

CSE 101 Homework 7

Brian Masse, Taira Sakamoto, Emily Xie, Annabelle Coles

December 4, 2025

1. Bus routes

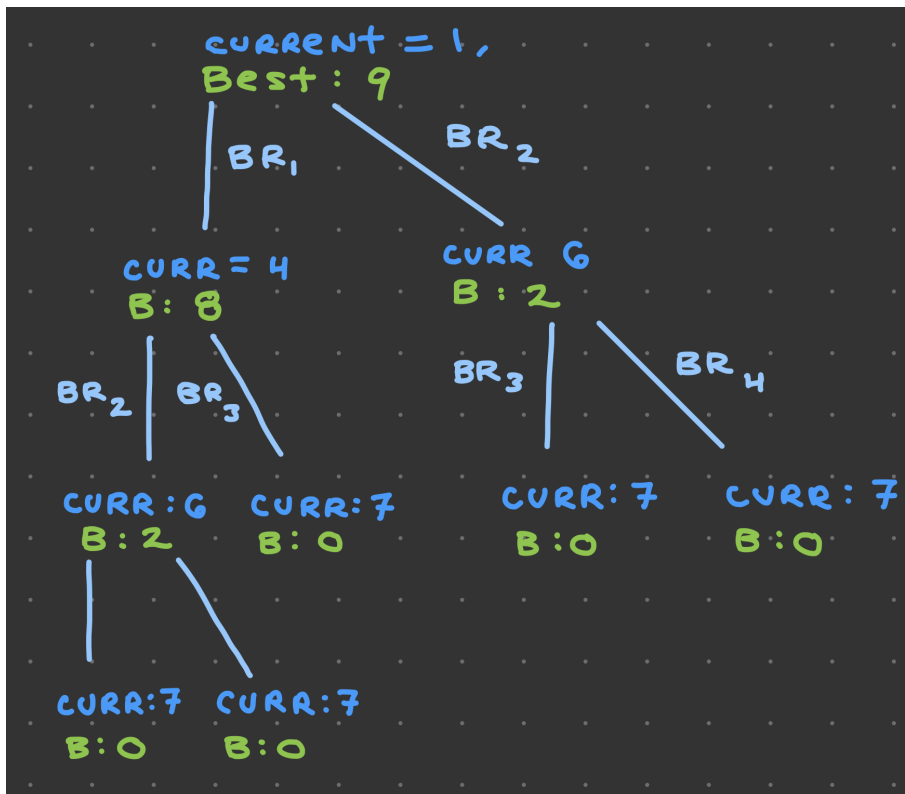
I am going by bus across town, along a path that includes bus stops $1 \dots m$. There are n different bus routes $BR_1 \dots BR_n$, where BR_i goes along my route between stop s_i to stop f_i , and costs c_i to ride. I want to go from stop 1 to stop m paying the smallest total amount as I can. You can assume there will always be a later bus for each route passing each stop.

$BTBusCosts(BR_1 \dots BR_n; current; m)$

- (a) IF $current \geq m$ return 0.
- (b) $Best = \text{infinity}$;
- (c) FOR $I = 1$ to n do:
- (d) IF $s_i \leq current < f_i$
- (e) THEN $Best = \min(Best, c_i + BTBusCosts(BR_1 \dots BR_n; f_i; m))$.
- (f) Return $Best$

Questions

- (a) Give the tree of recursive calls on the instance $current = 1, m = 7, BR_1 = (1, 4, 3), BR_2 = (1, 6, 7), BR_3 = (2, 7, 8), BR_4 = (5, 7, 2)$.



- (b) Give an upper bound for the total number of recursive calls for this algorithm.

Note that the worst case has bus routes of the following form, since it maximizes the number of recursive calls at each level.

$$\begin{aligned} BR_1 &= (1, 2) \\ BR_2 &= (1, 3) \\ &\vdots \\ BR_n &= (1, n+1) \end{aligned}$$

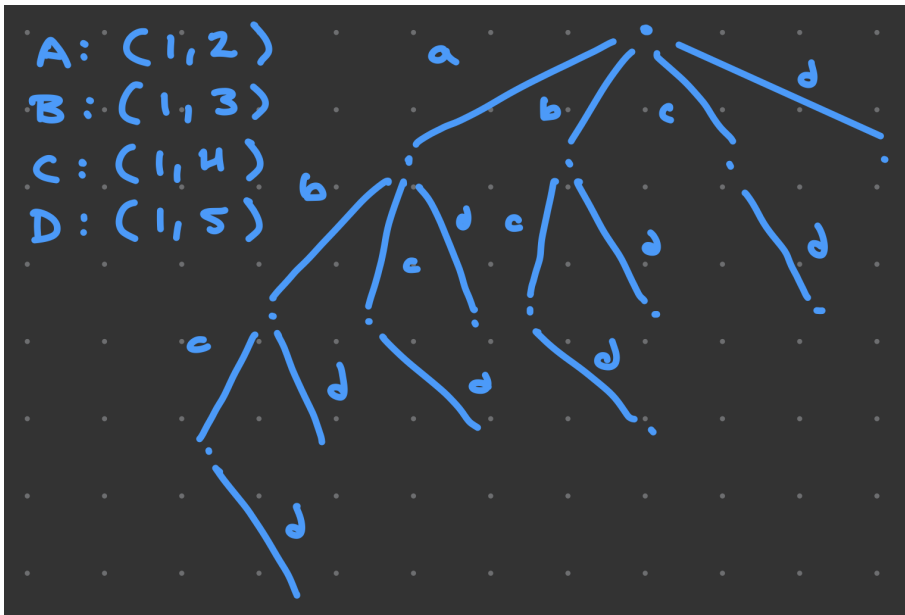
Let x be the distance from current position to position m . Then $T(x)$ is the number of recursive calls at a distance x to the finish:

$$\begin{aligned} T(x) &= T(x-1) + T(x-2) + \dots T(1) \\ &\leq x \cdot T(x-1) \text{ Since, } T(x-i-1) \leq T(x-i) \forall i \geq 1 \end{aligned}$$

