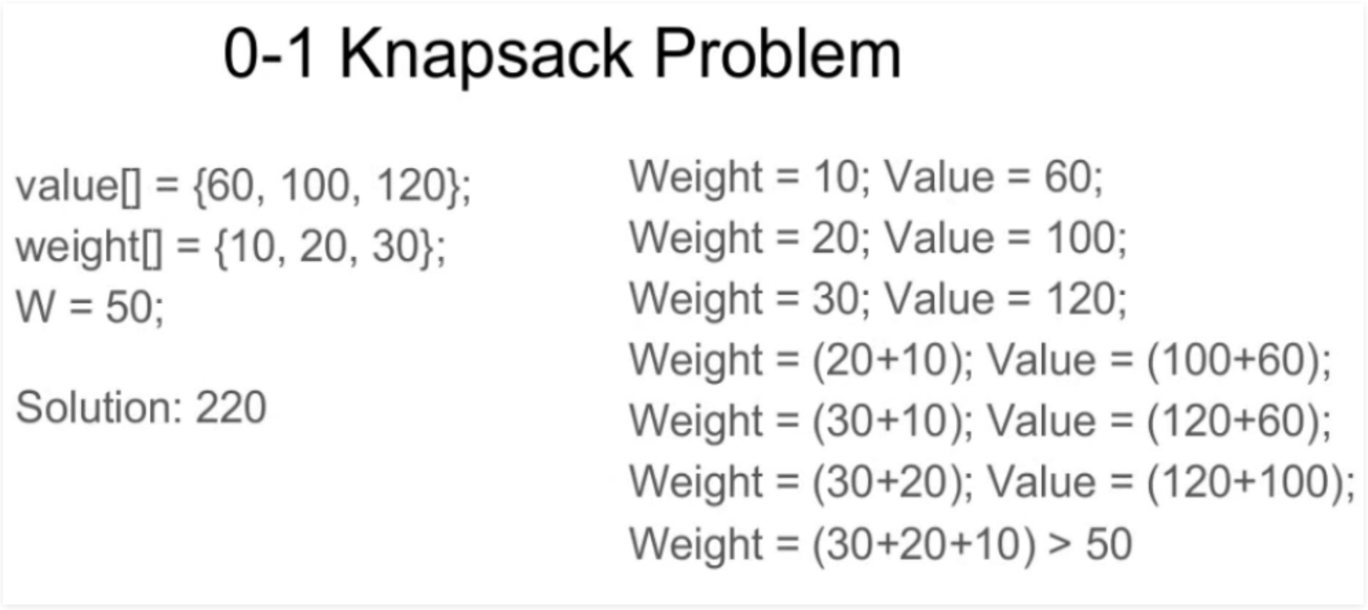
0-1 Knapsack Problem | DP-10

Difficulty Level : Medium ● Last Updated : 20 Apr, 2021

Given weights and values of n items, put these items in a knapsack of capacity W to get the maximum total value in the knapsack. In other words, given two integer arrays val[0..n-1] and wt[0..n-1] which represent values and weights associated with n items respectively. Also given an integer W which represents knapsack capacity, find out the maximum value subset of val[] such that sum of the weights of this subset is smaller than or equal to W. You cannot break an item, either pick the complete item or don't pick it (0-1 property).



0-1 Knapsack Problem

value[] = {60, 100, 120};
weight[] = {10, 20, 30};
W = 50;

Solution: 220

Weight = 10; Value = 60;
Weight = 20; Value = 100;
Weight = 30; Value = 120;
Weight = (20+10); Value = (100+60);
Weight = (30+10); Value = (120+60);
Weight = (30+20); Value = (120+100);
Weight = (30+20+10) > 50

Recommended: Please solve it on "***PRACTICE***" first, before moving on to the solution.

weight and value of all subsets. Consider the only subsets whose total weight is smaller than W. From all such subsets, pick the maximum value subset.
Optimal Sub-structure: To consider all subsets of items, there can be two cases for every item.

1. **Case 1:** The item is included in the optimal subset.
2. **Case 2:** The item is not included in the optimal set.

Therefore, the maximum value that can be obtained from 'n' items is the max of the following two values.

