**Summary:** Coming up with a dynamic programming algorithm, involves (typically) the following steps:

(A) Understand the structure of the optimal solution being computed.
(B) Derive recursive function for computing the desired quantity.
(C) Derive a recursive algorithm for computing the function (usually immediate from last step).
(D) Use implicit memoization to get an efficient algorithm.
(E) Use explicit memoization to get a more efficient algorithm.
(F) Figure out how the explicit memoization program fills the tables, and derive a dynamic program for the problem.
(G) Try to optimize your dynamic program to use less space.

Some of these steps can be skipped if things are sufficiently simple (or once you are sufficiently experienced). Here, we concern ourselves only with the first three steps.

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A ***subsequence*** of a sequence (for example, an array, linked list, or string), obtained by removing zero or more elements and keeping the rest in the same sequence order. A subsequence is called a ***substring*** if its elements are contiguous in the original sequence. For example:

- *SUBSEQUENCE*, *UBSEQU*, and the empty string $\varepsilon$ are all substrings (and therefore subsequences) of the string *SUBSEQUENCE*;
- *SBSQNC*, *SQUEE*, and *EEE* are all subsequences of *SUBSEQUENCE* but not substrings;
- *QUEUE*, *EQUUS*, and *DIMAGGIO* are not subsequences (and therefore not substrings) of *SUBSEQUENCE*.

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Describe recursive backtracking algorithms for the following problems. *Don't worry about running times.*

**1** LONGEST INCREASING SUBSEQUENCE. Given an array $A[1..n]$ of integers, compute the length of a *longest increasing subsequence*. A sequence $B[1..\ell]$ is ***increasing*** if $B[i] > B[i-1]$ for every index $i \geq 2$.

For example, given the array

$$\langle 3, \underline{\mathbf{1}}, \underline{\mathbf{4}}, 1, \underline{\mathbf{5}}, 9, 2, \underline{\mathbf{6}}, 5, 3, 5, \underline{\mathbf{8}}, \underline{\mathbf{9}}, 7, 9, 3, 2, 3, 8, 4, 6, 2, 7 \rangle$$

your algorithm should return the integer 6, because $\langle 1, 4, 5, 6, 8, 9 \rangle$ is a longest increasing subsequence (one of many).

**2** LONGEST DECREASING SUBSEQUENCE. Given an array $A[1..n]$ of integers, compute the length of a *longest decreasing subsequence*. A sequence $B[1..\ell]$ is ***decreasing*** if $B[i] < B[i-1]$ for every index $i \geq 2$.

For example, given the array

$$\langle 3, 1, 4, 1, 5, \underline{\mathbf{9}}, 2, \underline{\mathbf{6}}, 5, 3, \underline{\mathbf{5}}, 8, 9, 7, 9, 3, 2, 3, 8, \underline{\mathbf{4}}, 6, \underline{\mathbf{2}}, 7 \rangle$$

your algorithm should return the integer 5, because $\langle 9, 6, 5, 4, 2 \rangle$ is a longest decreasing subsequence (one of many).

**3** LONGEST ALTERNATING SUBSEQUENCE.

Given an array $A[1..n]$ of integers, compute the length of a *longest alternating subsequence*. A sequence $B[1..\ell]$ is ***alternating*** if $B[i] < B[i-1]$ for every even index $i \geq 2$, and $B[i] > B[i-1]$ for every odd index $i \geq 3$.

For example, given the array

$$\langle \underline{\mathbf{3}}, \underline{\mathbf{1}}, \underline{\mathbf{4}}, \underline{\mathbf{1}}, \underline{\mathbf{5}}, 9, \underline{\mathbf{2}}, \underline{\mathbf{6}}, \underline{\mathbf{5}}, 3, 5, \underline{\mathbf{8}}, 9, \underline{\mathbf{7}}, \underline{\mathbf{9}}, \underline{\mathbf{3}}, 2, 3, \underline{\mathbf{8}}, \underline{\mathbf{4}}, \underline{\mathbf{6}}, \underline{\mathbf{2}}, \underline{\mathbf{7}} \rangle,$$

your algorithm should return 17, because $\langle 3,1,4,1,5,2,6,5,8,7,9,3,8,4,6,2,7\rangle$ is a longest alternating subsequence (one of many).

**To think about later:**

**4** Given an array $A[1\,..\,n]$ of integers, compute the length of a longest *convex* subsequence of $A$. A sequence $B[1\,..\,\ell]$ is ***convex*** if $B[i]-B[i-1] > B[i-1]-B[i-2]$ for every index $i \ge 3$.

For example, given the array

$$\langle \underline{\mathbf{3}}, \underline{\mathbf{1}}, 4, \underline{\mathbf{1}}, 5, 9, \underline{\mathbf{2}}, 6, 5, 3, \underline{\mathbf{5}}, 8, \underline{\mathbf{9}}, 7, 9, 3, 2, 3, 8, 4, 6, 2, 7\rangle$$

your algorithm should return the integer 6, because $\langle 3,1,1,2,5,9\rangle$ is a longest convex subsequence (one of many).

**5** Given an array $A[1\,..\,n]$, compute the length of a longest *palindrome* subsequence of $A$. Recall that a sequence $B[1\,..\,\ell]$ is a ***palindrome*** if $B[i] = B[\ell-i+1]$ for every index $i$.

For example, given the array

$$\langle 3, 1, \underline{\mathbf{4}}, 1, 5, \underline{\mathbf{9}}, 2, 6, \underline{\mathbf{5}}, \underline{\mathbf{3}}, \underline{\mathbf{5}}, 8, 9, 7, \underline{\mathbf{9}}, 3, 2, 3, 8, \underline{\mathbf{4}}, 6, 2, 7\rangle$$

your algorithm should return the integer 7, because $\langle 4,9,5,3,5,9,4\rangle$ is a longest palindrome subsequence (one of many).