Page No.
Date : / /

Unit : 5 : Dynamic Programming

* Explain Dynamic Programming with its characteristics and application.

=> Dynamic Programming is used to find optimal solution.

Dynamic Programming is gives better solution to the Greedy Approach.

Dynamic Programming solution is always represent in tabular form.

- Characteristics :

1 The Problem can be divided into stages.

2 In Dynamic Programming, subproblem in a bottam-up fashion.

3 Solution are found using the tabular form.

SMVS
Page No.
Date : / /

4 ~~Dev~~ Divided Problem into part for find ~~small~~ optimal solution.

5 Principles of optimality allows to solve the problem in recursively.

- Application :

1 Used to find 1/0 Knapsack Problem.

2 Used to find Optimal Merge portions.

3 Used to find Shortest Path Problems.

4 Provides Mathematical Optimization.

5 Find Matrix chain multiplication sequence.

6 Used to find Longest Common Subsequence.

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SMVS
Page No.
Date : / /

* Explain Matrix Chain Multiplication using Dynamic Programming.

=> Matrix Chain Multiplication is used to find matrix multiplication order.

Using this Problem, we can reduse the number of multiplication.

Method :

$$M[i, j] = \begin{cases} \text{Don't Care}(x), & i > j \\ 0, & i = j \\ \min_{i \le k < j} (M[i, k] + M[k+1, j] + d_{i-1} d_k d_j) \end{cases}$$

K = Value of i, which is increment for condition

Using this formula, we can find the solution.

Ex. $A_1 = 4 \times 10$, $A_2 = 10 \times 3$, $A_3 = 3 \times 12$
$A_4 = 12 \times 20$, $A_5 = 20 \times 7$

For Finding the solution, we have to find value of d.

SMVS
Page No.
Date : / /

$[A_1]$ $[A_2]$ $[A_3]$ $[A_4]$ $[A_5]$
$4 * 10$ $10 * 3$ $3 * 12$ $12 * 20$ $20 * 7$

d_0 d_1 d_2 d_3 d_4 d_5

Hence, $d_0 = 4$, $d_1 = 10$, $d_2 = 3$,
$d_3 = 12$, $d_4 = 20$, $d_5 = 7$

For Finding the ~~valu~~ solution we have to create table.

Here, There are 5 Matrix.
So, We have to create 5x5 Matrix.

i/j	1	2	3	4	5
1	0	120	264	1080	1344
2	X	0	360	1320	1350
3	X	X	0	720	1140
4	X	X	X	0	1680
5	X	X	X	X	0

Using the Formula, we have to Find the table value.

Page No.
Date :

i	j	k	Condition	Value
1	1	1	i = j , 1 = 1	0
2	1	2	i > j , 2 > 1	x
3	1	3	i > j , 3 > 1	x
4	1	4	i > j , 4 > 1	x
5	1	5	i > j , 5 > 1	x
2	2	2	i = j , 2 = 2	0
3	2	3	i > j , 3 > 2	x
4	2	4	i > j , 4 > 2	x
5	2	5	i > j , 5 > 2	x
3	3	3	i = j , 3 = 3	0
4	3	4	i > j , 4 > 3	x
5	3	5	i > j , 5 > 3	x
4	4	4	i = j , 4 = 4	0
5	4	5	i > j , 5 > 4	x
5	5	5	i = j , 5 = 5	0

Page No.
Date : / /

i	j	K	Condition	Value
1	2	1	$1 \leq 1 < 2$, So, Min $(M(1,1)+M(2,2)+d_0 d_1 d_2)$ $= Min(0+0+120) = 120$	120
		2	$1 \leq 2 < 2 \to$ False	
2	3	2	$2 \leq 2 < 3$, So, Min $(M(2,2)+M(3,3)+d_1 d_2 d_3)$ $= 360$	360
		3	$2 \leq 3 < 3 \to$ False	
3	4	3	$3 \leq 3 < 4$, So, Min $(Min(3,3)+M(4,4)+d_2 d_3 d_4)$ $= 720$	720
		4	$3 \leq 4 < 4 \to$ False	
4	5	4	$4 \leq 4 < 5$, So, Min $(M(4,4)+M(5,5)+d_3 d_4 d_5)$ $= 1680$	1680
		5	$4 \leq 5 < 5 \to$ False	
1	3	1	$1 \leq 1 < 3$, So, Min $M(1,1)+M(2,3)+d_0 d_1 d_3$ $= 840$	

