ALGORITHMS AND DATA STRUCTURES

Introduction and Overview

LECTURE #1

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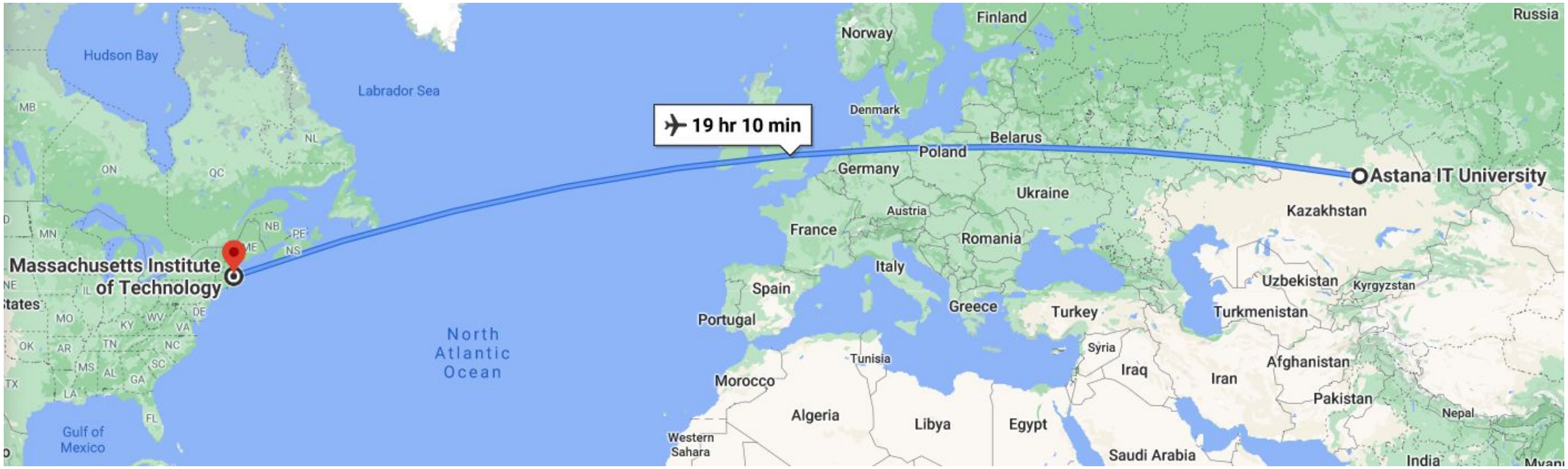
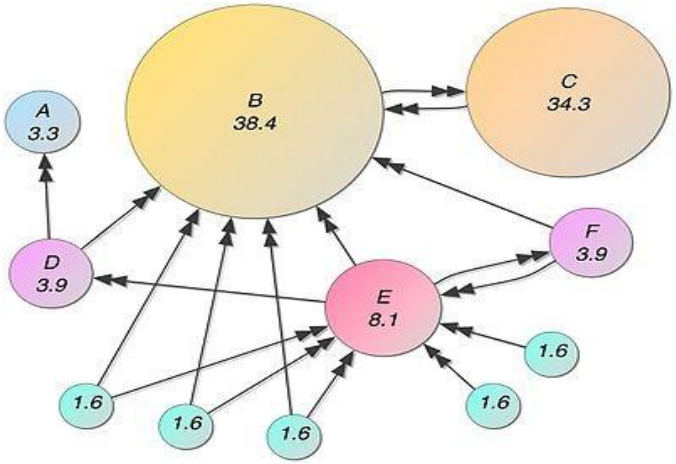
Define Algorithm (1)

- **Origin:**
  - Al-Khwārizmī, rendered as (Latin) *Algoritmi*
- **Definition:**
  - Procedure approach to solve "computational problems"
- **Example:**
  - Find the shortest path from AITU to MIT



Define Algorithm (2)

A *procedure* for solving a problem in terms of
1. the **actions** to execute and
2. the **order** in which these actions execute
is called an **algorithm**. The following example demonstrates that correctly specifying the order in which the actions execute is important.



