NANYANG TECHNOLOGICAL UNIVERSITY SINGAPORE

SC1007
Data Structures and Algorithms

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Overview of SC1007

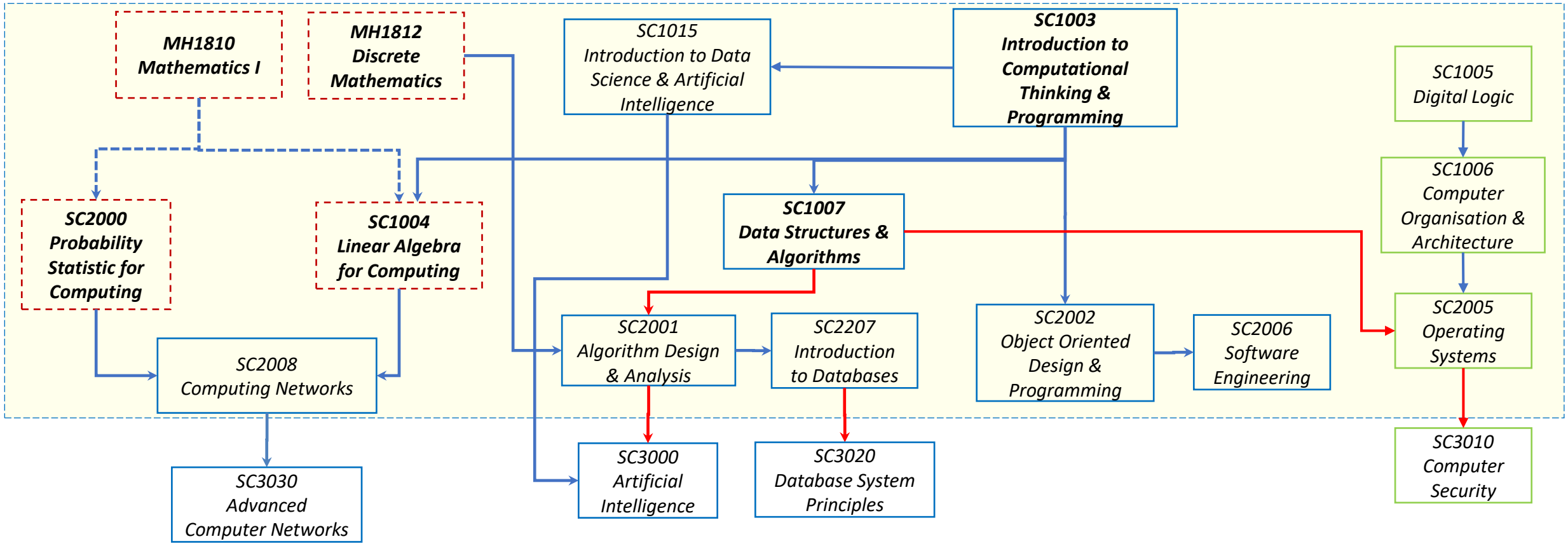
Data Structures:

- Concepts of pointers and structures (aggregates)
- Introduce some classical data structures
  - Linear: Linked list, stack, queue
  - Non-linear: tree
- Implement these data structures

Algorithms:

- Analysis of Algorithm – time complexity and space complexity
- Introduce to some typical algorithms and their applications

Why Learn Algorithms?



Why Learn Algorithms?