1. Maximum value obtained by n-1 items and W weight (excluding nth item).
2. Value of nth item plus maximum value obtained by n-1 items and W minus the weight of the nth item (including nth item).

If the weight of 'nth' item is greater than 'W', then the nth item cannot be included and **Case 1** is the only possibility.

Below is the implementation of the above approach:

C++

```
/* A Naive recursive implementation of
 0-1 Knapsack problem */
#include <bits/stdc++.h>
using namespace std;

// A utility function that returns
// maximum of two integers
int max(int a, int b) { return (a > b) ? a : b; }

// Returns the maximum value that
// can be put in a knapsack of capacity W
int knapSack(int W, int wt[], int val[], int n)
{

    // Base Case
    if (n == 0 || W == 0)
    // than Knapsack capacity W, then
    // this item cannot be included
    // in the optimal solution
    if (wt[n - 1] > W)
        return knapSack(W, wt, val, n - 1);

    // Return the maximum of two cases:
    // (1) nth item included
    // (2) not included
    else
        return max(
            val[n - 1]
                + knapSack(W - wt[n - 1],
                           wt, val, n - 1),
            knapSack(W, wt, val, n - 1));
}

// Driver code
int main()
{
    int val[] = { 60, 100, 120 };
    int wt[] = { 10, 20, 30 };
    int W = 50;
    int n = sizeof(val) / sizeof(val[0]);
    cout << knapSack(W, wt, val, n);
    return 0;
}

// This code is contributed by rathbhupendra
```

C

```
/* A Naive recursive implementation
of 0-1 Knapsack problem */
#include <stdio.h>

// A utility function that returns
// maximum of two integers
int max(int a, int b) { return (a > b) ? a : b; }

// Returns the maximum value that can be
// put in a knapsack of capacity W
int knapSack(int W, int wt[], int val[], int n)
{
    // Base Case
    // Knapsack capacity W, then this item cannot
    // be included in the optimal solution
    if (wt[n - 1] > W)
        return knapSack(W, wt, val, n - 1);

    // Return the maximum of two cases:
    // (1) nth item included
    // (2) not included
    else
        return max(
            val[n - 1]
                + knapSack(W - wt[n - 1],
                           wt, val, n - 1),
            knapSack(W, wt, val, n - 1));
}

// Driver program to test above function
int main()
{
    int val[] = { 60, 100, 120 };
    int wt[] = { 10, 20, 30 };
    int W = 50;
    int n = sizeof(val) / sizeof(val[0]);
    printf("%d", knapSack(W, wt, val, n));
    return 0;
}
```

Java

```
/* A Naive recursive implementation
of 0-1 Knapsack problem */
class Knapsack {

    // A utility function that returns
    // maximum of two integers
    static int max(int a, int b)
    {
      return (a > b) ? a : b;
    }

    // Returns the maximum value that
    // can be put in a knapsack of
    // capacity W
    static int knapSack(int W, int wt[], int val[], int n)
    {
        // If weight of the nth item is
        // more than Knapsack capacity W,
        // then this item cannot be included
        // in the optimal solution
        if (wt[n - 1] > W)
            return knapSack(W, wt, val, n - 1);

        // Return the maximum of two cases:
        // (1) nth item included
        // (2) not included
        else
            return max(val[n - 1]
                           + knapSack(W - wt[n - 1], wt,
                                      val, n - 1),
                           knapSack(W, wt, val, n - 1));
    }

    // Driver code
    public static void main(String args[])
    {
        int val[] = new int[] { 60, 100, 120 };
        int wt[] = new int[] { 10, 20, 30 };
        int W = 50;
        int n = val.length;
        System.out.println(knapSack(W, wt, val, n));
    }
}
/*This code is contributed by Rajat Mishra */
```

Python

```
# A naive recursive implementation
# of 0-1 Knapsack Problem

# Returns the maximum value that
# can be put in a knapsack of
# capacity W


def knapSack(W, wt, val, n):

    # Base Case
    if n == 0 or W == 0:
        return 0
    if (wt[n-1] > W):
        return knapSack(W, wt, val, n-1)

    # return the maximum of two cases:
    # (1) nth item included
    # (2) not included
    else:
        return max(
            val[n-1] + knapSack(
                W-wt[n-1], wt, val, n-1),
            knapSack(W, wt, val, n-1))

# end of function knapSack


#Driver Code
val = [60, 100, 120]
wt = [10, 20, 30]
W = 50
n = len(val)
print knapSack(W, wt, val, n)

# This code is contributed by Nikhil Kumar Singh
```