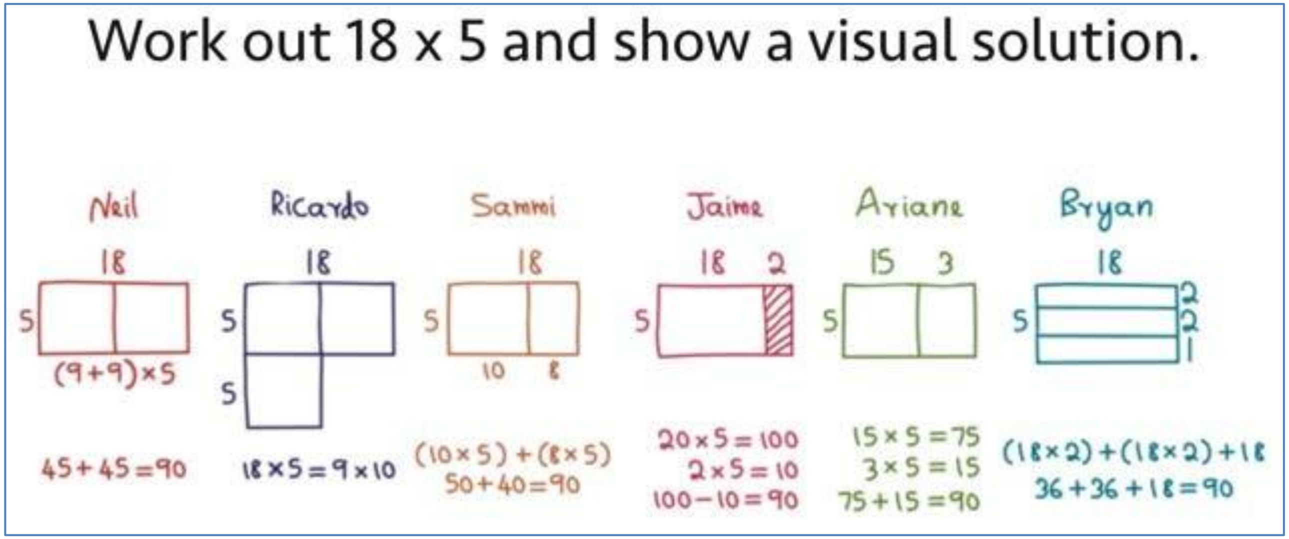
Find the most relevant web page for a query (Google) : PageRank

Main Features of an Algorithm

- Various features
  - Reusability/modularity
  - Simplicity
  - Memory footprint
  - Speed
- Algorithm is all about efficiency: Time vs. Space
- Time complexity: Developing a formula for predicting *how fast* and algorithm is, based on <u>input size</u>.
- Space complexity: Developing a formula for predicting *how much memory* an algorithm requires, based on <u>input size</u>.
- Memory is extensible, time is not!

Data Structures and Algorithms (1)

- To solve a given problem by using computers, you need to design an algorithm for it.
- Multiple algorithms can be designed to solve a problem.



- An algorithm that provides the maximum efficiency should be used for solving the problem.

Data Structures and Algorithms (2)

- The efficiency of and algorithm can be improved by using an appropriate data structure.
- Data structures help in creating programs that are simple, reusable, and easy to maintain.
- To solve a problem, you need a computer to write a program.
- A program is made up of two parts:
  - Algorithm
  - Data structures
    - Arrays
    - Queues
    - Lists
    - Linked Lists
    - Trees
    - Graphs

Example of an Algorithm

Consider the “rise-and-shine algorithm” followed by one executive for getting out of bed and going to work.

(1) Get out of bed;
(2) take off pajamas;
(3) take a shower;
(4) get dressed;
(5) eat breakfast;
(6) carpool to work.

This routine gets the executive to work well prepared to make critical decisions. Suppose that the same steps are performed in a slightly different order:

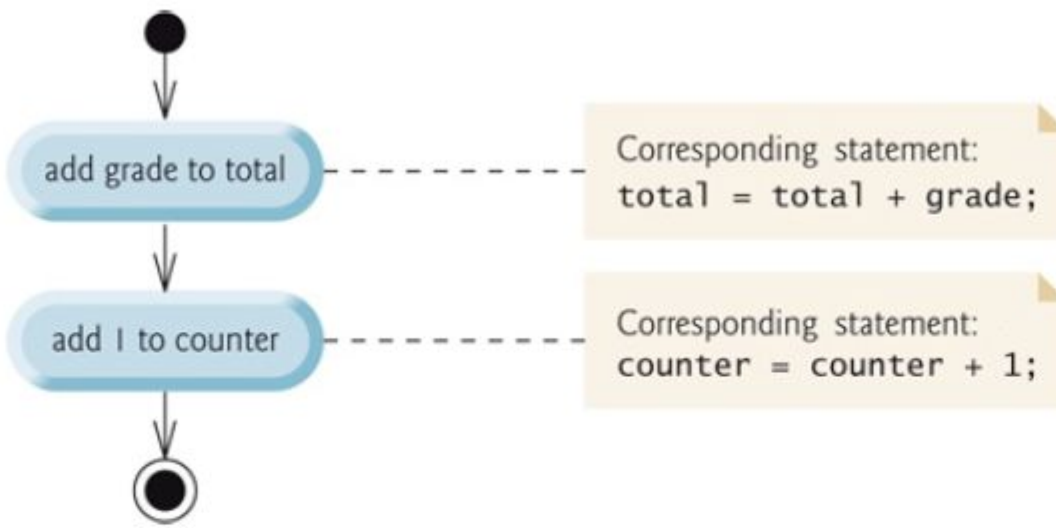
(1) Get out of bed;
(2) eat breakfast;
(3) take off pajamas;
(4) take a shower;
(5) Get dressed;
(6) carpool to work.