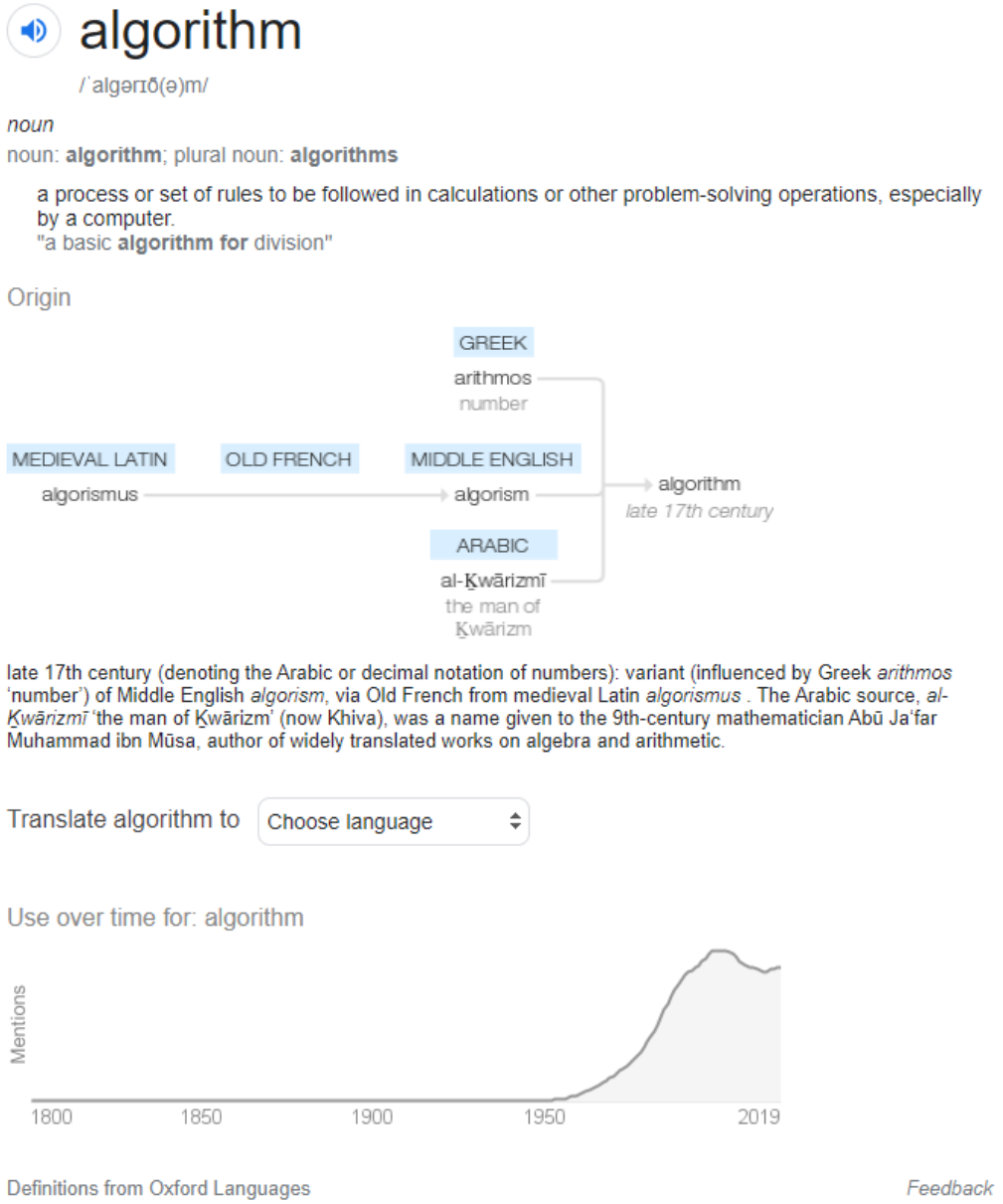
- Given two arrays num1 and num2. Both are sorted in ascending order. The length is m and n, respectively. Please find the median of the two arrays. The time complexity needs to be $O(\log(m+n))$.
- You are given a grid with two dimensions. The grid cell values are 1 or 0 only, where 1 represents land and 0 represents water. An island is lands surrounded by water. Each island is formed by connecting nearby lands vertically and/or horizontally. Please give the number of island in the given grid.
- Given a string s, please find the longest palindrome substring (e.g., tenet).

Why Learn Algorithms?

To Continuously Build a Way of Thinking.

What is an Algorithm

- Appear in Webster's New World Dictionary after 1957
- It is derived from the name of a Persian Mathematician in the 9th century.
- Euclidean algorithm for finding the greatest common divisor of two numbers – Euclid's Elements (300 B.C.)



https://en.wikipedia.org/wiki/Algorithm
Knuth's The Art of Computer Programming

What is an Algorithm

- An algorithm is a sequence of unambiguous instructions for solving a problem, i.e., for obtaining a required output for any legitimate input in a finite amount of time.

