage (rating: not S_K) forms redundancy

eg:- R(ABCDEF) (D, E, F: non prime)

{ AB → C, B → D, D → E, AD → F, C → A } ⇒ forms redundancy

{AB, BC} cand key.

not S_K

FD $X \rightarrow Y$ forms redundancy [X: not S_K]

		1NF	2NF	3NF	BCNF
1.	Proper subset of C_K → Non prime (PA → NPA)	✓	✗	✗	✗
2.	Non Prime → Non Prime (NP → NP)	✓	✓	✗	✗
3.	Proper subset of C_K and Non Prime → Non Prime (P_NP → NP)	✓	✓	✗	✗
4.	Proper subset of C_K → Proper subset of C_K (PA → PA)	✓	✓	✓	✗

⇑ more redundancy

⇑ 0% redundancy over FD's

Second Normal Form (2NF)

Relational schema R in 2NF iff NO Partial dependencies in Rel R

Partial Dependency:

X: any C_K of R

Y ⊂ X

Z non prime of R

Y → Z : partial dependency.

Third Normal Form (3NF)

Relational schema R in 3NF iff every non trivial FD $X \rightarrow Y$ with

(i) X must be S_K

(Or)

(ii) Y must be prime Attribute

$X \rightarrow Y$ (X: S_K (Or) Y: Prime)

{PA → PA} allowed in 3NF which can form redundancy.

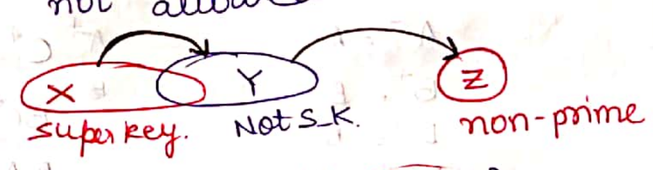
Boyce Codd NF (BCNF)

Relational schema are in BCNF iff every non trivial FD $X \rightarrow Y$ with

(i) X must be S_K ($X \rightarrow Y$: X: S_K)

(R in BCNF) <=> (0% redundancy in R over FD's)

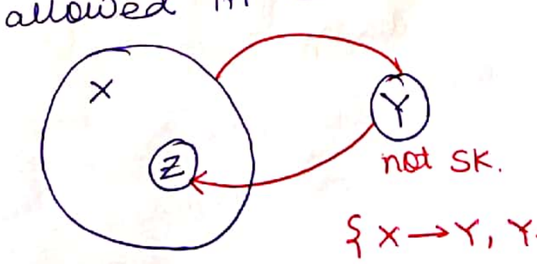
⇒ Non Prime Attribute transitively determined by S_K is not allowed in ~~BCNF~~ 3NF



{X → Y, Y → Z} ↳ not in 3NF

⇒ Prime Attribute transitively determined by superkey is allowed in 3NF but not allowed in BCNF

X: only C_K.



{X → Y, Y → Z} (Z: prime)

Q- R(ABCDE)

{ABD → C, BC → D, CD → E}

Highest NF satisfied by R?

(a) 1NF ✓ (b) 2NF ✗ (c) 3NF ✗ (d) BCNF ✗

ABD → C

BC → D

CD → E PD

$(ABD)^+ = ABCDE$

$(ABC)^+ = ABCDE$

{ABD, ABC} : C_K

{A, B, C, D} : PA

BCNF :-

ABD → C ✓

not S_K BC → D ✗

2NF :

S_K ABD → C ✓

PA BC → D PA ✓

CD → E ✗ NPA

~~not S_K~~ PA PD

3NF :-

S_K ABD → C ✓

PA BC → D PA ✓

not S_K CD → E ✗ NPA

2NF Testing :- (Proper Subset of C_K)$^+$ = {only PA}

Candidate Key : ABD

$A^+ = A$

$B^+ = B$

$D^+ = D$

$AB^+ = AB$

$BD^+ = BD$

$AD^+ = AD$

ABC

$C^+ = C$

$BC^+ = BCDE$ non prime

$AC^+ = AC$

∴ BC → E is PD in rel R

Q- R(ABCD)

{AB → C, BC → D}

$(AB)^+ = ABCD$ ↳ C_K

✓ ✗ BCNF

✓ ✗ 3NF

✓ ✓ 2NF

ABC

$B^+ = B$

$A^+ = A$

NO PD

Q- R(ABCD)

{AB → C, C → A, AC → D}

$(AB)^+ = ABCD$

$(CB)^+ = ABCD$

A, C, B ← PA

✓ ✗ ✗ BCNF

✓ ✓ ✗ 3NF

✓ ✓ ✗ 2NF

INF

AB ⇒ $A^+ = A$, $B^+ = B$

BC ⇒ $C^+ = ACD$ NP

Q- R(ABCD)

{A → B, B → AC, C → D}

$A^+ = ABCD$

$B^+ = ABCD$

✓ ✓ ✗ BCNF

✓ ✓ ✗ 3NF

✓ ✗ ✓ ✗ ✓ 2NF

Proper subset of C_K.

$B^+ = \phi$

$A^+ = \phi$

Q- R(ABCDEF)

{AB → C, C → D, CD → AE, DE → F, EF → B}

✓ ✗ ✗ ✗ ✗ BCNF

✓ ✓ ✓ ✓ ✓ 3NF.

$(AB)^+ = ABCDEF$ ✓

$(AEF)^+ = ABCDEF$ ✓

$(AC)^+ = AE$

$(AF)^+ = AF$

$(ADE)^+ = ABDEFC$ ✓

$(ACE)^+ = ACEDFB$

PA = A, B, C, D, E, F

Q- R(ABCDEF)

{AB → C, C → DE, E → F, F → B}

(AB, AF, AE, AC)

A, B, C, E, F

✓ ✗ ✗ ✗ BCNF

✓ ✗ ✓ ✓ 3NF

✗ 2NF

✗ 1NF

Q- R(ABCDE) $(AE)^+ = ABCDE$, $(DE)^+ = DAE$, $(CE)^+ = CED$, $(BE)^+ = BCE$

{A → B, B → C, C → D, D → A}

	×	×	×	×	BCNF
	✓	✓	✓	✓	3NF

PA: A, B, C, D, E

Q A Relational schema R with only ~~on~~ simple C-K, no compound keys in relational schema

(a) R in 1NF but may not 2NF

(b) R in 2NF but may not 3NF

(c) R in 3NF but may not BCNF

(d) BCNF

if C-K are simple then PD not possible

Q If Relational schema R with only Prime attribute then R always in 3NF but may not BCNF

(C)

Q Relational schema R with no non-trivial FD's are always in BCNF may not in 4NF

R(ABC) {No nontrivial FD's}

ABC : C-K

NO non trivial FD's in R ⇒ No Redundancy in R over FD's (R in BCNF)

Q Relational schema R with only two attributes R always in

R(AB) {A → B} (C-K) BCNF, also 4NF

R(AB) {B → A} (C-K)

R(AB) {A → B (C-K), B → A (C-K)}

R(AB) {no non trivial FD} → C-K

Q- if R in 3NF and at most one compound Cand key in R, then

* Cand key in R

(a) R in BCNF

(b) R not BCNF

(c) R may not BCNF

(d) None

ABC (AB, BC)

AB → C

C → A

(a)

if R in 3NF but not BCNF

then ① (proper subset of C-K) → (proper subset of other C-K) exist in R

now, R is 3NF & only 1 compound Cand-Key then above situation can't occur.

∴ R is BCNF

② At Least two compound keys

③ Overlapped Cand keys ↳ R(ABC) {AB → C, C → A}

[AB, BC] : CK

⇓ overlapped CK's

Decomposition into Higher NF:

Decompose relation R into 2NF, 3NF, BCNF with lossless join and dependency Preserving.

R(.....YZ) {.....Y → Z} PD

FK

R_1(.....Y) R_2(Y Z) → S-K, Y → Z] LLJ, DP, no PD

eg:- R(Sid Sname Cid Phno) {Sid → Sname} PD Sidcid Phno : C-K

FK

2NF decomp.

R_2(Sid Sname) R_1(Sid Cid Phone)

no non-trivial FD

∴ NO PD, LLJ, DP

BCNF

Q- R(ABCDE)

AB : C_K

{AB → C, B → D, D → E}

PD-

B → D

B → E

B^+ = BDE

A C B	B D E
AB → C	B → DE, D → E ×3NF

FK

2NF

A B C	B D	D E
AB → C	B → D	D → E

FK, FK

LLJ
DP
3NF ✓
BCNF ✓

Q- R(ABCDEFG)

{AB → C, C → D, A → E, E → F, B → G}

How many min relation required for 2NF decomp? 2 3

$(AB)^+$ = ABCDEFG.

C_K

A^+ = AEF

B^+ = BG

A → E
E → F
A → F

~~AB C~~ ~~C D~~ ×

A B C D	A E F	B G

min 3 relation
$$
& foreign key

LLJ ✓
NO PD
DP ✓

2NF ✓

AB → C ①
C → D ②

A → E ③
E → F ④

B → G ⑤

for 3NF.

Q- R(ABCD)

{A → B, C → D}

How many min relations required for 2NF

(a) 1 (b) 2 (c) 3 (d) 4

$(AC)^+$ = ABCD

A^+ = AB

C^+ = CD

(c)

A B	C D	A C
A → B	C → D	No non trivial FD

LLJ ✓
2NF ✓
BCNF ✓

Q R(ABCDE)

{AB → C, BC → A, AC → B} decompose into BCNF

$(ABDE)^+$ = ABCDE

$(BCDE)^+$ = ABCDE

$(ACDE)^+$ = ABCDE

C_K : {ABDE, BCDE, ACDE}

AB → C BC → A AC → B

3NF but not BCNF

BCNF decomp.:

R_2(AB C)
AB → C
BC → A
AC → B

R_1(AB DE)
or BC or AC

no non trivial FD

LLJ ✓
DP ✓
BCNF ✓

AB BC AC

X Y ✓

sid sid ✓

sid cid stud ID ×

R(A B C) R_1(D E) ✓

R(AB C) R_2(D E) ×

R(AB C) R_2(DE F) ✓

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Q- R(ABC) {AB → C, C → A} decompose into BCNF

$(AB)^+ = ABC$

$(BC)^+ = ABC$

AB, BC ⇒ C.K.

C	A

C → A

$R_1 \bowtie R_2$ (ABC)

C → A BC

~~A~~	B	C

~~AB → C~~

no non trivial FD

LLJ ✓
BCNF ✓
Not DP

Q- R(ABCD) {ABC → D, D → AB} decompose into BCNF

$(ABC)^+ = ABCD$

$(CD)^+ = ABCD$

A	B	D

D → AB

C	D

no non trivial FD

LLJ ✓
BCNF ✓
DP ✗

Not every relation can decompose into BCNF with DP

Every relation possible to decompose into BCNF with lossless Join decomposition

Every relation possible to decompose into 3NF with LLJ and PD

DB design Goals based on Normilization	1 NF	2 NF	3 NF (Most accurate NF)	BCNF	4NF
1. ** LLJ decomp	Yes	Yes	Yes	Yes	maynot
2. ** DP decomp (dependency preserving)	Yes	Yes	Yes	maynot	maynot
3. 0% redundancy	NO	NO	NO	Yes over FD's, NO over MVD's	Yes over FD's & MVD's

5 NF [Join dependency NF] (JDNF)

If decomposition satisfy 4NF and lossless join decomposition, then decomposition is 5NF.

6 NF [Domain Key NF] (DKNF)

If 4NF, lossless join and DP of FD & MVD's is satisfied.

Queries

Procedural Query Lang

⇒ Formulation of how data retrieved from DB tabels

what data retrieved from DB table

⇒ Relational Algebra

Non Procedural Query Lang

⇒ Formulation of what data retrieved from DB files.

⇒ Relational Calculus [uses FOL, predicate (first order logic) Calculus formula]

- Tuple Relational Calculus (TRC)
- Domain relational Calculus (DRC)

SQL [IBM]

QBE (Querry By example) [microsoft]

Relational Algebra

Basic operators :-

Unary operator:

- π : Projection
- σ : Selection
- ρ : Rename

- × : Cross Product
- ∪ : Union
- − : Set difference

Derived operators

- ∩ : Intersection (Using −)
- ⋈ : Join (Using ×, σ, π)
- / or ÷ : Division (Using π, ×, −)

Projection (π) :

$\pi_{list_Attr}(R)$: Retrieve specific attributes from R

Selection (σ) :

$\sigma_P(R)$: Retrieve records of Rel R those are satisfied condition P.

R

A	B	C
4	2	4
5	2	4
6	2	5
6	2	5

$\pi_{BC}(R)$

BC
2 4
2 5

} distinct tuples

$\sigma_{A \geq 5}(R)$

A	B	C
5	2	4
6	2	5

} distinct tuples

Q- Which is true

(i) π is computative

(ii) σ is commutative

(a) (i) ~~(b)~~ ii (c) i, ii (d) none

$\phi_2 \phi_1 (R)$

↳ if order of opr^n doesnot matter then commutative

$\pi_{list_2}(\pi_{list_1}(R)) \neq \pi_{list_1}(\pi_{list_2}(R))$

$\pi_B(\pi_{BC}(R))$ $\qquad$ $\pi_{BC}(\pi_B(R))$

Invalid Query

$\sigma_{L_1}(\sigma_{L_2}(R)) = \sigma_{L_2}(\sigma_{L_1}(R))$

$\sigma_{A \geq 6}(\sigma_{A \geq 5}(R)) = \sigma_{A \geq 5}(\sigma_{A \geq 6}(R))$

$\sigma_{center=Kol}(\sigma_{Branch=CS}(R)) = \sigma_{Branch=CS}(\sigma_{center=Kol}(R))$

$= \sigma_{C1 \wedge C2}(R)$

Q- Which of LHS query can't replace with RHS query $list_1$ $list_2$ attributes of R. C_1 C_2 conditions over Attr of R

~~(a)~~ $\pi_{list_1}(\sigma_{C1}(R)) \longrightarrow \sigma_{C1}(\pi_{list_1}(R))$

(b) $\sigma_{C2}(\pi_{list_2}(R)) \longrightarrow \pi_{list}(\sigma_{C2}(R))$

(c) $\sigma_{C2}(\sigma_{C1}(R)) \longrightarrow \sigma_{C1}(\sigma_{C2}(R))$

(d) none.

R (Sid Sname age)

(a)✓

$\pi_{sid}(\sigma_{age \geq 20}(R)) \longrightarrow \sigma_{age \geq 20}(\pi_{sid}(R))$ ×

$\sigma_{sid=S10}(\pi_{sid\,sname}(R)) \longrightarrow \pi_{sid\,sname}(\sigma_{sid=S10}(R))$ ✓

Cross - Product (×)

R×S : results all attributes of relation R followed by all attributes of relation S and each record of relation R pairs with every record of relation S

R

A	B	C
2	4	7
8	4	3
7	5	7

n distinct tuples

Arity : X

S

C	D
7	5
6	5

m distinct tuples

Arity : Y

$R \times S \Rightarrow$

A	B	C	C	D
2	4	7	7	5
2	4	7	6	5
8	4	3	7	5
8	4	3	6	5
7	5	7	7	5
7	5	7	6	5

Arity : $x+y$

Cardinality : $n*m$

eg:-

R

A	B
2	4
5	6

S

C	D
empty	

$R \times S$

A	B	C	D

} empty

$R \times S$ product result empty record set if either R or S is empty record set

JOIN

- ↳ Natural Join ($\bowtie$)
- ↳ Conditional Join ($\bowtie_c$)
- ↳ Outer Join
  - ↳ Left Outer Join ($⟕$)
  - ↳ Right outer Join ($⟖$)
  - ↳ Full Outer Join ($⟗$)

Natural Join :

$$\boxed{R \bowtie S = \pi_{\text{distinct attribute}}\left(\sigma_{\text{equality b/w common attri of R \$S}}(R \times S)\right)}$$

eg: $R \bowtie S = \pi_{ABCD}\left(\sigma_{R.C = S.C}(R \times S)\right)$

A	B	C	C	D
2	4	7	7	5
7	5	7	7	5

Q: $T_1(A\ B\ C)$ $T_2(B\ C\ D\ E)$

$$T_1 \bowtie T_2 = \pi_{ABCDE}\left(\sigma_{T_1.B = T_2.B \wedge T_2.C = T_1.C}(T_1 \times T_2)\right)$$

Q: $T_1(A\ B)$ $T_2(C\ D)$

$$T_1 \bowtie T_2 = (T_1 \times T_2)$$

∵ there is no common attribute

Natural Join equal to Cross product if Join condition empty. (no common attribute)

Conditional Join ($\bowtie_c$)

$$\boxed{R \bowtie_c S = \sigma_c(R \times S)}$$

eg:- $R \bowtie_{R.C < S.C} S = \sigma_{R.C < S.C}(R \times S)$

A	B	C	C	D
8	4	3	7	5
8	4	3	6	5

eg: $R \bowtie_{A<5} S = \sigma_{A<5}(R \times S)$

A	B	C	C	D
2	4	7	7	5
2	4	7	6	5

Left Outer Join :

$R ⟕ S \equiv (R \bowtie S) \cup$ { records of R those are failed Join condn with null value in other attribute }

eg:- R

A	B	C
2	4	7
8	4	3
7	5	7

S

C	D
7	5
6	5
1	

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$R \bowtie S$ =

A	B	C	D
2	4	7	5
7	5	7	5
8	4	3	NULL

Right Outer Join (⟖):

$R ⟖ S$ =

A	B	C	D
2	4	7	5
7	5	7	5
NULL	NULL	6	5

Full Outer Join (⟗):

$R ⟗ S \equiv (R \bowtie S) \cup (R ⟖ S)$

A	B	C	D
2	4	7	5
7	5	7	5
8	4	3	NULL
NULL	NULL	6	5

Usage of Join:

⇒ R(A...) S(B...)

Q- Retrieve "A" Val of R those are more than ∃ (some) "B" of S

any/atleast one

$\bowtie_C$ >some

R(A ...) S(B ...)

10, 20, 30, 40 | 15, 25, 30

$\pi_A(\sigma_{R.A>S.B}(R \times S))$

≡

$\pi_A(R \bowtie_{R.A>S.B} S)$

A	B
10	15
10	25
10	30
20	15
20	25
20	30

Rename operator (ρ):

Used for rename table / attributes for query processing.

eg: stud (sid , sname , age)

ρ (temp , stud) : Temp (sid sname age)

ρ (stud) : stud (I , N , A)
I, N, A

ρ (stud) : stud (I , sname , A)
sid → I
age → A

eg: R (A B C) S(C D)

A B C C D

$R \bowtie S$
R.C > S.C

eg:- R(A B C)

A B C A B C

ambiguity bec table is same

R×R

⇓

$R \bowtie \rho(T,R)$
R.C > T.C

(or)

$R \bowtie_{C>C1} \rho_{A1B1C1}(R)$

⇒ now we can differentiate

A	B	C	A1	B1	C1

when we use two instance of same table, renaming is used.

eg:- Emp (eid sal dno)

Retrieve eid's whose salary more than some emp sal of dept 5

$\pi_{Emp.eid}(\sigma_{Emp.dno=5}(Emp \bowtie_{Emp.sal>E.sal} \rho(Emp, E)))$

"or"

Emp

eid	sal	dno
e1	10	4
e2	20	5
e3	30	3
e4	40	5
e5	50	4

Emp

eid	sal	dno
e2	20	5
e4	40	5

eid sal dno eid sal dno

$\pi_{eid}(\sigma_{sal>S}(Emp \times \rho_{I,S,D}(\sigma_{dno=5}(Emp))))$

(or)

$$\pi_{eid}\left(Emp \underset{Sal>S}{\bowtie} \rho_{I,S,D}\left(\sigma_{d=5}(Emp)\right)\right)$$

Q- Emp(eid sal gen)

Retrieve female eid's whose salary more than salary of some male emp

$$\pi_{eid}\left(\left(\sigma_{gen=M}(Emp)\right) \underset{S>Sal.}{\bowtie} \rho_{I,S,G}\left(\sigma_{gen=F}(Emp)\right)\right)$$

6 comparison, 5 comparison, 5 comparison

Total = 5+5+6 = 16 comparison

cost of query

(or)

$$\pi_{cid}\left(Emp \underset{\substack{Gen=F \\ \wedge \\ G=M \\ Sal>S}}{\bowtie} \rho_{I,S,G}(Emp)\right)$$

more comparisons

Cross product = 25 result

25 × 3 = 75 comparisons

∴ 1st one is efficient because its cost is less.

Q R(A B C) S(C D)

$\sigma(R \times S) \equiv \left(\sigma_{A>5}(R) \underset{R.C>S.C}{\bowtie} \sigma_{D<5}(S)\right)$

$R.A>5 \wedge S.D<5 \wedge R.C>S.C$

> some

Emp

eid	Sal	Gen.
e1	10	F
e3	30	F
e5	50	F

dem

Emp

eid	Sal	Gen
e2	20	M
e4	40	M

male

Q - Enroll (Sid Cid fee)

Sid	Cid
S1	C1
S1	C2
S1	C4
S2	C2
S2	C3
S3	C4

= some

Course (Cid Instr) Koath

Cid	Instr
C1	Koath
C2	Koath
C3	Navathe
C4	Ullman

Retrieve Sid's enrolled some course taught by Koath.

$$\pi_{Sid}\left((Enroll) \underset{\substack{Enroll.Cid \\ = \\ course.Cid}}{\bowtie} \left(\sigma_{Inst=Koath}(Course)\right)\right)$$

4

6*2=12 ⇒ 16 comparisons

or

$$\pi_{Sid}\left(\sigma_{\substack{Enroll.Cid \\ = \\ course.Cid \\ \wedge \\ Ins=Koath}}(Enroll \times course)\right)$$

24 tuples in course product

2 comp for record.

⇒ 48 comparison

some/any/atleast one. $\left\{ \begin{array}{l} R \bowtie S \\ R \bowtie_C S \\ \sigma(R \times S) \end{array} \right.$

** Q- R(A....) S(B...)

Retrieve 'A' vals of R those are more than every "B" of S.

≤ some.

R(A)
10
20
30
40

R(A) S(B...)

10, 20, 30, 40 — 15, 25, 30

¬(> every) ≡ (≤ some)

$$\left\{ \begin{array}{l} \text{All 'A'} \\ \text{val of R} \end{array} \right\} - \left\{ \begin{array}{l} \text{'A' val of R which are} \\ \leq \text{some B val of S} \end{array} \right\}$$

$$\pi_A(R) - \pi_A\left(R \underset{R.A \leq S.B}{\bowtie} S\right)$$

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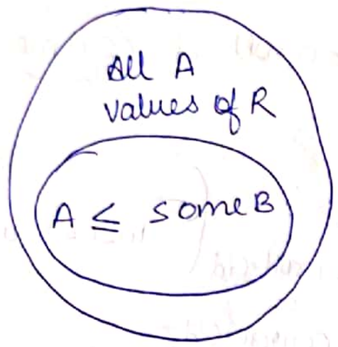
NOTE: These queries can't directly use join.

$\neg(> \text{every}) \equiv (\leq \text{some})$

$(> \text{every}) \equiv \neg(\leq \text{some})$



Q Emp (eid dno sal)

Retrieve emp 'eid's' whose salary more than every emp of dept 5

$\pi_{eid}(Emp) - \pi_{eid}\left((Emp) \bowtie_{Sal \leq S} \rho_{I,D,S}\left(\sigma_{dno=5}(Emp)\right)\right)$

'or' eid's sal > every emp of dept 5 $\equiv \{\text{all emp}\} - \{\text{eid's sal} \leq \text{some emp sal of dept 5}\}$

Q- Emp(eid gen sal).

Retrieve female emp whose sal less than every male emp.

female emp sal < every male emp $\equiv \{\text{All female emp. eid}\} - \{\text{temal emp sal} \geq \text{some male emp sal}\}$

$\pi_{eid}(Emp) - \pi_{eid}\left(\sigma_{Gen=F}(Emp) \bowtie_{Sal \leq Sal, IGS} \rho\left(\sigma_{Gen=M}(Emp)\right)\right)$

$\pi_{eid}(\sigma_{Gen=F}(Emp))$

Q Emp (eid sal)

Retrieve eid's who gets highest salary (max sal)

(max^m salary) = (Sal ≥ every emp sal)

Sal ≥ every emp Sal $\equiv \{\text{all emp eid's}\} - \{\text{Sal} \leq \text{some emp sal}\}$

// eid's whose salary is max^m.

// eid's whose salary is not max^m.

$\pi_{eid}(Emp) - \pi_{eid}\left((Emp) \bowtie_{Sal \leq S} \rho_{I,S}(Emp)\right)$

NOTE: R (A ...)

① [max 'A' val of R]

$\{A \geq \text{every } A\} \equiv \{\text{All 'A' val}\} - \{\text{'A'} < \text{some } A\}$

$\pi_A(R) - \pi_A\left(R \bowtie_{A < A1} \rho_{A \to A1}(R)\right)$

② [min 'A' val of R]

$\{A \leq \text{every } A\} \equiv \{\text{All 'A' val}\} - \{\text{'A'} > \text{some } A\}$

$\pi_A(R) - \pi_A\left(R \bowtie_{A > A1} \rho_{A \to A1}(R)\right)$

Q- Emp (eid sal dno)

Retrieve eid's whose sal is max for each dept.

$\{\text{sal} \geq \text{every emp sal of dept same}\} \equiv \{\text{All Emp eid}\} - \{\text{sal} < \text{some sal of dept same}\}$

// eid whose sal. max for same dept

// eid who sal not max for same dept.

$\pi_{eid}(Emp) - \pi_{eid}\left(Emp \bowtie_{sal < S \,\wedge\, Dno = D} \rho_{I,S,D}(Emp)\right)$

'or'

emp (eid	sal	dno)
e1	70	2
e2	80	2
e3	65	2
e4	60	3
e5	70	3

emp (eid	sal	dno)
	70	2
	80	2
	65	2
	60	3
	70	3

e_1 e_2 e_3 e_4 e_5

$= e_2 \,\&\, e_5$

Q- family (parent child childDOB)

parent	child	childDOB
A	B	1982
A	C	1984
B	D	2011
B	E	2012

Retrieve oldest child of each parent

[min DOB child]

$$\left(\text{child} \leq \text{every child DOB of each parent}\right) \equiv \left\{\text{all child}\right\} - \left\{\text{chid} > \text{every child DOB of each parent}\right\}$$

$$\pi_{child}(family) = - \pi_{child}\left(Family \bowtie_{DOB > D \,\wedge\, Parent = P} \rho_{P,C,D}(Family)\right)$$

Set Operations :-

$\cup$: Union

$-$: Set Difference

$\cap$: Intersection

$R \cup S$, $R \cap S$, $R - S$

A relation R and S must be union compatible.

R and S union compatible if and only if

(i) Arity of R = Arity of S

(ii) Domain of each attribute of R must be same domain of each attribute of S respectively

domain of attribute

Possible values accepted by attributes.

eg: $\pi_{sid\,sname}(\ldots) \underset{\cap}{\cup} \pi_{sid}(\ldots)$ ✗ cond^n 1 failed

$\pi_{sid\,sname}(\ldots) \underset{\cap}{\cup} \pi_{sid\,age}(\ldots)$ ✗ cond^n 2 failed

$\pi_{sid\,sname}(\ldots) \underset{\cap}{\cup} \pi_{StudIDStudName}(\ldots)$ ✓ (Renamed) but their domains are same.

$R \cup S$, $R \cap S$, $R - S$ set operations

(i) result distinct tuples

(ii) schema (table name, attribute names) of result same as schema of R.

Same in SQL

eg:- R

A	B	C
2	6	8
2	6	8
7	2	4
7	3	5

S

D	E	F
2	6	8
2	6	8
7	4	4
7	3	5

$R \cup S$ [OR] $\equiv$ R

A	B	C
2	6	8
7	2	4
7	3	5
7	4	4

distinct tuples

$R - S$ [But not] [only] $\equiv$ R

A	B	C
7	2	4

$R \cap S \equiv$ R

A	B	C
2	6	8
7	3	5

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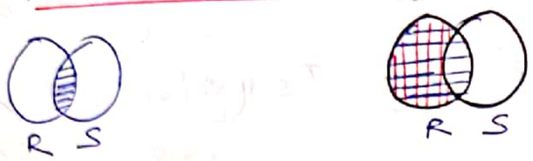
Q- R (A B) S (C D)

A	B
2	4
2	5

C	D
2	4
3	6

$$\boxed{R \cap S \equiv R - (R - S)}$$



$$\boxed{R \cap S \equiv R \bowtie \rho_{\substack{C \to A \\ D \to B}}(S)}$$

$$\boxed{R \cap S \equiv \pi_{A,B}\left(R \bowtie_{\substack{A=C \\ \wedge\ B=D}} S\right)}$$

∴ '∩' is derived operⁿ.

Q- Enroll (Sid Cid) Course (Cid Inst)

Retrieve Sid's enrolled some course taught by Koath or some course taught by Novathe.

(Sid enrolled some Koath course) OR (sid enrolled some Novathe course)

$$\pi_{sid}\left(Enroll \bowtie_{\substack{Enroll.Cid \\ = \\ Course.Cid}} \left(\sigma_{Inst=Koath}(Course)\right)\right) \cup$$

$$\pi_{sid}\left(Enroll \bowtie_{\substack{Enroll.Cid \\ = \\ Course.Cid}} \left(\sigma_{Inst=Navath.}(Course)\right)\right)$$

"OR"

$$\pi_{sid}\left(Enroll \bowtie \sigma_{\substack{Inst=Koath \\ \vee \\ Inst=Navathe}}(Course)\right)$$

Q- Retrieve Sid's enrolled some Koath course and some navathe course.

$$\pi_{sid}\left(Enroll \bowtie \sigma_{\substack{Inst=Koath \\ \wedge\ Inst=Navathe}}(Course)\right) \times$$

"or"

$$\pi_{sid}\left(Enroll \bowtie \sigma_{Inst=Koath}(Course)\right) \cap_{sid} \left(Enroll \bowtie \sigma_{Inst=Navathe}(Course)\right) ✓$$

Q- Retrieve Sid's enrolled only courses taught by Koath.

$$\pi_{sid}\left(Enroll \bowtie \sigma_{Inst=Koath}(Course)\right) - \pi_{sid}\left(\bowtie\right)$$

some Koath course

(only) Koath course

S1 C1 —	C1 Koath	
S1 C3 .	C3 Navathe	

{Sid's enrolled only courses taught by Koath} = {Sid enrolled some course} − {sid enrolled some non Koath course}

S1		S1
S2	−	S3
S3		

Example of '÷'

only / but not	÷ (−)

$$\pi_{sid}(Enroll) - \pi_{sid}\left(Enroll \bowtie \sigma_{Ins \neq Koath}(Course)\right)$$

DIVISION (/ or ÷)

pair with every

Q- Enroll (Sid Cid)

Sid	Cid
S1	C1
S1	C2
S1	C3
S2	C1
S2	C2
S3	C1

course (Cid ...)