Pseudocode

- Informal language that helps to understand and develop algorithms
- Pseudocode is similar to everyday language.
- Pseudocode:
  - Does not execute on computers
  - Help to “think out”
  - Can be easily converted to program

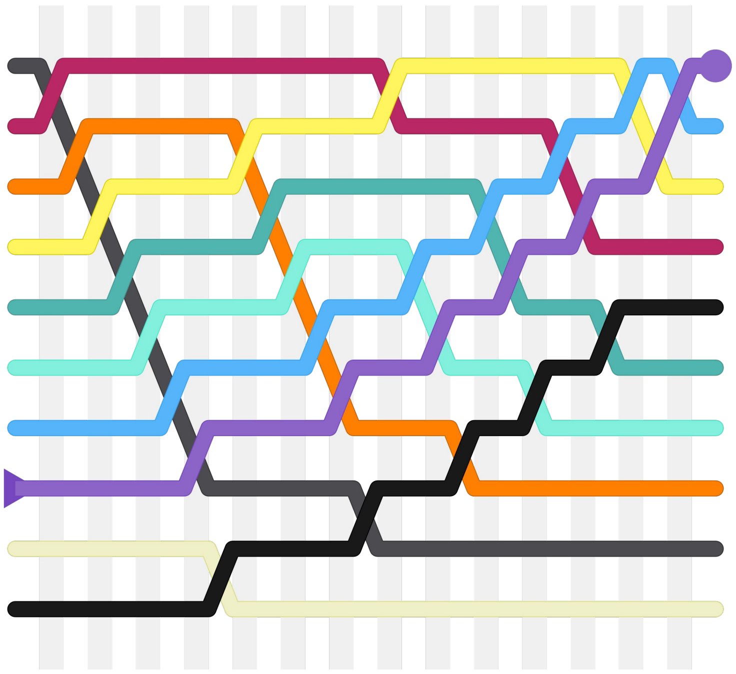
Control Structures

- Sequential execution – execution of statements in the order in which they are written
- Activity diagram:



Bubble sort algorithm

- Bubble Sort is the simplest sorting algorithm
- Several passes through the array
- Successive pairs of elements are compared
- Repeatedly swaps the adjacent elements if they are in wrong order
- At each i’th iteration of the outer loop the maximum (can be minimum) element is moved to the position of n-i-1



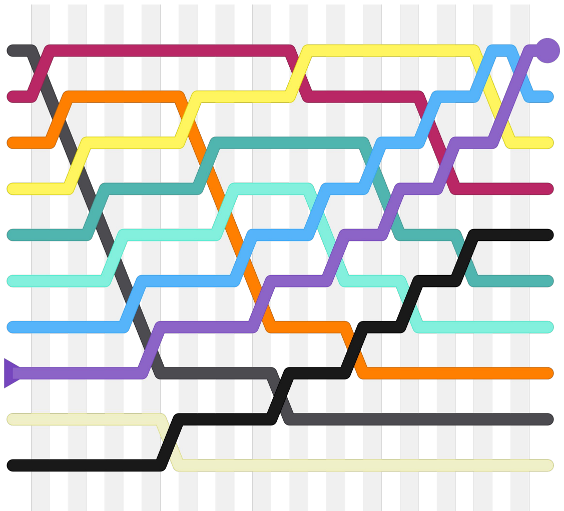
Bubble sort algorithm

Pseudocode:

Input: An array of n numbers, A[1…n]

Bubble-Sort(A)