SMVS Page No. Date: / /

i	j	k	Condition	Value
		2	$1 \leq 2 < 3$, So, Min($M(1,2) + M(3,3) + d_0 d_2 d_3$) $= 264$	264
		3	$1 \leq 3 \leq 3$, $\rightarrow$ False	

We have to select Minimum value For $M[1, 3] = 264$

i	j	k	Condition	Value
2	4	2	$2 \leq 2 < 4$, So, min ($M(2,2) + M(3,4) + d_1 d_2 d_4$) $= 1320$	
		3	$2 \leq 3 < 4$, So, Min ($M(2,3) + M(4,4) + d_1 d_3 d_4$) $= 2760$	1320
		4	$2 \leq 4 < 4 \rightarrow$ False	

We have to selet Minimum value For $M[2, 4]$

i	j	k	Condition	Value
3	5	3	$3 \leq 3 < 5 \rightarrow$ Min($M(3,3) + M(4,5) + d_2 d_3 d_5$) $= 1932$	
		4	$3 \leq 4 < 5 \rightarrow$ Min($M(3,4) + M(5,5) + d_2 d_4 d_5$ $= 1140$	

Page No.
Date : / /

i	j	k	Condition	Value
		5	$3 \le 5 < 5 \rightarrow$ False	
			We have to select Minimum value for $M[3,5]$	1140
1	4	1	$1 \le 1 < 4 \rightarrow$ So, Min($M(1,1) + M(2,4) + d_0 d_1 d_4$) $= 2120$	
		2	$1 \le 2 < 4 \rightarrow$ So, Min($M(1,2) + M(3,4) + d_0 d_2 d_4$) $= 1080$	1080
		3	$1 \le 3 < 4 \rightarrow$ So, Min($M(1,3) + M(4,4) + d_0 d_3 d_4$) $= 1224$	
		4	$1 \le 4 < 4 \rightarrow$ False	
			We have to select Minimum value for $M[1,4]$	
2	5	2	$2 \le 2 < 5 \rightarrow$ Min($M(2,2) + M(3,5) + d_1 d_2 d_5$) $= 1350$	
		3	$2 \le 3 < 5 \rightarrow$ Min($M(2,3) + M(4,5) + d_1 d_3 d_5$) $= 2880$	

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SMVS
Page No.
Date :

i	j	K	Condition	Value
		4	$2 \le 4 < 4 \rightarrow$ So, Min($m(2,4) + m(5,5) + d_1 d_4 d_5$) $= 2720$	1350

We have to select Minimum value for $m[2,5]$.

i	j	K	Condition	Value
1	5	1	$1 \le 1 < 5 \rightarrow$ So, Min($m(1,1) + m(2,5) + d_0 d_1 d_5$) $= 1630$	
		2	$1 \le 2 < 5 \rightarrow$ So, Min($m(1,2) + m(3,5) + d_0 d_2 d_5$) $= 1344$	1344
		3	$1 \le 3 < 5 \rightarrow$ So, Min($m(1,3) + m(4,5) + d_0 d_3 d_5$) $= 2280$	
		4	$1 \le 4 < 5 \rightarrow$ So, Min($m(1,4) + m(5,5) + d_0 d_4 d_5$) $= 1640$	
		5	$1 \le 5 < 5 \rightarrow$ False	

We have to select Minimum value for $m[1,5]$

From the table, Top of the Table ~~cornn~~ corner.

For Find the 5 Matrix multiplication, we require 1344 multiplication.

For $k=2$ we get 1344 value.

So, we have to divided Matrix ~~into two Part~~. upto Two Matrix

$M[1,5] = ([A_1] \times [A_2])([A_3] \times [A_4] \times [A_5])$

After that we have to take Previous value of 1344.
So, Value is 1080.