Introduction to The Design & Analysis of Algorithms

-Anany Levitin

- An algorithm is any well-defined computational procedure that takes some value, or set of values, as input and produces some value, or set of values, as output.

Introduction to Algorithms

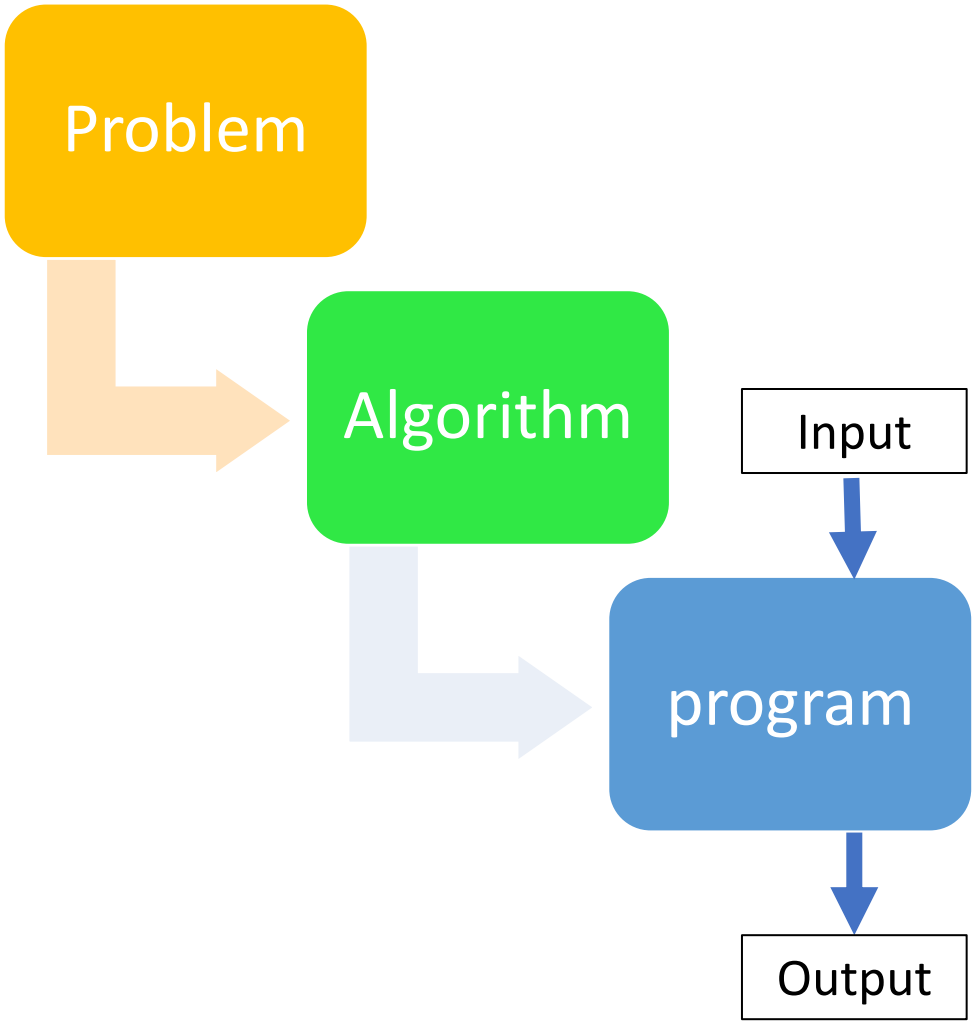
-T. H. Cormen et. al.

What is an Algorithm

- Correctness:
  - Output results must be correct and consistent for every given input instance
- Precision:
  - A series of well-defined and systematic steps
  - The steps should not contain any ambiguous word like maybe, roughly, about etc.
- Finiteness:
  - Terminates in a finite number of instructions

Algorithm VS Program

- A computer program is an instance, or concrete representation of an algorithm in some programming languages.
- Implementation is the task of turning an algorithm into a computer program.



