Dynamic Programming, Graph Algorithm Problems and Their Solutions In Code

compiled by D. Gueorguiev, 8/21/2024

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# Problems Solvable by Dynamic Programming

## The N-th Fibonacci Number

//TODO: Finish the section on the N-th Fibonacci number

## Rod Cutting Problem

Given a rod of length inches (or centimeters) and a table of prices for find the max obtainable revenue by cutting the rod and selling the pieces.

The problem must exhibit optimal substructure if in order to solve the original problem of size we solve similar problems of the same type but smaller sizes.

(1)

Execution time complexity:

(2)

The solution of (2) is given by

(3)

(3) represents exponential time complexity.

Let us assume we are given an integer n and a list p with len(p) >= n. We want to find the max revenue and a partition of n which achieves it.

in code:

def cut\_rod(n: int, p: list[int]):

if n == 0:

//TODO: Finish the section on the rod cutting problem

## Min Cost Path

Given a cost matrix cost[][] and a position (M,N) in cost[][], write a function that returns cost of minimum cost path to reach (M,N) from (0,0). Each cell of the matrix represents a cost to traverse through that cell. The total cost of a path to reach (M,N) is the sum of all the costs on that path (including both source and destination). You can only traverse down , right, and diagonally lower cells from a given cell, i.e. from a given cell (i,j), cells (i+1,j), (i,j+1), and (i+1,j+1) can be traversed.

Example:

1, 2, 3

4, 8, 2

1, 5, 3

The path with min cost is (0,0)->(0,1)->(1,2)->(2,2). The cost of the path is 1+2+2+3=8.

Naïve implementation of the solution using recursive algorithm

import sys

def minCost(cost, m, n):

if n < 0 or m < 0:

return sys.maxsize

elif m == 0 and n == 0:

return cost[m][n]

else:

return cost[m][n] + min(minCost(cost, m-1, n-1),

minCost(cost, m-1, n),

minCost(cost, m, n-1))

Slightly better implementation using recursive algorithm with memoization

import sys

def minCostMemoized(cost, m, n):

if n < 0 or m < 0:

return sys.maxsize

elif m == 0 and n == 0:

return cost[m][n]

if memo[m][n] != -1:

return memo[m][n]

memo[m][n] = cost[m][n] + min(

minCostMemoized(cost, m-1, n-1),

minCostMemoized(cost, m-1, n),

minCostMemoized(cost, m, n-1))

Here memo is a list of lists with sizes equal to the row length and col length of the cost matrix initialized originally to -1:

memo = [[-1] \* C for \_ in range(R)] # R = len(cost) and C = len(cost[0])

Dynamic Programming formulation and implementation of the min cost problem:

def minCost(cost, m, n):

tot\_cost = [[0 for x in range(n+1)] for x in range(m+1)]

tot\_cost[0][0] = cost[0][0]

# Initialize first column of tot\_cost array

for i in range(1, m+1):

tot\_cost[i][0] = tot\_cost[i-1][0] + cost[i][0]

# Initialize first row of tot\_cost array

for j in range(1, n+1):

tot\_cost[0][j] = tot\_cost[0][j-1] + cost[0][j]

# Construct rest of the tot\_cost array

for i in range(1, m+1):

for j in range(1, n+1):

tot\_cost[i][j] = min(tot\_cost[i-1][j-1], tot\_cost[i-1][j], tot\_cost[i][j-1]) + cost[i][j]

return tot\_cost[m][n]

Dynamic Programming formulation without the additional space complexity of tot\_cost

def minCost(cost, row, col):

# For 1st column

for i in range(1, row):

cost[i][0] += cost[i - 1][0]

# For 1st row

for j in range(1, col):

cost[0][j] += cost[0][j - 1]

# For rest of the 2d matrix

for i in range(1, row):

for j in range(1, col):

cost[i][j] += (min(cost[i - 1][j - 1],

min(cost[i - 1][j],

cost[i][j - 1])))

# Returning the value in

# last cell

return cost[row - 1][col - 1]

//TODO: Finish the section on the Min Cost Path problem

## Moving in An Array in an Optimal Way (Denardo)

//TODO: Finish the section on the problem of Moving In An Array in an Optimal Way

## Weighted Job Scheduling

//TODO: Finish the section on the Weighted Job Scheduling problem

## Longest Common Sequence

Let us consider strings in the form where are strings or characters. We say that the tuple forms a sequence in if appears on the left of for each pair such that . Given two strings and find the length of the largest common sequence .