For $k=4$, we get 1080 value.

So, we have to divided matrix upto 4 Matrix.

$M[1,5] = ([A_1] \times [A_2])(([A_3] \times [A_4]) \times [A_5])$

SMVS
Page No.
Date : / /

* Explain Longest Common Subsequence with Dynamic Programming.

=> For Finding the Longest Common Sub sequence, We have to Follow this method.

Step :

1 IF String A Length is n and String B Length is m than create the n+1 x m+1 table which index is start with 0.

2 So, String A_i will start with 0 to n and String B_i will start with 0 t m in table

3 We have to Find the table value using this Formula.

Row-wise we have to Find value.

$$C[i,j] = \begin{cases} 0, & \text{if } i=0 \text{ or } j=0 \\ C[i-1,j-1]+1, \nwarrow & j,i>0 \text{ and } a_i=b_j \\ \max(C[i,j-1]\leftarrow, C[i-1,j]\uparrow), & i>j>0 \ \& \ a_i \neq b_j \end{cases}$$

Page No.
Date : / /

4 According to C[i, j] condition we have to put Sign.

5 Bottam of the table we get answer.

If we get n answer than We have to select n string or character.

6 We have to follow the sign. When we get ↖ sign than we have to take this character

Ex. String A = ABCB and
B = BDCAB.

→ Here, Length of String A is 4 and Length of string B is 5.

So, we have to create table for $A_i \times B_j$ in which A is start with 0 to 4 and B is start with 0 to 5.

After that we have to find value of C[i, j].

SMVS
Page No.
Date : / /

		0	1	2	3	4	5
		Bj	B	D	C	A	B
0	Ai	0	0	0	0	0	0
1	A	0	0↑	0↑	0↑	1↖	1←
2	B	0	1←	1←	1←	1↑	2↖
3	C	0	1↑	2↑	2↖	2←	2↑
4	D	0	1↑	2↑	2↑	2↑	3↖

For i = 0 or j = 0, we have to take C[i, 0] = C[0, j] = 0

i	j	Condition	Value
1	1	$a_1 = b_1$ = Max(C[1,0], C[0,1]) = Max(0, 0↑) = 0↑	0↑
1	2	$a_1 \neq b_2$ = Max(C[1,1], C[0,2]) = Max(0, 0↑) = 0↑	0↑
1	3	$a_1 \neq b_3$ = Max(C[1,2], C[0,3]) = Max(0, 0) = 0↑	0↑
1	4	$a_1 = b_4$ = A = A = (C[0,3] + 1) = (0 + 1) = 1↖	1↖

Page No.
Date : / /

i	j	Condition	Value
1	5	$a_1 = b_5$, $A \neq B$, $Max(C[1,4], C[0,5]) = Max(1,0)$ $= 1 \leftarrow$	$1 \leftarrow$
2	1	$a_2 = b_1$, $B = B$, $(C[1,0] + 1) = 1 \nwarrow$	$1 \nwarrow$
2	2	$a_2 \neq b_2$, $B \neq D$ $Max(C[2,1], C[1,2])$ $= Max(1,0) = 1 \leftarrow$	$1 \leftarrow$
2	3	$a_2 \neq b_3$, $B \neq C$, $Max(C[2,2], C[1,3])$ $= Max(1,0) = 1 \leftarrow$	$1 \leftarrow$
2	4	$a_2 \neq b_4$, $B \neq A$ $= Max(C[2,3], C[1,4])$ $= Max(1,1) = 1 \uparrow$	$1 \uparrow$
2	5	$a_2 \neq b_5$, $B = B$ $= (C[1,4] + 1) = 1 + 1 = 2 \nwarrow$	$2 \nwarrow$
3	1	$a_3 \neq b_1$, $C \neq B$ $= Max(C[3,0], C[2,1])$ $= Max(0,1) = 1 \uparrow$	$1 \uparrow$
3	2	$a_3 \neq b_2$, $C \neq D$ $= Max(C[3,1], C[2,2])$ $= Max(1,1) = 1 \uparrow$	$1 \uparrow$