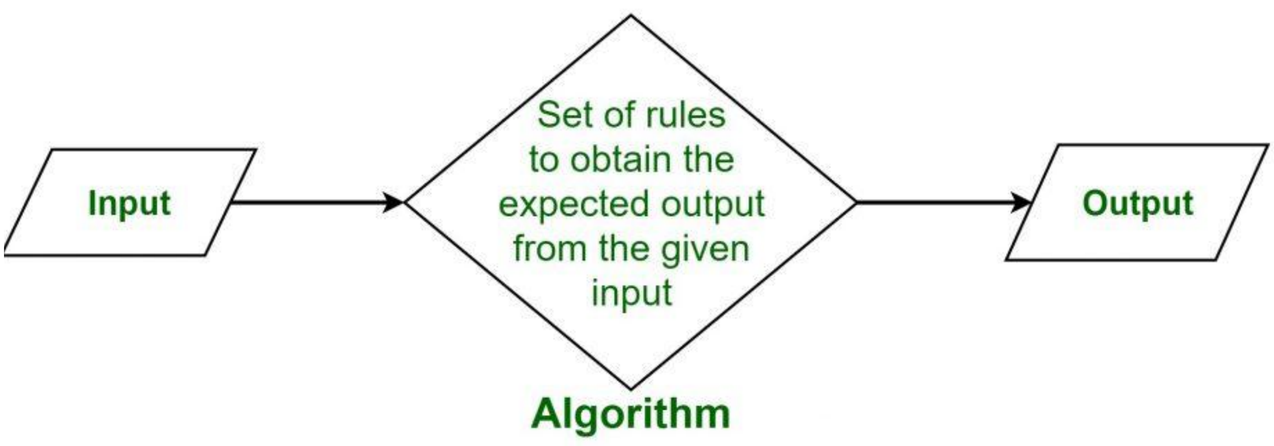
1. for i = (A.length-1) to 0
2.   for j = 0 to (i -1)
3.   if (A[j] > A[j+1])
4.   swap A[j] and A[j+1]



Reverse Array

```
n = 5;
A[n] = {1, 2, 3, 4, 5};
for (i = 0; i < n/2; i++){
        temp = A[i];
        A[i] = A[n - i - 1];
        A[n - i - 1] = temp;
}
```

- Here we do not need to initialize second array in order to reverse on array.
- Reversing of the array also can be considered as an algorithm, as an algorithm can be defined as set of rules to obtain expected output



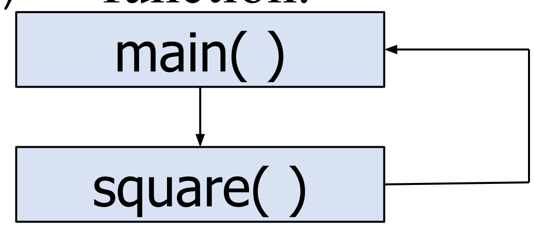
Checking array

- In order to check array: is it sorted or not?

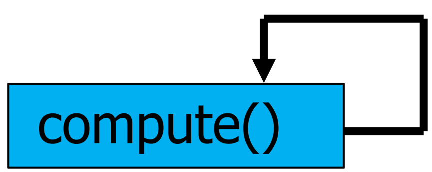
```
n = 5;
A[n] = {1, 2, 3, 5, 4};
bool is_sorted = true;
for (i = 0; i < n-1; i++){
//here we check by pair so, we will not check n and n+1 element
    if (A[i] > A[i+1]){
            is_sorted = false;
            break;
    }
}
```

Recursion

- So far, we have seen methods that call other functions.
  - For example, the `main()` method calls the square() function.



- Recursive Method:
  - A recursive method is a method that calls itself.



Why we need Recursion?

- Some problems are more easily solved by using recursive functions.
- If you go on to take a computer science algorithms course, you will see lots of examples of this.
- For example:
  - Traversing through a directory or file system.
  - Traversing through a tree of search results.
- For today, we will focus on the basic structure of using recursive methods.

Simplest recursion code:

```
#include <iostream>
using namespace std;
void count(int);
int main()
{
    count(0);
    cout<<endl;
}

void count (int index)
{
    cout<<index<<" ";
    if (index < 2) {
count(index+1);
    }
}
```

This program simply counts from 0-2:

012

This is where the recursion occurs. You can see that the count() function calls itself.

Visualizing recursion

• To understand how recursion works, it helps to
visualize what's going on.

• To help visualize, we will use a common concept
called the *Stack*.

• A stack basically operates like a container of trays
in a cafeteria. It has only two operations:

– Push: you can push something onto the stack.