#### Naïve Implementation

def longest\_common\_sequence(s1: str, s2: str, m: int, n: int):

“““

Determine the length of the longest common sequence.

:param s1: str

:param s2: str

:param m: int

:param n: int

“““

if m == 0 or n == 0:

return 0

elif s1[m-1] == s2[n-1]:

return 1 + longest\_common\_sequence(s1, s2, m-1, n-1)

else:

return max(longest\_common\_sequence(s1, s2, m, n-1),

longest\_common\_sequence(s1, s2, m-1, n))

**Excerpt 7**: naïve implementation for the longest common sequence

Question to the candidate: what is the problem with the Naïve implementation?

Answer: awful time complexity which is exponential

Question to candidate: Why the time complexity is exponential, and can it be eliminated?

Answer: It is exponential because the same string fragments are searched multiple times. In this case using recursion by itself alone does not do us favor. Yes, it can be avoided by using memoization.

Details:

Let us have the following two strings “DIMIT” and “DMTI”. Let us find out how the function in Excerpt 7 will execute. For brevity we will denote the function longest\_common\_sequence on Excerpt 7 with .

#### Dynamic Programming implementation

Optimal Subproblem formulation

Initially,

//TODO: Finish the section on the LCS problem

## 0/1 Knapsack Problem

Given are items where each item has some weight and profit associated with it. Also, it is given a bag with capacity - that is, the bag can hold at most weight in it. The task is to put such combination of items in the bag so that the profit is maximized. The constraint is that we can put an item in the bag, or we cannot put it at all, it is not possible to put only a fraction of it.

Input: N = 3, W = 4, profit = [1, 3, 4], weight = [4, 5, 1]

Let us denote with

Naïve recursive algorithm:

# A naive recursive implementation

# of 0-1 Knapsack Problem

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))

1 ) find the subset of elements , each with a weight less than . That is,

2 )

//TODO: Finish the section on the 0/1 Knapsack problem

## Floyd-Warshall Algorithm

//TODO: Finish the section on the Floyd-Warshall algorithm

## Bellman-Ford Algorithm

//TODO: Finish the section on the Bellman-Ford algorithm

## Vertex Cover Problem

//TODO: Finish the section on the Vertex Cover problem

## Travelling Salesman Problem

//TODO: Finish the section on the TSP problem

## Longest Palindromic Subsequence

//TODO: Finish the section on the Longest Palindromic Subsequence problem

## Minimum Insertions to Form a Palindrome

//TODO: Finish the section on the Min Inserts to Form A Palindrome problem

## Matrix Chain Multiplication

//TODO: Finish the section on the Matrix Chain Multiplication

# Problems Solvable By Recursive Backtracking

## N Queens Problem

Place queens on board so that no pair of Queens attack each other.

For example, when N = 4 we have:

.Q..

...Q

Q...

..Q.

//TODO: Finish the section on the N Queens problem

## 2 x 2 Sudoku Solver

//TODO: Finish the section on the 2 x 2 sudoku solver algorithm

# Related Graph Algorithms

## Dijkstra’s Shortest Path Algorithm

//TODO: Finish the section on the Dijkstra’s Shortest Path algorithm

## Breath-First Search Algorithm

//TODO: Finish the section on the Breath-First Search algorithm

## Depth-First Search Algorithm

//TODO: Finish the section on the Depth-First Search algorithm

# References

[GeeksForGeeks Dynamic Programming Intro](https://www.geeksforgeeks.org/dynamic-programming/)

[Dynamic Programming: Models and Applications, Eric Denardo, 1982, Yale U.](https://github.com/dimitarpg13/graphs_and_dynamic_programming/blob/master/books/dynamic-programming-models-and-application-denardo.pdf)

[Dynamic Programming, Richard Bellman, Princeton, 1957, Sixth Print 1972](https://github.com/dimitarpg13/graphs_and_dynamic_programming/blob/master/books/1957-bellman-dynamicprogramming.pdf)

[Digraphs Theory, Algorithms, and Applications, Bang-Jensen, and Gutin, 2007](https://github.com/dimitarpg13/graphs_and_dynamic_programming/blob/master/books/DigraphsJensenGutin.pdf)