Cid
C1
C2
C3

Retrieve sid's enrolled every course

$$\pi_{sid\,cid}(Enroll) / \pi_{cid}(course) \equiv \boxed{Sid: S1}$$

Expansion of / :-

⇒ Retrieve sid's enrolled every course

$$\pi_{sid\,cid}(E) / \pi_{cid}(C)$$

not enrolled every S_2, S_3

≠

enrolled some S_1, S_2, S_3

(a) Retrieve sid's not enrolled every course [sid's enrolled proper subset of all courses]

$$\pi_{sid}\Big(\underbrace{\pi_{sid}(E) \times \pi_{sid}(C)}_{\text{every sid of enrolled rel pairs with all courses}} - \underbrace{\pi_{sid\,cid}(E)}_{\text{Given enrolled records}}\Big)$$

S2
S3

disqualified sid's for division

(b) {Sid's enrolled every course} ≡ {sid enrolled some course} − {sid's not enrolled every course}

$$\boxed{\pi_{sid\,cid}(E) / \pi_{cid}(C) \equiv \pi_{sid}(E) - \pi_{sid}\big(\pi_{sid}(E) \times \pi_{sid}(C) - \pi_{sid\,cid}(E)\big)}$$

Q- Enroll (Sid Cid)

Sid	Cid
S1	C1
S1	C2
S1	C3
S2	C2
S2	C4
S3	C4

course (Sid Inst)

Cid	Inst
C1	Korth
C2	Korth
C3	Navathe
C4	Ullman

(a) Retrieve sid's enrolled some course taught by Korth.

(b) Retrieve sid's enrolled every course taught by Korth.

(a) $\pi_{sid}(Enroll \bowtie \sigma_{Ins=Korth}(course))$

⇒ S1, S2

(b) $\pi_{sid\,cid}(Enroll) / \pi_{sid}(\sigma_{Ins=Korth}(Course))$

⇒ S1 ≡

S1 C1, S1 C2, S3 C1
S2 C1, S2 C2, S3 C2

$$\pi_{sid}(E) - \pi_{sid}\big(\pi_{sid}(E) \times \pi_{cid}(\sigma_{Ins=Korth}(C)) - \pi_{sid\,cid}(E)\big)$$

sid enrolled proper subset of Korth courses.

S1
S2
S3

S2
S3

S2 C1
S3 C1
S3 C2

Q- Stud.(sid gen)

Enroll (sid Cid)

(a) Retrieve cid's enrolled some female stud

(b) Retrieve cid's enrolled every female stud.

(a) $\pi_{cid}(Enroll \bowtie \sigma_{gen=F}(Stud))$

(b) $\pi_{cid\,sid}(E) / \pi_{sid}(\sigma_{Gen=F}(Stud)) \equiv \pi_{cid}(E) - \pi_{cid}\big(\pi_{cid}(E) \times \pi_{sid}(\sigma_{Gen=F}(Stud)) - \pi_{cid\,sid}(E)\big)$

$\pi_{E,Cid,Stud.sid}(\sigma_{Gen=F}(Stud))$

Cid's enrolled proper subset of all females

Atleast two: $\sigma_p(T_1 \times T_2)$

Only two: Atleast two − Atleast three

Atmost two: All − Atleast three.

Q- Enroll (Sid Cid)

(a) Retrieve sid's enrolled at least 2 courses

NOTE:

FOL:-

fun: $C(x)$ x is student in class

$S(x)$ x studied maths

⇒ some student in class studied maths

$\exists x\,(C(x) \wedge S(x))$

⇒ Atleast two students in class studied maths

Some X student in class studied maths (and) Some Y student in class studied maths (and) $X \neq Y$

$\exists x\, \exists y\,((C(x) \wedge S(x)) \wedge (C(y) \wedge S(x)) \wedge (X \neq y))$

Enroll (Sid Cid) $\times_{\neq}$ Enroll (Sid Cid)

S1	C1	S1	C1
S1	C2	S1	C2
S1	C3	S1	C3
S2	C1	S2	C1
S2	C2	S2	C2
✗ S3	C3	S3	C3

$\pi_{sid}\left(\text{Enroll} \bowtie_{\substack{sid=s \\ \wedge\ cid \neq c}} \rho_{s,c}(\text{Enroll})\right)$

(b) Retrieve sid's enrolled at least 3 courses

sid	cid	sid	cid	sid	cid
S1	C1	S1	C1	S1	C1
S1	C1	S1	C1	S1	C2
⋮		⋮			
S1	C1	S1	C2	S1	C1
⋮					
S1	C1	S1	C2	S1	C3
S1	C2	S1	C1	S1	C3

$T_1 \bowtie_{\theta} T_2$

$\pi_{sid}\left(\text{Enroll} \bowtie_{\substack{sid=s1 \\ cid \neq c1 \\ \wedge\ c1 \neq c2}} \rho_{s1}\left(\text{Enroll} \bowtie_{\substack{sid=s \\ cid \neq c}} \rho_{s,c}(\text{Enroll})\right)\right)$

s1 c1
s1 c2
s2 c2

"or"

$\pi_{T_1 sid}\left(\sigma_{\substack{T_1 sid = T_2 sid \\ \wedge\ T_2 sid = T_3 sid \wedge T_1 cid \neq T_2 cid \wedge T_2 cid \neq T_3 cid \wedge T_1 cid \neq T_3 cid}}\left(\rho(T_1, \text{Enroll}) \times \rho(T_2, \text{Enroll}) \times \rho(T_3, \text{Enroll})\right)\right)$

Cost = 5 comparison × 216 records ⇒ 1080

NOTE:

⇒ Only one student in class studied maths

[atleast one student in class studied maths] but not [atleast two student in class studied maths]

$\exists x\,(C(x) \wedge (P \wedge \neg q))$

$\exists x\,(C(x) \wedge S(x)) \wedge$

$\neg\, \exists x\, \exists y\,(C(x) \wedge S(x) \wedge C(y) \wedge S(y) \wedge (x \neq y))$

(c) Retrieve sid's enrolled only one course

(sid enrolled atleast one course) − (sid enrolled atleast two course)

$\pi_{sid}(\text{Enroll}) - \pi_{sid}\left(\text{Enroll} \bowtie_{\substack{sid=s \\ cid \neq c}} \rho_{s,c}(\text{Enroll})\right)$

Atleast two: $\sigma_p(T_1 \times T_2)$

Only two: Atleast two − Atleast three

Atmost two: All − Atleast three.

Q- Enroll (Sid Cid)

(a) Retrieve sid's enrolled at least 2 courses

NOTE:

FOL:-

fun: $C(x)$ x is student in class

$S(x)$ x studied maths

⇒ some student in class studied maths

$\exists x\ (C(x) \wedge S(x))$

⇒ Atleast two students in class studied maths

X ---- Y ----

Some X student in class studied maths (and) Some Y student in class studied maths (and) $X \neq Y$

$$\exists x\, \exists y \left((C(X) \wedge S(X)) \wedge (C(Y) \wedge S(X)) \wedge (X \neq Y) \right)$$

Enroll (Sid Cid) $\times_{\neq}$ Enroll (Sid Cid)

S1	C1	S1	C1
S1	C2	S1	C2
S1	C3	S1	C3
S2	C1	S2	C1
S2	C2	S2	C2
S3	C3	S3	C3

$$\pi_{sid}\left(\text{Enroll} \bowtie_{\substack{sid=s \\ \wedge\ cid \neq c}} \rho_{s,c}(\text{Enroll})\right)$$

(b) Retrieve sid's enrolled at least 3 courses

sid	cid	sid	cid	sid	cid
S1	C1	S1	C1	S1	C1
S1	C1	S1	C1	S1	C2
S1	C1	S1	C2	S1	C1
S1	C1	S1	C2	S1	C3
S1	C2	S1	C1	S1	C3

$T_1 \bowtie T_2$

$$\pi_{sid}\left(\text{Enroll} \bowtie_{\substack{sid=S1 \\ cid \neq C1 \\ \wedge\ C \neq S2}} \rho_{S1}\left(\text{Enroll} \bowtie_{\substack{sid=s \\ cid \neq c \\ c \neq C1}} \rho_{s,c}(\text{Enroll})\right)\right)$$

S1 C1
S2 C2

"or"

$$\pi_{T_1 sid}\left(\sigma_{\substack{T_1 sid = T_2 sid \\ \wedge\ T_2 sid = T_3 sid \wedge T_1 cid \neq T_2 cid \wedge T_2 cid \neq T_3 cid \wedge T_1 cid \neq T_3 cid}}\left(\rho(T_1, \text{Enroll}) \times \rho(T_2, \text{Enroll}) \times \rho(T_3, \text{Enroll})\right)\right)$$

Cost = 5 comparison × 216 records ⇒ 1080

NOTE:

⇒ Only one student in class studied maths

[atleast one student in class studied maths] but not [atleast two student in class studied maths]

$\exists x\ (C(x) \wedge S(x))$ $\wedge$

$\neg\ \exists x\, \exists y\ (C(x) \wedge S(x) \wedge C(y) \wedge S(y) \wedge (x \neq y))$

(c) Retrieve sid's enrolled only one course

(sid enrolled atleast one course) − (sid enrolled atleast two course)

$$\pi_{sid}(\text{Enroll}) - \pi_{sid}\left(\text{Enroll} \bowtie_{\substack{sid=s \\ cid \neq c}} \rho_{s,c}(\text{Enroll})\right)$$

(d) Retrieve sid's only 2 courses

(sid's enrolled. atleast 2 course) − (sid enrolled atleast 3 courses)

Q Retrieve sid's enrolled atmost 1 course

Stud. (sid ...)

S1
S2
S3
S4

enroll (sid cid)

S1	C1
S1	C2
S1	C3
S2	C1
S2	C2
S3	C3.

(all students of stud) − (sid's enrolled at least 2 courses)

$\pi_{sid}(Stud) - \pi_{sid}\left(Enroll \underset{sid=S \,\wedge\, Cid \neq C}{\bowtie} \rho_{S,C}(Enroll)\right)$

NOTE: Atmost (1)

$\exists x\,(C(x)) \wedge \neg \exists x \exists y\,(C(x) \wedge S(x) \wedge C(y) \wedge S(y) \wedge (x \neq y))$

Q- Stud (sid sname) with 200 tuples.
Enroll (sid cid) with 100 tuples

How many (max, min) tuples in result of Stud ⋈ Enroll.?

Stud (sid sname) = Enroll (sid cid)

S1	A
S2	B
S3	A
S4	B
S5	C
S6	C
S7	A

200 tuples

S1	C1
S1	C2
S1	C3
S2	C2

100 tuples

max = 100 tuples

min tuples = { 100 FK exist ; 0 no FK }

Q- R(A B C) with n tuples, no NULL values.
S(B D E) with m tuples

max tuples in R ⋈ S: n

min tuples in R ⋈ S: n → FK ; 0 → no FK

R(A B C) = S(B D E)

A	B
1	1
2	1
3	2
4	2
5	3
6	4
	4
	5

B
1
2
3
4
5
6
7

max = n.
min = m

Q R(A B C) with n tuples
S(A D E) with m tuples

max = max(m,n)
min = min(m,n)

max in R ⋈ S : min(m,n)
min in R ⋈ S : { min(m,n) ; 0 → (no FK) }

R(A ...) s(A ...)

2	2
3	3
4	4
5	

Q R(A B C) with n tuples
S(D B E) with m tuples

max in R ⋈ S : mn.
min in R ⋈ S : { → 0 }

R(A B C) = S(D B E)

A	B
6	1
	1
	2
	2
	3
	4

B
1
1
2
2
3
3
4
4

Q R(A B C) with 1000 tuples
S(B D E) with 2000 tuples

functional dependencies
{A → B, B → C, B → DE} exists.
How max tuples in R ⋈ S.

1000

⇒ Rel R with X set of attributes && n distinct tuples

Rel S with Y set of attributes && m distinct tuples

(i) Required Cond^n to perform R divide by S

$X \supset Y$

(ii) Attribute set in result of R divide by S

$X - Y$

(iii) Cardinality (min, max tuples) of R / S

$\pi_{AB}(R) / \pi_B(S) \equiv$

A
empty

$\pi_{AB}(R)$		$\pi_B(S)$
a1	2	2
a2	3	3
a1	3	4
a2	4	
a3	2	
a3	4	

$\pi_{AB}(R) / \pi_B(S) \equiv$

A
a_1
a_2

$\lfloor \frac{n}{m} \rfloor$

$\pi_{AB}(R)$		$\pi_B(S)$
a_1	2	2
a_1	3	3
a_1	4	4
a_2	2	
a_2	3	
a_2	4	

∴ $\{0 \text{ to } \lfloor n/m \rfloor\}$

Q- E (Sid Cid) C (Cid Inst)

E	
S1	C1
S1	C2
S2	C2
S3	C3

C	
C1	Navathe
C2	Navathe
C3	Ullman

How many records in result RA query?

$\pi_{sid,cid}(E) / \pi_{cid}(\sigma_{Ins=Korth}(C))$

(a) 0 (b) 2 (c) 3 (d) 4

sid	cid
S1	C1
S1	C2
S2	C2
S3	C3

cid
Empty

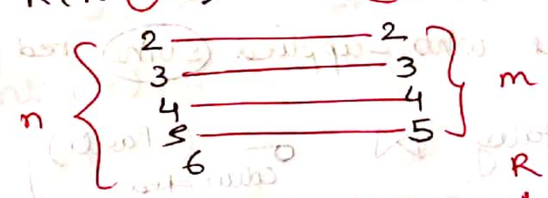
(C)

if rel R with N distinct records and relation S with 0 records, no. of records in result of R|S is almost n records.

Q- Rel R with n distinct tuples
Rel S with m distinct tuples

RA Expression	Cardinality (min, max) tuples
$R \times S$	nm
$R \bowtie S$, $R \bowtie_c S$	{0 to nm}
$R \ltimes S$	{n to nm}
$R \rtimes S$	{m to nm}
$R \bowtie S$	{max(m,n) to nm}
$R \cup S$	{max(n,m) to n+m}
$R \cap S$	{0 to min(n,m)}
$R - S$	{0 to n}
R / S	{0 to $\lfloor \frac{n}{m} \rfloor$}

R(A B C) S(B D E)



$R \rtimes S = 5$

RA

1. > some
   $\bowtie_c$
2. > every
   all – ≤ some.
3. max | min
4. max | min for group
5. ∪, ∩, –, or and only
6. / pairs every
   ⋈ pairs same
7. atleast two
   only two
   atmost two

Structured Query Lang (SQL)

Relational Algebra Query equal SQL Query

SQL Query :-

SELECT DISTINCT A1, A2, ... An : Projection (π)

FROM R1, R2, ... Rm : CROSS PRODUCT ($\times$)

WHERE (P); each record. : Selection (σ) operator

RA Query :-

$$\pi_{A1 \ldots An}\left(\sigma_P\left(R1 \times R2 \times \ldots \times Rm\right)\right)$$

SQL : _____

*1] SQL Query (RA logic)

2] SQL Query fun.

Q- Catalog (Sid Pid) = Parts (Pid color) red.

Sid	Pid
S1	P1
S1	P2
S1	P3
S2	P2
S3	P3

Pid	color
P1	Red
P2	Red
P3	Green.

Retrieve supplier who supplied (some) red part

sid
S1
S2

$$\pi_{sid}\left(\text{Catalog} \bowtie \sigma_{colour=Red}(\text{Parts})\right)$$

"or"

$$\pi_{sid}\left(\sigma_{colour=Red \,\wedge\, Catalog.Pid = Parts.Pid}(\text{Catalog} \times \text{Parts})\right)$$

```
SELECT DISTINCT SID
FROM Catalog C , Parts AS P
WHERE ((C.Pid = P.Pid) and
       ( color = red));
```

AS → used for renaming

S1	P1	P1	red
S1	P2	P2	red
S2	P2	P2	Red.

SID
S1
S1
S2

⇓ it is not distinct SELECT

⇒

SID
S1
S2

⇓ SELECT DISTINCT

Aggregate Func :-

COUNT ( )
SUM ( )
AVG ( )
MIN ( )
MAX ( )
⇒

Aggregate func^n computes aggregation of non-NULL values, i.e NULL values discard by aggregate func^n.

```
Create Table R
( A integer (3),
  B integer (3)
);
```

R

A	B	RowID
20	5	1
40	10	2
NULL	5	3
NULL	NULL	4
80	5	5
40	20	6

Count (*) : # of records

Count (A) : # of non null val of "A".

Count (Distinct A) : # of distinct ~~values~~ val of "A" of non null.

```
SELECT Count (*) A1,
       Count (A) A2,
       Count (DISTINCT A) A3
FROM R;
```

op :

A1	A2	A3
6	4	3

select & from mandatory for each Select clause there must be a from clause

SELECT SUM(A) A1, SUM (DISTINCT A) A2,
AVG (A) A3, AVG (DISTINCT A) A4,
MIN (A) A5, MAX(A) A6

FROM R;

o/p:

A1	A2	A3	A4	A5	A6
180	140	45	46.6	20	80

$$AVG(A) = \frac{SUM(A)}{COUNT(A)} = \frac{180}{4} = 45$$

$$AVG(DISTINCT\ A) = \frac{SUM(DISTINCT\ A)}{COUNT(DISTINCT\ A)} = \frac{140}{3} =$$

Select Avg (A), B
From R;

⇒ (error) because result can't be put in tabular format

o/p:-

Avg (A)	B
45	5
	10
	5
	⋮

} NOT IN TABULAR FORMAT

Select A
from R
where A = ~~avg~~ max (A); each record.

20 = max (20) ✓
40 = max (40) ✓

it will not throw any error

o/p:

A
20
40
80
40

∴ aggregate func^n usage in where clause is not useful.

If aggregate func^n used in where clause cond^n, then func^n computes for aggregation in each record, so no use of using aggregate func^n in where clause.

Basic SQL Clauses

⑥
⑤ Select [DISTINCT] A1, A2, ... An } mandatory clauses
① from R1, R2, ... Rm
② [WHERE (P)] each record.
③ [GROUP BY (Attribute)]
④ [HAVING (Condition)] each group
⑦ [ORDER BY (Attribute) [DESC]]; by default ascending

⇓
flow of execution of queries.

Query Execution Flow

FROM (Cross Product (×))
⇓
WHERE (Selection operator (σ)) of R.A
⇓
GROUP BY
⇓
HAVING
⇓
SELECT } (Projection : (π))
⇓
DISTINCT
⇓
ORDER BY

GROUP BY :

Group by used to group data records based on specific attribute values of group by clause.

If GROUP BY clause used in Query

① every Attribute of ~~Group~~ Group by must be in SELECT clause

② Allowed to use aggregate fun's in SELECT clause and aggregate fun computes aggregation of each group

③ Not allowed to select any other attribute in SELECT clause.

Q R

A	B	C
a_1	b_1	90
NULL	b_5	40
a_3	b_2	70
a_1	b_1	70
a_3	b_2	50
NULL	b_5	50
a_1	b_2	NULL

GROUP BY (A)

A	B	C
a_1	b_1	90
a_1	b_1	70
a_1	b_2	NULL
NULL	b_5	40
NULL	b_5	50
a_3	b_2	70
a_3	b_2	50

aggregate is separate

(a) o/p

A
a_1
NULL
a_3

(b)

A	AVG(C)
a_1	80
NULL	45
a_3	60

(a) ③ SELECT A
① FROM R.
② GROUP BY A;

*(b) SELECT A, AVG(C)
FROM R
GROUP BY A;

it is allowed only when group by exist

(c) ① Select Avg(C)
① from R
② GROUP BY (A);

~~Avg(C)~~
~~80~~
~~45~~
~~60~~

A is not present in select clause.

(d) Select A
① from R
② GROUP BY (A,B)

B is not present in select clause

(e) Select B
from R
GROUP BY A;

selection do not contain A

(f) Select A, B
from R
GROUP BY A;

B cannot be present in select clause.

	SQL stand	SQL compiler
(c)	Invalid	Avg(C): 80, 45, 60
(d)	Invalid	A: a_1, a_1, NULL, a_3
(e)	Invalid	ERROR → for single group value of A, multiple values of B exist. eg:- $a_1 \to b_1, b_2$ ∴ result can't be in tabular format
(f)	Invalid	a_1, NULL, a_3 → can't be in tabular format.

HAVING :-

Having clause used to select groups based on which are satisfied having clause cond^n.

Having clause cond^n is tested for each group.

Cond^n of having clause must be
1. over aggregation (or)
2. over func^n like some(), every() etc. (should not use direct attribute comp in having clause)

(a) Select A
from R
GROUP BY A:
HAVING Avg(C)>50;

o/p

A
a_1
a_3

(b) Select A, AVG(C)
FROM R
GROUP BY A
HAVING some(C) >55;

A	AVG(C)
a_1	80
a_3	60

(c) Select A
from R
Group by A
having every (C) >45

A
a_3

(d) Select A
from R
group by A
having (C >55), it is not suitable for error

Nested Queries

1. Nested Query without Co-relation (Inner Query independent of outer Query)

SELECT Attributes
FROM Tables
WHERE Condition
GROUP BY Attributes
HAVING Condition
ORDER BY Attributes ;

(Inner Query)

eg: Emp (eid sal)

eid	sal
e1	80
e2	90
e3	70
e4	90

```
Select eid
from Emp
Where sal = (select max(sal)
             from Emp);
```

90

② ① Bottom Querry

o/p

eid
e2
e4

```
Select eid
FROM Emp, (select max(sal) Msal
           FROM emp) temp (a one table)
where emp.sal
=
temp.Msal;
```

emp × temp

eid	sal
e1	80
e2	90
e3	70
e4	90

Msal
90

o/p

eid
e2
e4

→ Execution Flow – Bottom to top
→ Inner query computes only once.

2. Co-related Nested Query: (Inner Query is dependent on outer Query)

→ Inner query where clause uses attribute defined in Outer Query.
⇒ Co-related nested Query allowed WHERE clause HAVING clause of outer Query

eg: Co-relation in where clause – it is co-related
R(A...) S(B...)

```
Select A
Top ① from R
Top ③ where ( select Count (*)
              from S
              where R.A < S.B ) < 3 ;
```

② Bottom

4 3 2 2 5 0
20 40 60 50 10 80

R

A
20
40
60
50
10
80

S

B
20
40
60
50
10
80

⇒ Execution Flow ⇒ Top – Bottom – Top for each record of outer query
⇒ If co-relation in where clause inner query recomputes for each record of outer query

⇒ If Co-relation in having clause, Inner Query recomputes for each group of outer query

eg:- Co-relation in HAVING clause

Emp (eid dno sal gen)

it is not corelated as no relation b/w outer & inner query

```
Select dno
① from Emp T1
① Group By dno
③ having Avg(sal) > ( Select Avg(sal)
                      from Emp T2
                      where T2.gen = male
                      and T2.dno = T1.dno
                      );
```

55 70 ② 45 85 ✗ 3

Emp (T1)

dno	sal	gen
2	60	F
2	70	F
2	40	M
2	50	M
3	80	M
3	90	M
3	60	F
3	50	F

o/p

dno
2

↳ now it is corelated

⇒ Query retrieves dept no for which Avg(Sal) of dept is more than avg(sal) of male emp of same dept.

eg:- Select eid
from emp
where sal = (Select sal
from emp
where dno = 5);

ERROR

sal = 50 (can't compare)

Sal
20
40
60

Fun used for Nested Query

- IN / NOT IN
- ANY
- ALL (*)
- EXISTS / NOT EXISTS

⇒ it is used when, we want to use comparison of outer query with set of values of inner query. like previous example.

best suitable for non-corelated nested Query

best suitable for corelated nested Query

eg: R(A) S(B)

```
Select *
② from R
where ( Select min(B)
        ① from S) < 50;
```

40 60

if R(A) S(B)

R(A)	S(B)
✓20	40
✓40	60
✓60	80
✓80	

if R(A) S(B)

R(A)	S(B)
✗ 20	60
✗ 40	80
✗ 60	
✗ 80	

⇑
it is syntactically correct
it will not throw any error
but result of Query is meaningless

IN FUN :

⇒ Used for membership test

⇒ X IN Y (set of Y values of inner query)

True if X value is member of Y set

if X value must be equal to some Y value.

⇒ IN fun can used for equi Join Queries (Natural Join / Conditional Join with equal Condition)

eg:- Enroll (Sid Cid) = some course (Cid Inst) Korth

Retrieve Sid's enrolled some course taught by Korth

```
Select Sid
From Enroll
                = Some.
where Cid IN( Select Cid
              from course
or
= ANY where Inst = Korth);
```

Enroll $\bowtie_{Ins=Korth}$ (course)

eg:- R(A B) S(C D)

$\bowtie_c$: Some

(i) $\pi_{A,B}\left(\begin{matrix} R \bowtie S \\ R\cdot A = S\cdot C \\ \wedge \; R\cdot B = S\cdot D \end{matrix}\right)$ (A,B) = some (C,D)

$R \cap S$

(ii) Select distinct A,B
$R \cap S$ from R
where (A,B) IN (Select C,D
from S);

(iii) Select distinct A,B
from R
where (A,B) NOT IN (Select A,B
from R
where (A,B) NOT IN (Select C,D
from S));

$R \cap S = R - (R - S)$

R−S

which is true

(a) Q_1, Q_2 result same but not Q_3
(b) Q_2, Q_3 same but not Q_1
(c) $Q_1\ Q_3$ same but not Q_2
(d) $Q_1\ Q_2\ Q_2$ result same

(d)

ANY && ALL fun:-

⇒ preceded by comparison operator <, <=, >, >=, =, <> (not equal.)

⇒ X > ANY Y

True if X value > atleast one Y value of Y set

X > ALL Y

True if X value > every value of Y set

⇒ ANY can used for conditional Join ($\bowtie_c$) Queries.

eg: R(A...) S(B...)

(a) Retrieve 'A' val of R those are more than some 'B' val of S
$\bowtie_c$

$\pi_A\left(\begin{matrix} R \bowtie S \\ R\cdot A > S\cdot B \end{matrix}\right) \equiv$ Select A
from R
where A > ANY (select B
from S)

>some

(b) Retrieve 'A' val of R those are more than every 'B' of S

$\pi_A(R) - \pi_A\left(\begin{matrix} R \bowtie S \\ A \le B \end{matrix}\right) \equiv$ Select A
from R
where A > ALL (Select B
from S);

>ALL (Every)

NOTE:
⇒ IN fun, (= ANY) func^n are same
⇒ (< > ALL) func^n can be replaced as NOT IN
⇒ ANY can be used for any form of cond^n join.
⇒ ANY is used for only one attribute
⇒ IN can ~~be~~ have more than one comparison i.e, it can have set of attributes comparison

eg:- Enroll (Sid Cid) course (Cid Inst) Korth

= some

Retrieve Sid's enrolled some course taught by Korth

```
Select Sid
From Enroll
                = some.
where Cid IN ( Select Cid
               from course
               where Inst = Korth);
  or
= ANY
```

Enroll $\bowtie_{Inst=Korth}$ (course)

eg:- R(A B) S(C D)

$\bowtie_c$: Some

(i) $\pi_{A,B}\left(\begin{matrix} R \bowtie S \\ R.A = S.C \\ \wedge \\ R.B = S.D \end{matrix}\right)$ (A,B) = Some (C,D)

$R \cap S$

(ii) Select distinct A,B
from R
where (A,B) IN (Select C,D
from S);

$R \cap S$

(iii) Select distinct A,B
from R
where (A,B) NOT IN (Select A,B
from R
where (A,B) NOT IN (Select C,D
from S));

R−S

$R \cap S = R - (R - S)$

which is true

(a) Q_1, Q_2 results same but not Q_3
(b) Q_2, Q_3 same but not Q_1
(c) $Q_1\ Q_3$ same but not Q_2
(d) $Q_1\ Q_2\ Q_2$ result same

(d)

ANY && ALL fun:-

⇒ preceded by comparison operator <, <=, >, >=, =, <> (not equal.)

⇒ X > ANY Y

True if X value > atleast one Y value of Y set

X > ALL Y

True if X value > every value of Y set

⇒ ANY can used for conditional Join ($\bowtie_c$) Queries.

eg: R(A...) S(B...)

(a) Retrieve 'A' val of R those are more than some 'B' val of S
$\bowtie_c$

$\pi_A\left(\begin{matrix} R \bowtie S \\ R.A > S.B \end{matrix}\right) \equiv$ Select A from R where A > ANY (select B from S);

>some

(b) Retrieve 'A' val of R those are more than every 'B' of S

$\pi_A(R) - \pi_A\left(\begin{matrix} R \bowtie S \\ A \le B \end{matrix}\right) \equiv$ Select A from R where A > ALL (Select B from S);

>ALL (Every)

NOTE:
⇒ IN fun, (= ANY) func^n are same
⇒ (< > ALL) func^n can be replaced as NOT IN
⇒ ANY can be used for any form of cond^n join.
⇒ ANY is used for only one attribute
⇒ IN can ~~be~~ have more than one comparison i.e, it can have set of attributes comparison

EXISTS :

⇒ used to test result of inner query empty or not

⇒ EXISTS (Inner Query)

TRUE if result of inner query not empty

[Atleast one (some) record should in result of inner query]

⇒ EXISTS clause used for conditional Join Queries

Join Cond^n in where clause of inner Query

eg: R(A ...) S(B ...)

R	S
✗ 10	15 ✗ ✓ ✓ ✓
✓ 20	25 ✗ ✗ ✓ ✓
✓ 30	30 ✗ ✗ ✗ ✓
✓ 40	

$\pi_A (R \bowtie_{R.A > S.B} S)$

(a) Select A
① from R
③ where exists (Select B
from S
② where ~~R.A~~ > S.B);
~~10~~ ~~20~~ ~~30~~ 40

(b) Select A
from R
where NOT Exists (Select B
from S
where R.A ≤ S.B);

notexist ✗ ✗ ✗ ✓ empty

R: A = 10, 20, 30, 40 ✓ ✓ ✓ ✗ exist

S: B = 15, 25, 30

A val. of R ≤ some B of S

A val of R > every B of S

$\pi_A(R) - \pi_A(R \bowtie_{R.A \le S.B} S)$

Exist : Some → atleast

Not Exist : Every.

eg: Emp (eid dno sal)

Retrieve eid's whose sal more than every emp of dept 5

RA: $\pi_{eid}(Emp) - \pi_{eid}\left(Emp \bowtie_{D=5 \wedge sal \le S} \rho_{I,D,S}(Emp) \right)$

SQL : Select Eid
from Emp
EXCEPT
Select eid.
FROM Emp T_1 , Emp T_2
where T_2.dept =5 and
T_1.sal <= T_2.sal ;

Set difference

it is pure relational query i.e it doesnot use, any func^n.

SQL : Select eid
from emp
where sal > ALL (select sal
from Emp
where dno =5);

nested query

SQL : Select eid
from emp T_1
where NOT EXISTS (Select ~~eid~~ *
from emp T_2
where T_1.sal ≤ T_2.sal
and T_2.dno = 5);

Co-related nested Query.

T_1.sal ≤ some T_2.sal of dept 5

T_1.sal > every T_2.sal of dept 5

We cannot use * in any queries except Exist

Q (a) select eid
from emp
when dno = 5;

$\pi_{eid}(\sigma_{d=5}(emp))$

e_1

same

(b) select *
from emp
where dno = 5;

e_1 5 80

$\sigma_{d=5}(Emp)$

Q ⇒ exist func^n for non-corelated query is not meaningful.

select eid
from emp T_1
where not exists (select *
from emp T_2
where T_2.dno=5);

⇓
result is empty or not empty
∴ meaningless

(c) select distinct eid
from emp
where dno = 5;

From ⇓ where ⇓ Select ⇓ distinct

(c) is more costly

Acc. to Query Optimi: ↓ we should not use it until required.

