Count of Subset Sum

We'll cover the following

Problem Statement

Given a set of positive numbers, find the total number of subsets whose sum is equal to a given number 'S'.

Example 1:

```
Input: {1, 1, 2, 3}, S=4
Output: 3
The given set has '3' subsets whose sum is '4': {1, 1, 2}, {1, 3}, {1, 3}
Note that we have two similar sets {1, 3}, because we have two '1' in our input.
```

Example 2:

```
Input: {1, 2, 7, 1, 5}, S=9
Output: 3
The given set has '3' subsets whose sum is '9': {2, 7}, {1, 7, 1}, {1, 2, 1, 5}
```

Basic Solution

This problem follows the **0/1 Knapsack pattern** and is quite similar to Subset Sum (https://www.educative.io/collection/page/5668639101419520/5633779737559040/5646239437684736). The only difference in this problem is that we need to count the number of subsets, whereas in the Subset Sum (https://www.educative.io/collection/page/5668639101419520/5633779737559040/5646239437684736) we only wanted to know if there exists a subset with the given sum.

A basic brute-force solution could be to try all subsets of the given numbers to count the subsets that have a sum equal to 'S'. So our brute-force algorithm will look like:

```
for each number 'i'
  create a new set which includes number 'i' if it does not exceed 'S', and recursively
      process the remaining numbers and sum
  create a new set without number 'i', and recursively process the remaining numbers
return the count of subsets who has a sum equal to 'S'
```

Code

Here is the code for the brute-force solution:

Java | JS | Python3 | C++

```python
def count_subsets(num, sum):
  return count_subsets_recursive(num, sum, 0)


def count_subsets_recursive(num, sum, currentIndex):
  # base checks
  if sum == 0:
    return 1
  n = len(num)
  if n == 0 or currentIndex >= n:
    return 0

  # recursive call after selecting the number at the currentIndex
  # if the number at currentIndex exceeds the sum, we shouldn't process this
  sum1 = 0
  if num[currentIndex] <= sum:
    sum1 = count_subsets_recursive(
      num, sum - num[currentIndex], currentIndex + 1)

  # recursive call after excluding the number at the currentIndex
  sum2 = count_subsets_recursive(num, sum, currentIndex + 1)

  return sum1 + sum2


def main():
  print("Total number of subsets " + str(count_subsets([1, 1, 2, 3], 4)))
  print("Total number of subsets: " + str(count_subsets([1, 2, 7, 1, 5], 9)))


main()
```

The time complexity of the above algorithm is exponential $O(2^n)$, where 'n' represents the total number. The space complexity is $O(n)$, this memory is used to store the recursion stack.

Top-down Dynamic Programming with Memoization

We can use memoization to overcome the overlapping sub-problems. We will be using a two-dimensional array to store the results of solved sub-problems. As mentioned above, we need to store results for every subset and for every possible sum.

Code

Here is the code:

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```python
def count_subsets(num, sum):
  # create a two dimensional array for Memoization, each element is initialized to '-1'
  dp = [[-1 for x in range(sum+1)] for y in range(len(num))]
  return count_subsets_recursive(dp, num, sum, 0)


def count_subsets_recursive(dp, num, sum, currentIndex):
  # base checks
  if sum == 0:
    return 1

  n = len(num)
  if n == 0 or currentIndex >= n:
    return 0

  # check if we have not already processed a similar problem
  if dp[currentIndex][sum] == -1:
    # recursive call after choosing the number at the currentIndex
    # if the number at currentIndex exceeds the sum, we shouldn't process this
    sum1 = 0
    if num[currentIndex] <= sum:
      sum1 = count_subsets_recursive(
        dp, num, sum - num[currentIndex], currentIndex + 1)

    # recursive call after excluding the number at the currentIndex
    sum2 = count_subsets_recursive(dp, num, sum, currentIndex + 1)

    dp[currentIndex][sum] = sum1 + sum2

  return dp[currentIndex][sum]


def main():
  print("Total number of subsets " + str(count_subsets([1, 1, 2, 3], 4)))
  print("Total number of subsets: " + str(count_subsets([1, 2, 7, 1, 5], 9)))


main()
```

Bottom-up Dynamic Programming

We will try to find if we can make all possible sums with every subset to populate the array `db[TotalNumbers][S+1]`.

So, at every step we have two options:

1. Exclude the number. Count all the subsets without the given number up to the given sum => `dp[index-1][sum]`
2. Include the number if its value is not more than the 'sum'. In this case, we will count all the subsets to get the remaining sum => `dp[index-1][sum-num[index]]`

To find the total sets, we will add both of the above two values:

```
dp[index][sum] = dp[index-1][sum] + dp[index-1][sum-num[index]])
```

Let’s start with our base case of size zero:

num\sum	0	1	2	3	4
1	1				
{1, 1}	1				
{1,1,2}	1				
{1,1,2,3}	1				

'0' sum can always be found through an empty set

1 of 12

num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1				
{1,1,2}	1				
{1,1,2,3}	1				

With only one number, we can form a subset only when the required sum is equal to the number

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2			
{1,1,2}	1				
{1,1,2,3}	1				

sum: 1, index:1=> (dp[index-1][sum] + dp[index-1][sum - 1])

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1		
{1,1,2}	1				
{1,1,2,3}	1				

sum: 2, index:1=> (dp[index-1][sum] + dp[index-1][sum - 1])

4 of 12

num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1				
{1,1,2,3}	1				

sum: 3,4, index:1=> (dp[index-1][sum] + dp[index-1][sum - 1])

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2			
{1,1,2,3}	1				

sum: 1, index:2=> dp[index-1][sum], as sum is less than the number at index 2 (i.e., 1 < 2)

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2	2		
{1,1,2,3}	1				

sum: 2, index:2=> (dp[index-1][sum] + dp[index-1][sum - 2])

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2	2	2	
{1,1,2,3}	1				

sum: 3, index:2=> (dp[index-1][sum] + dp[index-1][sum - 2])

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2	2	2	1
{1,1,2,3}	1				

sum: 4, index:2=> (dp[index-1][sum] + dp[index-1][sum - 2])

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2	2	2	1
{1,1,2,3}	1	2	2		

sum: 1,2, index:3=> dp[index-1][sum] , as the sum is less than the element at index '3'

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2	2	2	1
{1,1,2,3}	1	2	2	3	

sum: 3, index:3=> (dp[index-1][sum] + dp[index-1][sum - 3])

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num\sum	0	1	2	3	4
1	1	1	0	0	0
{1, 1}	1	2	1	0	0
{1,1,2}	1	2	2	2	1
{1,1,2,3}	1	2	2	3	3

sum: 4, index:3=> (dp[index-1][sum] + dp[index-1][sum - 3])

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Code

Here is the code for our bottom-up dynamic programming approach:

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```
def count_subsets(num, sum):
  n = len(num)
```

```python
  dp = [[-1 for x in range(sum+1)] for y in range(n)]

  # populate the sum = 0 columns, as we will always have an empty set for zero sum
  for i in range(0, n):
    dp[i][0] = 1

  # with only one number, we can form a subset only when the required sum is
  # equal to its value
  for s in range(1, sum+1):
    dp[0][s] = 1 if num[0] == s else 0

  # process all subsets for all sums
  for i in range(1, n):
    for s in range(1, sum+1):
      # exclude the number
      dp[i][s] = dp[i - 1][s]
      # include the number, if it does not exceed the sum
      if s >= num[i]:
        dp[i][s] += dp[i - 1][s - num[i]]

  # the bottom-right corner will have our answer.
  return dp[n - 1][sum]


def main():
  print("Total number of subsets " + str(count_subsets([1, 1, 2, 3], 4)))
  print("Total number of subsets: " + str(count_subsets([1, 2, 7, 1, 5], 9)))


main()
```

The above solution has time and space complexity of $O(N * S)$, where 'N' represents total numbers and 'S' is the desired sum.

Challenge

Can we further improve our bottom-up DP solution? Can you find an algorithm that has $O(S)$ space complexity?

Show Hint

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```python
def count_subsets(num, sum):
  # TODO: Write - Your - Code
  return -1
```

Solution

```python
def count_subsets(num, sum):
  n = len(num)
  dp = [0 for x in range(sum+1)]
```

```
  dp[0] = 1

  # with only one number, we can form a subset only when the required sum is equal to the numb
  for s in range(1, sum+1):
    dp[s] = 1 if num[0] == s else 0

  # process all subsets for all sums
  for i in range(1, n):
    for s in range(sum, -1, -1):
      if s >= num[i]:
        dp[s] += dp[s - num[i]]

  return dp[sum]


def main():
  print("Total number of subsets " + str(count_subsets([1, 1, 2, 3], 4)))
  print("Total number of subsets: " + str(count_subsets([1, 2, 7, 1, 5], 9)))


main()
```

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