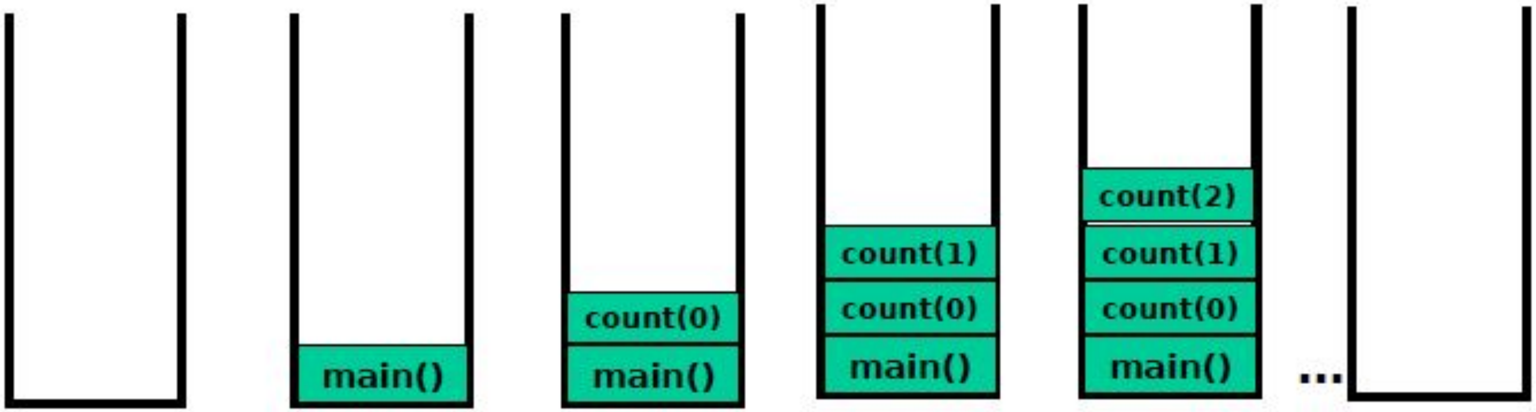
– Pop: you can pop something off the top of the stack.

– Let's see an example stack in action.

Stacks and Methods

- When you run a program, the computer creates a stack for you.
- Each time you invoke a method, the method is placed on top of the stack.
- When the method returns or exits, the method is popped off the stack.
- The diagram on the next page shows a sample
stack for a simple Java program.

Stacks and Recursion



Time: 0

Empty Stack

Time 1:

Push: main()

Time 2:

Push: count(0)

Inside count(0):
print (index);
→ 0
if (index < 2)

count(index+1);

Time 3:

Push:

count(1)

Inside count(1):
print (index); →
1
if (index < 2)

count(index+1);

Time 4:

Push:

count(2)

Inside count(2):
print (index); →
2
if (index < 2)
count(index+1);
This condition now fails!

Hence, recursion stops, and we proceed to pop all functions off the stack.

Times 5-8:

Pop everything

Finding factorial:

- Computing factorials are a classic problem for examining recursion.
- A factorial is defined as follows:
- n! = n * (n-1) * (n-2) …. * 1;
- For example:

  1! = 1 (Base Case)

  2! = 2 * 1 = 2

  3! = 3 * 2 * 1 = 6

  4! = 4 * 3 * 2 * 1 = 24

  5! = 5 * 4 * 3 * 2 * 1 = 120

If you study this table closely, you will start to see a pattern. The pattern is as follows:

You can compute the factorial of any number (n) by taking n and multiplying it by the factorial of (n-1).

For example:

5! = 5 * 4!

(which translates to 5! = 5 * 24 = 120)

Seeing the Pattern

- Seeing the pattern in the factorial example is difficult at first.
- But, once you see the pattern, you can apply this pattern to create a recursive solution to the problem.
- Divide a problem up into:

– What it can do (usually a base case)

– What it cannot do

- What it cannot do resembles original problem
- The function launches a new copy of itself (recursion step) to solve what it cannot do.

Recursion vs. Iteration

- Iteration

– Uses repetition structures (for, while or do...while)

– Repetition through explicitly use of repetition structure

– Terminates when loop-continuation condition fails

– Controls repetition by using a counter

- Recursion

– Uses selection structures (if, if...else or switch)

– Repetition through repeated method calls

– Terminates when base case is satisfied

– Controls repetition by dividing problem into simpler one

Recursion vs. Iteration (cont.)

- Recursion
  - More overhead than iteration
  - More memory intensive than iteration
  - Can also be solved iteratively
  - Often can be implemented with only a few lines of code