Q- R

A	B
2	4
3	5
4	8

S

C	D
5	6
7	2
9	5

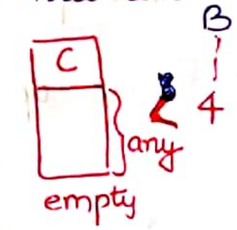
How many records in result of SQL Query

(a) select *
from R
where B > ANY(select C
from S
where D > 10);

false

empty

it is failed to check atleast one true condn



$\pi_{AB}\left(R \bowtie_{R.B>S.C} (\sigma_{D>10}(C))\right)$: 0 tuples

empty

(b) select *
from R
where B ≥ exists (select Count (*)
from S
where R.B > S.C
and D > 10);

not empty

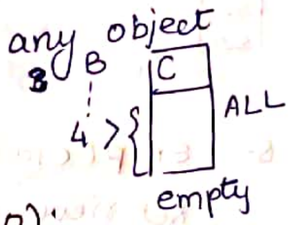
3

Count(*)
0

$\pi_{AB}(R) - \pi_{AB}\left(\underbrace{R \bowtie_{B \leq C} \sigma_{D>10}(S)}_{\text{empty}}\right)$: 3 tuples

(c) select *
from R
where B > ALL (select C
from S
where D > 10);

it is not failed by any object



3

Count () : result never empty set

(d) select *
from R
where exist (select sum(c)
from S
where R.B > S.C
and D > 10);

empty set

0

x of ANY(...) :
TRUE if atleast one val if set should satisfy cond (op) with x

$\forall x\,(P(x))$: except at least one false case
→ True, for every x P(x) must be true
→ False, for some x P(x) must be false

$\exists x\,(P(x))$: expect at least one true case.
→ True for some x P(x) must be true
→ False for every x P(x) must be false.

- $X = \{ \quad \}$ // empty

A op ANY X — False

A op ALL X — True

sid

$\pi_{sid}(\text{Enroll} \bowtie \sigma_{ins=Korth}(\text{Course}))$ — Some ($\exists$)

empty

sid
s1
s2
s3

$\pi_{sid,cid} / \pi_{cid}(\sigma_{ins=Korth}(\text{Course}))$ — Every ($\forall$)

Q- Emp(eid, sal)

Retrieve eid's who gets highest salary.

RA: $\pi_{eid}(\text{Emp}) - \pi_{eid}(\text{Emp} \bowtie_{sal<S} \rho_{I,S}(\text{Emp}))$

SQL: Select eid

* from emp

except

Select T_1.eid

from Emp T_1, Emp T_2

where T_1.sal < T_2.sal

SQL: Select eid

from emp

where sal = (Select max(sal) from emp);

SQL: Select sid

from emp

where sal $\geq$ ALL (Select sal from emp);

Q- Emp(eid sal)

Retrieve eid's who gets 2nd highest sal

$\rho(\text{Temp}, \pi_{eid,sal}(\text{Emp} \bowtie_{sal<S} \rho_{I,S}(\text{Emp})))$ → it is computed

emp

e1	60
e2	90
e3	70
e4	50

Temp

e1	60
e3	70
e4	50

$\pi_{eid}(\text{Temp}) - \pi_{eid}(\text{Temp} \bowtie_{sal<S} \rho_{I,S}(\text{Temp}))$ ← 3 times computation needed.

to solve this problem.

With clause: result of with clause can reuse

Sub-Query many times for query processing.

To avoid re computation of same sub query.

with clause is used.

```
WITH temp (eid, sal) as
    ( select distinct T1.eid, T1.sal
      from emp T1, Emp T2
      where T1.sal < T2.sal)

Select eid
from temp
[where sal = (select max(sal) from temp);]
    or
except
select T1.eid
from Temp T1, Temp T2
where T1.sal < T2.sal;
```

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Using Nested Query with aggregation

```
Select eid
from emp
where sal = ( select max(sal)
              from emp
              where sal < ( select max(sal)
                            from emp) ) ;
```

~~e1~~	~~60~~
~~e2~~	~~90~~
e3	70
~~e4~~	~~50~~

70

e1	60
~~e2~~	~~90~~
e3	70
e4	50

90

K^{th} max

Nested Query
- (K+1) level
- (K+1) instances of emp

Co-related
- 2 level
- 2 instances of emp

Co-related Query

for 2nd max. (K^{th} max)

of T_2 distinct sal such that $T_1.sal < T_2.sal$

Emp (T_1) eid	sal
e1	70
e2	70
e3	60
e4	60
e5	50
e6	40
e7	30

Emp (T_2) eid	sal
e1	70
e2	70
e3	60
e4	60
e5	50
e6	40
e7	30

} distinct

```
Select eid
① from emp T1
③ where ( select count (distinct T2.sal)
          ② from emp T2
            where T1.sal < T2.sal ) = 0
```

highest

(K-1)

K^{th} highest

Q- Emp(eid dno sal)

Retrieve eid's who gets max^m salary for each dept.

$$\pi_{eid}(Emp) - \pi_{eid}\left(Emp \bowtie_{sal<S \wedge dno=D} \rho_{I,D,S}(Emp)\right)$$

Using Groupby and Aggregation

emp(eid	dno	sal)	=	Temp(dno	Max sal)
~~e1~~	2	70		2	90
e2	2	90		3	60
~~e3~~	2	60			
~~e4~~	3	40			
e5	3	60			

```
Select eid
from emp, ( select dno, max(sal) Max Sal
            from emp
            group by dno) temp

where emp.dno = temp.dno
      and sal = MaxSal ;
```

Q family (parent, child, child DOB)

Retrieve youngest child of each parent

```
select child
from family, ( select parent, max(DOB) DOB
               from family
               group by parent) temp

where family.parent = temp.parent
      and child DOB = DOB ;
```

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"or"

```
Select child
from family
where (parent, child DOB) IN ( Select parent, max(child DOB)
                               from family
                               Group by parent);
```

Q- Works (eid pid)

Retrieve eid's who works for only one project

```
Select eid          ← eid's works for
from works            atleast one project
Except

Select T1.eid       ← eid's works
from works T1, work T2   for atleast
where T1.pid <> T2.pid   2 project
      and T1.eid = T2.eid
```

Using Group by and Having clause.

Work (eid pid.) having count(*)=1

eid	pid
e1	p1
e1	p2
e2	p2
e3	p2
e3	p3
e3	p4

```
Select eid.
from work
GROUP by eid
having count(*)=1;
```

over aggregation

"or"

```
Select eid
from (Select eid, count(*)
      from work
      group by eid) temp
where count = 1;
```

⇒ Having clause with condn, aggregate func can translate into where clause nested query.

Q emp(eid, dno, gen, sal)

Retrieve dno's for which avg sal of female employee of each dept is more than avg sal of all male employees.

1	70	F
1	80	F
2	70	M
2	60	M
3	50	M
3	40	M
3	70	F
3	20	F

```
select dno
from emp T1
group by dno
having Avg(sal) > ( select avg(sal)
                    from emp T2
                    where T1
```

2	M	70
2	F	40
2	F	60
3	M	70
3	M	60
3	F	80

```
Select dno
from emp
where gen = F
group by dno
having avg(sal) > ( select avg(sal)
                    from emp
                    where gen = M);
```

⇓

2	F	40
2	F	60
3	F	80

⇑ grp by.

"or"

```
Select dno
from (select dno, avg(sal) Avg_Sal.
      from emp
      where gen = F
      group by dno ) temp
where avgsal > ( Select avg(sal)
                 from emp
                 where gen = m);
```

Q ~~em~~ Same question

just add same dept. in the last

```
Select dno
from emp T1
where gen=F
group by dno
having (Avg(Sal) >( Select Avg(sal)
                     from emp T2
                     where gen=M
                     and T2.dno = T1.dno);
```

"or"

```
Select dno
from ( Select dno, Avg(sal) Avg Sal
       from emp
       where gen=fem
       group by dno) temp

where Avg_Sal > (Select Avg(sal)
                 from emp
                 where gen=male
                 and emp.dno = temp.dno);
```

SQL Queries equal to Division (/) of RA:

Enroll (sid cid) Course (cid Instr)

Retrieve sid's enrolled every course taught by Korth:

1] SQL co-related Query

T_1 · Enroll (sid cid) Course (cid Inst) T_2 · Enroll (sid cid)

sid	cid
S1	C1
S1	C2
S1	C3
S1	C5
S2	C4
S2	C1
S3	C5

S1, S2, S3

ϕ = empty

cid	Inst
C1	K
C2	K
C3	K
C4	U
C5	N

sid	cid
S1	C1
S1	C2
S1	C3
S1	C5
S2	C4
S2	C1
S3	C5

{All Korth course id's} − {cid's of enroll(T_2) enrolled by T_1.sid} ≡ ϕ

```
Select distinct sid
① from Enroll T1
③ where NOT EXISTS (
    Select cid
    from course
    where Inst = Korth
    EXCEPT
    Select cid
    from enroll T2
    where T2.sid = T1.sid);
```

② C1 C2 C3 — C1 C2 C3 C5

C1 C2 C3 — C1 C2 C3 C5

C1 C2 C3 — C1 C2 C3 C5

S1 S2 S3

"or"

```
Select sid
from ( select distinct sid.
       from enroll) T1
where not exists ( - - -
```

Q $\pi_{AB}(R) \div \pi_B(S)$

```
Select distinct A
from R T1
where not exists ( select B
                   from S
                   except
                   select B
                   from R T2
                   where T1.A = T2.A
);
```

UNION
INTERSECT
EXCEPT

ER Model

Entity Relationships Diagrams used for high level DB design — Diagrametic Representation of DB design

DB design steps:

High level DB design

1. Requirements → What type of data stored in DB
   → Type of operations etc

2. Conceptual & logical DB design (ER diagram) : Entity sets && Relationships sets
   → RDBMS tabels

Low level DB design

3. Normalization : To eliminate/reduce redundancy

4. Physical DB design : Design of index.

5. Security & Application Design.
   ↓
   Low level DB design

Main Components of DB Design:

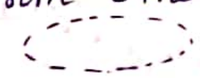
1. Attributes
2. Entity Set
3. Relationship Sets

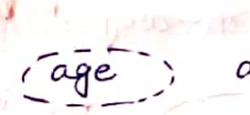
Attributes :-

Attribute

Key attribute

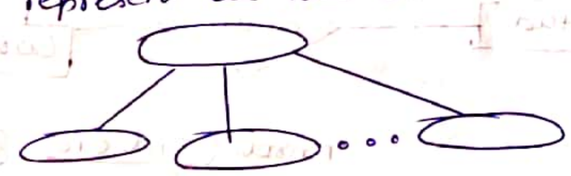
Multi Valued Attribute

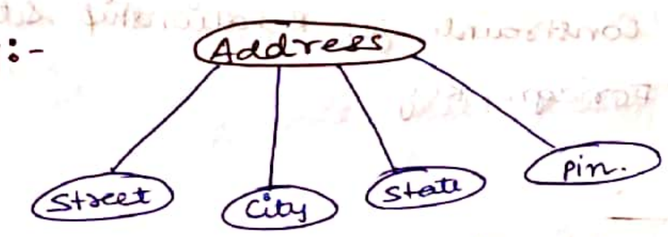
Derived Attribute : Value of attribute derived from other stored Attribute 

eg:- DOB 

age = sysdate − DOB

Composite Attribute : Attribute which can represent as two or more attribute



eg:- 

Entity Set : Set of similar entities (tuples) represent by

eg:-

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Relationship set :

Used to relate two or more entity set

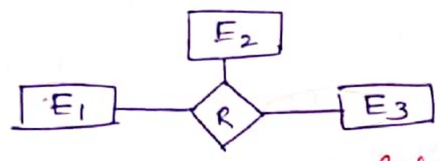
Represented as ◇

eg:-

⇒ 2 foriegn key

Binary Relationship set.

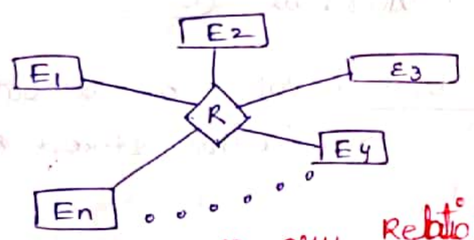
eg:-



→ 3 f_key

Ternary Relationship set

eg:-

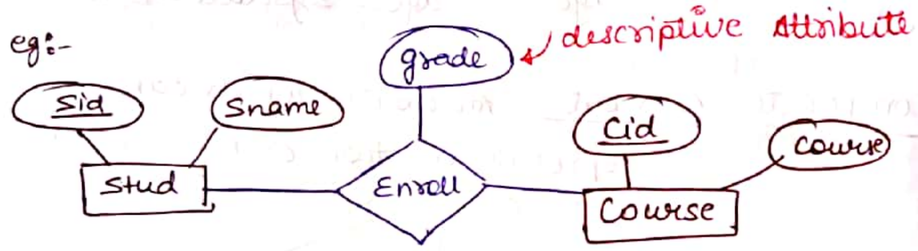


→ n f_key.

n-ary Relationship set

E

eg:-



Enroll (Sid Cid grade)

Integrity constraint for Relationship Set

- Foriegn Key

Participation :

If every entity of entity set must related to relationship set then total participation otherwise partial participation.

(═══) Total participation: must be 100% participation

(——) Partial participation: may | may not 100% participation

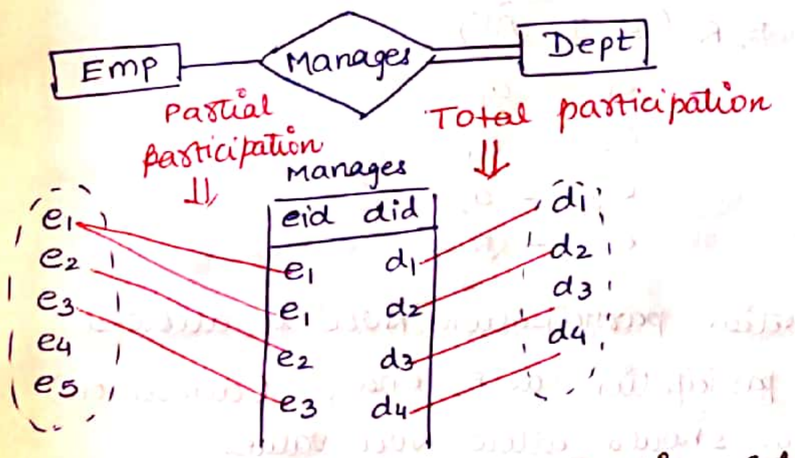
High level DB - Nosiam

Low level DB

Requirement :

Q- Emp & dept are entity sets manages relationship set used to relate emp and dept such that each dept there must be one manager.

Ans:-



Cardinality (mapping) of Relationship set :

Mapping
- One (atmost one)
- many (0 or more)

Mapping for Binary Relationship Set :-

1. One : One mapping
2. One : Many mapping
3. Many : One mapping
4. Many : Many mapping.

Candidate keys of relationship set is based on Mapping.

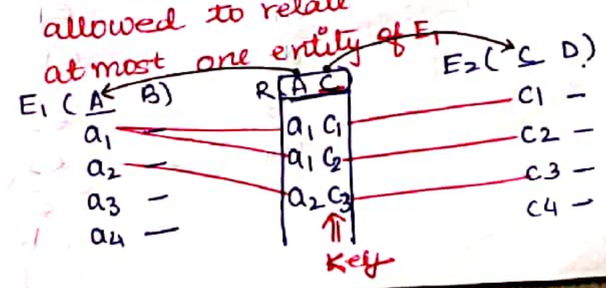
One : Many Mapping :-

eg:- E_1 E_2 entity sets and R Rel set related b/w E_1 E_2 with 1:M mapping.

⇒ Min 2 RDBMS tables required and 1 foriegn key.

each entity of E_1 can relate many entity of E_2

E_2 entity allowed to relate at most one entity of E_1



For one to many mapping. candidate key of relationship set is key of many side (right side) entity set.

FD for E_1 : $\{A \rightarrow B\}$

E_2 : $\{C \rightarrow D\}$

R : $\{C \rightarrow A\}$

RDBMS design

foreign key.

E_1(A B) E_2R (C D A)

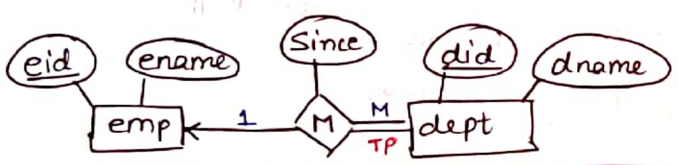
a_1	-	c_1	-	a_1
a_2	-	c_2	-	a_1
a_3	-	c_3	-	a_2
a_4	-	c_4	-	NULL

because of partial participation "NULL" is allowed

i.e, if Partial participation at E_2 end, (atmost one)
then F_key should allow NULL values

and, if Total participation at E_2 end. (exactly one)
then, F_key must be NOT NULL.

Q- Given ERD



Emp(eid ename) M(eid did since) dept(did dname)

Emp	M			dept
e_1	e_1	d_1	2010	d_1
e_2	e_1	d_2	2015	d_2
e_3	e_2	d_3	2015	d_3
e_4	e_2	d_4	2016	d_4

RDBMS design

Emp(eid ename) Dept_M (did dname eid since)

d_1	-	e_1	2010
d_2	-	e_1	2015
d_3	-	e_2	2015
d_4	-	e_2	2016

NO NULL values in f_key

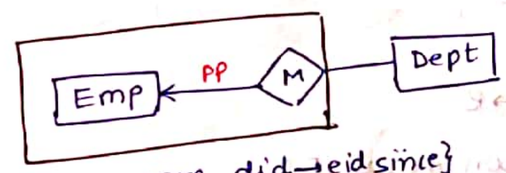
```
CREATE TABLE Dept_M
( did      varchar(10)  Primary Key,
  dname    varchar(30),
  eid      varchar(10)  NOT NULL,
  since    date,
  Foreign Key (eid) references emp);
```

because of total participation at dept side.

without manager info we can't insert new department since we considered total participation.

If we want to insert new dept without manager info then partial participation is used.

If 1:M mapping merges with left side entity set:



{eid→name did→eid since}

emp_M

eid	ename	did	since
e_1	A	d_1	2010
e_1	A	d_2	2015
e_2	B	d_3	2015
e_2	B	d_4	2016
× e_3	C	NULL	

∵ did is C-key

dept

did
d_1
d_2
d_3
d_4

disadv :-

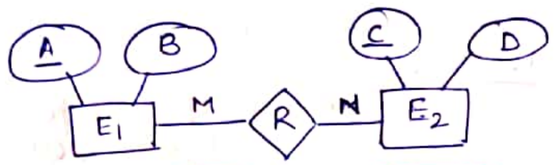
1. ~~Because~~ of Partial Participation on emp entity side failed, emp entities which are not related to manages relationship set is not possible to insert

2. Forms data redundancy.

Eid → Ename

not S.K. forms redundancy

Many : Many Mapping :-



E_1 (A B) R (A C) E_2 (C D)

E_1		R		E_2	
a_1	-	a_1	c_1	c_1	-
a_2	-	a_1	c_2	c_2	-
a_3	-	a_2	c_2	c_3	-
a_4	-	a_3	c_2	c_4	-

M : N

For many to many mapping C_Key of relationship set AC

FD for E_1 : $A \rightarrow B$

R : No non trivial FD

E_2 : $C \rightarrow D$

Drawback:

if R combines with E_1 :- partial participation at E_1 voilate

RE_1 (A B C) $A \rightarrow B$

C-K : AC

Data redundancy due to PD

if R combines with E_2 : same drawback.

RE_2 (A C D)

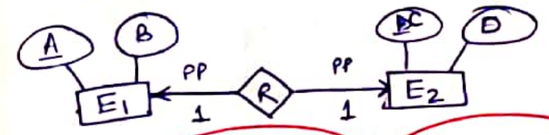
$C \rightarrow D$

RDBMS design

E_1 (A B) R (A C) E_2 (C D)

min 3 RDBMS tables and 2 F_Key's.

1 : 1 Mapping :-



1:1 Mapping

PP at both ends

- min 2 Rel tables and 1 foreign key.
- 2 cand_key req. required.

E_1		R		E_2	
a_1	-	a_1	c_2	c_1	-
a_2	-	a_2	c_3	c_2	-
a_3	-	a_3	c_4	c_3	-
a_4	-			c_4	-

Key Key.

For 1:1 mapping C_keys of relationship set R is {A, C}

FD for E_1 : $A \rightarrow B$

E_2 : $C \rightarrow D$

R : $A \rightarrow C$
$C \rightarrow A$

R can combine either with E_1 or with E_2

if combined with E_2 :

RDBMS design:

E_1 (A B) E_2R (C D A) F_Key.

E_1		E_2R		
a_1	-	C1	-	NULL
a_2	-	C2	-	a_1
a_3	-	C3	-	a_2
a_4	-	C4	-	a_3

{A → C
C → AD}

A, C ⇒ C_Key

Alt_Key P_Key

In 1:M → f_Key is not unique

1:1 → f_Key is unique

Drawback:

if E_1, E_2, R combines in one table :-

$A \rightarrow BC$
$C \rightarrow AD$

C-K = {A, C}

if A is P_Key,

A	B	C	D
a_1	-	c_2	-
a_2	-	c_3	-
a_3	-	c_4	-
NULL		c_1	-

not allowed ← NULL

Partial participation of E_2 is lost.

if C is P_Key.

A	B	C	D
NULL	-	c_1	-
a_1	-	c_2	-
a_2	-	c_3	-
a_3	-	c_4	-
a_4	-	NULL	-

not allowed ← a_4

Partial participation of E_1 is lost.

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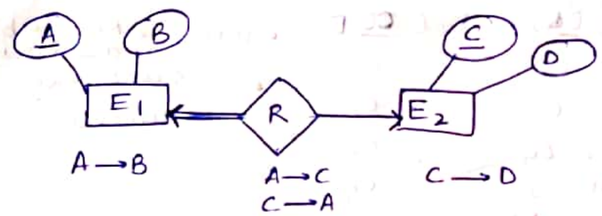
E_1, E_2 entity sets, relationship set R related b/w E_1 & E_2 with 1:1 mapping and atleast one end total participation.



$\exists$ C which is not related to A
∴ A should allow nulls

$E_1 R E_2$ (A B C D) { A, C } C_keys

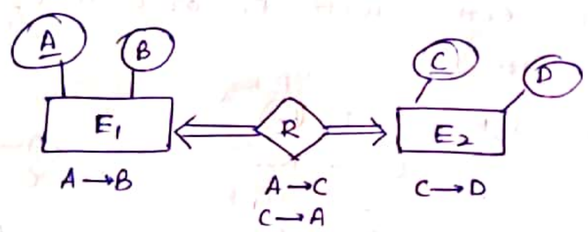
A	B	C	D
NULL	NULL	c_1	–
a_1	–	c_2	–
a_2	–	c_3	–
a_3	–	c_4	–

bec. of PP at E_2 side

A → All_Key, C → P_Key.

E_1 : n entities
E_2 : m entities
$(n \leq m)$

min 1 table req and no t_key.



possible only if, $(n = m)$

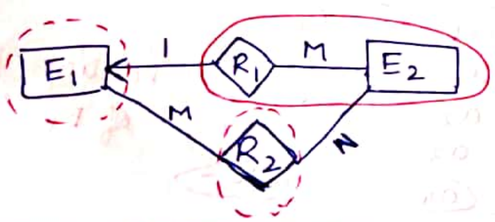
$E_1 R E_2$ (A B C D) { A, C } C_keys

A ⇑ Key NO NULL (PK)
C ⇑ Key NO NULL (UNIQUE NOT NULL)
(or)
(UNIQUE NOTNULL) (PK)

min 1 RDBMS table req and no t_keys.

Q- E_1 E_2 entity sets and R_1 R_2 relationship sets related b/w E_1, E_2 with 1:M and M:M mapping respectively. How many min Relational tables req.

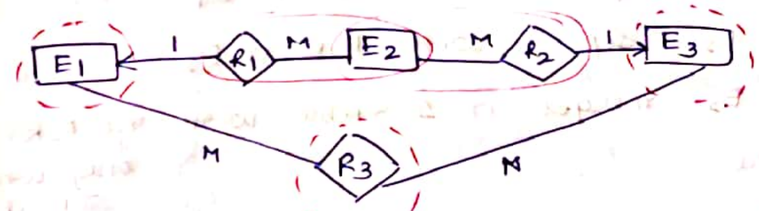
a) 2 b) 3 c) 4 d) 5



min 3 rel table

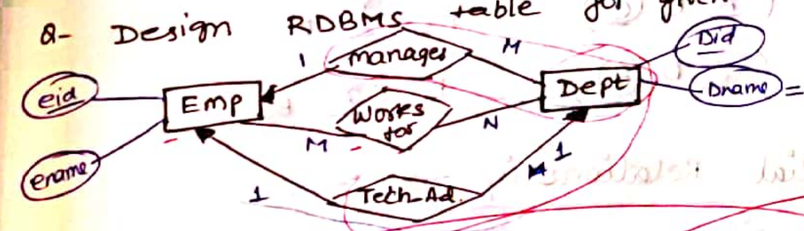
Q- E_1 E_2 E_3 entity set R_1 relationship b/w E_1, E_2 is 1:M mapping.
" R_2 " " E_2 E_3
" M:1 " R_3 " " E_3 E_1
" M:M ".

How many min tables req.



= 4 tables and 4 t_keys

Q- Design RDBMS table for given ER diagram.



= 3 and 4 t_keys

Emp(eid ename)

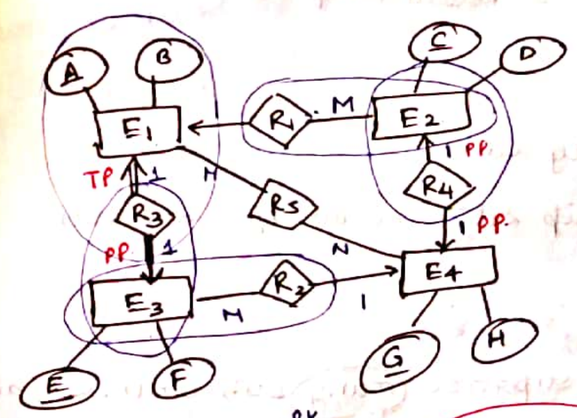
M_Dept_TechAd. (did dname. Manager eid)

did	dname	Manager	eid
d_1		e_1	NULL
d_2		e_1	e_1
d_3		e_2	e_2
d_4		e_3	e_3

A_Key.

Worksfor. W-f (eid did)

Q-



Find RDBMS table

(a) min rel. table req. = 4
(b) No. of t_key req for minimised DB design ⇒ 5
(c) Total no. of attributes for all relations for minimised DB design. ⇒ 13

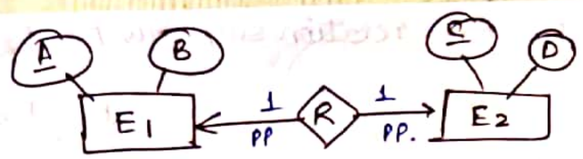
$R_1 E_2 R_4$ (C D A G) C ↑ PK, G ↓ A_K.

E_4 (G H)

R_5 (A G)

$E_1 R_3 E_3 R_2$ (A B E F G) A ↓ A_K., E ↓ PK

Q-



30% partici at E_1 end = PP

60% partici at E_2 end = PP

a) E_1, E_2 sepa. with F_K in E_1

b) E_2 E_2 sep with F_K in E_2

c) E_1 E_2 merges in 1 table with no F_K ⇓ only when TP at one end.

d) none

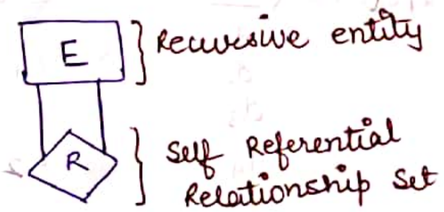
(a) R E_1 (A B C) E_2 (C D)

(b) R E_2 (C D A) E_1 (A B)

Self Referential Relationship set :-

Entities of Entity set E related to some other entities of same entity set E

Can be
1:1
1:M
M:1
M:N mapping.

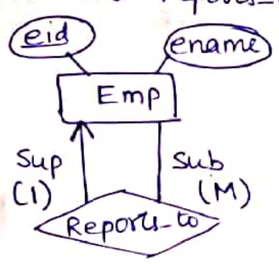


Q- given specification

Emp(eid, ename) entity set.

Reports_to relationship set, related b/w supervisor and subordinate.

i) each supervisor can supervise many sub-ordinates and each sub-ordinate reports_to one supervisor.



Emp(eid ename)

eid	ename
e_1	A
e_2	A
e_3	B
e_4	C

Reports_to (Sup Sub)

Sup	Sub
e_1	e_2
e_1	e_3
e_2	e_4

Emp_Reports

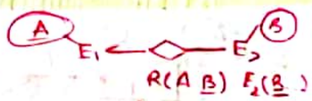
eid	ename	Sup
e_1	A	NULL
e_2	A	e_1
e_3	B	e_1
e_4	C	e_2

f_K.

⇑ eid of emp sub of Reports_to

⇓ not unique

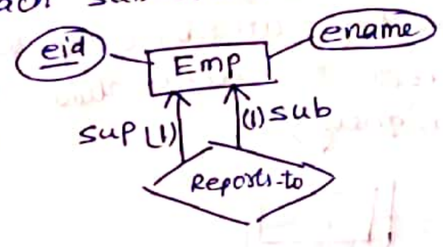
min 1 RDBMS table & 1 F_key.



$R(A\ \underline{B})$ $E_2(\underline{B})$

E_2 $R(\underline{B} \ldots A)$

ii) each supervisor can supervise one sub-ordinate and each sub-ordinate reports_to one supervisor.



Emp (eid ename)

eid	ename
e_1	A
e_2	A
e_3	B
e_4	C

Reports_to (sup sub)

sup	sub
e_1	e_2
e_2	e_3
e_3	e_4

Emp-Reports

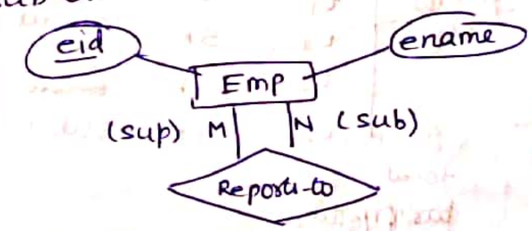
eid	ename	Sup
e_1	A	NULL
e_2	A	e_1
e_3	B	e_2
e_4	C	e_3

f_K

⇓ unique

Card_key = { eid, sup }

(iii) each supervisor can supervise many sub-ordinate and each sub-ordinate reports_to many supervisor



Emp(eid ename)

eid	ename
e_1	A
e_2	A
e_3	B
e_4	C

Reportsto (Sup Sub)

Sup	Sub
e1	e2
e1	e3
e4	e3

Emp_Reports

⇓

we can't combine.

min. 2 relational tables and 2 foreign keys

Card-key { Subsup }

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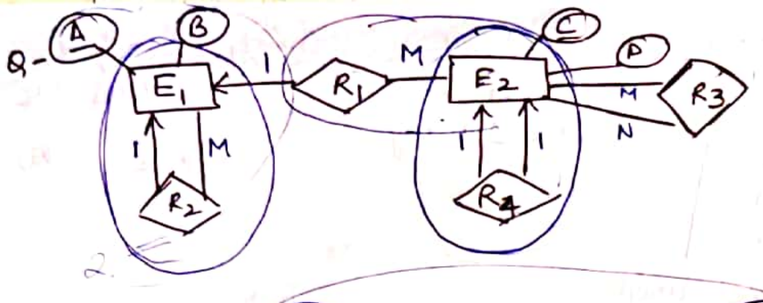
Q-



5 f_K 9 attri
3 tables

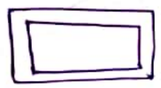
E1 R2 (A B O) R1E2R4 (C D O) R3 (O O)

A_K.