Example 1: Arithmetic Series

- There are many ways (algorithms) to solve a problem
- Summing up 1 to n

Algorithm 1 Summing Arithmetic Sequence

```
1: function Method_One(n)
2: begin
3: sum ← 0
4: for i = 1 to n do
5:     sum ← sum + i
6: end
```

Algorithm 2 Summing Arithmetic

```
1: function Method_Two(n)
2: begin
3: sum ← n * (1 + n)/2
4: end
```

Algorithm 3 Summing Arithmetic Sequence

```
1: function Method_Three(n)
2: begin
3: if n=1 then
4:     return 1
5: else
6:     return  n+Method_Three(n − 1)
7: end
```

Example 2: Fibonacci Sequence

- 1, 1, 2, 3, 5, 8, …
- The n^{th} term is

$$f(n) = f(n-1) + f(n-2)$$

Which is a better algorithm?

Algorithm 4 Fibonacci Sequence: A Simple Recursive Function

```
1: function Fibonacci_Recursive(n)
2: begin
3: if n<1 then
4:     return 0
5: if n==1 OR n==2 then
6:     return 1
7: return Fibonacci_Recursive(n − 1)+Fibonacci_Recursive(n − 2)
8: end
```

Is there any better algorithm?

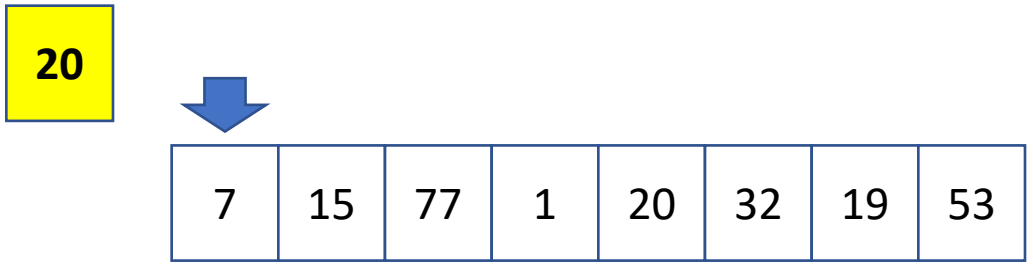
Algorithm 5 Fibonacci Sequence: A Simple Iterative Function

```
1: function Fibonacci_Iterative(n)
2: begin
3: if n<1 then
4:     return 0
5: if n==1 OR n==2 then
6:     return 1
7: F_1 ← 1
8: F_2 ← 1
9: for i = 3 to n do
10:    begin
11:    F_i ← F_{i−2} + F_{i−1}
12:    F_{i−2} ← F_{i−1}
13:    F_{i−1} ← F_i
14:    end
15: return F_n
16: end
```

Problem Types

- Searching
- Graph Problems (SC2001)
- Sorting (SC2001)
- String Processing (SC2001)
- Geometric Problems
- Numerical Problems
- Combinatorial Problems