Solving the recurrence relation with base case $T(1) = 1$

$$\begin{aligned} T(x) &\leq x \cdot T(x-1) \\ &\vdots \\ &\leq (x)(x-1) \dots T(1) \\ &\leq x! \end{aligned}$$

Supplemental Diagram:



- (c) Which variables change during this recursion?
Only the value of *current* changes each iteration.

(d) Define sub-problems: Use the above to define a set of sub-problems that can be used to convert the BT algorithm to a DP algorithm, and define an array or matrix to hold the answers to these subproblems.

- Each subproblem starts at some $i \in 1, \dots, m$ and returns the lowest cost path from i to m . Each operates with the same bus stops and works towards the same final point m . The total number of distinct subproblems is m .
- The solutions to subproblems can be stored in a length m array, where each position is the cost to get from position i to m

(e) What are the base cases?

The singular base case is $i = m$, the subproblem where you start at the end. The cost is 0.

(f) Translate the BT algorithm into a definition of array/matrix values from other values

On iteration k , $k \in \{1, \dots, m\}$:

for BR_i such that $s_i \leq k < f_i$:

$costs[k] = \min(costs[k], c_i + costs[f_i])$

(g) In what order should we fill this array or matrix?

This matrix will be filled from the last position $k = m$ to the first position $k = 1$

(h) Assemble these pieces into a DP algorithm.

```
def bus_stops(BR1...BRn, curr, m):  
  
    // there may not be a valid path from every point i to m,  
    // so fill all spots except the ending  
    cost = [ infinity ]  
    cost[m] = 0  
  
    // go from the end of the route to the start  
    for k from m - 1 to 1:  
  
        // si, fi, ci represent the start, finish, and cost of a bus route  
        // they are defined and accessible from outside the function  
        for all BRi in BR1...BRn such that si <= k < fi:  
            cost[k] = min(cost[k], ci + cost[fi])  
  
    return cost[1]
```

(i) Give a time analysis for your DP algorithm.

- Assuming accessing costs array is $O(1)$ then the main loop $\in O(m) \cdot O(1) \in O(m)$

- Assume finding all relevant BR_i can be done in worst case $\in O(n)$

Therefore, the total runtime of the algorithm is $\in O(n \cdot m)$

- (j) Give the array or matrix for your DP algorithm on the given example.

$m = 7$	1	2	3	4	5	6	7
$BR_1 = (1, 4, 3)$	∞	∞	∞	∞	∞	∞	0
$BR_2 = (1, 6, 7)$	9	2	8	8	2	2	0
$BR_3 = (2, 7, 8)$							
$BR_4 = (5, 7, 2)$							

2. Bounded difference sequence

We say a sequence of numbers $a_1, ..a_n$ is K -bounded difference if $|a_{i+1}-a_i| \leq K$ for all $1 \leq i \leq n-1$. The maximum bounded difference subsequence problem is, given sequence $a_1, ..a_n$, and a real number $K > 0$, decide the length ℓ of the longest subsequences $a_{i_1}, ..a_{i_\ell}$, $1 = i_1 < i_2 < ...i_\ell$ including position one which is K -bounded difference.

For example, if $a[1..5] = 2, 7, 1, 4, 3$ and $K = 2$, $2, 1, 3$ is a maximum length K bounded subsequence, as is $2, 4, 3$.

3. Minimum weight connected subtree of given size

You are given a binary tree of size n , where every vertex x has pointers $lc.x$, and $rc.x$ (which could be NIL if those children don't exist) and each vertex has a value, $value.x > 0$. You are also given an integer $1 \leq k \leq n$. You want to find the connected sub-tree with exactly k vertices, which minimizes the total weight of vertices in the sub-tree.

4. Road trip

You are going on a long trip. You start on the road at mile post 0. Along the way there are n hotels, at mile posts $a_1 < a_2 < \cdots < a_n$, where each a_i is measured from the starting point. The only places you are allowed to stop are at these hotels, but you can choose which of the hotels you stop at. You must stop at the final hotel (at distance a_n), which is your destination.

You'd ideally like to travel 200 miles a day, but this may not be possible (depending on the spacing of the hotels). If you travel x miles during a day, the *penalty* for that day is $(200 - x)^2$. You want to plan your trip so as to minimize the total penalty—that is, the sum, over all travel days, of the daily penalties.

5. Knapsack variant

Consider the variant of knapsack where you are allowed to choose items more than once. You still have n items each with values v_i and costs c_i , and a budget U . If you pick item i p_i times, you must have $\sum_{1 \leq i \leq n} p_i c_i \leq U$, and your objective is to maximize $\sum_{1 \leq i \leq n} p_i v_i$. Each p_i must be a non-negative integer.