Weak Entity set:

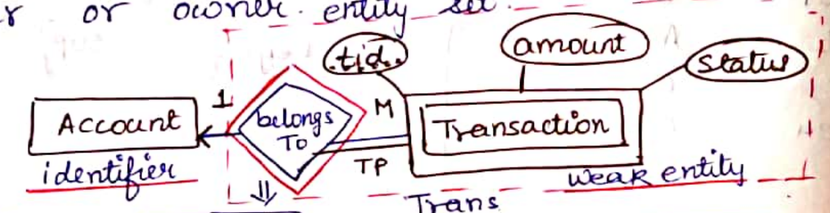
Entity set with no key. (attributes of weak entity set not sufficient to differentiate entities of weak entity set uniquely)

Representation :



entities of weak entity set depends on other strong entity set entities which is called Identifier or owner entity set.

eg:-



aid .....
a_1
a_2
a_3
a_4
a_5

tid	aid
t_1	a_1
t_1	a_2
t_2	a_2
t_2	a_3

Weak

partial key

tid	amount	status
t_1	5 K	debit
t_1	5K	credit
t_2	4K	debit
t_2	4K	debit

total participation

RDBMS design

account Trans belongsto

aid ....

tid	aid	amount	status

min 2 rel. tables

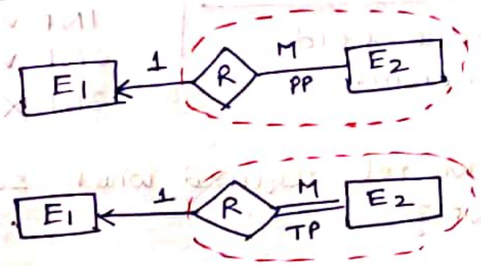
NOTE: Participation Towards weak Entity set and must be total.

Mapping b/w identifier and weak entity set must be 1 : M.

Multivalued attribute and weak entity set allowed to represent in ER diag but not allowed in RDBMS.

** ERD with only single Valued attributes :-

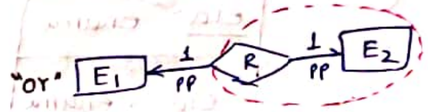
min 2 Rel tables && 1 f_K



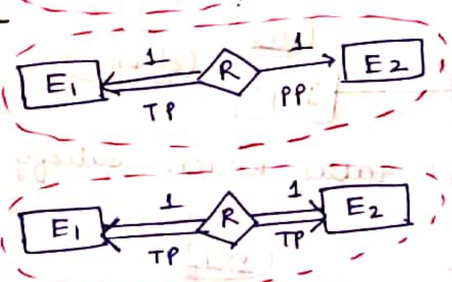
min 3 rel table && 2 F_K

min 2 ref table && 1 f_K

"or"



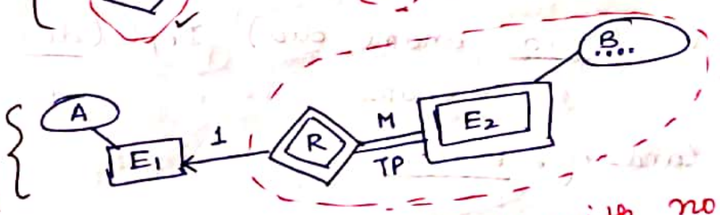
min 1 table && no F_K



min 1 table && 1 f_K.

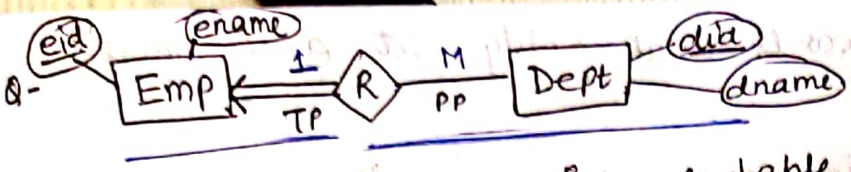
min 2 table && 2 f_K

min 2 rel table && 1 f_K



All these design are in BCNF with no redundancy

Q-



ⓐ How many min rel table

FD of Emp: eid → ename
Dept: did → dname

R: did → eid

Dept_R_Emp

eid	ename	Did	Dname
did → dname eid eid → ename			

min 1 table
INF ✓
2NF ✓
3NF ✗

ⓑ How many min rel required. which satisfy ~~BCNF~~ 3NF?

min 2 table

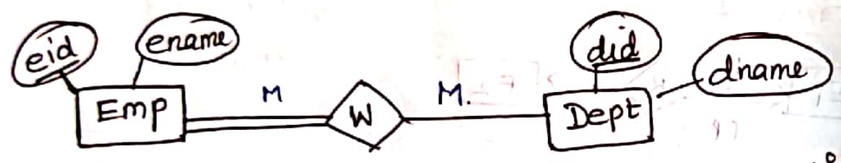
Emp

eid	ename
eid → ename	

R_Dept

did	dname	eid
did → dname eid		

Q-



ⓐ How many min rel tables which satisfy INF?

emp — eid → ename

W — no non trivial FD

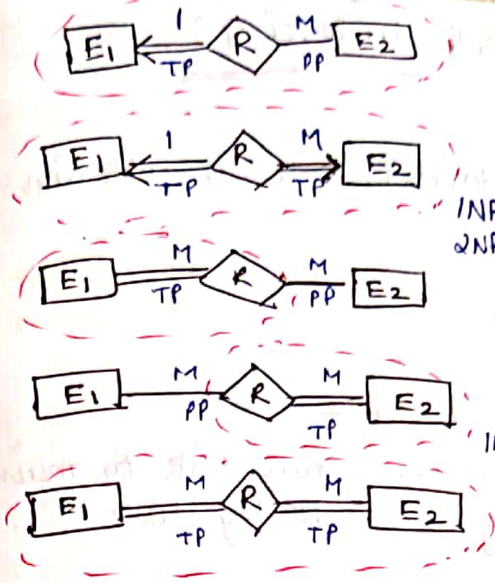
dept — did → dname

• min 2 tables req. INF ✓ 2NF ✗

Emp_W (eid ename did) Dept (did dname)
eid → ename did → dname

Cand Key: Eid did

ⓑ How many min rel tables which satisfy 2NF?



→ min 1 Table

min 1 table

INF✓ 2NF✓

min 2 table

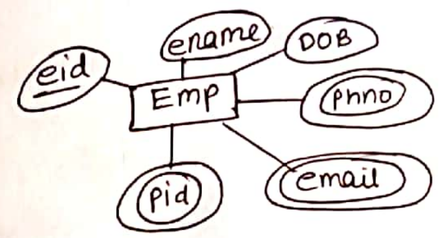
min 2 tables

INF✓

min 1 table

not in BCNF

Q-



min rel tables req for INF?
1

{eid → ename DOB}

FD (single valued Dep)

Emp(eid pno email pid ename DOB)

eid → ename DOB

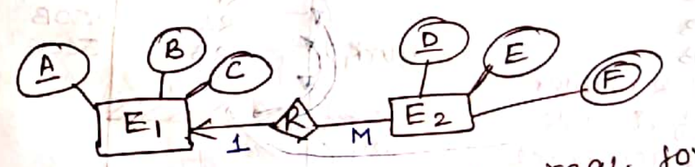
INF ✓
2NF ✗
⇓
2 rel table

eid	ename	DOB
eid → ename DOB		

eid	phno	email	pid
no non trivial FD			

⇒ 2NF✓
3NF✓
BCNF✓

Q-



How many rel. tables req. for 3NF

E1: A → BC

R: D → A

E2: D → E

D → F : we need not have to bother for INF, 2NF, 3NF, BCNF

1:M mapping combine with RHS entity set

min 2 table INF✓ { E1(A BC) E2R(D E F A)
D → E A

⇓

E1 (A B C)
A → BC

D	E	A
D → AE		

D	E
no non-trivial FD's	

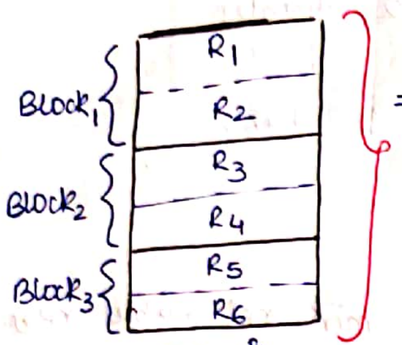
Cand Key: {DF}

:- BCNF✓
min 3 tables for 3NF as well as BCNF

File Organisation && Indexing :

DB is collection of files (tables). File is collection of blocks (pages).

Block is set of records



DB file (Table)

Stored in Disk

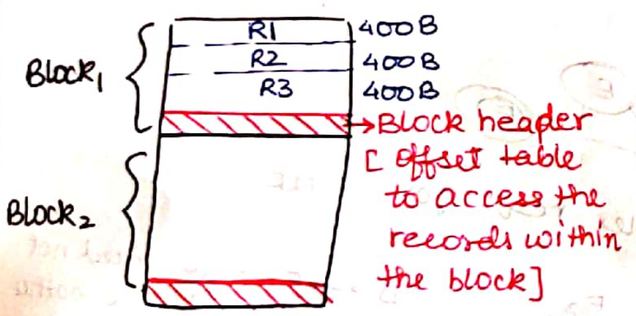
⇒ data access from disk to main memory, block by block

Records in DB file can be

① Fixed length record

```
Create table R
(
    A  char(100),
    B  char(100),
    C  char(200)
);
```

⇒ Records of R fixed length



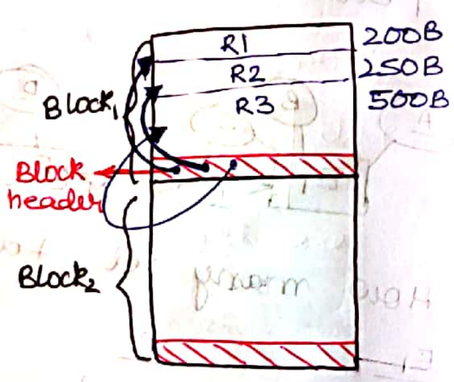
DB file for Rel R

⇒ Unspanned org is preffered.

② Variable length record

```
Create table S
(
    A  char(100),
    B  char(100),
    C  text // variable length
);
```

⇒ Records of S variable length.



DB file for Rel S

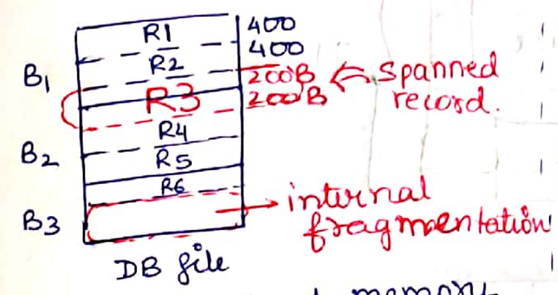
⇒ spanned org is preffered.

Records Organization in DB table

① Spanned org

Record allowed to span in more than one block

eg: Block : 1000 B
Record : 400 B



DB file

Adv:
- no wasted of memory
- no memory hole.
- disk utilisation is good.

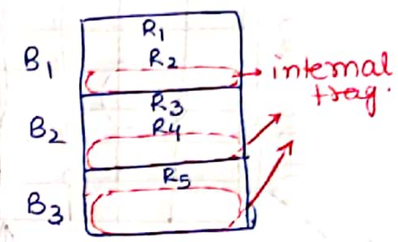
Possible to allocate DB file without internal fragmentation except for last block of the file

Disadv:
- Access cost is more to access the spanned records because we need to access 2 blocks in order to get R3

② Unspanned org.

Complete record must be stored in one block. i.e, record not allowed to span.

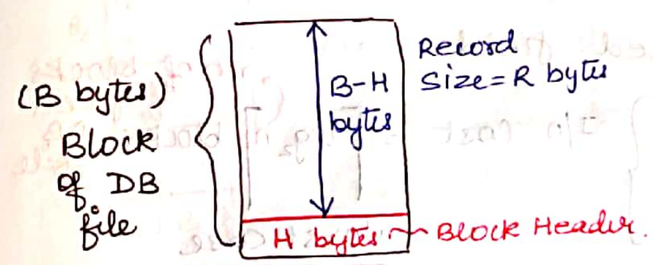
eg: Block : 1000 B
record : 400B



Disadv: more internal frag. which leads to wastage of disk space.

Adv: Access cost is less.

Block Factor of DB file :-
max possible records per block



Block factor of DB file $= \left\lfloor \frac{B-H}{R} \right\rfloor$ records/block

// because it is unspanned org.

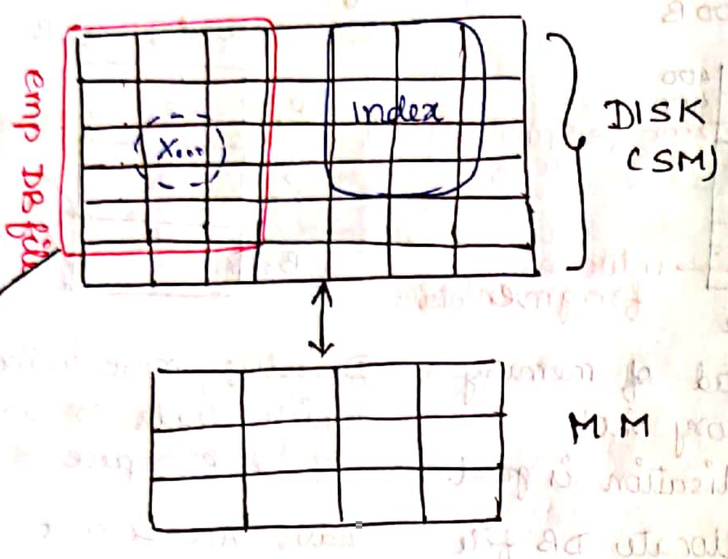
eg:- $B_f = \left\lfloor \frac{B-H}{R} \right\rfloor = \left\lfloor \frac{1000-0}{400} \right\rfloor = 2$ R/Block ⇐ Fixed ~~variable~~ length or Unspanned org.

$B_f = \frac{B-H}{R} = \frac{1000-0}{400} = 2.5$ R/Block ⇐ spanned org.

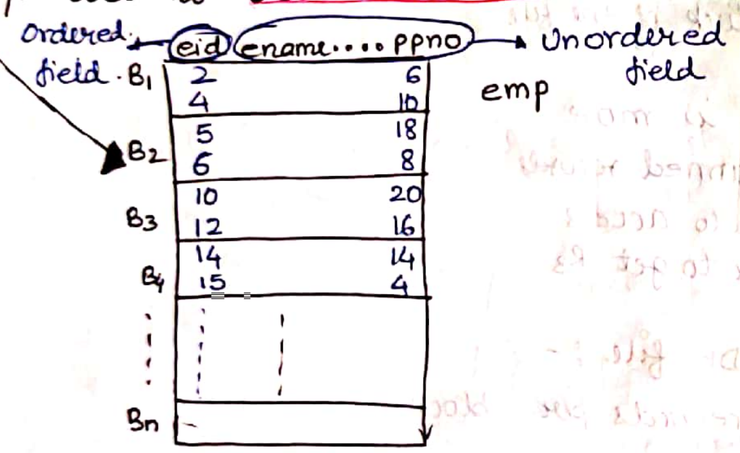
Scanned by CamScanner

Access Cost (I/O Cost):

no. of secondary memory blocks (disk blocks) required to transfer from disk to main memory in order to access the required records.



I/O Cost to access record without index :-



a) based on ordered field.

Select *
from emp
where eid = x ;

ordered field.

I/O Cost = $\lceil \log_2 n \rceil$ blocks.

no of blocks of given DB file

Worst Case

b) based on Unordered field.

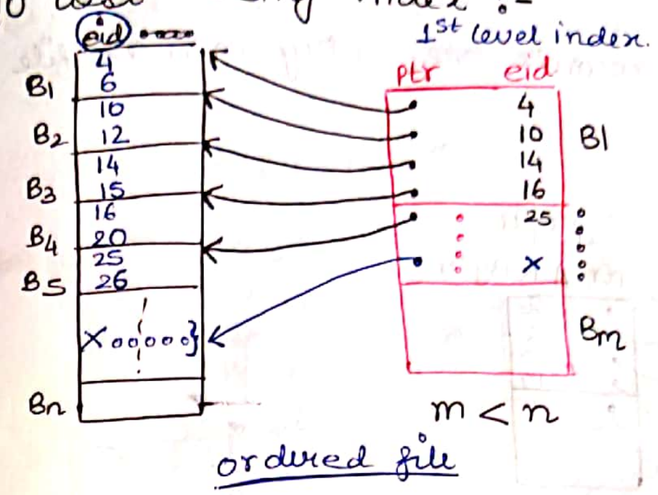
Select *
from emp
where ~~eid~~ ppno = y;

unordered field.

I/O Cost = N blocks

Worst Case

I/O Cost Using Index :-



I/O Cost to access record using 1st level indexing : $\lceil \log_2 m \rceil + 1$ blocks

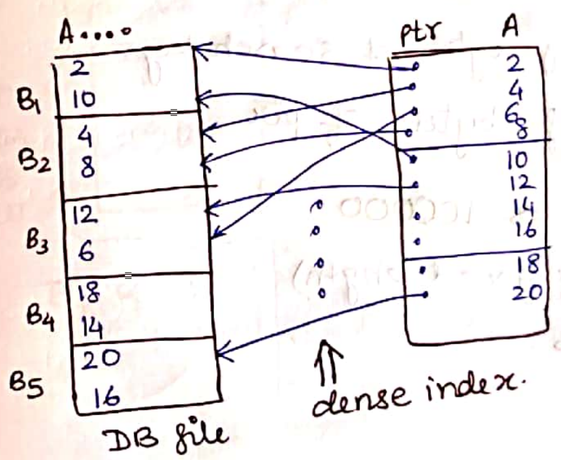
⇒ N, Q, ERD } develop

* Index
* T&C } build components DBMS s/w

Categories :-

Dense Index:

Index entry for each record of DB file

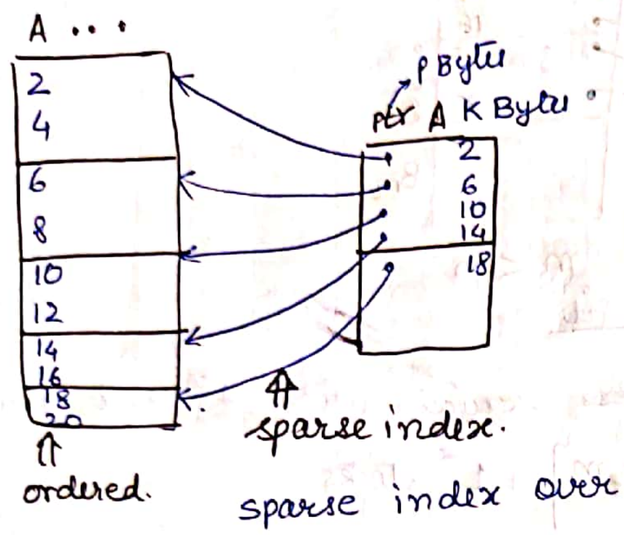


# of index entities in index files = # of records of DB files

Dense index can build over ordered field and over unordered field.

Sparse Index:

For set of DB records one entry in index file



sparse index over key

$\#$ of index file entries $=$ $\#$ of blocks of DB file

Block factor of DB file $= \left\lfloor \frac{B-H}{R} \right\rfloor$ records/block

$\Rightarrow$ Block factor of index file $= \left\lfloor \frac{B-H}{K+P} \right\rfloor$ Enteries/block.

K: $\#$ of bytes of search key

P: $\#$ of bytes of ptr

Q- $\#$ of records in DB file $\Rightarrow$ 100,000

Record size : 100 B (fixed length)

Block size : 1024 B

Search key : 12 B

Pointer : 9 B

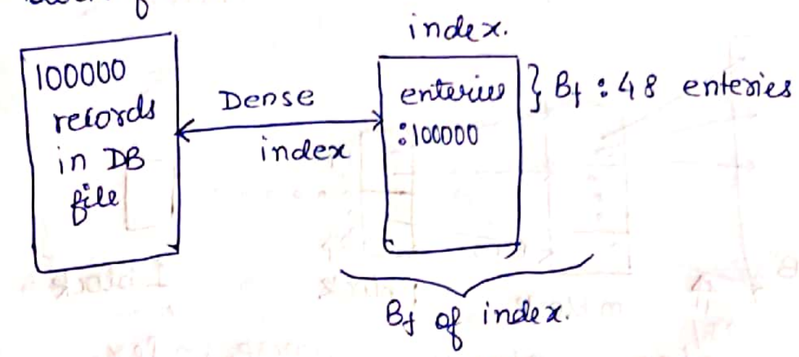
① if dense index used
find $\#$ of block of 1st level index

② if sparse index used
find $\#$ of blocks of 1st level index

(a) $\#$ of records $= \frac{\cancel{1024}\ 256}{\cancel{12}\ 3}$ $\Rightarrow$

Block factor =

(b)

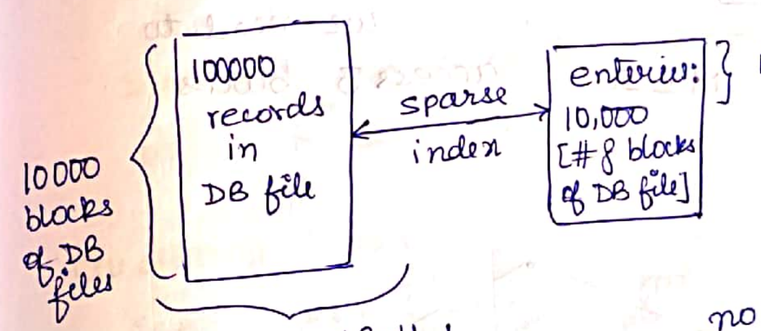


$B_f = \left\lfloor \frac{B-H}{K+P} \right\rfloor = \left\lfloor \frac{1024-0}{12+9} \right\rfloor = 48$ entries/block

$\#$ of ~~entries~~ dense index blocks $= \left\lceil \frac{100000}{48} \right\rceil$

$= 2084$ blocks

(b) $\#$ of sparse blocks $\Rightarrow$



B_f of DB $= \left\lfloor \frac{B-H}{R} \right\rfloor$

$= \left\lfloor \frac{1024}{100} \right\rfloor$

$= 10$ R/block

no. of blocks $\Rightarrow \frac{100000}{10}$

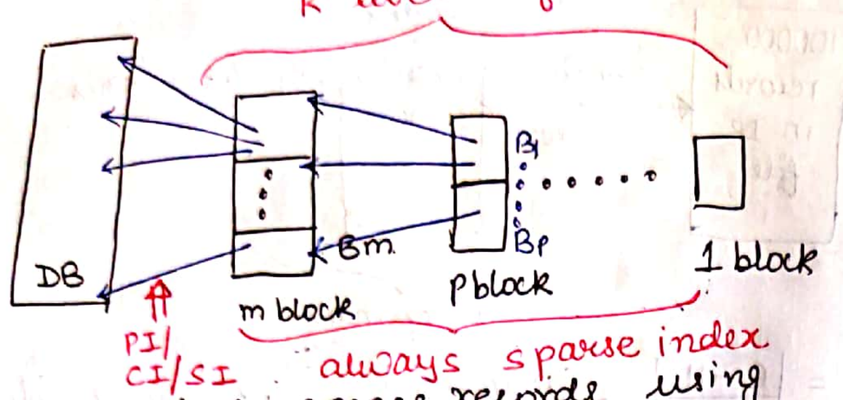
$= 10{,}000$ blocks

$\#$ of sparse index blocks $= \left\lceil \frac{10{,}000}{48} \right\rceil = 209$ blocks

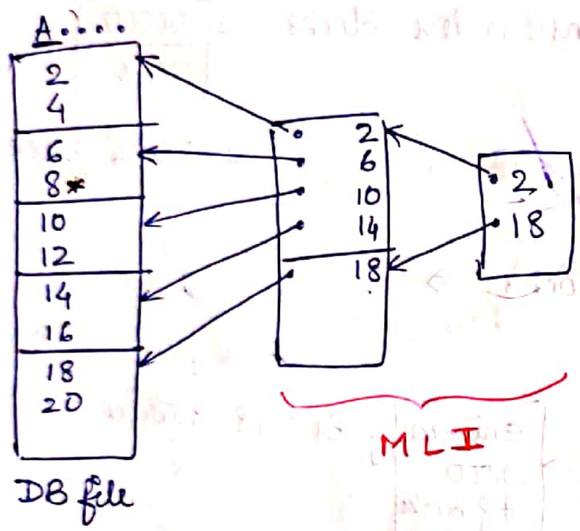
Scanned by CamScanner

Multilevel Index :

Index to Index until last level one block of index.

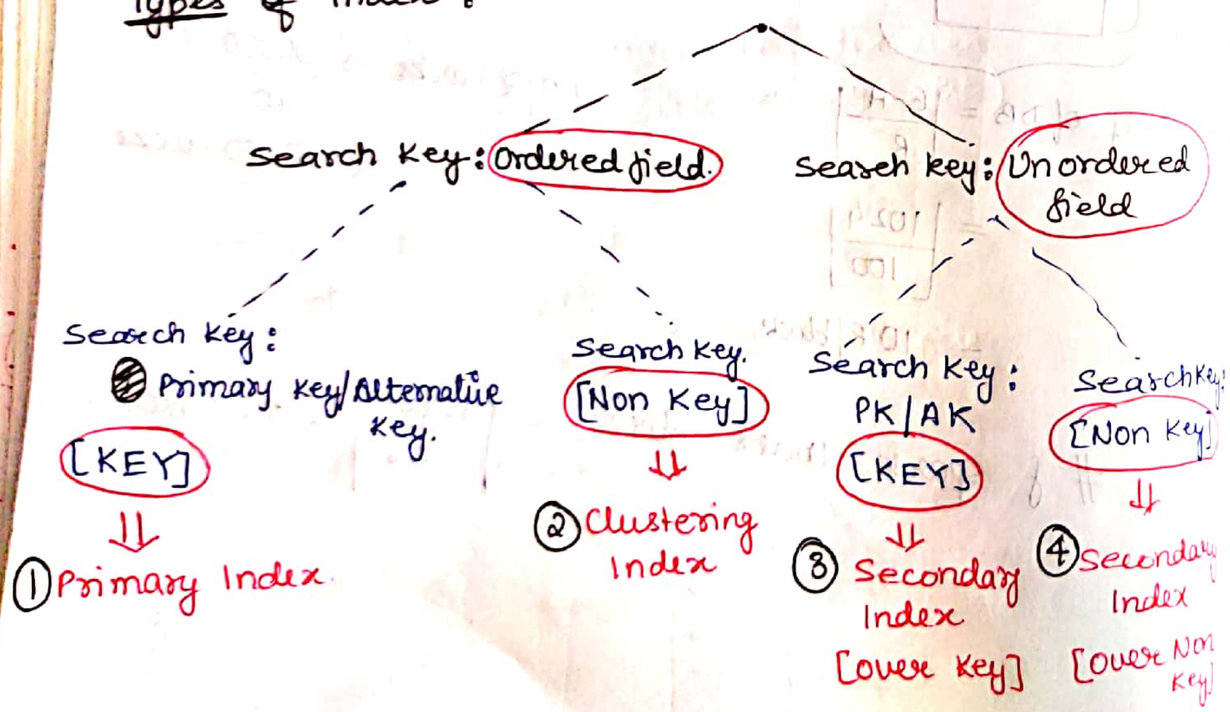


I/O cost ~~of~~ to access records using multilevel Index : (K+1) blocks



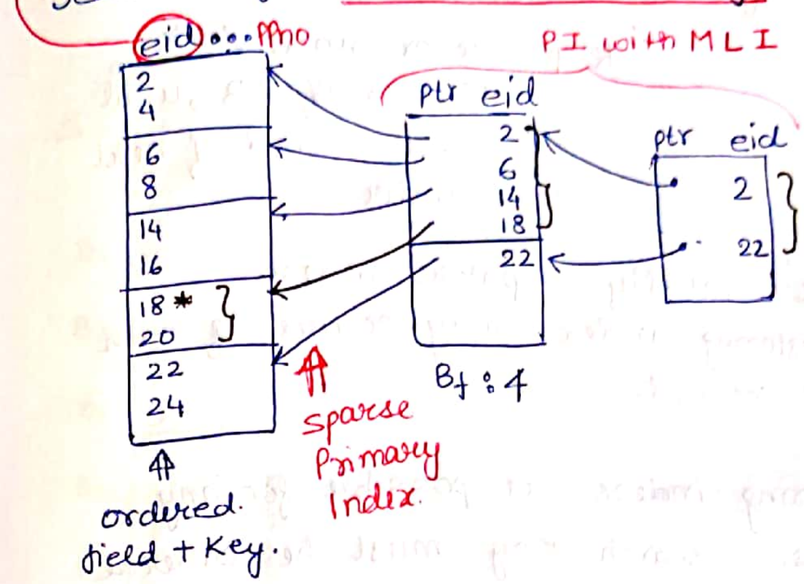
⇒ to access 8 we need to access 3 blocks

Types of Index :



Primary ~~Key~~ Index

Search Key : Ordered field + Key



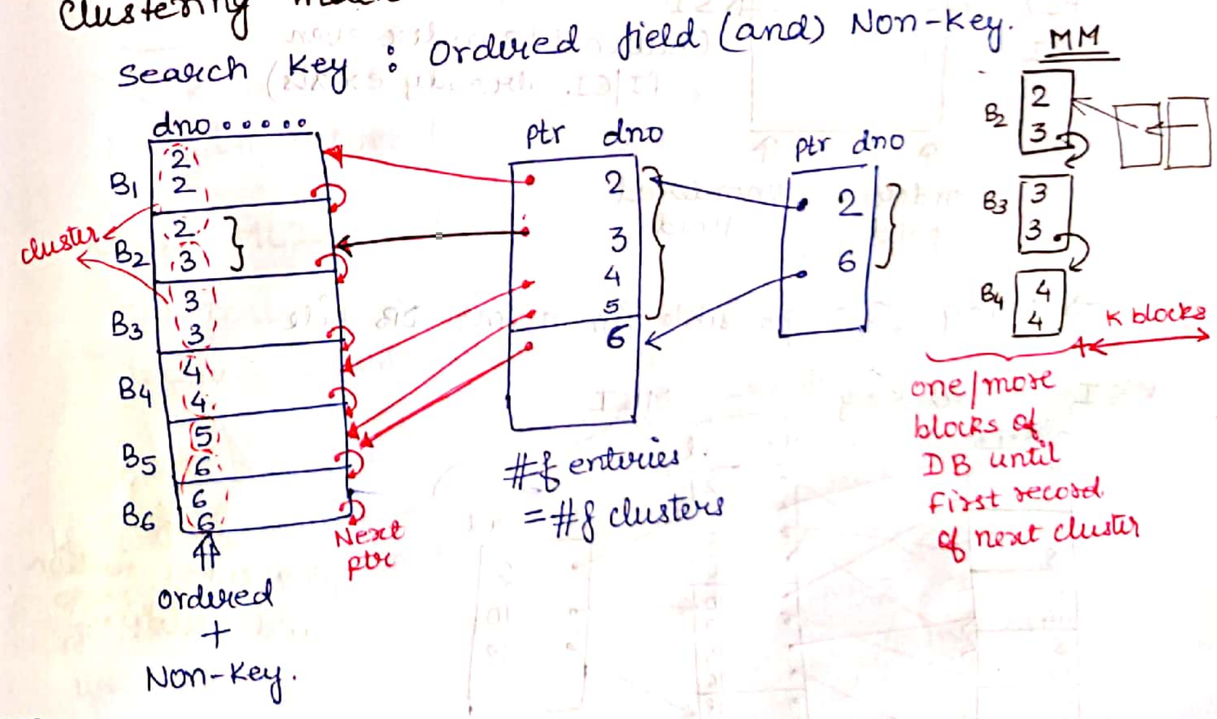
Primary Index can be either dense or sparse (sparse PI index is preffered) Atmost one PI is possible for any relation (DB file) ⇓ search key must be ordered field.

because it will reduce block numbers and levels in MLI

I/O cost to access records using ~~1st level~~ PI with MLI. (K+1) blocks

Clustering Index.