C#

```
/* A Naive recursive implementation of
0-1 Knapsack problem */
using System;

class GFG {

    // A utility function that returns
    // maximum of two integers
    static int max(int a, int b)
    {
        return (a > b) ? a : b;
    }

    // Returns the maximum value that can
    // be put in a knapsack of capacity W
    static int knapSack(int W, int[] wt,
                        int[] val, int n)
    {
        // If weight of the nth item is
        // more than Knapsack capacity W,
        // then this item cannot be
        // included in the optimal solution
        if (wt[n - 1] > W)
            return knapSack(W, wt,
                            val, n - 1);

        // Return the maximum of two cases:
        // (1) nth item included
        // (2) not included
        else
            return max(val[n - 1]
                       + knapSack(W - wt[n - 1], wt,
                                  val, n - 1),
                       knapSack(W, wt, val, n - 1));
    }

    // Driver code
    public static void Main()
    {
        int[] val = new int[] { 60, 100, 120 };
        int[] wt = new int[] { 10, 20, 30 };
        int W = 50;
        int n = val.Length;

        Console.WriteLine(knapSack(W, wt, val, n));
    }
}

// This code is contributed by Sam007
```

PHP

```
<?php
// A Naive recursive implementation
// of 0-1 Knapsack problem

// Returns the maximum value that
// can be put in a knapsack of
// capacity W
function knapSack($W, $wt, $val, $n)
{
    // Base Case
    if ($n == 0 || $W == 0)
    // W, then this item cannot be
    // included in the optimal solution
    if ($wt[$n - 1] > $W)
        return knapSack($W, $wt, $val, $n - 1);

    // Return the maximum of two cases:
    // (1) nth item included
    // (2) not included
    else
        return max($val[$n - 1] +
               knapSack($W - $wt[$n - 1],
               $wt, $val, $n - 1),
               knapSack($W, $wt, $val, $n-1));
}

    // Driver Code
    $val = array(60, 100, 120);
    $wt = array(10, 20, 30);
    $W = 50;
    $n = count($val);
    echo knapSack($W, $wt, $val, $n);

// This code is contributed by Sam007
?>
```

Javascript

```
<script>

    /* A Naive recursive implementation of
    0-1 Knapsack problem */

    // A utility function that returns
    // maximum of two integers
    function max(a, b)
    {
         return (a > b) ? a : b;
    }

    // Returns the maximum value that can
    // be put in a knapsack of capacity W
    function knapSack(W, wt, val, n)
    {

        // Base Case
        // more than Knapsack capacity W,
        // then this item cannot be
        // included in the optimal solution
        if (wt[n - 1] > W)
            return knapSack(W, wt, val, n - 1);

        // Return the maximum of two cases:
        // (1) nth item included
        // (2) not included
        else
            return max(val[n - 1] +
            knapSack(W - wt[n - 1], wt, val, n - 1),
            knapSack(W, wt, val, n - 1));
    }

    let val = [ 60, 100, 120 ];
    let wt = [ 10, 20, 30 ];
       let W = 50;
    let n = val.length;

    document.write(knapSack(W, wt, val, n));

</script>
```

Output

```
220
```

It should be noted that the above function computes the same sub-problems again and again. See the following recursion tree, K(1, 1) is being evaluated twice. The time complexity of this naive recursive solution is exponential (2^n).

```
In the following recursion tree, K() refers
to knapSack(). The two parameters indicated in the
following recursion tree are n and W.
The recursion tree is for following sample inputs.
wt[] = {1, 1, 1}, W = 2, val[] = {10, 20, 30}
                       K(n, W)
                       K(3, 2)
                   /             \
        /            \                /         \
       K(1, 2)      K(1, 1)        K(1, 1)     K(1, 0)
       /  \         /   \              /        \
     /      \     /       \          /            \
K(0, 2)  K(0, 1)  K(0, 1)  K(0, 0)  K(0, 1)   K(0, 0)
Recursion tree for Knapsack capacity 2
units and 3 items of 1 unit weight.
```

Complexity Analysis:

- **Time Complexity:** $O(2^n)$.
  As there are redundant subproblems.
- **Auxiliary Space :** O(1).
  As no extra data structure has been used for storing values.