Searching: Find a Search Key In a Given Set

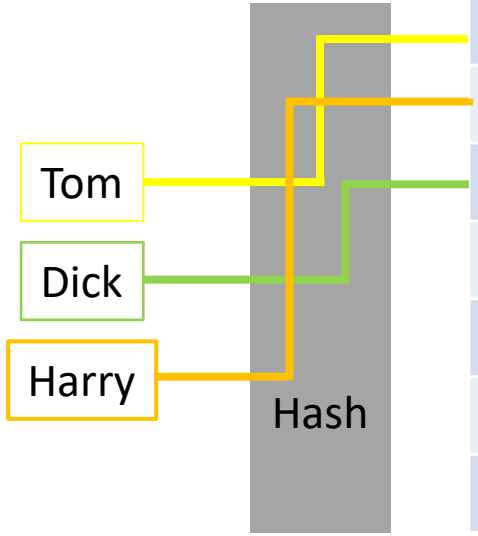


Linear Search/ Sequential Search

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

Sudoku

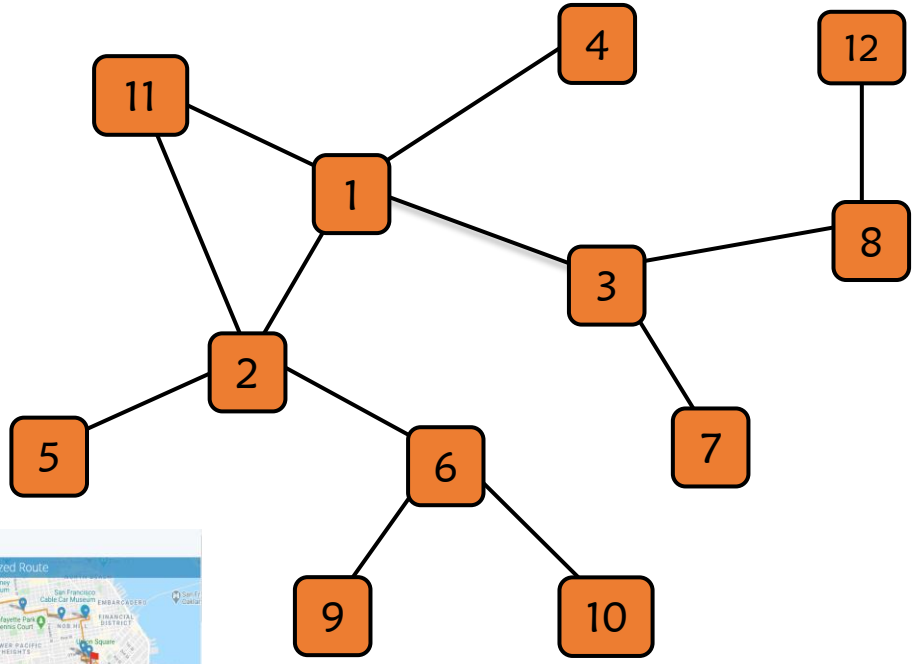
Hash Table

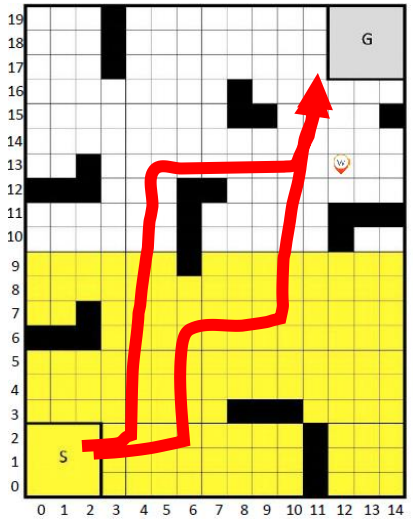


Index	Data
001	Tom, +123456
002	Harry, +369852
003	Dick, +965483
..	…
…	…
..	..
..	..

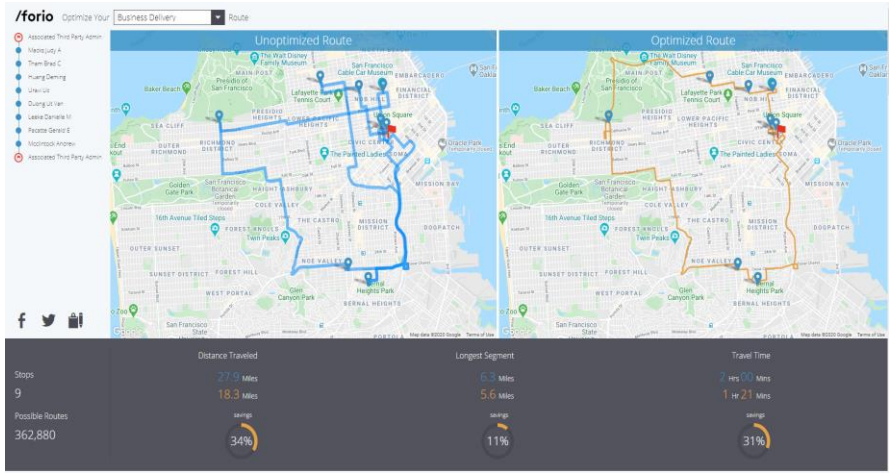
Graph Problems

- A graph is a mathematical structure consisting of a collection of vertices and edges.
- Each edge has one or two vertices associated to it.