Search Key : Ordered field (and) Non-Key.



eg: I/O Cost

Select * from emp dno=3;

I/O cost to access one cluster of records using clustering with MLI =

K + one or more block access of DB, until first record of next cluster

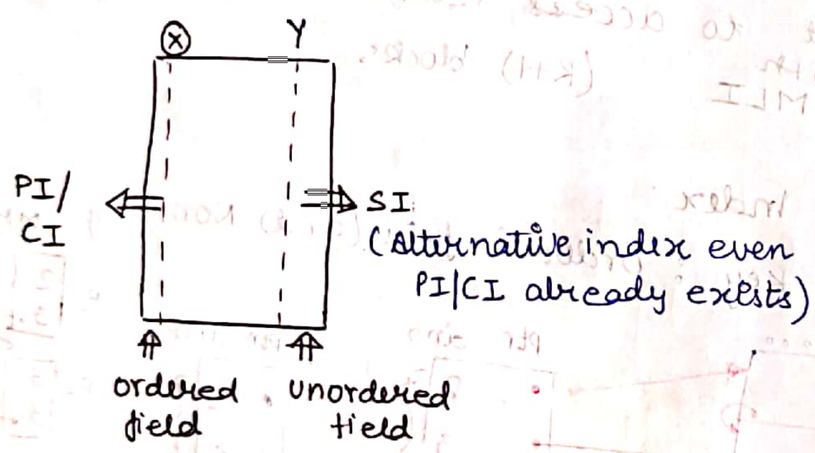
Clustering Index mostly sparse Index but dense clustering index may occurs if each cluster with 1 record.

Atmost 1 clustering index is possible for any DB file because search key must be ordered field.

For any DB file either Primary Index / Clustering index is possible but not both.

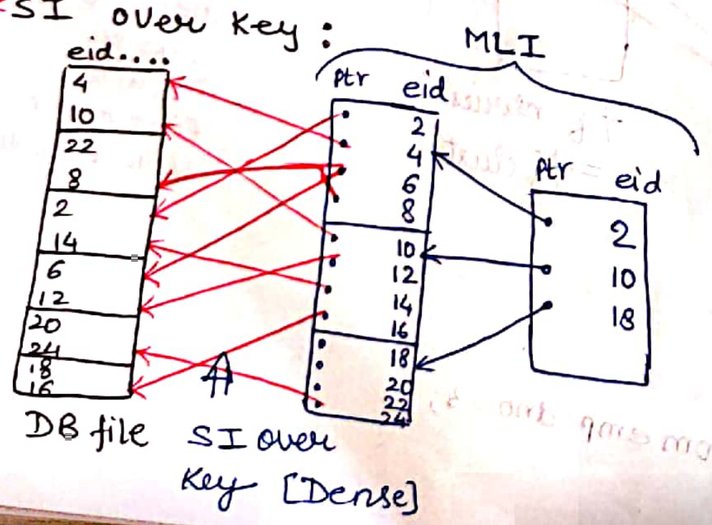
Secondary Index :

Search key : Unordered field (and) key / Non key



⇒ Many SI possible for same DB file

*SI over Key :

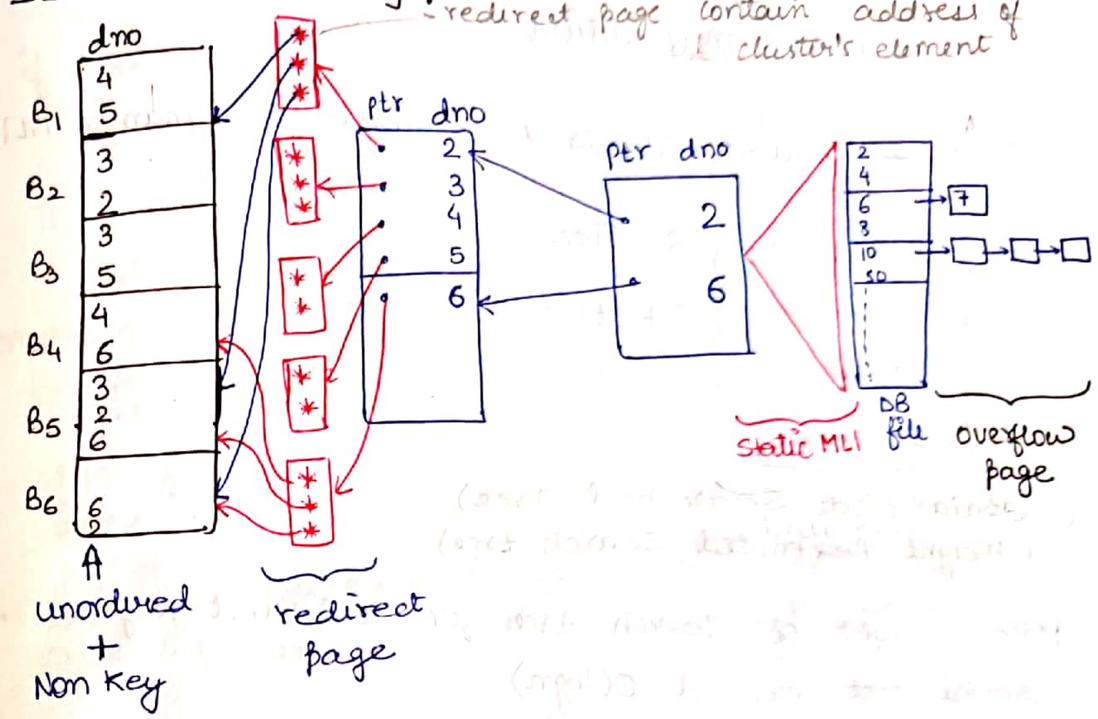


it is not suitable for frequent insertion and deletion

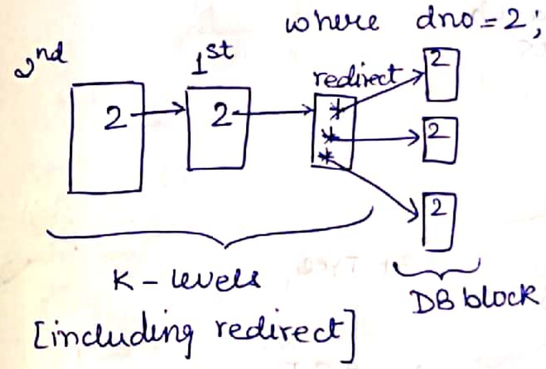
Secondary Index over key is always dense index.

I/O cost to access record using SI with MLI = (K+1) blocks

SI over Non-Key : redirect page contain address of cluster's element



I/O Cost : Select *
from emp
where dno = 2;



⇒ { K + # of blocks of DB is # of records of given non key } blocks

Static MLI :

I/O cost can be O(n) ← Disadv.

because of overflow pages

To avoid this disadvantage we go for dynamic MLI

If we add another entry in SI over key we need to change index entries and hence all MLI will change. so to avoid this we maintain overflow page so that we need not change index & we keep new entries in overflow page. So there may be many overflow page in same block. ~~Hence we need~~

Dynamic MLI

- No overflow pages
- Index file should update based on records insertion / deletion
- Require Standard DS used for Dynamic MLI

{ B Tree
{ B+ tree

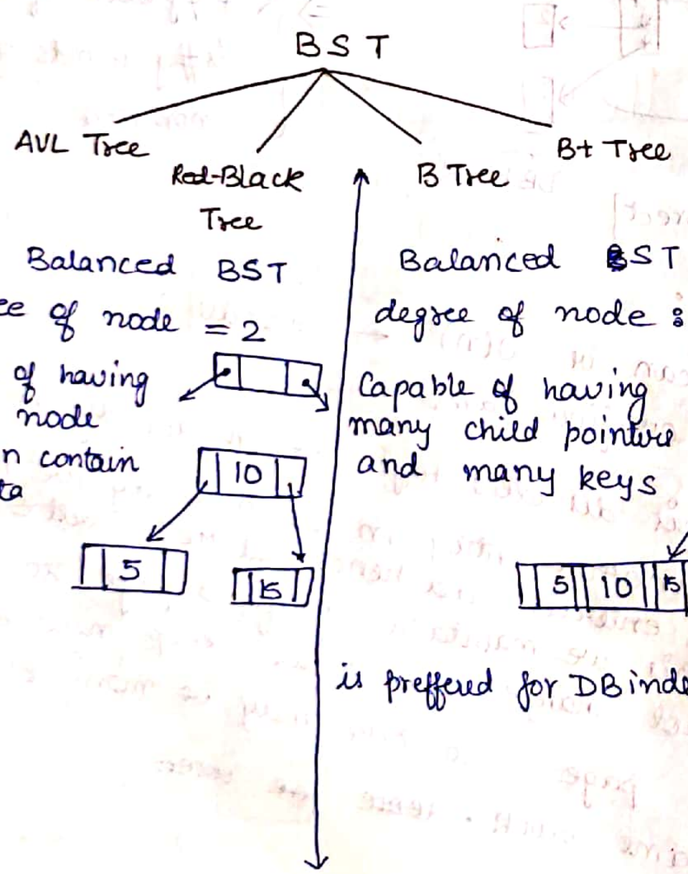
B/B+ Trees

(Balanced Searched Tree)
(Height Restricted Search tree)

Max height of search tree for n distinct keys should not exceed O(logn)

Time complexity to search key in BST is O(logn)

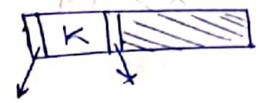
BST is best DS for search operations.



Why B/B+ tree used for DB Index rather than Balanced BST ?

- In AVL, one block contain 1 ~~data~~ key
- In B+, one block contain multiple keys

- if Balanced BST used for DB index :

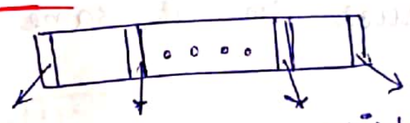


Block [AVL tree Node]

∵ it contain only 1 key, so it contains more levels of index which increases I/O Cost to access data

- Wastage of disk space bec. each index block used for 1 key. remaining spaced is unused.
- DB file in disk. Index to DB file also must be in Disk && Data accessed from disk block by block

if B/B+ Tree index used for DB ~~fl~~ index.



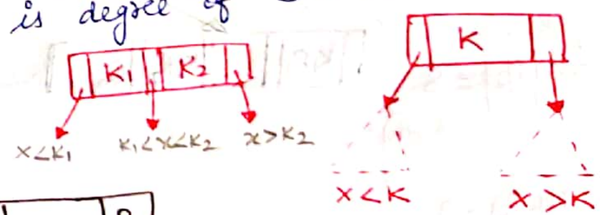
Block [B Tree node/ B+ Tree node]

∵ it contain multiple keys in one block so less levels of index hence reduces I/O cost to access data.

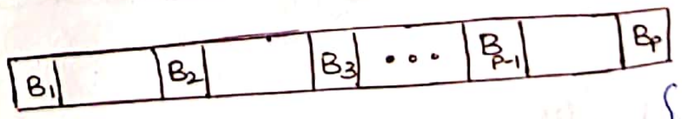
Also less wastage of disk space because each index block can store many keys & not one index block for one key.

B Tree Def :

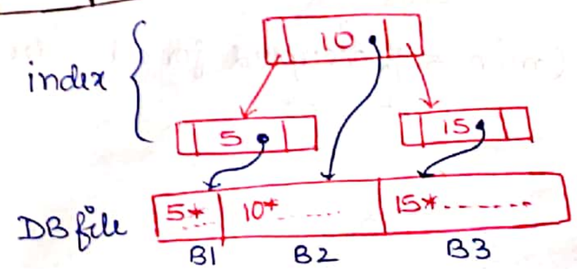
Order P : max possible child pointers (block pointer) which can store in B tree node is degree of B tree.

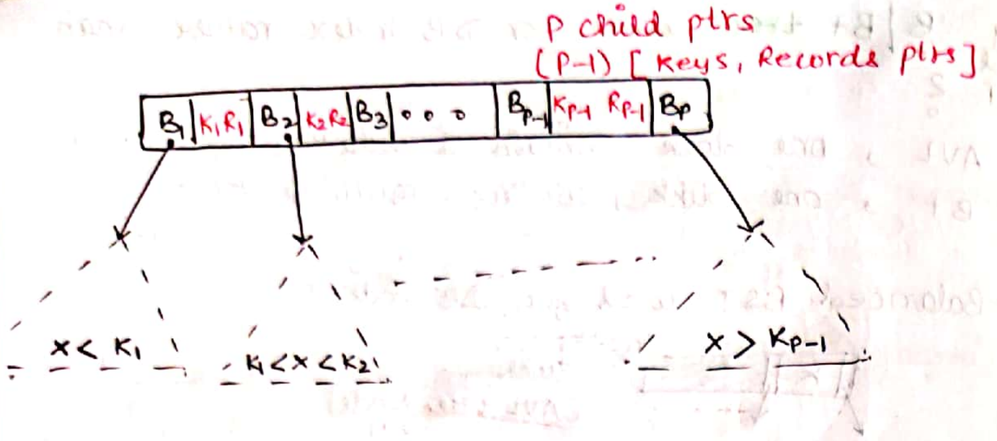


a) node structure :



Pointers :-
- pointer to child node
- points to DB file

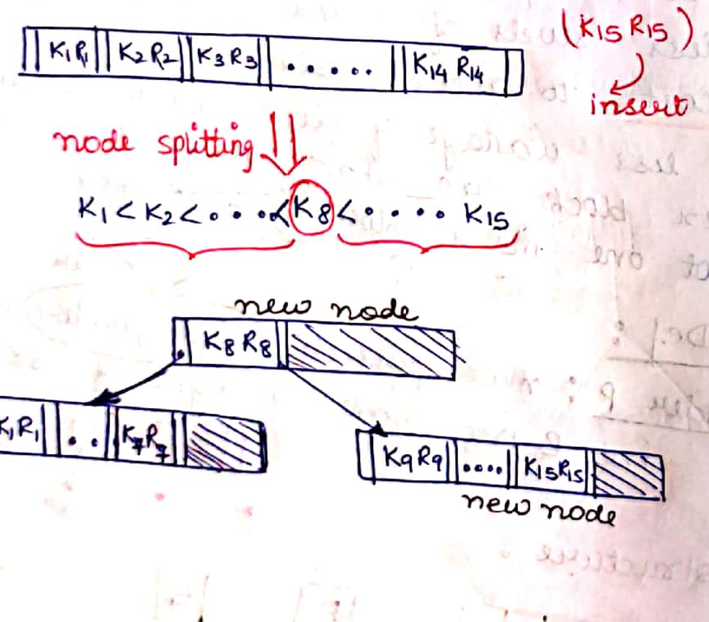




and b) Balancing Condition:

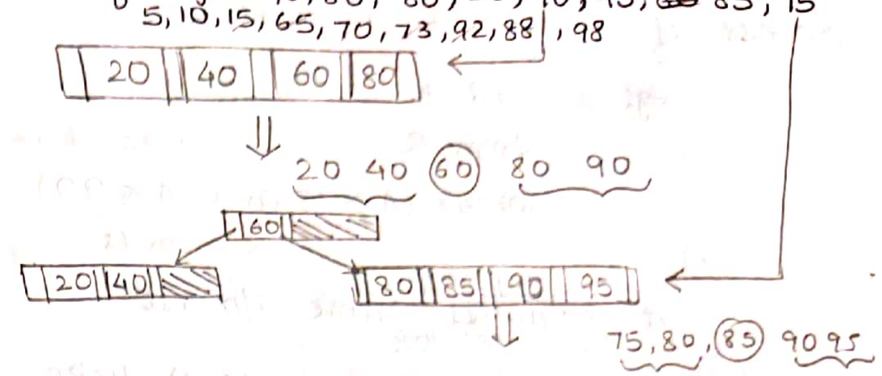
- every internal node except Root
  atleast $\lceil p/2 \rceil$ blocks ptrs with $(\lceil p/2 \rceil - 1)$ Keys
  at most p block ptrs with (p-1) Keys
- Root can be atleast 2 block ptrs with 1 key
  atmost p block ptrs with (p-1) keys
- Every leaf node must be at same level

eg: order p: 15 (max Cp per node)

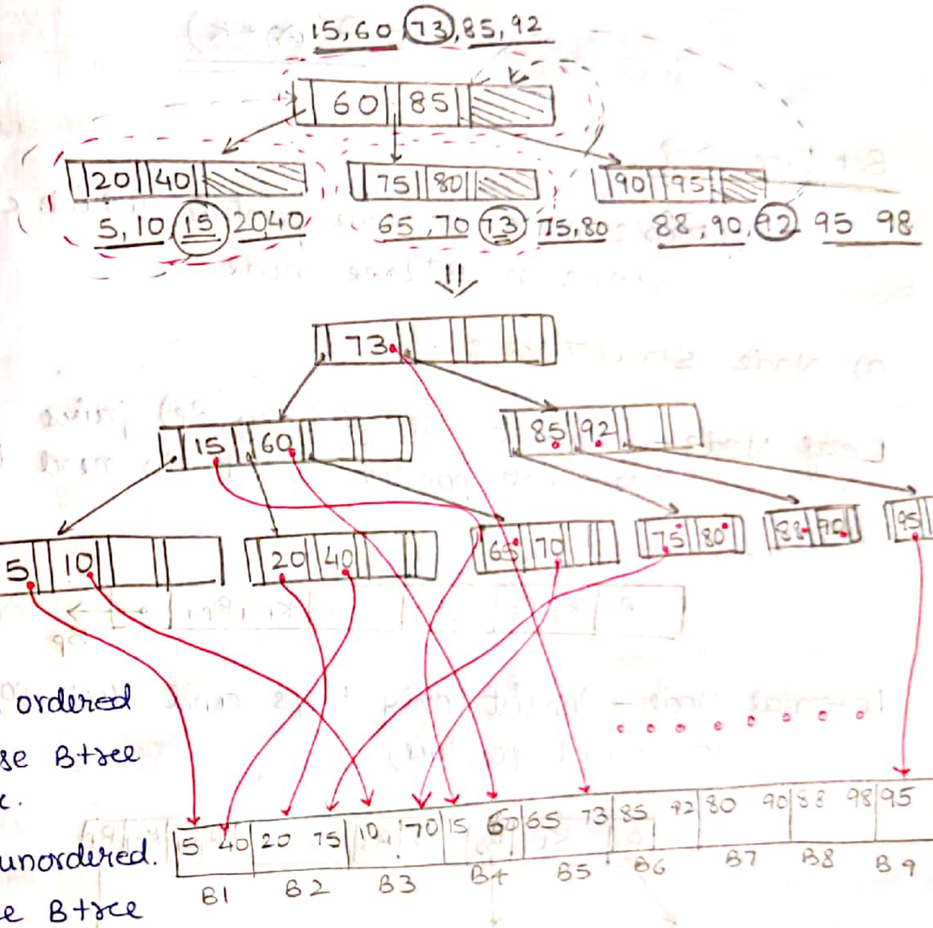


(min 50% occupied for all nodes except root)

Q- Construct B tree with order p : 5 (max Cp per node) and sequence of Keys 40, 60, 80, 20, 90, 95, 85, 75, 5, 10, 15, 65, 70, 73, 92, 88, 98



* next key insertion should be in appropriate leaf node



- if DB file ⇒ ordered then sparse B+tree index.
- if DB file ⇒ unordered then dense B+tree index.
  # of index = # of records

B Tree index best suitable for random access of any one record

eg: Select *
from R
where A = 70,
any one record access

I/O Cost for random access of any one record : (K+1) blocks.

Disadvantage:-
B tree index not best suitable for sequential access of range of records.

eg: Select *
from R
where $A \geq 75$ and $A \leq 90$ — Range of records

x records

it requires more I/O cost.

Worst case I/O Cost :- $x(k+1)$ blocks

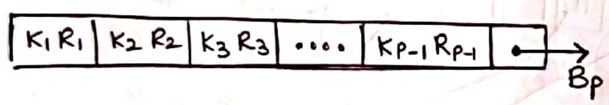
$\approx \Theta(x * k)$

B+ Tree Def:

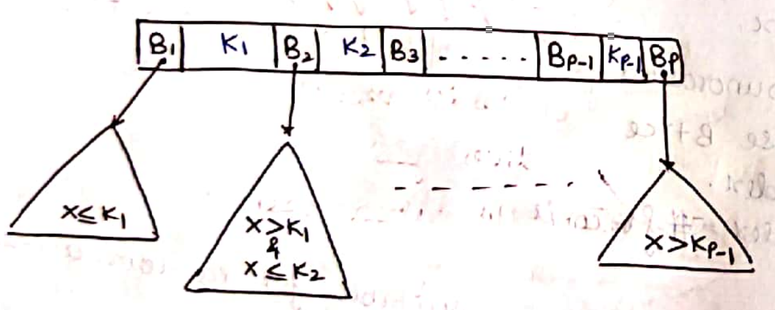
Order p : max possible pointers which can store in B^+ tree node.

a) Node Structure :

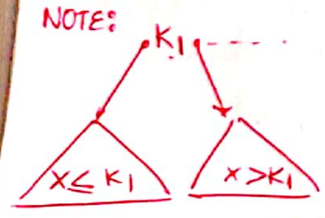
Leaf Node – Consist set of (Key, Rp) pairs and one block pointer pointed to next leaf node.



Internal Node – Consist only Keys and block pointers (no record pointers).

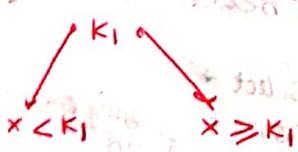


NOTE:



left biasing

left side keys > right side keys



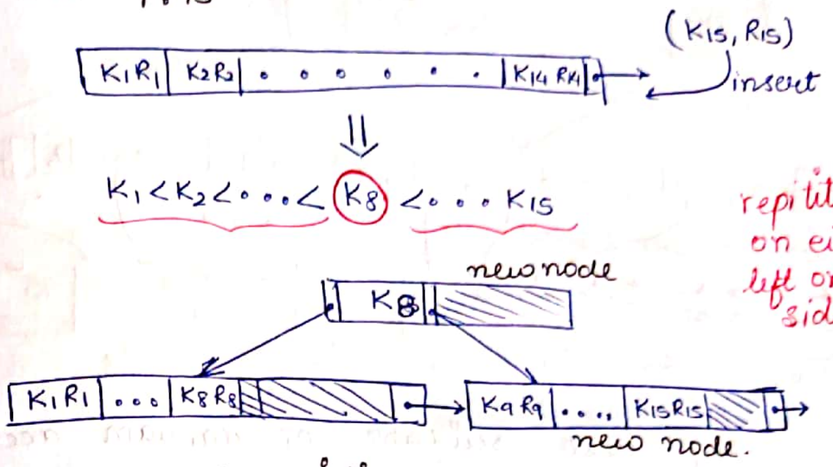
right biasing

right side keys > left side keys

(b) Balancing condition : same as B Trees.

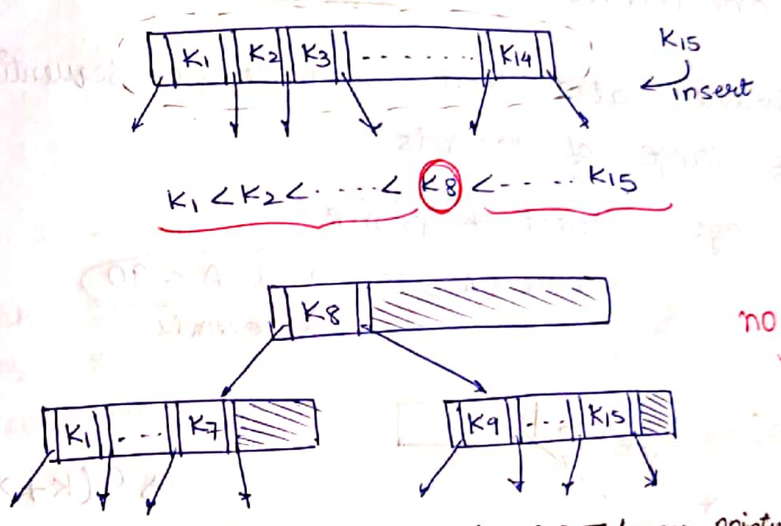
eg:- Leaf splitting

Order p: 15



repitition on either left or right side

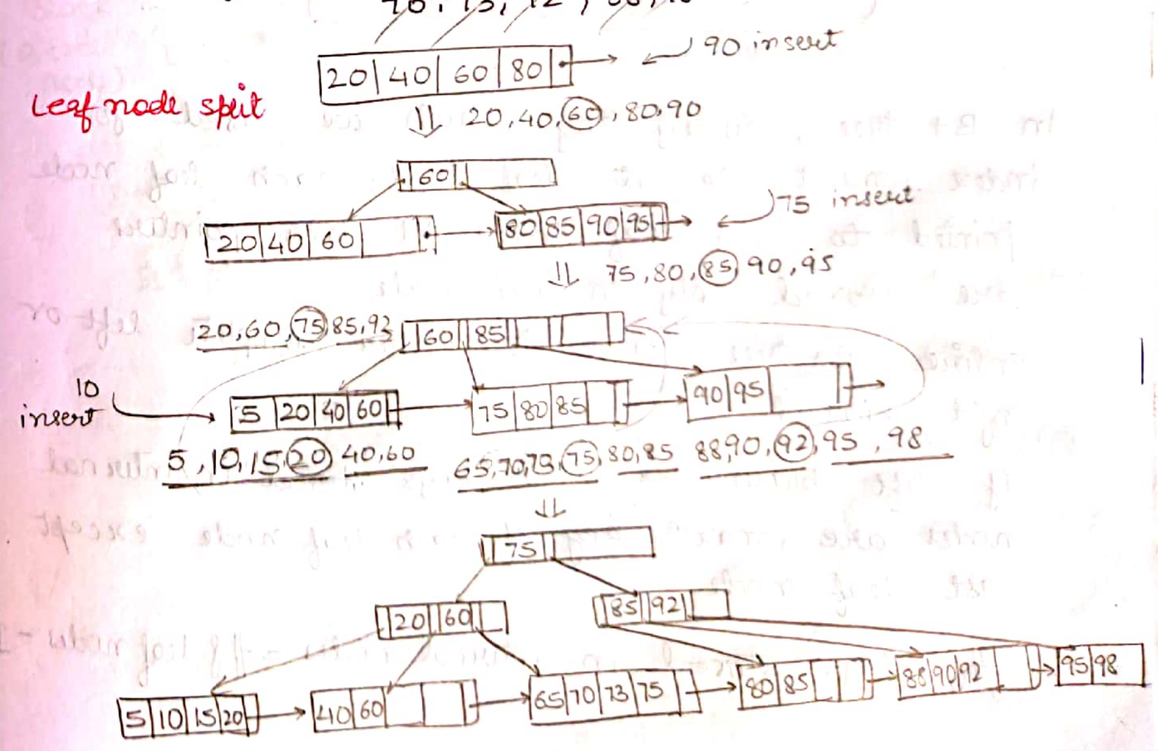
Internal node splitting



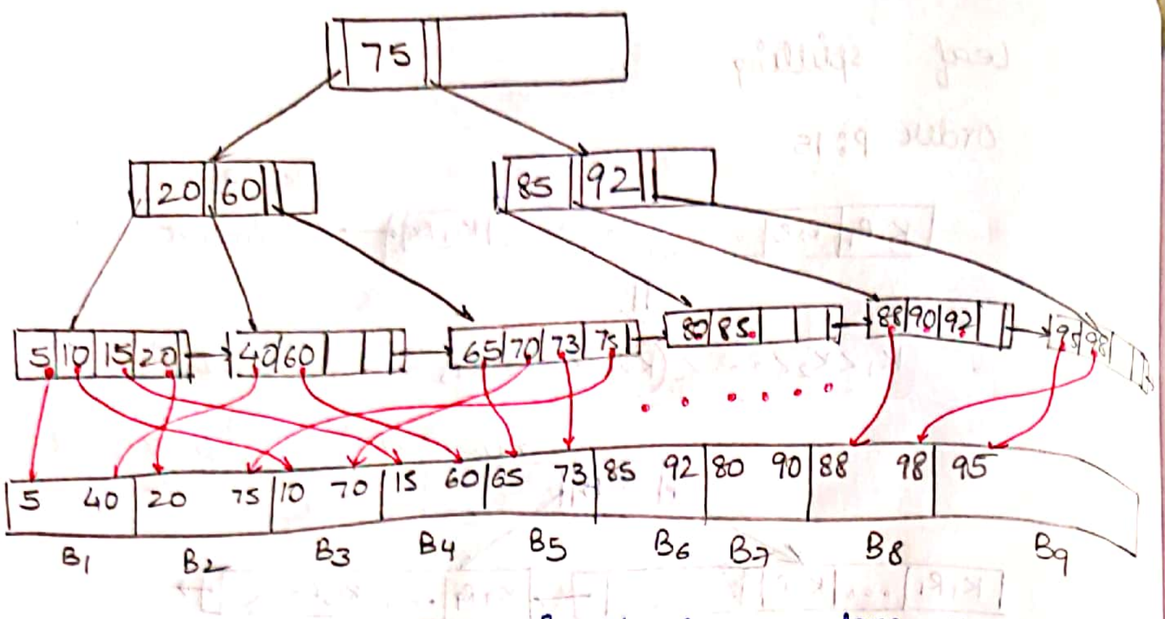
no more repitition

Q- Construct B+ tree with order p : 5 (max pointers per node)
sequence of keys : 40, 60, 80, 20, 90, 95, 85, 75, 5, 10, 15, 65, 70, 73, 92, 88, 98

Leaf node split



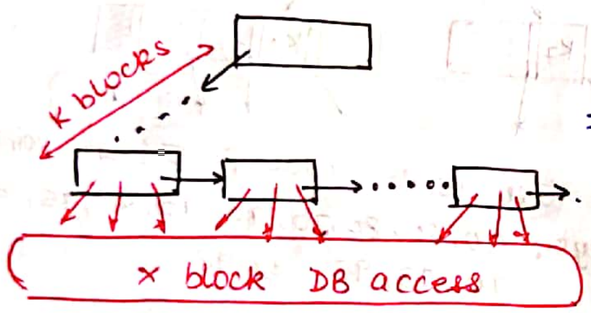
Scanned by CamScanner



B+ Tree index best suitable for random access of any one record with <u>I/O Cost</u> : (K+1) Blocks

B+ Tree index also best suitable for sequential access of range of records.

eg: Select * from R
where $A \geq 75$ and $A \leq 90$
x records



$\Rightarrow \Theta(K+x)$ blocks

In B+ tree, every key which we used for index must be at leaf level. each leaf node pointed to next leaf node. All data pointers are stored only in leaf node.

entire B+ tree must be either complete left or right biased.