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i	j	Condition	Value
3	3	$a_3 = b_3$, $C = C$ $C[2,2] + 1 = 1 + 1 = 2 \nwarrow$	$2 \nwarrow$
3	4	$a_3 \neq b_4$, $C \neq A$ $= Max(C[3,3], C[2,4])$ $= Max(2, 1) = 2 \leftarrow$	$2 \leftarrow$
3	5	$a_3 \neq b_5$, $C \neq B$ $= Max(C[3,4], C[2,5])$ $= Max(2,2) = 2 \uparrow$	$2 \uparrow$
4	1	$a_4 = b_1$, $B = B$ $= C[3,0] + 1 = 0 + 1 = 1 \nwarrow$	$1 \nwarrow$
4	2	$a_4 \neq b_2$, $B \neq D$ $= Max(C[4,1], C[3,2])$ $= Max(1, 1) = 1 \uparrow$	$1 \uparrow$
4	3	$a_4 \neq b_3$, $B \neq C$ $= Max(C[4,2], C[3,3])$ $= Max(1,2) = 2 \uparrow$	$2 \uparrow$
4	4	$a_4 \neq b_4$, $B \neq A$ $= Max(C[4,3], C[3,4])$ $= Max(2, 2) = 2 \uparrow$	$2 \uparrow$
4	5	$a_4 = b_5$, $B = B$ $= C[3,4] + 1 = 2 + 1 = 3 \nwarrow$	$3 \nwarrow$

Bottom of the table, we get the answer.

Here, We get 3 value. So, We get String with Length 3.

Where we get ↖ Sign, this character we have to select.

So, String become BCB.

* Explain 0-1 knapsack Problem with Dynamic Programming.

=> 0-1 knapsack Problem is used to select n different things according to its weight.

Using this step, we can solve the 0-1 knapsack Problem.

Step :

1 Take Number of Item as a i and take Maximum Weight as a M.

If Number of Item is n and Maximum weight is m than

Page No.
Date : / /

We have to create table for i and M.

2 Item index is started with 0 to n and Weight index is started with 0 to m.

3 Using this Condition, We have to Find table values.

$$C[i, M] = \begin{cases} 0 & , \text{if } i = 0 \text{ or } M = 0 \\ C[i-1][M], & w_i > M \\ \text{Max}(V_i + C[i-1][M-w_i], \\ \quad C[i-1, M]) & , w_i < M \end{cases}$$

Here, w_i = Weight of ith item

V_i = Value of ith item

4 Bottom of the table, we get the Maximum profit value.

5 For select the item, we have to use this Formula.

if $C[i, M] \neq C[i-1, M]$

$i = i - 1$

$M = M - w_i$

else $i = i - 1$

Ex.

Item	1	2	3	4
Weight	2	3	4	5
Value	3	4	5	6

Maximum Weight = 5 Kg.

Here, There are Four item and Maximum weight 5.

So, We have to create table, For i = 0 to 4 and M = 0 to 5.

i\M	0	1	2	3	4	5
0	0	0	0	0	0	0
1	0	0	3	3	3	3
2	0	0	3	4	4	7
3	0	0	3	4	5	7
4	0					

Using the formula, We have to find the value.

We have to find ~~rowwi~~ row-wise value.

SMVS
Page No.
Date : / /

For $i = 0$ or $M = 0$, $C[0, M] = C[i, 0] = 0$.

i	j	Condition	Value
1	1	$W_1 > 1$, $2 > 1$, $C[1,1] = C[0,1] = 0$	0
1	2	$W_1 = 2$, $2 = 2$ $Max(3 + C[0,0], C[0,2])$ $= Max(3, 0) = 3$	3
1	3	$W_1 < 3$, $2 < 3$ $= Max(3 + C[0,1], C[0,3])$ $= Max(3, 0) = 3$	3
1	4	$W_1 < 4$, $2 < 4$ $= Max(3 + C[0,2], C[0,4])$ $= Max(3, 0) = 3$	3
1	5	$W_1 < 5$, $2 < 5$ $= Max(3 + C[0,3], C[0,5])$ $= Max(3, 0) = 3$	3
2	1	$W_2 > 1$, $3 > 1$ $= C[2,1] = C[1,1] = 0$	0
2	2	$W_2 > 2$, $3 > 2$ $= C[2-1, 2] = C[1,2] = 3$	3