Since subproblems are evaluated again, this problem has Overlapping Sub-problems property. So the 0-1 Knapsack problem has both properties (see this and this) of a dynamic programming problem.

Method 2: Like other typical Dynamic Programming(DP) problems, re-computation of same subproblems can be avoided by constructing a temporary array K[][] in bottom-up manner. Following is Dynamic Programming based implementation.

Approach: In the Dynamic programming we will work considering the same cases as mentioned in the recursive approach. In a DP[][] table let's consider all the possible weights from '1' to 'W' as the columns and weights that can be kept as the rows.
The state DP[i][j] will denote maximum value of 'j-weight' considering all values from '1 to ith'. So if we consider 'wi' (weight in 'ith' row) we can fill it in all columns which have 'weight values > wi'. Now two possibilities can take place:

- Fill 'wi' in the given column.
- Do not fill 'wi' in the given column.

Now we have to take a maximum of these two possibilities, formally if we do not fill 'ith' weight in 'jth' column then DP[i][j] state will be same as DP[i-1][j] but if we fill the weight, DP[i][j] will be equal to the value of 'wi'+ value of the column weighing 'j-wi' in

```
Let weight elements = {1, 2, 3}
Let weight values = {10, 15, 40}
Capacity=6

0   1   2   3   4   5   6

0  0   0   0   0   0   0   0

1  0  10  10  10  10  10  10

2  0  10  15  25  25  25  25

3  0

Explanation:
For filling 'weight = 2' we come
across 'j = 3' in which
we take maximum of
(10, 15 + DP[1][3-2]) = 25
  |        |
'2'       '2 filled'
not filled

0   1   2   3   4   5   6

0  0   0   0   0   0   0   0

1  0  10  10  10  10  10  10

2  0  10  15  25  25  25  25

3  0  10  15  40  50  55  65
```

```
we come across 'j=4' in which
we take maximum of (25, 40 + DP[2][4-3])
= 50

For filling 'weight=3'
we come across 'j=5' in which
we take maximum of (25, 40 + DP[2][5-3])
= 55

For filling 'weight=3'
we come across 'j=6' in which
we take maximum of (25, 40 + DP[2][6-3])
= 65
```

C++

```cpp
// A dynamic programming based
// solution for 0-1 Knapsack problem
#include <bits/stdc++.h>
using namespace std;

// A utility function that returns
// maximum of two integers
int max(int a, int b)
{
    return (a > b) ? a : b;
}

// Returns the maximum value that
// can be put in a knapsack of capacity W
int knapSack(int W, int wt[], int val[], int n)
{
    int i, w;
    int K[n + 1][W + 1];

    // Build table K[][] in bottom up manner
    for(i = 0; i <= n; i++)
    {
        for(w = 0; w <= W; w++)
        {
            if (i == 0 || w == 0)
```

```
                                K[i - 1][w - wt[i - 1]],
                                K[i - 1][w]);
            else
                K[i][w] = K[i - 1][w];
        }
    }
    return K[n][W];
}

// Driver Code
int main()
{
    int val[] = { 60, 100, 120 };
    int wt[] = { 10, 20, 30 };
    int W = 50;
    int n = sizeof(val) / sizeof(val[0]);

    cout << knapSack(W, wt, val, n);

    return 0;
}

// This code is contributed by Debojyoti Mandal
```