If left biasing is used, keys stored in internal nodes are max^m key of each leaf node except last leaf node.

#f keys stored in internal nodes = #f leaf nodes - 1

**Q- Find best possible order of B/B+ tree node:

block size = 1024 B
Search key = 10 B
Block pointer = 12 B
Record pointer = 9 B
Order p: max possible block pointers in B tree node

What is best possible order of B tree node?

Block (B Tree) node $\boxed{p * B_p + (p-1) * (R_p + K)}$ order p: max $B_p \leq$ Block Size

$$p * 12 + (p-1)(9+10) \leq 1024$$
$$12p + 19p - 19 \leq 1024$$
$$31p \leq 1043$$
$$p \leq \frac{1043}{31} \Rightarrow p = \left\lfloor \frac{1043}{31} \right\rfloor = 33$$

Q- Block size = 512 B
Key size = 8B
Block pointer = R_p = 10 B
Order p: max possible keys can store in B tree node?

What is best possible order of B tree node?

Block (B tree node) $\boxed{(p-1) * (K + R_p) + (p+1) B_p} \leq$ Block size.

Order: max key/node.

$$(p+1)\,10 + p(8+10) \leq 512$$
$$28p + 10 \leq 512$$
$$p = \left\lfloor \frac{502}{28} \right\rfloor = 17$$ // max keys store in BTree node

Q- Block Size = 1024B

Search Key = 10B

$B_p = 12B$

$R_p = 9B$

Order p : max possible block pointers in B+ tree node

Q what is best possible order of B+ tree

a) leaf node?

b) internal node?

a) $\boxed{(P-1)*(K+R_p)+1*B_p} \leq$ Block Size

Order p : max ptrs

$(P-1)R_p$ $\quad$ $1\,B_p$

$(P-1)*(10+9)+12 \leq 1024$

$19p - 19 + 12 \leq 1024$

$19p \leq 1031$

$P = \left\lfloor \frac{1031}{19} \right\rfloor = 54$

b) order p :

$\downarrow$

$p\,B_p$

$\boxed{P*B_p+(P-1)K} \leq$ Block Size

$(P-1)\,10 + 12p \leq 1024$

$P = \left\lfloor \frac{1034}{22} \right\rfloor = 47$

when P of leaf & internal node are same?

$(P-1)(K+R_p) + B_p = P\,B_p + (P-1)K$

$\cancel{(P-1)K} + (P-1)R_p = (P-1)B_p + \cancel{(P-1)K}$

$\boxed{B_p = R_p}$

NOTE: If size of R_p = size of B_p then B+ leaf node order equal to internal node order

Q- Block Size = 512B

search key = 8B

$B_p = R_p = 10B$

order p : max possible keys can store in B+ tree node

what is best possible order of B+ tree node?

a) leaf node

order p

p keys $\quad$ 1 B_p

$P(K+R_p) + B_p \leq$ Block Size

$P(18) + 10 \leq 512$

$P = \left\lfloor \frac{502}{18} \right\rfloor = 27$

b) internal node.

$\downarrow$

$(P+1)\,B_p$

$P[K] + (P+1)\,B_p \leq$ Block Size.

$8p + 10p + 10 \leq 512$

$18p \leq 502$

$P = \left\lfloor \frac{502}{18} \right\rfloor = 27$

Q- B: 1024 B

Key: 20 B

B_p: 15B

order p: max keys per node.

what is B+ tree best possible order.

internal node :- $\because R_p$ is not given.

$\cancel{P*B_p+(P-1)}$

$PK + (P+1)B_p \leq 1024$

$20p + (P+1)15 \leq 1024$

$35p \leq 1009$

$P = \left\lfloor \frac{1009}{35} \right\rfloor = 28$

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Key = 8
$R_p = B_p = 10B$

512B Block

B Tree Node
Order p: 17
[max 17 keys per node]

B+ Tree Node
order p: 27
[max 27 keys per node]

if Block size allocated for B Tree node = B+ Tree node Block size

then,

→ Order p: B Tree node < order p of B+ Tree node

→ ~~Be~~ # of B Tree nodes and levels of B Tree nodes for n distinct keys > # of B+ Tree nodes and levels of B+ Tree nodes for n distinct keys.

→ (I/O Cost) > (I/O cost)

Hence, B+ tree is best for both range and random access queries.

Therefore B+ tree is preffered than B tree for DB index because B+ tree index access cost for both random access and range queries are less than B tree index.

Q- Find min, max keys and nodes in B tree/B+ tree for given l levels and order p?

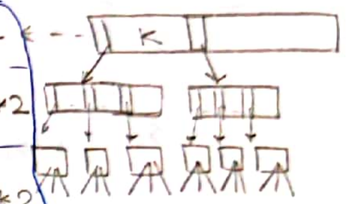
Q- How many min keys/nodes in B/B+ tree order p: 5 and level: 4?

order p: b/w 2 to p bp for root

b/w $\lceil p/2 \rceil$ (3) to p bp for other nodes

b/w $\lceil p/2 \rceil - 1$ to p-1 keys for leaf nodes

level	min Nodes	min Bp	min Keys
Root 1	1	2	1
2	2	2*3	2*2
3	6	6*3	6*2
leaf 4	18	–	18*2



rest are repeated in B+ trees

min 27 nodes in B/B+ tree

min 53 keys in B trees
min 36 keys in B+ trees

Q- How many max keys/nodes in B/B+ tree order p: 5 and level: 4?

order p: b/w 2 to p bp for root

b/w $\lceil p/2 \rceil$ (3) to p bp for other nodes

b/w $\lceil p/2 \rceil - 1$ to p-1 keys for leaf nodes.

level	max nodes	max Bp	max Keys
root 1	1	5	4
2	5	5*5	5*4
3	25	25*5	25*4
leaf 4	125	–	125*4

→ 500 keys in B+ tree.

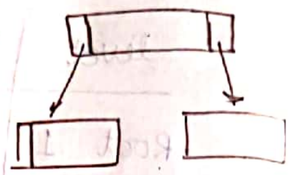
624 keys in B tree.

= 156 nodes in B/B+ tree.

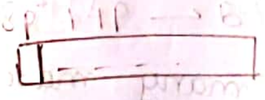
Q- How many B/B+ trees of order p: 5 and level l: 4 can have min key/nodes.

order p: b/w 1 to (2P) keys for root (10)
b/w p to 2P keys for otherwise.

level	min nodes	min Bp	min keys
root 1	1	2	1
2	2	2*6	2*5
3	2*6	12*6	12*5
leaf 4	72	–	72×5 → 360 B+
	87		431 → Btree



level	max nodes	max Bp	max Key
root 1	1	11	10
2	11	11*11	11*10
3	121	121*11	121*10
leaf 4	1331	–	1331*10 = 13310 → B+
	1464		14640 → B



Order P (max bp per node)
height (h) : 0, 1, 2, ..., h

height (h)	min nodes	min Bp	min Keys	max nodes	max Bp	max keys
0	1	2	1	1	P	P−1
1	2	$2\lceil P/2\rceil$	$2(\lceil P/2\rceil-1)$	P	P^2	$P(P-1)$
2	$2\lceil P/2\rceil$	$2\lceil P/2\rceil^2$	$2\lceil P/2\rceil(\lceil P/2\rceil-1)$	P^2	P^3	$P^2(P-1)$
3	$2\lceil P/2\rceil^2$	$2\lceil P/2\rceil^3$	$2\lceil P/2\rceil^2(\lceil P/2\rceil-1)$	P^3	P^4	$P^3(P-1)$
⋮	⋮			⋮		
h	$2\lceil P/2\rceil^{h-1}$	–	$2\lceil P/2\rceil^{h-1}(\lceil P/2\rceil-1)$	P^h	–	$P^h(P-1)$
	$1+\frac{2(\lceil P/2\rceil^h-1)}{\lceil P/2\rceil-1}$		$1+\frac{2(\lceil P/2\rceil-1)(\lceil P/2\rceil^h-1)}{(\lceil P/2\rceil-1)}$	$\frac{P^{h+1}-1}{P-1}$		$P^{h+1}-1$

$= 1+2(\lceil P/2\rceil^h-1)$ — max keys in B trees

min keys : $\Theta((P/2)^h)$ max keys : $\Theta(P^h)$

Height of B trees with n ~~nodes~~ key and order p **

$$\Rightarrow 2\lceil P/2\rceil^h-1 \le \text{keys} \le P^{h+1}-1$$

Range of keys in B tree with order p && height h

$$\Rightarrow 2\lceil P/2\rceil^{h-1}(\lceil P/2\rceil-1) \le \text{keys} \le P^h(P-1)$$

Range of keys in B+ trees

i) min height :- // Max fill factor each node or max keys per node

$$n = P^{h+1}-1 \Rightarrow h = \boxed{\log_P(n+1)-1}$$

$\Theta(\log_P n)$

(ii) max height :- // Min Keys per node

$$n = 2\lceil P/2\rceil^h-1 \Rightarrow \boxed{h = \log_{P/2}\left(\frac{n+1}{2}\right)}$$

$\Theta(\log_{P/2} n)$

$$\Rightarrow \log_P(n+1)-1 \le \text{height} \le \log_{P/2}\left(\frac{n+1}{2}\right)$$

Range of height in B trees with order P

Q- Which is True about B Tree order P and height h

a) Keys $\le 2\lceil P/2\rceil^h-1$

b) Keys $\ge P^{h+1}-1$

c) height $\ge \log_P(n+1)$

d) height $\ge \log_{P/2}\left(\frac{n+1}{2}\right)$

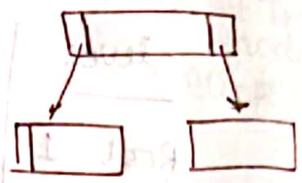
$\Theta\left(\left(\frac{P}{2}\right)^h\right) \le$ Keys $\le \Theta(P^h)$

$\Theta(\log_P n) \le$ height $\le \Theta(\log_{P/2} n)$

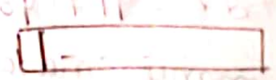
Q- How many B|B+ trees of order p:5 and level l:4 can have min key|nodes.

Order p: b/w 1 to (2P) keys for root (10)
b/w p to 2P keys for otherwise.

level	min nodes	min Bp	min keys
root 1	1	2	1
2	2	2*6	2*5
3	2*6	12*6	12*5
leaf 4	72	–	72×5 → 360 B+
	87		431 → Btree



level	max nodes	max Bp	max Key
root 1	1	11	10
2	11	11*11	11*10
3	121	121*11	121*10
leaf 4	1331	–	1331*10 = 13310 → B+
	1464		14640 → B



Order P (max bp per node)
height (h) : 0, 1, 2, ..., h

height (h)	min nodes	min Bp	min Keys	max nodes	max Bp	max keys
0	1	2	1	1	P	P−1
1	2	$2\lceil P/2\rceil$	$2(\lceil P/2\rceil-1)$	P	P^2	$P(P-1)$
2	$2\lceil P/2\rceil$	$2\lceil P/2\rceil^2$	$2\lceil P/2\rceil(\lceil P/2\rceil-1)$	P^2	P^3	$P^2(P-1)$
3	$2\lceil P/2\rceil^2$	$2\lceil P/2\rceil^3$	$2\lceil P/2\rceil^2(\lceil P/2\rceil-1)$	P^3	P^4	$P^3(P-1)$
⋮	⋮			⋮		
h	$2\lceil P/2\rceil^{h-1}$	–	$2\lceil P/2\rceil^{h-1}(\lceil P/2\rceil-1)$	P^h	B–	$P^h(P-1)$
	$1+\frac{2(\lceil P/2\rceil^h-1)}{\lceil P/2\rceil-1}$		$1+\frac{2(\lceil P/2\rceil-1)(\lceil P/2\rceil^h-1)}{(\lceil P/2\rceil-1)}$ $= 1+2(\lceil P/2\rceil^h-1)$	$\frac{P^{h+1}-1}{P-1}$		$P^{h+1}-1$ max keys in B trees

min keys : $\Theta((P/2)^h)$

max Keys : $\Theta(P^h)$

Height of B trees with n ~~nodes~~ key and order p **

$$\Rightarrow 2\lceil P/2\rceil^h - 1 \le \text{keys} \le P^{h+1}-1$$

Range of keys in B tree with order p && height h

$$\Rightarrow 2\lceil P/2\rceil^{h-1}(\lceil P/2\rceil-1) \le \text{keys} \le P^h(P-1)$$

Range of keys in B+ trees

i) min height :- // Max full factor each node or max keys per node

$$n = P^{h+1}-1 \Rightarrow h = \boxed{\log_P(n+1)-1}$$

$\Theta(\log_P n)$

(ii) max height :- // Min Keys per node

$$n = 2\lceil P/2\rceil^h - 1 \Rightarrow \boxed{h = \log_{P/2}\left(\frac{n+1}{2}\right)}$$

$\Theta(\log_{P/2} n)$

$$\Rightarrow \log_P(n+1)-1 \le \text{height} \le \log_{P/2}\left(\frac{n+1}{2}\right)$$

Range of height in B trees with order P

Q- Which is true about B Tree order P and height h

a) Keys $\le 2\lceil P/2\rceil^h - 1$

b) Keys $\ge P^{h+1}-1$

c) height $\ge \log_P(n+1)$

d) height $\ge \log_{P/2}\left(\frac{n+1}{2}\right)$

$\Theta\left(\left(\frac{P}{2}\right)^h\right) \le$ Keys $\le \Theta(P^h)$

$\Theta(\log_P n) \le$ height $\le \Theta(\log_{P/2} n)$

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⇒ Bulk Loading B+ Tree :

[Construction of B+ tree in bottom-Up approach]

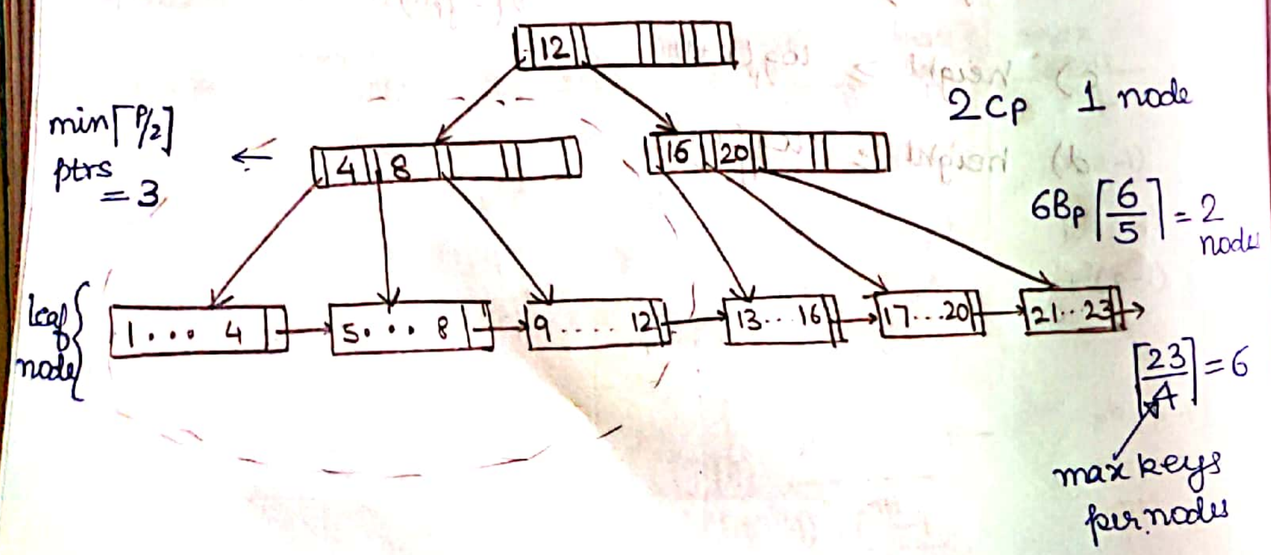
Design B+ tree leaf level to root level.

- Sort the keys which are used for B+ construction in ascending order.
- Design leaf nodes
  - → Distribute keys into leaf nodes
    result : # of leaf nodes.
- Design Internal nodes
  - → if m nodes at level l
    then m child pointers required at level (l-1)
    Distribute m child pointers into nodes
    result : # of nodes at level (l-1)
- Repeat step 3 until root.

Construct bulk loading B+ Tree for keys [1,2,3,.... 23] and order p : 5 [max ~~child~~ pointers per node]

a) with min levels of index or min index/ B+ tree nodes

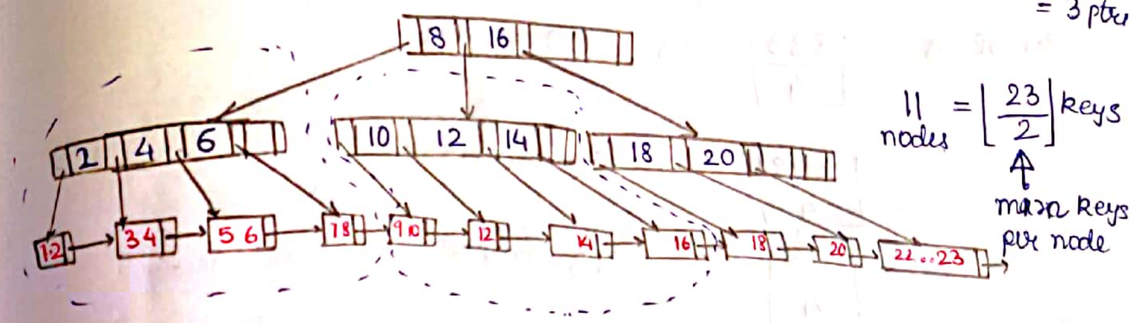
max possible keys/ pointers per node
(4 keys && 5 ptrs per node)



min B+ Trees nodes : 9
min levels : 3

b) with max levels of index or max index/ B+ tree nodes

min possible keys/ pointers per node
[2 keys && 3 ptrs per node] min ⌈p/2⌉ = 3 ptrs



⌊11Cp / 3⌋ = 3 nodes. no one should violate min. condition
we can also take. 3 4 4 ptrs.
4 4 3
4 3 4
5 3 3
⋮

Q- Construct bulk loading B+ tree for keys [1,.... 2500] and order p: 7 (max ptrs)

a) How many min/max levels of B+ tree?

(a) min levels :- max keys and pointer
(6 key, 7 ptr)

leaf nodes = ⌈2500/6⌉ = ~~2558~~ 417 nodes

Cp ⇒ Bp ⇒ ⌈417/7⌉ = ~~82~~ 60 nodes ⇒ 1st internal. min ⌈7/2⌉ ⇒ 4

⌈60/7⌉ ⇒ 9 nodes ⇒ 2nd.

⌈9/7⌉ ⇒ 2 nodes ⇒ 3rd.

⌈2/7⌉ ⇒ 1 node ⇒ 4th

417
72
489

min ~~total~~ level ⇒ 5

(b) max level :- min keys / ~~nodes~~ ptrs

(3 keys && 4 ptr)

min $\left\lceil \frac{7}{2} \right\rceil = 4$

leaf ⇒ $\left\lfloor \frac{2500}{3} \right\rfloor$ = 833 nodes

internal ⇒ $\left\lfloor \frac{833}{4} \right\rfloor$ ⇒ 208 nodes

$\left\lfloor \frac{208}{4} \right\rfloor$ = 52 nodes

$\left\lfloor \frac{52}{4} \right\rfloor$ = 13 nodes

$\left\lfloor \frac{13}{4} \right\rfloor$ = 3 nodes

3

1109

5+1 ↳ root

max level ⇒ 5

NOTE:
Bulk loading B+ Tree method can be used to find min / max levels of B+ Tree for given n-keys.

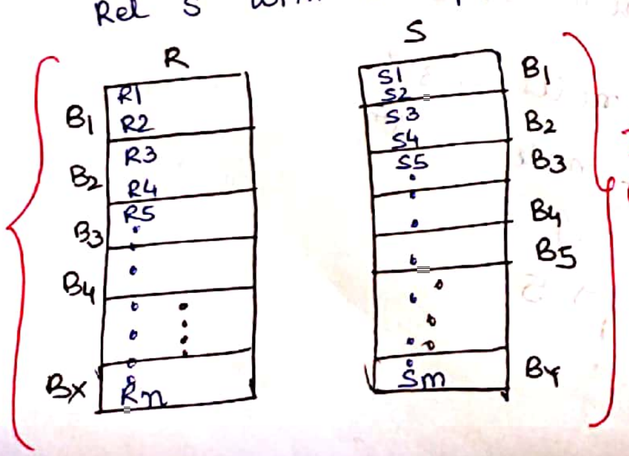
It is only applicable for B+ Tree.

JOIN ALGORITHMS

1. Nested loop Join Algo
2. Block Nested loop Join Algo.

Rel R with n tuples occupies in X blocks

Rel S with m tuples occupies in Y blocks



Nested loop Join Algo :-

Uses record no's for loop variable

R ⋈ S :
```
for (i=1; i≤n; i++)
{
    for (j=1; j≤m; j++)
    {
        Join { ith record of R,
               jth record of S }
    }
}
```

Record no. of outer rel

Record no. of inner rel

Disadv:
if main memory space allocated for join is limited then, more access cost required to perform join using nested loop join algo.

Block Nested loop Join Algo

R ⋈ S :
```
for (i=1; i≤X; i++)
{ for (j=1; j≤Y; j++)
  {
      Join { every record of
             ith block of R,
             jth block of S }
  }
}
```

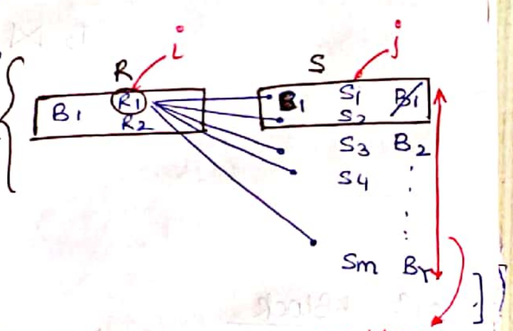
Block no. of outer Rel

Block no. of inner Rel

⇒ Assume only two blocks of main memory allocated to join R & S

At any time one block of R record and 1 block of S record can store in main memory.

a) R ⋈ S access cost using Nested loop join : only 2 block of MM



Y block access cost from S to join one record of R relation

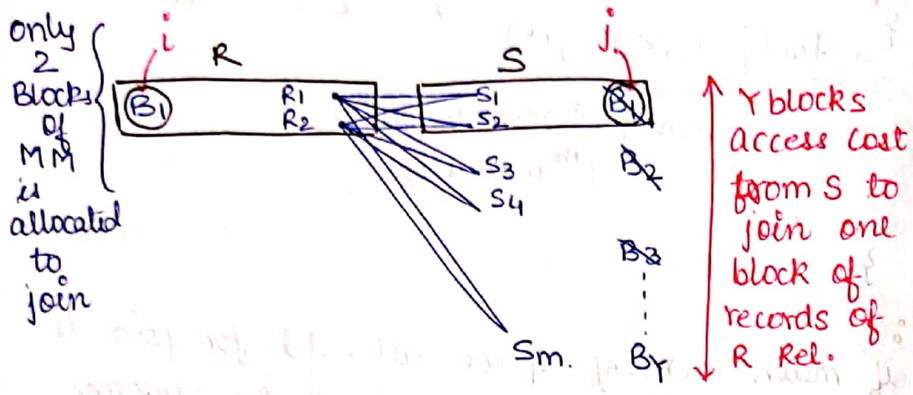
Total access time :

$(X + m * Y)$ blocks

if S is outer loop:

$(Y + m * X)$ blocks

b) R ⋈ S access cost using Block Nested loop Join Algo :



$(X + X * Y)$ blocks

Adv of Block Nested Algo over Nested loop Join:
less access cost if main memory space alloted is limited

Pg 69
Q18

T_1 : 2000 records
80 blocks

T_2 : 400 records
20 blocks

* Nest loop

$T_1 \bowtie T_2 \Rightarrow (X + n * Y)$
$= 80 + 2000 \times 20$
$\Rightarrow 40080$

$T_2 \bowtie T_1 \Rightarrow (Y + m * X)$
$= 20 + 400 \times 80$
32020 (c)

Q19 *Block

$T_1 \bowtie T_2 \Rightarrow (X + X * y)$
$= 80 + 80 \times 20$
$= 1680$

$T_1 \bowtie T_2 \Rightarrow (Y + y * X)$
$= 20 + 20 \times 80$
$= 1620$

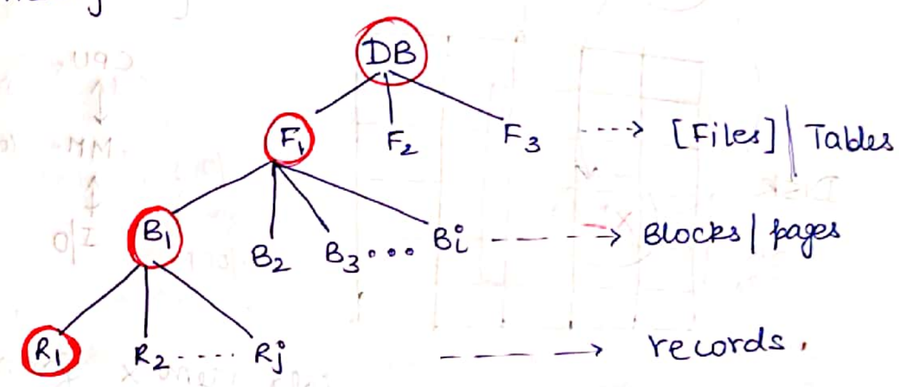
reduced ⇒ 32020
1620
30400 (b)

Q20 (a)

TRANSACTION AND CONCURRENCY CONTROL

Transaction:
set of logically related operations to perform unit of work

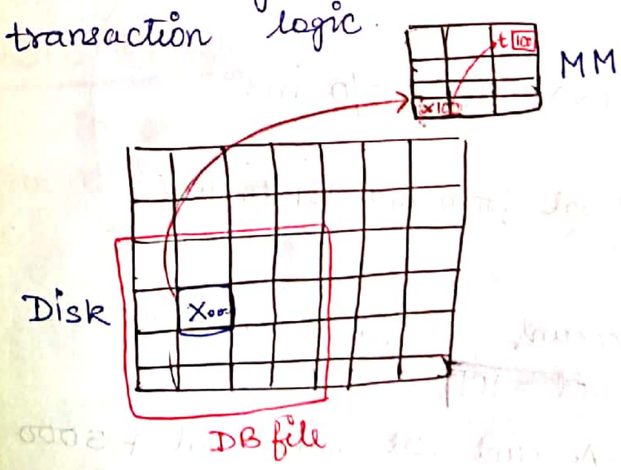
data item (shared Resource):
Data Base element which may require to access by many transaction.



Data item : Record
Block
file
DB

Main operations in Transaction:

Read(X) :- [X is data item]
X is value of X from database file (disk) to main memory in order to use value of X in transaction logic.



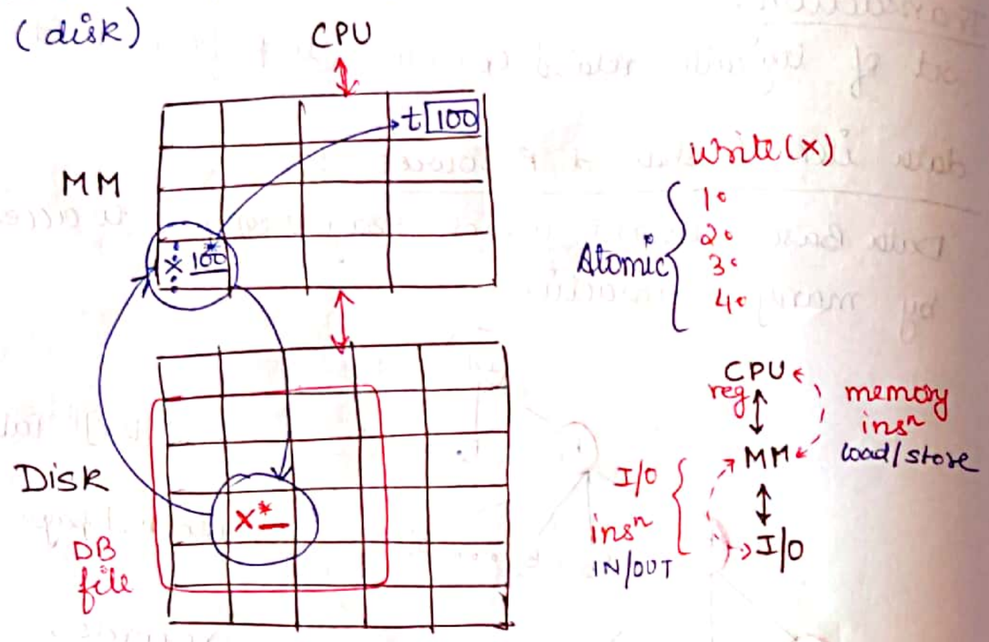
Read(X)
Atomic { 1. 2. 3.
⇓
no interruption
no context switch
without pre-emption

→ Find block which contain data item x from DB file

→ Transfer block to MM

→ Find address of data item x in MM block and copy value of x in programmed variable

Write (x): updation of data item x in DB file (disk)



→ find block which contain data item x from DB file

→ transfer block from disk to mm.

→ find address of data item x and update value of x in main memory block.

→ replace modified block of MM into DB file (disk)

• Read (x) and write (x) are I/O insn

Trans (T1): Transfer 5000 bal from Aid 101 to 102

```
begin trans T1
    Update Account set bal = bal - 5000
    where aid = 101;
    Update Account set bal = bal + 5000
    where aid = 102;
    Commit ; || Transaction executed successfully.
end Trans T1;
```

previous record value was required.

⇓ SQL Parser

```
begin Trans T1
    Read (bal of aid 101)
    bal = bal - 5000;
    Write (bal of aid 101)
    Read (bal of aid 102)
    bal = bal + 5000;
    write (bal of aid 102)
    Commit
end trans T1
```

Set of R/W operation : Transaction

Trans (T2): Set bal of 101, 102 aid's as 5000

```
begin Trans T2
    Update Account set bal = 5000
    where aid = 101;
    Update Account set bal = 5000
    where aid = 102;
    Commit;
End Trans T2;
```

previous record value is not required

⇓ SQL parser

```
begin Trans T2
    Write (bal = 5000 where aid = 101)
    Write (bal = 5000 where aid = 102)
    Commit
end Trans T2
```

Blind Write

Trans (T3)

```
R(A)
R(B)
W(A)
W(C)
W(D)
Commit
```

] Blind write

ACID Properties

To preserve integrity (correctness) transactions must satisfy acid property.