Page No.
Date: / /

i	j	Condition	Value
2	3	$W_2 = 3,\ 3 = 3$ $= Max(4 + C[0,0], C[1,3])$ $= Max(4, 3) = 4$	4
2	4	$W_2 < 4,\ 3 < 4$ $= Max(4 + C[0,1], C[1,4])$ $= Max(4, 3) = 4$	4
2	5	$W_2 < 5,\ 3 < 5$ $= Max(4 + C[1,2], C[1,5])$ $= Max(7, 3) = 7$	7
3	1	$W_3 > 1,\ 4 > 1$ $= C[3-2, 1] = C[2, 1] = 0$	0
3	2	$W_3 > 2,\ 4 > 2$ $= C[3-2, 2] = C[2, 2] = 3$	3
3	3	$W_3 > 3,\ 4 > 3$ $= C[3-2, 3] = C[2, 3] = 4$	4
3	4	$W_3 = 4,\ 4 = 4$ $= Max(5 + C[1,0], C[2,4])$ $= Max(5, 4) = 5$	5
3	5	$W_3 < 5,\ 4 < 5$ $= Max(5 + C[2,1], C[2,5])$ $= Max(5, 7) = 7$	7

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SMVS
Page No.
Date : / /

i	j	Condition	Value
4	1	$W_4 > 1$, $5 > 1$ $C[4-1, 1] = C[3, 1] = 0$	0
4	2	$W_4 > 2$, $5 > 2$ $C[4-1, 2] = C[3, 2] = 3$	3
4	3	$W_4 > 3$, $5 > 3$ $C[4-1, 3] = C[3, 3] = 4$	4
4	4	$W_4 > 4$, $5 > 4$ $C[4-1, 4] = C[3, 4] = 5$	5
4	5	$W_5 = 5$, $5 = 5$ $= Max(5 + C[3, 0], C[3, 5])$ $= Max(5, 7) = 7$	7

For Select the item,

Bottom of the table, we get 7 value, which is maximum Profit Value at $i = 4$ and $m = 5$

For $i = 4$ and $m = 5$

$C[i, m] = C[4, 5] = 7$
$C[i-1, m] = C[3, 5] = 7$
So, $i = i - 1 = 4 - 1 = 3$

Page No.
Date : / /

For $i = 3$ and $m = 5$.

$c[i, m] = c[3, 5] = 7$
$c[i-1, m] = c[2, 5] = 7$
$\therefore i = i - 1 = 3 - 1 = 2$

For $i = 2$ and $m = 5$

$c[i, m] = c[2, 5] = 7$
$c[i-1, m] = c[1, 5] = 3$
So, $m = 5 - w_2 = 5 - 3 = 2$
$i = i - 1 = 2 - 1 = 1$

For $i = 1$ and $m = 2$

$c[i, m] = c[1, 2] = 3$
$c[i-1, m] = c[0, 2] = 0$
So, $m = 2 - w_1 = 2 - 2 = 0$
$i = i = i - 1 = 0$

So, Selected Item is Item 1 and Item 2.

SMVS
Page No.
Date : / /

* Explain Making Change Problem.

=> This are the Basic steps to Perform Making Change Problem.

Step:

1 If We have D Coin mean d value coins and we have to create n value For making change.

2 Create a table For D\n with value of D start with 0 to d an value of n start with 0 to n

3 Using this Formula, we can find the values of table,

$$C[i,j] = \begin{cases} 1 + C[1, j-d_1] & , \quad i=1 \\ C[i-1, j] & , \quad j < d_i \\ \min(C[i-1, j], \\ 1 + C[i, j-d_i]) & , \quad \text{other} \end{cases}$$

4 Bottom of the table we get minimum number of coin.

5 For Finding the Coin value,

if $C[i, j] \neq C[i-1, j]$

$j = j - d_i$

else

$i = i - 1$

Ex. Make a table of number of dimonization (1, 4, 6) and amount (8).