C

```
// A Dynamic Programming based
// solution for 0-1 Knapsack problem
#include <stdio.h>

// A utility function that returns
// maximum of two integers
int max(int a, int b)
{
    return (a > b) ? a : b;
}

// Returns the maximum value that
// can be put in a knapsack of capacity W
int knapSack(int W, int wt[], int val[], int n)
{
    int i, w;
    int K[n + 1][W + 1];

    // Build table K[][] in bottom up manner
```

```
            if (i == 0 || w == 0)
                K[i][w] = 0;
            else if (wt[i - 1] <= w)
                K[i][w] = max(val[i - 1]
                          + K[i - 1][w - wt[i - 1]],
                          K[i - 1][w]);
            else
                K[i][w] = K[i - 1][w];
        }
    }

    return K[n][W];
}

// Driver Code
int main()
{
    int val[] = { 60, 100, 120 };
    int wt[] = { 10, 20, 30 };
    int W = 50;
    int n = sizeof(val) / sizeof(val[0]);
    printf("%d", knapSack(W, wt, val, n));
    return 0;
}
```

Java

```
// A Dynamic Programming based solution
// for 0-1 Knapsack problem
class Knapsack {

    // A utility function that returns
    // maximum of two integers
    static int max(int a, int b)
    {
          return (a > b) ? a : b;
    }

    // Returns the maximum value that can
    // be put in a knapsack of capacity W
    static int knapSack(int W, int wt[],
                        int val[], int n)
    {
        int i, w;
        int K[][] = new int[n + 1][W + 1];
```

```
                for (w = 0; w <= W; w++)
                {
                    if (i == 0 || w == 0)
                        K[i][w] = 0;
                    else if (wt[i - 1] <= w)
                        K[i][w]
                            = max(val[i - 1]
                             + K[i - 1][w - wt[i - 1]],
                             K[i - 1][w]);
                    else
                        K[i][w] = K[i - 1][w];
                }
            }

            return K[n][W];
        }

        // Driver code
        public static void main(String args[])
        {
            int val[] = new int[] { 60, 100, 120 };
            int wt[] = new int[] { 10, 20, 30 };
            int W = 50;
            int n = val.length;
            System.out.println(knapSack(W, wt, val, n));
        }
    }
    /*This code is contributed by Rajat Mishra */
```

Python

```
# A Dynamic Programming based Python
# Program for 0-1 Knapsack problem
# Returns the maximum value that can
# be put in a knapsack of capacity W


def knapSack(W, wt, val, n):
    K = [[0 for x in range(W + 1)] for x in range(n + 1)]

    # Build table K[][] in bottom up manner
    for i in range(n + 1):
        for w in range(W + 1):
            if i == 0 or w == 0:
                K[i][w] = 0
            else:
                K[i][w] = K[i-1][w]

    return K[n][W]


# Driver code
val = [60, 100, 120]
wt = [10, 20, 30]
W = 50
n = len(val)
print(knapSack(W, wt, val, n))

# This code is contributed by Bhavya Jain
```

C#

```
// A Dynamic Programming based solution for
// 0-1 Knapsack problem
using System;

class GFG {

    // A utility function that returns
    // maximum of two integers
    static int max(int a, int b)
    {
         return (a > b) ? a : b;
    }

    // Returns the maximum value that
    // can be put in a knapsack of
    // capacity W
    static int knapSack(int W, int[] wt,
                        int[] val, int n)
    {
        int i, w;
        int[, ] K = new int[n + 1, W + 1];

        // Build table K[][] in bottom
        // up manner
        for (i = 0; i <= n; i++)
        {
            for (w = 0; w <= W; w++)
            {
                    K[i, w] = Math.Max(
                        val[i - 1]
                        + K[i - 1, w - wt[i - 1]],
                        K[i - 1, w]);
                else
                    K[i, w] = K[i - 1, w];
            }
        }

        return K[n, W];
    }

    // Driver code
    static void Main()
    {
        int[] val = new int[] { 60, 100, 120 };
        int[] wt = new int[] { 10, 20, 30 };
        int W = 50;
        int n = val.Length;

        Console.WriteLine(knapSack(W, wt, val, n));
    }
}

// This code is contributed by Sam007
```