A : Atomicity } maintained by Recovery management component of DBMS s/w (Theory basic)

D : Durability

I : Isolation } maintained by Concurrency Control component *** of DBMS s/w

C : Consistency } maintained by USER DB Administrator / DB developer / end User

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Atomicity : all (commit) or none (Rollback)

execute all operations of transaction including commit or execute none of the operations of transaction before termination of transaction.

eg: Trans T_1 : Transfer 500 from A to B

begin Trans T_1
- R(A)
- A = A − 500
- W(A)
- R(B)
- B = B + 500
- W(B)
- Commit

end Trans T_1

Rollback

failed

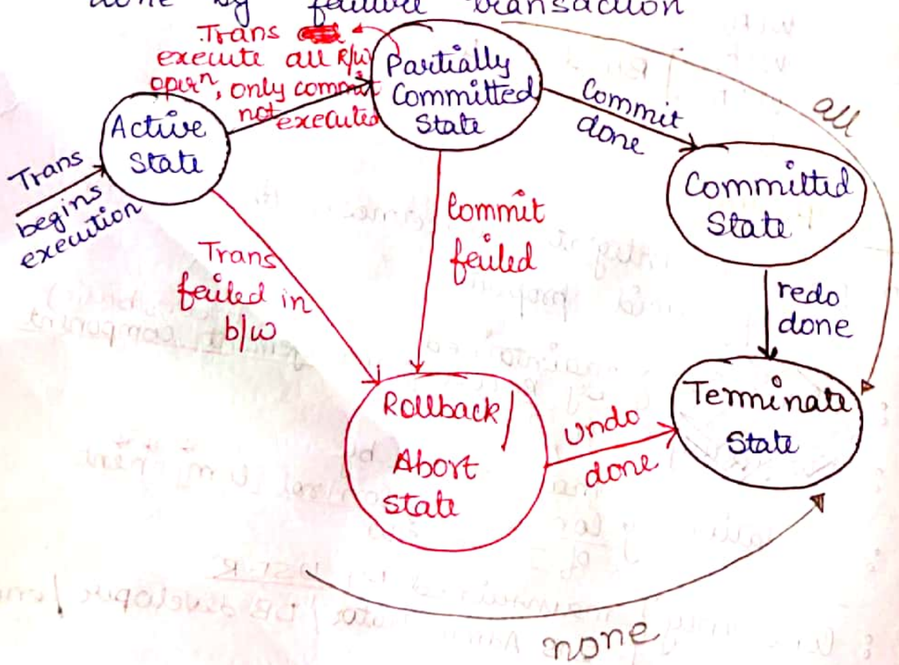
A: ~~2000~~ ~~1500~~ 2000	B_1
B: 3000	B_2
C: —	B_3

(DB Table)
DB file Correct
[Data ~~incorrect~~ becoz of atomicity voilation]

Recovery Management Component (RMC) :

(Abort) Rolls backs transaction which is failed anywhere before commit.

Rollback (Abort) :
Undo all operations of DB file which are done by failure transaction



Transaction Log :

File maintained by RMC in disk to record all activities of each transaction

eg:
1. T_1 begins
2. T_1 R, A, 2000
3. T_1 W, A, 2000, 1500
4. T_1 R, B, 3000
5. T_1 W, B, 3000, 3500
6. failed

Dirty Block

A: ~~2000~~ 1500	1	B_1
	0	
B: ~~3000~~ 3500	1	B_2
	0	
C: —	0	B_3

begin T_1
- R(A)
- A = A − 500
- W(A)
- R(B)
- B = B + 500
- W(B)
- commit

end T_1

UNDO Operations of Trans

All updations of DB file because of Transaction failure (Rollback)
- Reset all W( ) to previous value
- Reset all dirty bit to 0
- Clear log entries

REDO Operations

All updations required in DB file because of Transaction commit and clean log entries of Transaction
- Set dirty bits to 0
- Clear log entries
- Deallocate resources allocated to Trans

T_1 Commit → T_1 redo
T_2 Commit → T_2 redo
T_3 Commit → T_3 redo
T_4 Commit → T_4 undo

Overhead

if transaction → rarely then no problem., redo and undo can occur immediately but if transaction → frequently then, we cannot perform immediate redo & undo oprn and thus redo & undo becomes overhead. So ~~to~~ we go for consistency check point to remove this overhead.

Consistency Check Point :

if consistency check point issues then:
- all committed transaction until previous check point performs redo
- all Trans of Rollback state until previous check point performs undo

9:00 AM start
- T_1 begin
- T_2 begin
- T_3 begin
- T_2 Rollback
- T_4 begin
- T_4 Commit
- T_3 commit

9:05 AM Check Point ⇒ T_3 T_4 redo } simultaneously
T_2 undo
- T_5 begin
- T_6 begin
- T_7 begin
- T_6 commit
- T_5 Commit

9:10 AM Check Point ⇒ T_5 T_6 redo
- T_8 begin
- T_8 commit

9:13 AM system Crash ⇒ T_8 redo } Crash recovery
T_1 T_7 undo

System Crash Recovery

- All Committed transaction until previous checkpoint performs redo
- All uncommitted transaction in ~~whole~~ entire system, change state to rollback and performs undo

Q- Consider given log

1. T_1 begins
2. T_1 W, A, 0, 10
3. T_2 begins
4. T_3 begin
5. T_2 W, B, 5, 10
6. T_2 Commit
7. T_3 W B, 10, 50
8. Check Point ⇒ T_2 redo
9. T_4 begin
10. T_4 W, A, 10, 20
11. T_4 Commit
12. T_5 begin
13. T_5 W, C, 10, 50
14. T_3 Commit
15. System Crash ⇒ T_3, T_4 redo

What is Crash recovery?

a) T_2 T_3 T_4 redo, T_1 T_5 undo
b) T_3 T_4 redo, T_1 T_5 undo
c) T_2 redo, T_1 T_2 T_3 T_4 undo
d) T_2 T_3 redo, T_1 T_4 T_5 undo

Durability:

Transaction should able to recover under any case of failure and if failure occur during redo and undo, also should be able to recover.

Trans failure

recovery must then only durability satisfied

1. Power failure
2. S/W Crash
   - ↳ OS overloaded
   - ↳ DBMS overloaded
3. Concurrency Control protocol may kill transaction
4. Disk Crash (H/W Crash)

log file && Trans state are stored in DISK

RAID Architecture

DISK Design

RAID: Redundant Array of Independent Disks

Consistency: [USER]

Logic of DB operations requested to perform transactions must be logically correct.

Trans: Transfer 500 from A to B

(A+B) before execution of T_1

equal

(A+B) after execution of T_1

T_1: Consistent

Isolation :

Concurrent execution of two or more transaction result must be equal to result of any serial execution of transactions.

Schedule

Time order execution sequence of two or more transactions

ex:

S:

	T_1	T_2	T_3
1.	$r_1(A)$		
2.			$w_3(A)$
3.		$r_2(B)$	
4.	$w_1(A)$		
5.			$w_3(B)$
6.		$r_2(C)$	

↳ **Serial Schedule :**

- Trans must execute one after other

ex: T_1 : Transfer 500 from A to B

T_2 : Increment 2% to A & B

	T_1	T_2
S1	$r_1(A)$	
	$A = A - 500$	
	$w_1(A)$	
	$r_1(B)$	
	$B = B + 500$	
	$w_1(B)$	
	Commit	
S2		$r_2(A)$
		$w_2(A)$
		$r_2(B)$
		$w_2(B)$
		Commit
S3	$r_1(A)$	
	$w_1(A)$	
	$r_1(B)$	
	$w_1(B)$	
	Commit	
S4		$r_2(A)$
		$A = A + A * 0.2$
		$w_2(A)$
		$r_2(B)$
		$B = B + B * 0.2$
		$w_2(B)$
		Commit

T_2 reads A after T_1 writes ↳ $T_1 : T_2$

T_2 reads B after T_1 writes ↳ $T_1 : T_2$

T_1 reads A after T_2 writes ↳ $T_2 : T_1$

- $T_1 \rightarrow T_2$ Serial Schedule
- $T_2 \rightarrow T_1$ Serial Schedule

Adv:
- No chance of incorrect result
- every serial schedule result always preserve integrity (correctness)

Dis:
- Degree of concurrency is very less

↳ **Concurrent Schedule :**

- simultaneous / Concurrent / Interleaved execution of two or more transactions

ex:

	T_1	T_2
	$r_1(A)$	
	$w_1(A)$	
		$r_2(A)$
		$w_2(A)$
		$r_2(B)$
		$w_2(B)$
		C2
	$r_1(B)$	
	$w_1(B)$	
	C1	

T_1 reads A before T_2 writes ↳ $T_2 : T_1$

T_2 reads B before T_1 writes ↳ $T_1 : T_2$

S3

A: ~~2000~~ ~~1500~~ $\boxed{1800}$

B: ~~3000~~ ~~3500~~ $\boxed{4100}$

Not equal

$T_1 : T_2$ serial

$T_2 : T_1$ serial

↓ both satisfied then incorrect

(Non serializable) Incorrect result

S4

	T_1	T_2
	$r_1(A)$	
	$w_1(A)$	
		$r_2(A)$
		$w_2(A)$
	$r_1(B)$	
	$w_1(B)$	
	C1	
		$r_2(B)$
		$w_2(B)$
		C2

A: ~~2000~~ ~~1500~~ $\boxed{1800}$

A: ~~3000~~ ~~3500~~ $\boxed{4200}$

Correct result

equal to : $T_1 : T_2$ serial → satisfied ∴ correct

Degree of concurrency : no of users can use DB simultaneously.

- Throughput less
- resource utilisation not good
- Response time high

A: 2000 B: 3000

T_1	T_2	T_2	T_1
A = ~~1500~~	$\boxed{1800}$	A = ~~2400~~	$\boxed{1900}$
B = ~~3500~~	$\boxed{4200}$	B = ~~3600~~	$\boxed{4100}$
final		final	

Serial : Serializable

Adv :
- Throughput more
- resource utilisation is good
- Response time

Concurrency controller should not allow concurrent execution.

if concurrent execn result is incorrect.

It should allow those execn whose result is correct.

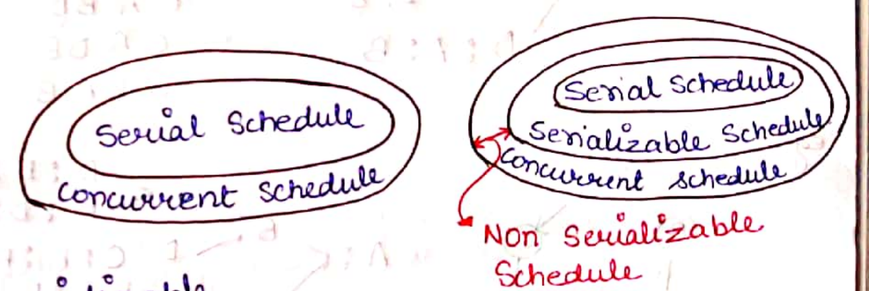
→ if concurrent execn result is equal to any one of serial result, then result of concurrent execn is correct else it is incorrect.

⇒ Serializable if correct

Isolation also called serializable Schedule

Serializable Schedule :

Schedule S is serializable if and only if S must be equal to some serial schedule.



S1, S2, S4 → serializable

***Testing of Serializability :

↳ Conflict Serializable Schedule **

1. Topological order *
2. Conflict pair
3. Precedence Graph
4. Conflict Equal Schedule *

Topological Order :-

[Graph Traversal algo, only for Directed Acyclic Graph]

Graph G

1. visit vertex (V) whose in-degree "0" and delete "V" from Graph
2. Repeat ① for all vertices of Graph.

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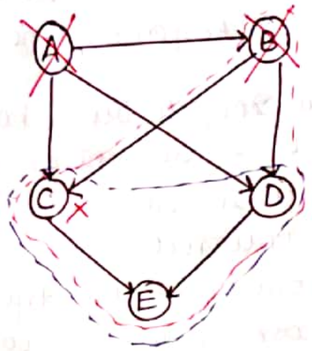
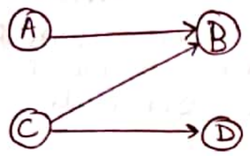
eg:



A : B < C : D : E
D : C : E

A B C D E
A B D C E } Two topological orders.

eg:



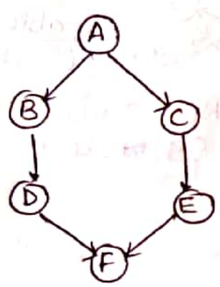
find #f topological orders.

A : C < B : D
D : B
C : A < A < B : D
D : B
D : A : B

A C B D
A C D B
C A B D
C A D B
C D A B

5

eg:



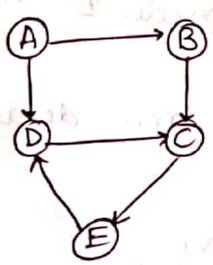
A : B < C < D : E : F
E : D : F
D : C : E : F
C < B < D : E : F
E : D : F
E : B : D : F

6

Q- #f topological orders for null Graph of n vertices
$= n!$

{ A B C D } $\Rightarrow 4!$ tological order.

Q-



For cyclic Graph,
#f Tological orders $= 0$

Conflict Pair :-
pair of operations from schedule (S) is conflict pair
iff, 1. Atleast one write
and 2. Over same data item
and 3. from different trans

eg: S : ..... $r_i(A)$ .... $w_j(A)$
S : ..... $w_i(A)$ ..... $r_j(A)$
S : ..... $w_i(A)$ .... $w_j(A)$

$T_i \rightarrow T_j$

Common: transaction must be different

Non-conflict Pair

eg: S : .... $r_i(A)$ ... $r_j(A)$
S : .... $r_i(A)/w_i(A)$ ..... $r_j(B)/w_j(B)$

S:

T_1	T_2
$r_1(A)$	
$r_1(B)$	
	$w_2(B)$
	$r_2(C)$
	$w_2(C)$

operation of same transaction neither conflict pair nor non-conflict pair

S:

T_1	T_2
$r_1(A)$	
	$w_2(B)$

$\Longleftrightarrow$ equal

T_1	T_2
	$w_2(B)$
$r_1(A)$	

S:

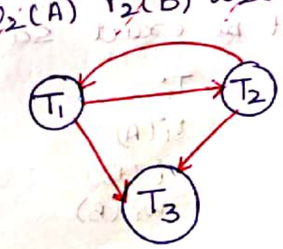
T_1	T_2
$r_1(A)$	
	$w_2(A)$

$\Longleftrightarrow$ not equal

T_1	T_2
	$w_2(A)$
$r_1(A)$	

Precedence Graph :-
Graph G (V, E)
Vertices (V) : Transactions of schedule
Edges (E) : Conflict Pair precedence

eg: S: $r_1(A)$ $w_2(A)$ $r_2(B)$ $w_2(B)$ $w_3(B)$ $w_1(A)$ $w_3(A)$



Precedence Graph of Schedule (S)

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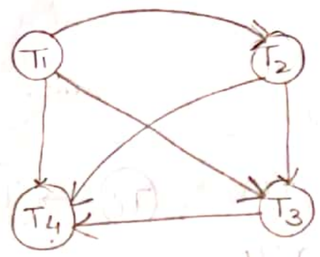
Q S: $r_1(A)$ $r_2(A)$ $r_3(A)$ $r_4(A)$ $w_1(B)$ $w_2(B)$ $w_3(B)$ $w_4(B)$



Conflict Equal Schedule :-

S1 S2 schedule Conflict Equal iff

- S_2 should derive by interchanging of consecutive non conflict pairs of S_1

S1 $\xleftrightarrow{\text{interchange}}$ S2

consecutive non conflict pairs

Q- Test S_1 S_2 conflict equal or not.

S_1: $r_1(A)$, $r_2(A)$, $r_3(A)$, $w_1(B)$, $w_2(B)$, $w_3(B)$

$r_1(A) \to w_1(B)$ (2, 3)

Cond ① ✓

Cond ② ✓

S_2: $r_2(A)$, $r_1(A)$, $w_1(B)$, $r_3(A)$, $w_2(B)$, $r_3(A)$, $w_3(B)$

$r_1(A) \to w_1(B)$ (2, 3)

$w_1(B)$, $w_1(B)$, $r_3(A) \Rightarrow w_2(B)$, $w_2(B)$, $r_3(A)$

$T_1 \to T_2$, $T_1 \to T_3$, $T_3 \to T_2$

Total 3 interchanges

They are equal

$T_1 \to T_2$, $T_1 \to T_3$, $T_3 \to T_2$

T_1	T_2
$r_1(A)$	
$w_1(B)$	
	$w_2(C)$

⇒ they are non-conflict pair but not consecutive ∴ we donot interchange as execn changes

T_1	T_2
$r_1(A)$	
$w_1(B)$	
	$w_2(B)$

⇒ result changes if conflict pair get interchanged.

S1 S2 Conflict equal iff

① each trans T_i of S_1 must be exact same trans in S_2

S_1: ---- T_i ---- $r_i(A)$ $r_i(B)$ $w_i(B)$

S_2: ------ T_i ------ $r_i(A)$ $r_i(B)$ $w_i(B)$

and ② every conflict pair precedence of S_1 must be same precedence in S_2

Q- S_1: $r_1(A)$ $w_1(B)$ $r_2(A)$ $r_2(B)$ $r_1(B)$ $w_1(B)$ $T_1 \to T_2$

S_2: $r_1(A)$ $w_1(A)$ $r_1(B)$ $w_1(B)$ $r_2(A)$ $r_2(B)$ $T_1 \to T_2$

Not equal.

if S_1, S_2 conflict equal, then precedence graph of S_1 S_2 is same

if S_1 S_2 with not same precedence graph then S_1 S_2 are also not conflict equal

if S_1 S_2 with same precedence graph then S_1 S_2 may/may not conflict equal.

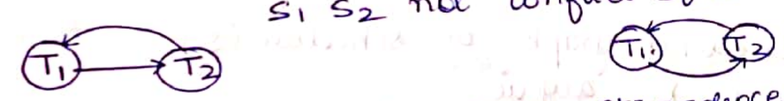
Q- S_1:

T_1	T_2
$r_1(A)$	
	$w_2(A)$
$w_1(A)$	
	$r_2(A)$

S_2:

T_1	T_2
$r_1(A)$	
	$w_2(A)$
	$r_2(A)$
$w_1(A)$	

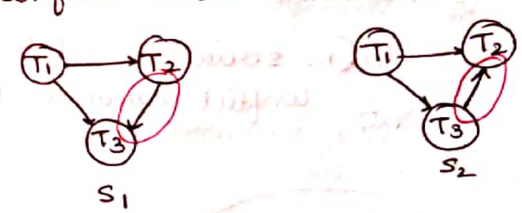
S_1 S_2 not conflict equal



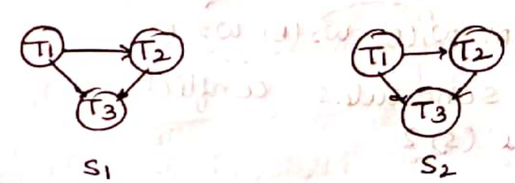
if S_1 S_2 schedules 1. with same precedence graph and 2. Acyclic Precedence graph.

then, S_1 S_2 are conflict equal.

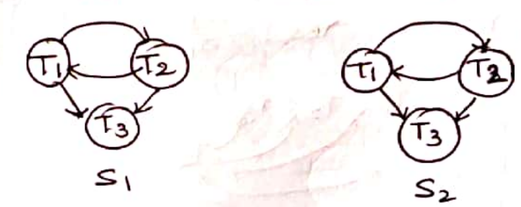
Conflict equal Testing using Precedence Graph:

1. 

S_1 S_2 not conflict equal

2. 

S_1 S_2 Conflict equal.

3. 

S_1, S_2 may/may not conflict equal

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Conflict Serializability

Given schedule S is conflict serializable schedule iff,

Some serial schedule S' must be conflict equal to some given schedule S.

{Given Schedule (S)} $\xleftrightarrow[\text{equal}]{\text{conflict}}$ {S': Serial Schedule}

conflict serializable schedule

{Precedence Graph of S also must be acyclic} $\xleftrightarrow[\text{equal}]{\text{conflict}}$ {S': Precedence Graph of Serial Schedule is Acyclic}

Testing Cond^n for Serializability

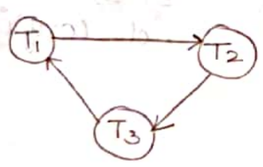
Schedule S is conflict serializable schedule iff, precedence graph of schedule (S) must be acyclic

and, conflict equal serial schedule of S are topological orders of precedence graph

eg:

S: $r_1(A)$ $w_2(A)$ $w_2(B)$ $r_3(B)$ $r_3(C)$ $w_1(C)$

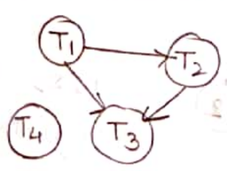
Test S' conflict serializable



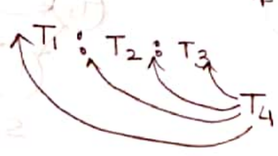
no (no serial schedule conflict equal to S)

eg: S: $r_1(A)$ $r_2(A)$ $r_3(A)$ $r_4(A)$ $w_1(B)$ $w_2(B)$ $w_3(B)$

How many serial schedules conflict equal to Schedule (S)?



Yes



T_1 T_2 T_3 T_4
T_1 T_2 T_4 T_3
T_4 T_1 T_2 T_3
T_4 T_4 T_2 T_3

4 } Serial Schedule are conflict equal to Sche (S)

4 transaction means 4! serial schedule (24) out of which only 4 are conflict equal.

↳ View Serializable schedule

Schedule S is view serializable schedule iff, some serial schedule S' must be view equal to given schedule S

{Given Schedule (S)} $\xleftrightarrow[\text{equal}]{\text{View}}$ {S': Serial Schedule}

View Serializable Schedule.

⇒ View equal schedule

S_1 S_2 Schedules view equal

iff

(i) Initial Read

S_1: ---- t_i ---- $R(X)$ (initial DB)

S_2: ---- T_i $R(X)$ (initial DB)

if T_i reads(X) from initial DB in S_1, then in S_2 also T_i should read(X) from initial DB

(ii) Updated Read

S_1: --- T_i -- T_j ---- $W(X)$ $R(X)$

S_2: ------ T_i T_j $W(X)$ $R(X)$

eg: S_1

T_1	T_2	T_3
	$W_2(A)$	
$R(A)$		
		$W(A)$

(not view equal)

S_2

T_1	T_2	T_3
	$W(A)$	
		$W(A)$
$R(A)$		

if T_i reads(X) which is updated ~~up~~ by T_j in S_1 then in S_2 also T_i must read X update by T_j only

(iii) Final write

S_1: ------ T_i ---- final write $W(X)$

S_2: ---- T_i $W(X)$ ← final write

eg: S_1

T_1	T_2	T_3
	$W(A)$	
$R(A)$		
		$W(A)$
$W(B)$		
	$W(B)$	
		$W(B)$

← View equal

S_2

T_1	T_2	T_3
	$W(A)$	
		$W(A)$
$R(A)$		
	$W(B)$	
$W(B)$		
		$W(B)$

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if T_i performs final write of data item X in S_1 then in S_2 also final write of X must be by T_i

Q- S1 S2 S3 Test View Equal

S_1:

T_1	T_2	T_3
	W(A)	
R(A)		W(A)
W(B)	W(B)	W(B)

S_2:

T_1	T_2	T_3
	W(A)	
R(A)		W(A)
W(B)		
		W(B)

S1 S2 not equal.

Q- S1:

T_1	T_2	T_3
W(A)		
	W(A)	
		W(A)

S2:

T_1	T_2	T_3
	W(A)	
W(A)		
		W(A)

conflict equal ✗
View equal ✓

Q- S_1: $\overset{IR}{r_2(A)}$ $\overset{IR}{r_2(B)}$ $\overset{IR}{r_3(C)}$ $\overset{IR}{r_1(C)}$ $w_2(A)$ $w_1(A)$ $r_3(A)$ $w_1(B)$ $w_2(B)$ $w_3(B)$

S_2: $\overset{IR}{r_1(C)}$ $\overset{IR}{r_2(A)}$ $\overset{IR}{r_3(C)}$ $\overset{IR}{r_2(B)}$ $w_2(A)$ $w_1(A)$ $r_3(A)$ $w_2(B)$ $w_1(B)$ $w_3(B)$

a) Test S1 S2 view equal?

Yes they are view equal but not conflict equal.

S1 S2 conflict equal
every R-W, W-R → if failed then view equal also failed
W-W
conflict pairs of S1 S2 must be same precedence.

⇓

S1 S2 view equal
every Initial Read
Updated Read
final write of S_1 S_2 must be same.

Testing of View Serializability :-

Final Write :-

Given Sched(S)	View equal Serial (S')
X: T_i T_j (final write)	$T_i \rightarrow T_j$
Y: T_i T_j T_k (final write)	$T_i \rightarrow T_j \rightarrow T_k$, $T_j \rightarrow T_i \rightarrow T_k$] → $(T_i; T_j) \rightarrow T_k$
Z: T_i (final write)	every serial view equal (Any sequence)

Initial Read :-

Given schedule(S)			View equal Serial (S')
data item	Initial Read	write	
X	T_i	T_j	$T_i \rightarrow T_j$
Y	T_i T_j	T_j T_k	$T_i \rightarrow T_j$ T_k, $T_j \rightarrow T_k$
Z	T_i	No other trans write(Z)	every serial order view equal

Updated Read :-

Given schedule(S)	View equal Serial (S')
a) $W_i(X) \rightarrow R_j(X)$ and T_k some other trans also writes (X)	$T_i \xrightarrow{T_k \times} T_j$ [T_i must before T_j && T_k should not be in b/w T_i && T_j]
b) $W_i(Y) \rightarrow R_j(Y)$ and no other trans writes (Y)	$T_i \rightarrow T_j$

Q- S: $r_1(A)$ $w_3(A)$ $w_1(A)$ $w_2(A)$
test S is VSS?

Given schedule (S)

FW: A: T_3 T_1 T_2

IR:

Data	IRead	Write
A	T_1	T_3 T_1 T_2

View equal Serial (S')

$(T_3\ T_1) \rightarrow T_2$

$T_1 \rightarrow (T_3\ T_2)$

S': [T_1 : T_3 : T_2] Serial Schedule view equal to Sched (S)
S is View serializable

Q- S: $r_2(A)$ $r_2(B)$ $w_2(A)$ $w_2(C)$ $w_1(A)$ $r_1(C)$ $r_3(A)$ $w_1(B)$ $w_2(B)$ $w_3(B)$

Given schedule

IR:

Data	IR	Write
A	T_2,	T_2 T_1
B	T_2	T_1 T_2 T_3
C		

FW
A: T_2 T_1
B: T_1 T_2 T_3
C: T_2

Update (no other trans write C)
C: $T_2(W)$ $T_1(R)$
A: $T_1(W)$ $T_3(R)$
(other trans write A)

View equal serial s'

$T_2 \rightarrow (T_1)$
$T_2 \rightarrow (T_1, T_3)$

$T_2 \rightarrow T_1$
$(T_1, T_2) \rightarrow T_3$
any seq.

$T_2 \rightarrow T_1$
$T_1 \xrightarrow{T_2^x} T_3$

A: $T_2 \rightarrow T_1 \rightarrow T_3$
B: $T_2 \rightarrow T_1 \rightarrow T_3$
C: $T_2 \rightarrow T_1$.

S': $[T_2 \rightarrow T_1 \rightarrow T_3]$
Serial View equal to serial S
S is VSS

Q- S: $r_1(A)$ $r_2(A)$ $r_3(A)$ $r_4(A)$ $w_1(B)$ $w_2(B)$ $w_3(B)$ $w_4(B)$ $w_2(C)$ $r_4(C)$ $w_3(D)$. How many serial schedule VSS.

Given schedule

IR:

Data	IR	Write
A	T_1, T_2, T_3, T_4	-
B		
B		

FW:
A: -
B: T_1 T_2 T_3 T_4
C: T_2
D: T_3

Update: C: $T_2(W)$ $T_4(R)$

View equal serial s'

every serial order view equal.

$(T_1\ T_2\ T_3) \rightarrow T_4 \rightarrow 3!$
any order
any order. $= 6$

$T_2 \rightarrow T_4$.

Pg 6+

(T1) S_3: $r_1(A)$ $r_3(D)$ $w_1(B)$ $r_2(B)$ $w_3(B)$ $r_4(B)$ $w_2(C)$ $r_5(C)$ $w_4(E)$ $r_5(E)$ $w_5(B)$

Given schedule

IR:

DI	IR	W
A	T_1	-
B	~~T_3~~	~~T_1 T_2 T_5~~
~~C~~	~~T_5~~	~~T_2~~
D	T_3	-
~~E~~	~~T_5~~	~~T_4~~

FW:
A: -
B: T_1 T_3 T_5
C: T_2
D: -
E: T_4

Update:
B: $T_1(W)$ T_2, $T_3(W)$ T_4
C: T_2 T_5
E: T_4 T_5

View equal s'

-
~~$(T_2\ T_4) \rightarrow (T_1\ T_3\ T_5)$~~
~~$T_5 \rightarrow T_2$~~
-
~~$T_3 \rightarrow T_4$~~

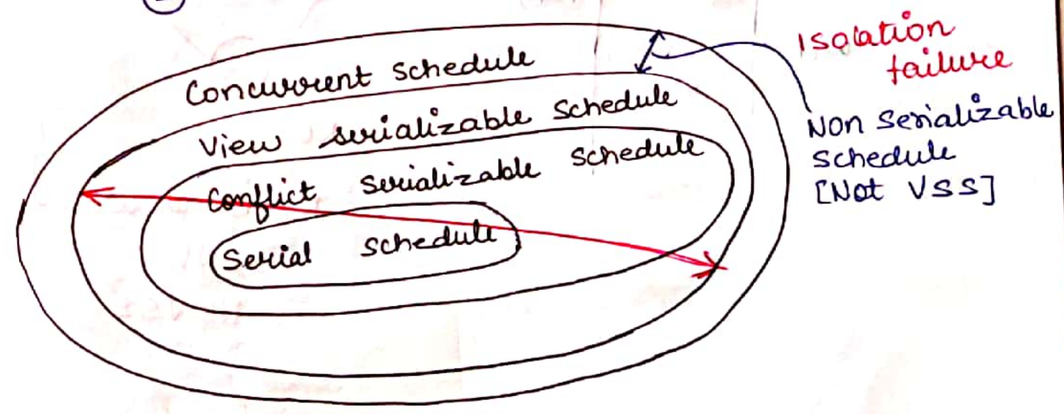
-
$(T_1\ T_3) \rightarrow T_5$
$T_1\ T_2\ T_3\ T_4\ T_5$
-
-
$T_1 \rightarrow T_2$
$T_3\ T_5$
$T_1 \rightarrow T_2$
$T_1 \times T_5$
$T_3 \rightarrow T_4$
$T_2 \rightarrow T_5$
$T_4 \rightarrow T_5$

$T_1 : T_2 : T_3 : T_4 : T_5$
$T_3 : T_1 : T_4 : T_2 : T_5$
$T_3 : T_1 : T_2 : T_4 : T_5$

$T_1 : T_3 : T_2 : T_5$ → 2
$T_3 : T_1 : T_2 : T_5$ → 3
$T_1 : T_2 : T_3 : T_5$ → 1

1 $T_1 : T_2 : T_3 : T_4 : T_5$
2 $T_3 : T_4 : T_1 : T_2 : T_5$

⇒



Classification based on serializibility

Conflict serializable testing cond^n is only sufficient but not necessary cond^n for serializability cond^n.

