Dynamic Programming | Set 10 (0-1 Knapsack Problem)

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).

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

A simple solution is to consider all subsets of items and calculate the total 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.

1) Optimal Substructure:
To consider all subsets of items, there can be two cases for every item: (1) the item is included in the optimal subset, (2) not included in the optimal set.
Therefore, the maximum value that can be obtained from n items is max of 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 weight of the nth item (including nth item).

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

2) Overlapping Subproblems
Following is recursive implementation that simply follows the recursive structure mentioned above.

C/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
   if (n == 0 || W == 0)
       return 0;

   // 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 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;
}
```

Run on IDE

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)
     {
        // Base Case
    if (n == 0 || W == 0)
        return 0;

    // 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 program to test above function
    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 */
```

Run on IDE

Python

```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 weight of the nth item is more than Knapsack of 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))

# end of function knapSack

# To test above function
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
```

Run on IDE

Output:

```
220
```

It should be noted that the above function computes the same subproblems again and again. See the following recursion tree, K(1, 1) is being evaluated twice. 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(3, 2)         ---------> K(n, W)
                   /            \ 
                 /                \               
            K(2,2)                  K(2,1)
          /       \                  /    \ 
        /           \              /        \
       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.
```

Since suproblems are evaluated again, this problem has Overlapping Subprolems property. So the 0-1 Knapsack problem has both properties (see this and this) of a dynamic programming problem. Like other typical Dynamic Programming(DP) problems, recomputations of same subproblems can be avoided by constructing a temporary array K[][] in bottom up manner. Following is Dynamic Programming based implementation.

C++

```cpp
// 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
   for (i = 0; i <= n; i++)
   {
       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];
}

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;
}
```

Run on IDE

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];

     // 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][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 program to test above function
    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 */
```

Run on IDE

Python

```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
            elif 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 program to test above function
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
```

Run on IDE

Output:

```
220
```

Time Complexity: O(nW) where n is the number of items and W is the capacity of knapsack.

Asked in: Amazon, Flipkart, GreyOrange , Microsoft, Mobicip, Morgan Stanely, Oracle, Payu, Snapdeal, Visa

References:

http://www.es.ele.tue.nl/education/5MC10/Solutions/knapsack.pdf

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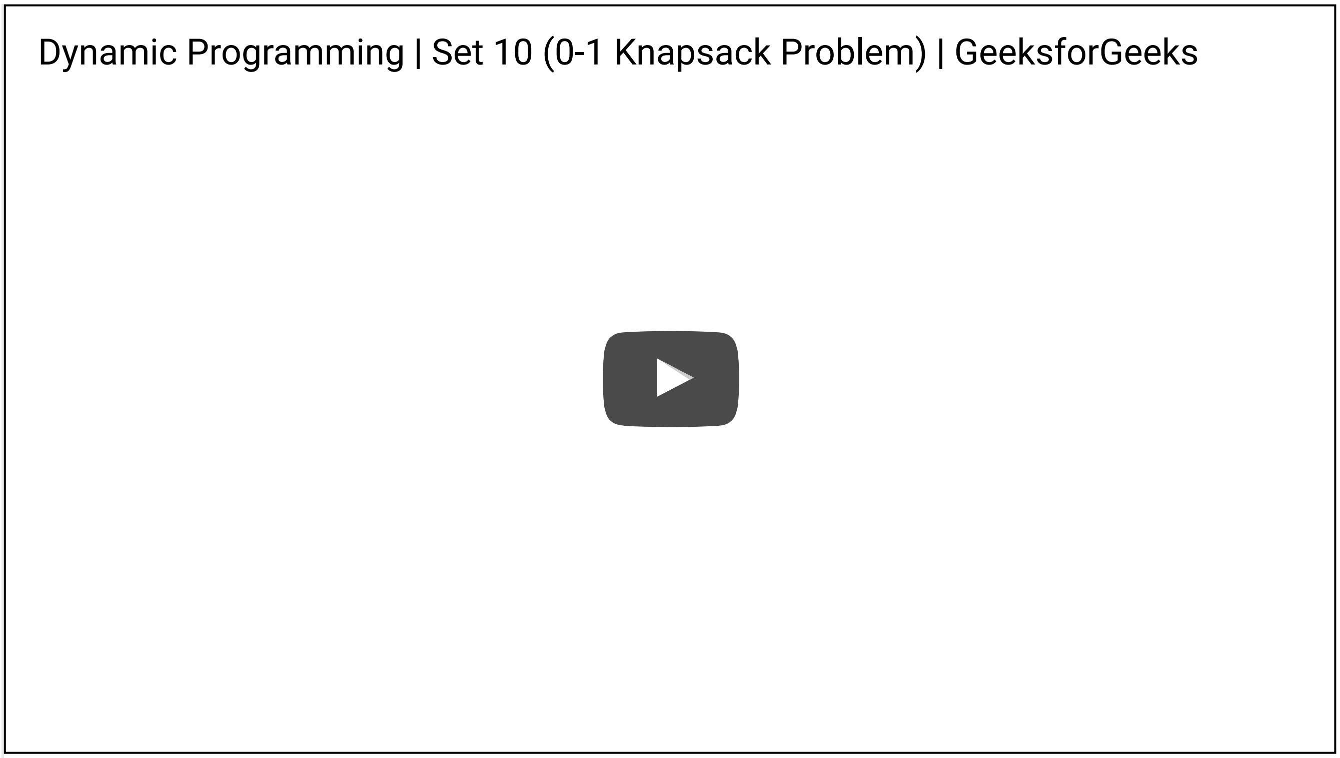

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