PHP

```
<?php
// A Dynamic Programming based solution
// for 0-1 Knapsack problem

// Returns the maximum value that
// can be put in a knapsack of
// capacity W
function knapSack($W, $wt, $val, $n)
{

    $K = array(array());

    // Build table K[][] in
    // bottom up manner
    for ($i = 0; $i <= $n; $i++)
    {
        for ($w = 0; $w <= $W; $w++)
```

```
                $K[$i][$w] = max($val[$i - 1] +
                                 $K[$i - 1][$w -
                                 $wt[$i - 1]],
                                 $K[$i - 1][$w]);
            else
                $K[$i][$w] = $K[$i - 1][$w];
        }
    }

    return $K[$n][$W];
}

    // Driver Code
    $val = array(60, 100, 120);
    $wt = array(10, 20, 30);
    $W = 50;
    $n = count($val);
    echo knapSack($W, $wt, $val, $n);

// This code is contributed by Sam007.
?>
```

Javascript

```
<script>
    // A Dynamic Programming based solution
    // for 0-1 Knapsack problem

    // A utility function that returns
    // maximum of two integers
    function max(a, b)
    {
          return (a > b) ? a : b;
    }

    // Returns the maximum value that can
    // be put in a knapsack of capacity W
    function knapSack(W, wt, val, n)
    {
        let i, w;
        let K = new Array(n + 1);

        // Build table K[][] in bottom up manner
        for (i = 0; i <= n; i++)
        {
```

```
                    K[i][w] = 0;
                else if (wt[i - 1] <= w)
                    K[i][w]
                        = max(val[i - 1]
                         + K[i - 1][w - wt[i - 1]],
                         K[i - 1][w]);
                else
                    K[i][w] = K[i - 1][w];
            }
        }

        return K[n][W];
    }

    let val = [ 60, 100, 120 ];
    let wt = [ 10, 20, 30 ];
    let W = 50;
    let n = val.length;
    document.write(knapSack(W, wt, val, n));
</script>
```

Output

```
220
```

Complexity Analysis:

- **Time Complexity:** O(N*W).
  where 'N' is the number of weight element and 'W' is capacity. As for every weight element we traverse through all weight capacities 1<=w<=W.
- **Auxiliary Space:** O(N*W).
  The use of 2-D array of size 'N*W'.

Method 3: This method uses Memoization Technique (an extension of recursive approach).
This method is basically an extension to the recursive approach so that we can overcome the problem of calculating redundant cases and thus increased complexity. We can solve this problem by simply creating a 2-D array that can store a particular state (n, w) if we get it the first time. Now if we come across the same state (n, w) again instead of

C++

```cpp
// Here is the top-down approach of
// dynamic programming
#include <bits/stdc++.h>
using namespace std;

// Returns the value of maximum profit
int knapSackRec(int W, int wt[],
                int val[], int i,
                int** dp)
{
    // base condition
    if (i < 0)
        return 0;
    if (dp[i][W] != -1)
        return dp[i][W];

    if (wt[i] > W) {

        // Store the value of function call
        // stack in table before return
        dp[i][W] = knapSackRec(W, wt,
                               val, i - 1,
                               dp);
        return dp[i][W];
    }
    else {
        // Store value in a table before return
        dp[i][W] = max(val[i]
                       + knapSackRec(W - wt[i],
                                     wt, val,
                                     i - 1, dp),
                        knapSackRec(W, wt, val,
                                     i - 1, dp));

        // Return value of table after storing
        return dp[i][W];
    }
}

int knapSack(int W, int wt[], int val[], int n)
{
    // double pointer to declare the
    // table dynamically
    int** dp;
    for (int i = 0; i < n; i++)
        dp[i] = new int[W + 1];

    // loop to initially filled the
    // table with -1
    for (int i = 0; i < n; i++)
        for (int j = 0; j < W + 1; j++)
            dp[i][j] = -1;
    return knapSackRec(W, wt, val, n - 1, dp);
}

// Driver Code
int main()
{
    int val[] = { 60, 100, 120 };
    int wt[] = { 10, 20, 30 };
    int W = 50;
    int n = sizeof(val) / sizeof(val[0]);
    cout << knapSack(W, wt, val, n);
    return 0;
}
```