=> Here, We have three Coin and $N = 8$

So, We have to create table For d/n From 0 to 3, to 0 to 8.

i	D	j								
		0	1	2	3	4	5	6	7	8
0	-	0	0	0	0	0	0	0	0	0
1	1	0	1	2	3	4	5	6	7	8
2	4	0	1	2	3	1	2	3	4	2
3	6	0	1	2	3	1	2	1	2	2

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SMVS
Page No.
Date : / /

For $C[i, 0] = C[0, j] = 0$ and Using the formula, we have to Find colum-wise table value.

i	j	d_i	Condition	Value
1	1	1	$= 1 + C[1, 1-1] = 1 + C[1, 0] = 1$	1
2	1	4	$4 < 1,\ j < d_i,\ = C[2-1, 1]$ $= C[1, 1] = 1$	1
3	1	6	$j < d_3,\ = C[3-1, 1] = C[2, 1] = 1$	1
1	2	1	$= 1 + C[1, 2-1] = 1 + C[1, 1]$ $= 1 + 1 = 2$	2
2	2	4	$j < d_2,\ = C[2-1, 2] = C[1, 2] = 2$	2
3	2	6	$j < d_3 = C[3-1, 2] = C[2, 2] = 2$	2
1	3	1	$= 1 + C[1, 3-1] = 1 + C[1, 2] = 3$	3
2	3	4	$j < d_2,\ = C[2-1, 3] = C[1, 3] = 3$	3
3	3	6	$j < d_3 = C[3-1, 3] = C[2, 3] = 3$	3
1	4	1	$= 1 + C[1, 4-1] = 1 + C[1, 3] = 4$	4
2	4	4	$= \min(C[2-1, 4], 1 + C[2, 4-4])$ $= \min(C[1, 4], 1 + C[2, 0])$ $= \min(4, 1) = 1$	1

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i	j	d_i	Condition	Value
3	4	6	$j < d_3$, $C[3-1,4] = C[2,4] = 1$	1
1	5	1	$= 1 + C[1,5-1] = 1 + C[1,4] = 5$	5
2	5	4	$\min(C[2-1,5], 1+C[2,5-4])$ $= \min(C[1,5], 1+C[2,1])$ $= \min(5, 2) = 2$	2
3	5	6	$j < d_3$, $C[3-1,5] = C[2,5] = 2$	2
1	6	1	$= 1 + C[1,6-1] = 1 + C[1,5] = 6$	6
2	6	4	$= \min(C[1,6], 1+C[2,2])$ $= \min(6, 3) = 6$	6
3	6	6	$= \min(C[2,6], 1+C[3,0])$ $= \min(6, 1)$	1
1	7	1	$= 1 + C[1,7-1] = 1 + C[1,6] = 7$	7
2	7	4	$= \min(C[1,7], 1+C[2,3])$ $= \min(7, 4) = 4$	4
3	7	6	$= \min(C(2,7), 1+C[3,1])$ $= \min(4, 2) = 2$	2
1	8	1	$= 1 + C[1,8-1] = 1 + C[1,7] = 8$	8

SMVS
Page No.
Date : / /

i	j	d_i	Condition	Value
2	8	4	$= \text{Min}(c[1,8], 1+c[2,4])$ $= \min(8, 2) = 2$	2
3	8	6	$= \text{Min}(c[2,8], 1+c[3,2])$ $= \text{Min}(2, 3) = 2$	2

From the table, Bottom of the table we get 2 value.

So, We required Minimum 2 Coin For Create 8 value.