CSS Testing
Precedence Graph of S is Acyclic
P Problem
$O(n^2)$
$\longrightarrow$ S is Serializable Schedule

View serializable Testing cond^n is both sufficient and necessary condition for serializability testing

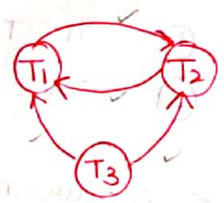
S satisfy View serializable cond^n
NPC Problem
$O(2^n)$
$\longleftrightarrow$ S is Serializable Schedule

$\Rightarrow$ if schedule (S) not Conflict Serializable schedule (CSS) and no blind write then,
{Schedule (S) not View serializable.}

eg:

T_1	T_2	T_3
R(A)		
	R(A)	
		R(A)
W(A)		
	W(A)	

$r_1(A)\ r_2(A)\ r_3(A)\ w_1(A)\ w_3(A)$



{Not CSS + No Blind write}
$\Downarrow$
NO VSS

Q] $T_1 : r_1(A)\ r_1(B)\ w_1(B)$
$T_2 : r_2(A)\ r_2(B)\ w_2(B)$
How many concurrent scheduled possible b/w T_1 T_2

①

T_1	T_2
r(A)	
	r(A)
r(B)	
w(B)	
	r(B)
	w(B)

②

T_1	T_2
r(A)	
r(B)	
w(B)	
	r(A)
	r(B)
	w(B)

③

T_1	T_2
r(A)	
r(B)	
	r(A)
	r(B)
w(B)	
	w(B)

④

T_1	T_2
r(A)	
	r(A)
	r(B)
	w(B)
r(B)	
w(B)	

S:

T_1	T_2
1. r(A)	
2.	O
3. r(B)	
4.	O
5. w(A)	
6.	O

$\Downarrow$ $\Downarrow$

$\ast\ {}^6C_3 \ast {}^3C_3 \Rightarrow \frac{6\times5\times4}{6} = 20$

$\frac{6!}{3!\,3!} = 20$ concurrent schedule.

Q] T_1 T_2 transactions with n, m operations each
How many concurrent schedule possible b/w T_1 T_2

${}^{n+m}C_n \quad {}^mC_m \Rightarrow {}^{n+m}C_n = \frac{(n+m)!}{n!\,m!}$

Q7. $\frac{6!}{3!\,3!} = 20 \Rightarrow$ ~~CSS~~ $\Rightarrow$ ~~TB~~ ~~contain~~ ~~non-serializable~~

Concurrent execution serializable

④ equal to $T_1 T_2$ serial

S':

T_1	T_2
r(A)	
r(B)	
w(B)	
	r(A)
	r(B)
	w(B)

Conflict equal

$S: r_1(A)\ r_1(B)\ w_1(B) : r_2(B)\ w_2(B)$

$r_2(A)$

equal $T_2 T_1$ serial

S':

T_1	T_2
	r(A)
	r(B)
	w(B)
r(A)	
r(B)	
w(B)	

conflict equal

④ Serializable equal to T_2 T_1 serial

$S: r_2(A)\ r_2(B)\ w_2(B) : r_1(B)\ w_1(B)$

$r_1(A)$

20 Concurrent

8 Serializable — 12 non serializable

2 serial — 6 non serial schedule which are serializable

Ans = 6

26.

T_1: $r_1(A)$ $w_1(A)$ $r_1(B)$ $w_1(B)$

T_2: $w_2(B)$ $w_2(A)$

$\Rightarrow \frac{6!}{4!\,2!} \Rightarrow \frac{\cancel{6}^{3} \times 5}{\cancel{2}} = 15$ concurrent

Serializable:

T_1	T_2
r(A)	
w(A)	
r(B)	
w(B)	
	w(B)
	w(A)

2

15

2 serializable — 13

2 Serial — 0 non serial serialized

$r_1(A) : w_1(A) : r_1(B) : w_1(B) : w_2(B) : w_2(A)$

Ans : 0

B.14 ~~T_1: $r_1(P)$ $r_1(Q)$~~

T_1: $r_1(P)$ $r_1(Q)$ $w_1(Q)$

T_2: $r_2(Q)$ $r_2(P)$ $w_2(P)$

$\Rightarrow \frac{6!}{3!\,3!} = 20$

2 serial

(b)

non-serial serializable = 0

Recoverability Classification :-

Concurrent execution may leads
- → Irrecoverable Problem
- → Cascading Rollback Problem
- → Lost update Problem

These problems can occur even if the schedule is serializable schedule.

Serializable cond^n not sufficient to avoid
- → Irrecoverable
- → Cascading Rollback
- → Lost Update

Irrecoverable Schedule

Schedule S is irrecoverable iff,

T_j Reads data item X which is updated by T_i

(and)

commit of T_j before commit/rollback of T_i

eg:-

T_i	T_j
W(X)	
	R(X)
	!
	commit
Commit/Rollback	

IRRECOVERABLE

T_1 : withdraw 5000 from 'A'

T_2 : check bal of 'A'

A: 20000

T_1	T_2
R(A)	
A = A − 5000	
W(A)	
	R(A)
	commit

Sys Crash

IRREC

Result of T_2 incorrect && not possible to rollback, because T_2 already committed

Uncommitted Read (Dirty Read)

T_i	T_j
W(X)	
	R(X)
C/Roll	

Transaction T_j reads data item X which is updated by uncommitted trans T_i

Recoverable Schedule

Schedule (S) recoverable iff

1] No uncommitted read in Schedule (S)

(OR)

2] If T_j reads X which is updated by T_i then commit of T_j must delay until Commit / Rollback (C/Roll) of T_i

T_i	T_j
W(X)	
	R(A)
C/R	
	commit

Q- Test given schedule recoverable / CLR / strict Recoverable

①

T_1	T_2
W(A)	
	R(A)
	R2
C1	

✓ ✗ ✗

②

T_1	T_2
R(A)	
	R(A)
	W(A)
W(A)	
C1	
	C2

✓✓ ✗

③

T_1	T_2
R(A)	
	R(A)
W(A)	
C1	
	W(A)
	C2

✓✓✓

④

T_1	T_2	T_3
W(A)		
	W(A)	
	R(A)	
	W(B)	
R(B)		
W(C)		
	W(C)	
	C2	
C1		
		C3

Dirty Read

Dirty read

✓ ✗ ✗

⑤

T_1	T_2	T_3
W(A)		
		R(A)
		W(A)
	R(A)	
		~~W(B)~~
W(B)		
	W(B)	R(B)
C1		
		C3
	C2	

✗

Not ✗ ✗

Cascading Rollback Problem (Cascade Abort)

Failure of one transaction forced to rollback some set of other transaction (because of dirty read cascading Rollback occurs)

T_1	T_2	T_3	T_4	T_5	T_6
W(A)					
	R(A)				
	W(A)				
	W(B)				
		W(A)			
			R(B)		
				R(B)	
				W(B)	
					R(B)

failed * Rollback

T_2 T_4 T_5 T_6 forced to roll back because of T_1 failure

Disadv: Wastage of CPU execution time and I/O access cost and resource utilisation.

Cascadeless rollback Schedule (avoid cascade abort)

Dirty reads not allowed.

T_i	T_j
W(X)	
C/R	R(X)

uncommitted read or dirty read not allowed.

if T_i writes X, T_j read request of X which is updated by T_i must delay until C/R of T_i

T_1	T_2	T_3
W(A)		
	W(A)	
	C2	
		R(A)
C1		

no issue ~~not dirty read~~.

not uncommitted read

if dirty read is present then schedule is Cascading Rollback Problem

Lost Update Problem :-

if T_j writes X which is already written (updated) by uncommitted transaction T_i then it can cause lost update problem

T_i	T_j
W(X)	
⋮	W(X)

T_1	T_2
R(A)	
W(A)	
	W(A) ← Lost
	C_2

failed *

A = ~~100~~ 100
~~200~~ ← by T_1
500 ← by T_2
lost

Strict Recoverable Schedule

Cascadeless Rollback

(and)

No Lost Update Problem

T_i	T_j
W(X)	
C/R	
	R(X)

done to avoid Irrecoverable and Cascading Rollback problem.

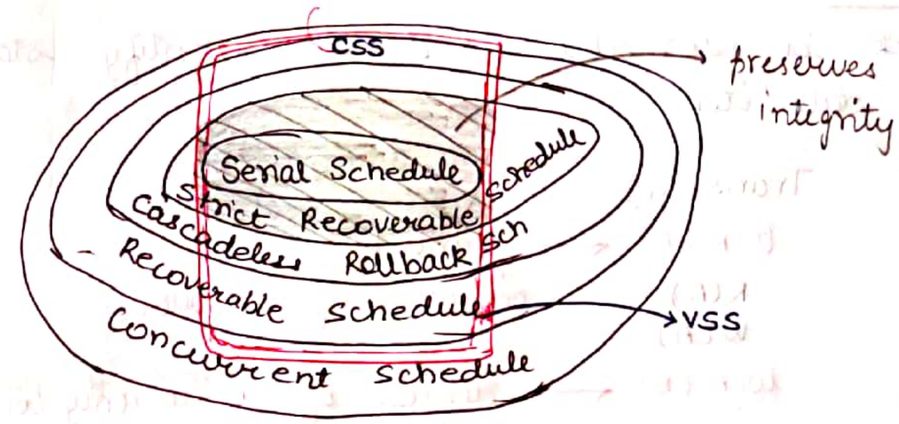
T_i	T_j
W(X)	
C/R	
	W(X)

done to avoid lost update problem.

Strict Recoverable

T_i	T_j
W(X)	
C/R	
	W(X) | R(X)

if T_i writes X then read of X or write of X of T_j must delay until commit or roll back of T_i



classification based on Recoverability :

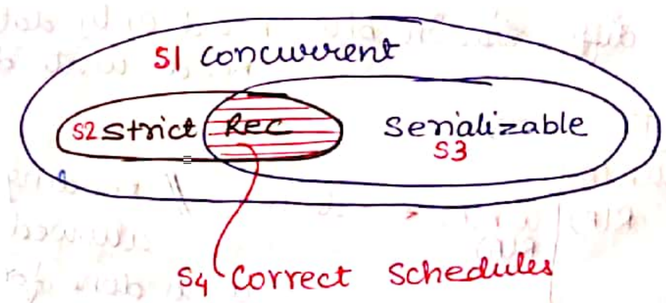
both recoverability and serializability classification are independent of each other.

Schedule(S) Preserves correctness (integrity)

iff S must be serializable

(and)

S must be strict recoverable



Concurrency Control Protocols Goal :

Concurrency control Protocol should not allow to execute if

→ S not serializable

(or)

→ S non strict recoverable

1. Locking Protocol
2. Time stamp ordering Protocol

Locking Protocol :-

Lock:

Lock is variable used to identify status of data item.

Trans (T_1)
- lock (A) ← grants by concurrency Controller
- R(A)
- W(A)
- lock (B) ← denied by Concurrency Controller
- ⋮ wait for data item
- lock (B) ← grants by Concurrency Controller
- W(B)
- Unlock (A)
- Unlock (B)

Lock is used to synchronise the transaction

Binary Lock

→ lock
→ unlock

No differentiation b/w Read Only data
Read write data

T_1	T_2
lock (A)	
⋮ R(A)	lock(A) ← denied. // Reading is not allowed simultaneously.
	R(A)

it is done for consistency

Disadv: less degree of concurrency.
Unable to differentiate Read only data with Read write data so that simultaneous read oper^n also not allowed. which leads to less degree of concurrency.

Shared - Exclusive locking:

Shared lock (S) Read only lock
Exclusive lock (X) Read / write lock

T_1	T_2
S(A)	
R(A)	
	S(A) ← Request granted.
	R(A)

Simultaneous read oper^n is now allowed. as it doesnot cause inconsistency.

T_1	T_2
S(A)	
	X(A) ← Request denied.

So more degree of concurrency.

lock Compatible table:

		Hold by T_i: S	X
Requesting by T_j	S	Yes	NO
	X	NO	NO

{ Inc(A)
A = A+1 }

{ Inc(A)
A←A+1 } → Increment lock, it is granted as it doesnot cause inconsistency

Two phase locking Protocol :-

[Guaranteed Serializable]

Trans (T)
- X(A)
- S (B)
- X (C)
- X (D)
- U(C)
- U(A)
- U(D)
- U(B)

Locking Phase. // User should collect all required data item before unlocking.

lock point of T

first unlock // no more ~~lock~~ request allowed

Unlocking Phase. [shrinking Phase]

Transaction (T) allowed to request lock on any data item in any mode until first unlock oper^n of Trans (T) [lock request not allowed in unlocking phase]

ex: Trans (T_1)
Transfer 500 from A to B

T_1
- X(A)
- R(A)
- W(A)
- X (B)
- U(A)
- R(B)
- W(B)
- U(B)
- Commit

2PL

Scanned by CamScanner

eg:- Trans (T_2)

display Total balance of A, B

T_2

S(A)
R(A)
S(B)
U(A)
R(B)
U(B)
Commit

2PL

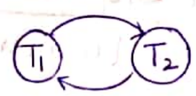
if T_1, T_2 executed concurrently, then guarenteed serializability

Concurrent execution of T_1 T_2 guarenteed serializable schedule.

If schedule (S) not conflict serializable schedule then schedule (S) not allowed by 2PL protocol.

eg- S:

T_1	T_2
X(A)	
R(A)	
X(B) W(A)	
U(A)	
	S(A)
	R(A) ✓
	S(B) ← denied because B is not unlocked by T_1
	R(B)
R(B)	
W(B)	
U(B)	



CSS ✗
2PL ✗

If schedule (S) allowed to execute by 2PL then Schedule (S) guarenteed Conflict serializable schedule and Conflict equal serial orders are lock point orders (topological order, lock point order are same)

⇒ S allowed by 2PL ⟹ S is CSS
Conflict equal serial Sched : lock Points order

T_1	T_2	T_3
	*	
*		
		*

last lock request

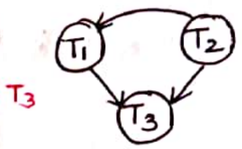
If S allowed by 2PL then S is CSS and equal serial

$T_2 : T_1 : T_3$

eg:- S : $r_1(A)$ $r_2(A)$ $r_3(A)$ $w_2(B)$ $w_1(B)$ $w_3(B)$

T_1	T_2	T_3
S(A)		
$r_1(A)$		
	S(A)	
	$r_2(A)$	
		S(A)
		$r_3(A)$
	X(B)	
	W(B)	
	U(A) U(B)	
X(B)		
W(B)		
U(A), U(B)		
		X(B)
		W(B)
		U(A) U(B)

- Allowed by 2PL
- CSS



$T_2 : T_1 : T_3$

- Lock Point Order = Serial Schedule Order
  T_2 T_1 T_3

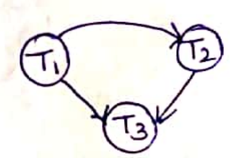
Every 2PL schedule is always Conflict serializable sched. but not every CSS can allowed to execute by 2PL

2PL schedule
Conflict serializable

Q: S: $w_1(A)$ $w_2(A)$ $w_3(A)$ $w_1(B)$ $w_2(B)$ $w_3(B)$
Which is true?

(a) S is CSS and in 2PL
(b) S is CSS and not in 2PL
(c) S is not CSS and in 2PL ← never
(d) S is not CSS && not in 2PL

CSS:



✓

if Cycle then donot check 2PL
∵ CSS(✗) → 2PL ✗

2PL Testing:

T_1	T_2	T_3
X(A)		
X(B) W(A)		
U(A)		
	X(A)	
	W(A)	
	X(B)	
	U(A)	
		X(A)
		W(A)
W(B)		
U(B)		
	W(B)	
		W(B)

denied ✗
denied.

∵ W(B) is not done

not allowed to execute by 2PL

Limitations of 2PL restriction

1] 2PL restriction may leads deadlock

T_1 : $r_1(A)$ $r_1(B)$ [$S(A)$ $S(B)$ $U(A)$ $U(B)$]

T_2 : $w_2(B)$ $w_2(A)$ [$X(B)$ $X(A)$ $U(B)$ $U(A)$]

T_1	T_2
$S(A)$	
$r(A)$	
	$X(B)$
	$w(B)$
	$U(B)$
denied → $S(B)$	
$r(B)$	
T_1 waiting for T_2	
	$X(A)$ ← denied, T_2 waiting for T_1
	$w(A)$

2] 2PL restriction may leads starvation

T_1	T_2	T_3	T_4	T_5 ....▶
	$S(A)$			
denied bec. of T_2 → $X(A)$				
	$U(A)$	$S(A)$		
denied bec. of T_3 → $X(A)$			$S(A)$	
		$U(A)$		
denied bec. of T_4 → $X(A)$				
↓				

Starvation

3] 2PL condition not sufficient to avoid IRREC problem, Cascading Rollback, lock update problems.

S:

T_1	T_2
$X(A)$	
$w(A)$	
$X(B)$	
$U(A)$	
	$S(A)$
	$R(A)$
$w(B)$	
$U(B)$	
	$X(B)$
	$w(B)$
	$U(A)$ $U(B)$
	$C2$
$C1$	

$T_1 \rightarrow T_2$ CSS ✓

S is serializable but not recoverable schedule

⇒ S allowed by 2PL

Strict 2PL Protocol :

basic 2PL :- lock requests of T not allowed in Unlocking phase of T

(and) **Strict Rec :** All exclusive lock of Trans(T) must hold until C/R of trans(T)

T_1	T_2
$X(A)$	
$w(A)$	
C/R	
$U(A)$	$R(A)/w(B)$

$X(A)$ must hold until C/R, i.e, no other trans grants for $S(A)/X(A)$

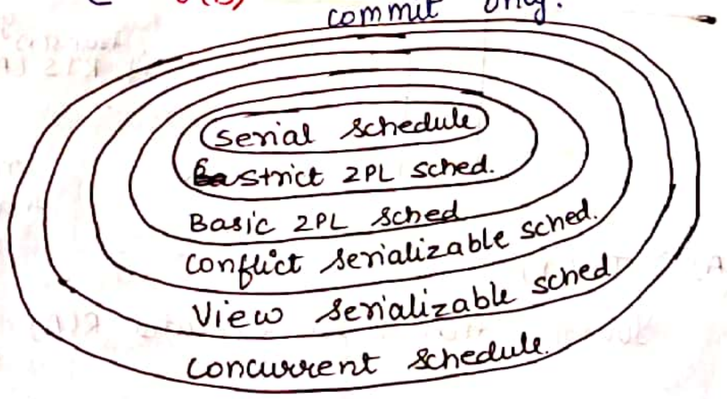
Strict 2PL schedule
- ↳ guarenteed conflict serializable
- ↳ Guarenteed strict Recoverable
- ↳ Deadlock & starvation are possible.

Ex of S/X and strict 2PL Trans

Trans(T)

Locking Phase:
- $S(A)$
- $R(A)$
- ✓$X(B)$
- $w(B)$
- $S(C)$
- $R(C)$
- ✓$X(D)$

Unlocking Phase:
- $w(D)$
- $U(A)$, $U(C)$]- shared lock can release before/after commit
- Commit
- $U(B)$, $U(D)$]- exclusive lock should release after commit only.



Scanned by CamScanner

Time Stamp Ordering Protocols :-

Time stamp of Transaction :

Unique value assigned by DBMS for each transaction in sequence order (Ascending Order)

TS Value →	10	20	30	40
	Older T_1	T_2	T_5	T_3 younger Trans
Trans				

TS value of transaction can be used as
↳ Transaction ID
and ↳ also can used to set priority

it also uses TS value of data item :

Read TS(x) : Highest trans TS value that has performed R(x) successfully.

Write TS(x) : Highest Trans TS value that has executed W(x) successfully.

eg:-

TS →	10 T_1	20 T_2	30 T_3	40 T_4
	R(A) W(A)			
		R(A)	R(A)	
				W(A)

RTS (A) ~~10~~ 30

WTS(A) = ~~10~~ 40

S:

	100 T	Younger that T

there is some younger than trans(T) has executed read (A)

if RTS (A) = 150
50
↓
no younger than T performs read.

if RTS(A) > TS(T)
Younger than T has executed R(A)

else
No younger than T has reads A

Basic Idea of TS

Ordering Protocol :-

Concurrent execution of two or more transaction result must be serial schedule result based on time stamp ordering. then TS ordering protocols are allowed to execute protocols.

If Read/Write request of Trans violates equal serial schedule condition based on TS orders then Roll back transaction.

S:

10 T_1	20 T_2	30 T_3
R(A)		W(A)
	R(A)	
W(B)	R(B)	
		R(C)
× W(C)		
RB T_1		

equal to serial based on TS orders

S: equal to serial
T_1 (10) : T_3 (20) : T_2 (30)

Conflict pair which are allowed
T_1 (10) → T_3 (20) T_3 (20) → T_2 (30) T_1 (10) → T_2 (30)
allowed.

4 $W_2(A)\ R_1(A) \Rightarrow T_2 \rightarrow T_1$ (not allowed)
∴ it is not equal to serial.

Basic TS Ordering Protocol :

Trans (T) issues R(X) :-

10 T_1	20 T_2
	R(A) W(A)
R(A)	

Roll back

	T	Younger than T Writes X ?
	R(X)	

if younger T W(X) then R(X) roll back else allowed.

if (WTS(X) > TS(T))
{ Rollback T
}
else
{ allowed R(X) by T and
Set RTS (X) = max { RTS(X), TS(T) }
}

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Trans T issues W(X):-

10 T_1	20 T_2
	R(A)
× W(A)	

10 T_1	20 T_2
	W(X)
× W(X)	

CSS: $T_2 \rightarrow T_1$
TS: $T_1 \rightarrow T_2$] → not match
∴ not allowed.

if (RTS(X) > TS(T))
Rollback T
else if (WTS(X) > TS(T))
Rollback T
else
{ allowed W(X) by T and
Set WTS(X) = TS(T)
}

Q: S: $r_1(A)$ ~~$r_2(A)$~~ $r_3(B)$ $w_3(B)$ $w_2(B)$ $w_2(A)$
$w_3(C)$ $w_2(C)$ $w_1(D)$ $r_1(D)$

Which Trans RB using BTS Protocol with TS value.

(i) $(T_1\ T_2\ T_3) = (30, 20, 10)$

expected equal serial.

$T_3 \rightarrow T_2 \rightarrow T_1$
10 20 30

T_1	T_2	T_3
r(A)		r(B)
w(B)	w(B) RB	
		w(C)
w(D) R(D)		

(ii) $(T_1\ T_2\ T_3) = (20\ 30\ 10)$

expected equal serial
$T_3 \rightarrow T_1 \rightarrow T_2$

T_1	T_2	T_3
r(A)		r(B)
w(B)	w(B) w(A)	
		w(C)
w(D) r(D)	w(C)	

NO Rollback.

Basic TS ordering Protocol allowed to execute schedule if schedule (S) is conflict serializable schedule and conflict Equal serial orders or TS orders of transactions

if (Topological Order of CSS = TS orders of Trans)
then (Basic TSOP allowed to execute
NO Rollbacks)

Thomas Write TS ordering Protocol:

Trans (T) issues R(X)

Same as B TSOP

Trans (T) issues W(X)

if (RTS(X) > TS(T))
Rollback T
else if (WTS(X) > TS(T))
{ Ignore W(X) of T
and continue execution
of T
}
else
{ allowed W(X) by T and
Set WTS(X) = TS(T)
}

T_1	T_2
	W(X)
W(X)	

ignor W(X) and continue executing of T

S:

10 T_1	20 T_2	30 T_3
R(A)		
	W(A)	
W(A)		
		W(A)

View equal

Ignore

BTSOP
bec of W(A) in T_1, Rollback T_1

TWTSOP

S': [T_1 : T_2 : T_3] serial sched.
10 20 30
$r_1(A)\ w_2(A)$: $w_2(A)\ w_3(A)$

S:

10 T_1	20 T_2
R(A)	
W(A)	
	R(A)
	R(B)
	W(B)
W(B)	

not view equal

BTSOP
Rollback T_1

TWTSOP
Rollback T_1

S': (T_1 T_2) $r_1(A)\ w_1(A)\ w_1(B)$: $r_2(A)\ r_2(B)\ w_2(B)$ serial
10 20

Schedule which is executed by TWTSOP result View equal serial schedule based on TS order of Transactions

Goal:-

S	10 T_1	20 T_2	30 T_3
View equal TSO			W(A)
		W(A)	
	W(A)		

BTSO/ TWRTS

→ Guarenteed serializable

→ free from Deadlocks

→ Not free starvation

Starvation:

10 T_1	20 T_2	30 T_1	40 T_3	50 T_1	60 T_4
R(A) becoz of T_2	W(A)				
		R(A) becoz of T_3	W(A)		
				R(A) becoz of T_4	W(A)

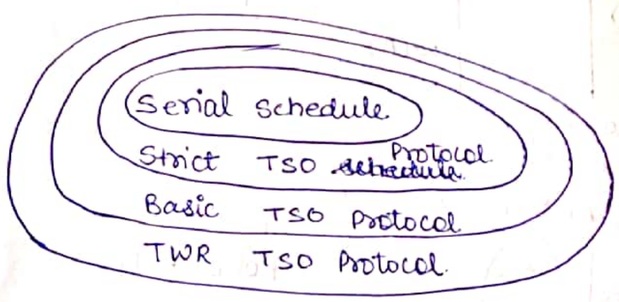
→ Not guarenteed for strict recoverable

Strict TS Ordering Protocol:

1] Basic TSO/TWRTS for serializability

and

2] strict recoverable must satisfy



Tuple Relational Calculus (TRC)

⇒ Non Procedural Query language
What data retrieve

⇒ Uses first Order logic and Predicate calculus formulas

Basic formulas

P, Q Predicate (simple stmt which can T/F)

$P \vee Q$

$P \wedge Q$

$\neg P$

$P \rightarrow Q$

$X \in Rel$ where X is variable

quantifier:

$\exists X \in Rel\ (P(X))$ TRUE if atleast one record (X) of rel satisfy P(X)

$\forall X \in Rel(P(X))$ TRUE if every record (X) of rel satisfy P(X)

Tuple Variables

free tuple Variable

$T \in stud$

T: Universe

Bounded Tuple Variable

$\exists T_1 \in stud\ (P(T_1))$

$\forall T_2 \in course\ (P(T_2))$

Variable bounded by quantifier

Format of TRC Query

Result Variable

$\{T / P(T)\}$:- T: Tuple Variable

P(T): Formula over tuple variable

Retrieves set of Tuples(T) those are satisfied formula P(T)

eg $\{T / \underbrace{T \in stud \wedge T.age > 20}_{P(T)}\}$

$\equiv \sigma_{age>20}(stud)$

Retrieves students whose age more than 20.

Q- Stud (sid sname Age)

Course (cid Cname Instructor)

Enroll (sidcid fee)

⇒ Retrieve sname's enrolled $\exists$ some $\exists$ course

Stud (sid	Sname)		Enroll (Sid	Cid)	T
$\exists T_1$ S1	A		$\exists T_2$ S1	C1	
S2	B		S1	C2	
S3	C		S2	C2	

(for some T_1, there should be one T_2 which satisfy the cond^n)

$\{ T / \exists T_1 \in Stud \ \exists T_2 \in Enroll$

$(\underset{S_1}{T_1 \cdot sid} = \underset{S_1}{T_2 \cdot sid}) \wedge \underset{S_1}{T = T_1 \cdot sname} \}$

always true

(or)

$\{ T \cdot sname / (T \in stud) \wedge (\exists T_1 \in Enroll (T_1 \cdot Sid = T \cdot Sid)) \}$

bec this is used in result

⇒ Retrieve sid's enrolled $\exists$ some course taught by Korth

~~$\exists T_1 \in$ Enr stud $\exists T_2$ Cr~~

Enroll (sid cid) $\exists T_1$ = course (cid Inst) $\exists T_2$ Korth

RA: π_{sid} (Enroll $\bowtie_{Ins = Korth}$ Course)

RC: $\{ T / \exists T_1 \in Enroll \ \exists T_2 \in Course.$
$(T_1 \cdot Cid = T_2 \cdot Cid \wedge T_2 \cdot Inst = Korth \wedge T = T_1 \cdot sid) \}$

⇒

Set operations :-

R & S relations

$R \cup S = \{ x \mid x \in R \overset{OR}{\vee} x \in S \}$

$R \cap S = \{ x \mid x \in R \overset{and}{\wedge} x \in S \}$

$R - S = \{ x \mid x \in R \underbrace{\wedge \neg (x \in S)}_{\text{but not}} \}$

⇒ Retrieve sid's whose age more than 20 (or) enrolled some Korth course

RA: $\pi_{sid}(\sigma_{age>20}(Stud)) \cup \pi_{sid}(\sigma_{E \cdot Cid = C \cdot Cid \wedge C \cdot Inst = Korth}(Enroll))$

RC: $\{ T / \exists T_1 \in Stud (T_1 \cdot age > 20 \wedge T = T_1 \cdot sid) \vee$
$\exists T_1 \in Enroll \ \exists T_2 \in Course$
$(T_1 \cdot Cid = T_2 \cdot Cid \wedge T_2 \cdot Inst = Korth \wedge T = T_1 \cdot sid) \}$

⇒ $\{ T / \exists T_1 \in stud (T = T_1 \cdot sid) \wedge$
$\neg (\exists T_1 \in stud \ \exists T_2 \in Stud ((T_1 \cdot age < T_2 \cdot age) \wedge (T = T_1 \cdot sid))) \}$

age ≥ every age

$\{ T / \exists T_1 \in Stud \ \forall T_2 \in stud (T_1 \cdot age \geq T_2 \cdot age \wedge T = T_1 \cdot sid) \}$

retrieves sid's whose age is maximum.

$P \wedge \neg Q = \underline{P - Q}$

⇒ $\{ T / \overset{P}{\exists T_1 \in Enroll (T = T_1 \cdot sid)} \wedge$
$\neg (\overset{q}{\exists T_1 \in Enroll \ \exists T_2 \in Enroll (T_1 \cdot sid = T_2 \cdot sid \wedge T_1 \cdot Cid \neq T_2 \cdot Cid \wedge T = T_1 \cdot sid)}) \}$

sid's enrolled exactly one course

$\pi_{sid}(E) - \pi_{sid}(\sigma_{T_1 \cdot sid = T_2 \cdot sid \wedge T_1 \cdot Cid \neq T_2 \cdot Cid.}(T_1 \times T_2))$

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Conclusion

*** Unsafe TRC Query :-

TRC Query with infinite set of records in result because TRC uses free variable for result and boundary of free variable is infinite.

eg:- $\{ T \mid \neg T \in stud \}$

result : Set of Tuples T those are not belongs to stud relation
[Infinite record set in result]

$\left\{ \text{Expressive Power of safe TRC Queries} \right\} \equiv$ equal to $\left\{ \text{expressive Power of Basic RA Queries} \right\}$

Basic RA Queries :-

- Queries which can formulate using
  $\{ \underbrace{\pi, \sigma, \rho, \cup, -, \times}_{\text{fundamental}}, \underbrace{\cap, \bowtie, \bowtie_c, ⟕, ⟖, ⟗, /}_{\text{derived}} \}$

- Queries failed to express using Basic RA also fails in Safe TRC

  → Count of records
  Count Attribute Values.
  Sum of Attribute Values
  Avg of Attribute Values

  → Ordering of records in Asc/Desc etc