Java

```
// Here is the top-down approach of
// dynamic programming
class GFG{

// A utility function that returns
// maximum of two integers
static int max(int a, int b)
{
    return (a > b) ? a : b;
}

// Returns the value of maximum profit
static int knapSackRec(int W, int wt[],
                       int val[], int n,
                       int [][]dp)
{

    // Base condition
    if (n == 0 || W == 0)
        return 0;
        // Store the value of function call
        // stack in table before return
        return dp[n][W] = knapSackRec(W, wt, val,
                                      n - 1, dp);

    else

        // Return value of table after storing
        return dp[n][W] = max((val[n - 1] +
                              knapSackRec(W - wt[n - 1], wt,
                                          val, n - 1, dp)),
                              knapSackRec(W, wt, val,
                                          n - 1, dp));
}

static int knapSack(int W, int wt[], int val[], int N)
{

    // Declare the table dynamically
    int dp[][] = new int[N + 1][W + 1];

    // Loop to initially filled the
    // table with -1
    for(int i = 0; i < N + 1; i++)
        for(int j = 0; j < W + 1; j++)
            dp[i][j] = -1;

    return knapSackRec(W, wt, val, N, dp);
}

// Driver Code
public static void main(String [] args)
{
    int val[] = { 60, 100, 120 };
    int wt[] = { 10, 20, 30 };

    int W = 50;
    int N = val.length;

    System.out.println(knapSack(W, wt, val, N));
}
}

// This Code is contributed By FARAZ AHMAD
```

```
# 0 / 1 Knapsack in Python in simple
# we can say recursion + memoization = DP

# driver code
val = [60, 100, 120 ]
wt = [10, 20, 30 ]
W = 50
n = len(val)

# We initialize the matrix with -1 at first.
t = [[-1 for i in range(W + 1)] for j in range(n + 1)]


def knapsack(wt, val, W, n):

    # base conditions
    if n == 0 or W == 0:
        return 0
    if t[n][W] != -1:
        return t[n][W]

    # choice diagram code
    if wt[n-1] <= W:
        t[n][W] = max(
            val[n-1] + knapsack(
                wt, val, W-wt[n-1], n-1),
            knapsack(wt, val, W, n-1))
        return t[n][W]
    elif wt[n-1] > W:
        t[n][W] = knapsack(wt, val, W, n-1)
        return t[n][W]


print(knapsack(wt, val, W, n))

# This code is contributed by Prosun Kumar Sarkar
```

C#

```
// Here is the top-down approach of
// dynamic programming
using System;
public class GFG
{
```

```
// Returns the value of maximum profit
static int knapSackRec(int W, int[] wt, int[] val,
                       int n, int[, ] dp)
{

    // Base condition
    if (n == 0 || W == 0)
        return 0;
    if (dp[n, W] != -1)
        return dp[n, W];
    if (wt[n - 1] > W)

        // Store the value of function call
        // stack in table before return
        return dp[n, W]
            = knapSackRec(W, wt, val, n - 1, dp);

    else

        // Return value of table after storing
        return dp[n, W]
            = max((val[n - 1]
                   + knapSackRec(W - wt[n - 1], wt, val,
                                 n - 1, dp)),
                  knapSackRec(W, wt, val, n - 1, dp));
}

static int knapSack(int W, int[] wt, int[] val, int N)
{

    // Declare the table dynamically
    int[, ] dp = new int[N + 1, W + 1];

    // Loop to initially filled the
    // table with -1
    for (int i = 0; i < N + 1; i++)
        for (int j = 0; j < W + 1; j++)
            dp[i, j] = -1;

    return knapSackRec(W, wt, val, N, dp);
}

// Driver Code
static public void Main()
{

    int[] val = new int[]{ 60, 100, 120 };
```

```
        Console.WriteLine(knapSack(W, wt, val, N));
    }
}

// This Code is contributed By Dharanendra L V.
```

Output:

```
220
```

Complexity Analysis:

- **Time Complexity:** O(N*W).
  As redundant calculations of states are avoided.
- **Auxiliary Space:** O(N*W).
  The use of 2D array data structure for storing intermediate states-:

[Note: For 32bit integer use long instead of int.]

References:

- http://www.es.ele.tue.nl/education/5MC10/Solutions/knapsack.pdf
- http://www.cse.unl.edu/~goddard/Courses/CSCE310J/Lectures/Lecture8-DynamicProgramming.pdf

https://youtu.be/T4bY72lCQac?list=PLqM7alHXFySGMu2CSdW_6d2u1o6WFTIO-
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