For Finding the value of Coin,

$c[i, j] = c[3, 8] = 2$
$c[i-1, j] = c[2, 8] = 2$
So, $i = i-1 = 3-1 = 2$

For $i = 2$ and $j = 8$

$\therefore c[i, j] = c[2, 8] = 2$
$\therefore c[i-1, j] = c[1, 8] = 8$
So, we have to take $i=2$ value coin.
So, $j = j - d_i = 8 - 4 = 4$

For $i = 2$ and $j = 4$

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Page No.
Date : / /

$\therefore$ $C[i, j] = C[2, 4] = 1$
$\therefore$ $C[i-1, j] = C[1, 4] = 4$

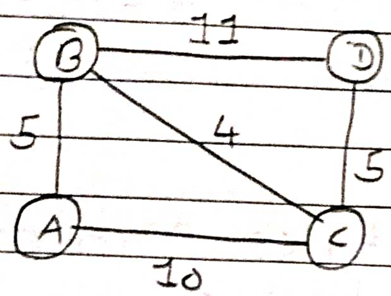
Again We have to take
$i = 2$ Value Coin.

$\therefore$ $j = j - d_2 = 4 - 4 = 0$

For Make 8 ~~ø~~ Value We
require Two Four Coines.

Page No.
Date : / /

* Find the shortest Path Using Dijkstra's Algorithm.

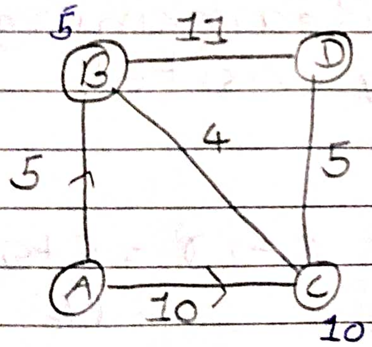


=> Using this step, We can find the Dijkstra's Algorithm.

We have to find Minimum value for Vertex Path.

We have to Find Value for every Vertex Path.

- Vertex : A : Vertex A is directly connected with B and C

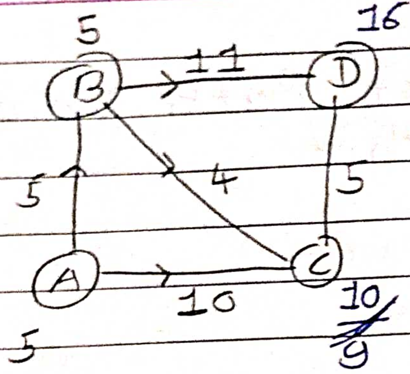


From A -> B = 5
A -> C = 10

Vertex B Value = 5
Vertex C Value = ~~5~~ 10

- Vertex B : Vertex B is directly connected with A, C and D
But A is already visit

Page No.
Date : / /

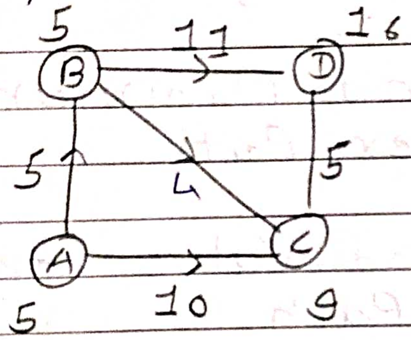


From B -> D = 5 + 11
= 16

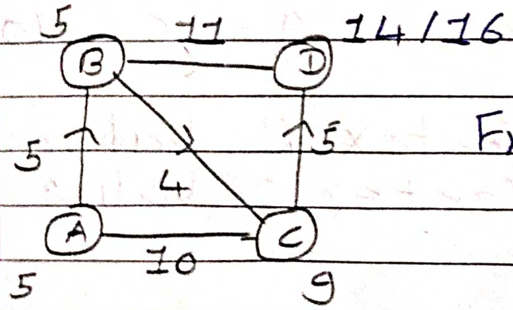
B -> C = 5 + 4
= 9

We have to take Minimum value for Vertex C.

So, Vertex C value = 9



- For Vertex C : For Vertex C we have to take only D Vertex because Reamaning Vertex is already visited.



From C -> D = 5 + 9
= 14

For D we have to we have to take Minimum value.

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Page No.
Date : / /

So, Vertex D value = 14

Here, All the Vertex are visited.
So, Shorest Path weight will be 14.

Finding the Path we have to do backtracking with minimum value.

From D to C we get Minimum value 5

From C to B we get Minimum value 4.

From B to A we get Minimum value 5.

So, Path will be A -> B -> C -> D