Path Finding

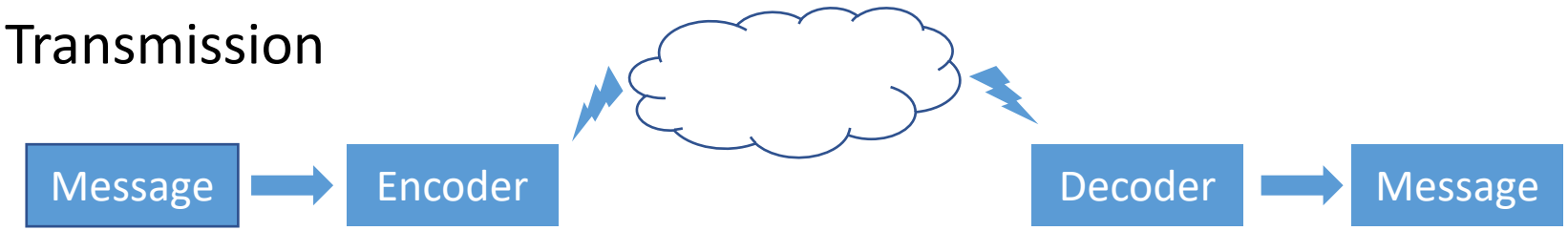


https://forio.com/app/showcase/route-optimizer/

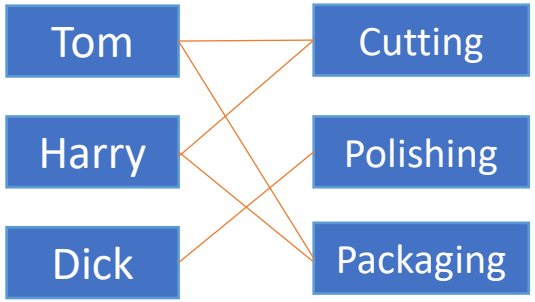
Traveler Salesman Problem

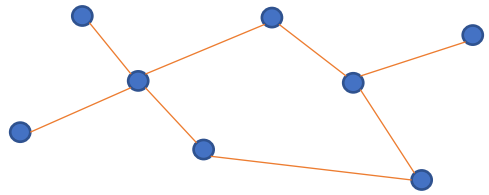
Combinatorial Problems

- The study of arrangements, patterns, designs, assignments schedules, connections and configurations.
- Cryptography:
  - Information Transmission



- Matching and Covering Problem





Minimum Vertex Cover Problem

Sorting Problems

- Rearrange items of a given list in certain order

Numerical Order

Lexicographical Order

- Find the top 5% of students in a class
- Find the median

7	15	77	1	20	32	19	53

19.5

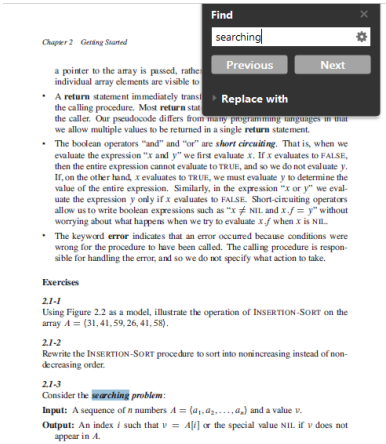
- **Stability:** Stable sorting algorithms sort repeated elements in the same order that they appear in the input.

String Processing

- String matching

PNEUMONOULTRAMICROSCOPICSILICOVOLCANOCONIOSIS

M	I	C	R	O



Text Matching

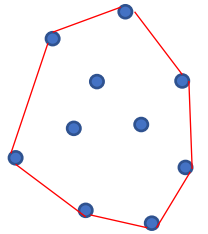
```
   1 attaaaggtt tataccttcc caggtaacaa accaaccaac tttcgatctc ttgtagatct
  61 gttctctaaa cgaactttaa aatctgtgtg gctgtcactc ggctgcatgc ttagtgcact
 121 cacgcagtat aattaataac taattactgt cgttgacagg acacgagtaa ctcgtctatc
 181 ttctgcaggc tgcttacggt ttcgtccgtg ttgcagccga tcatcagcac atctaggttt
 241 cgtccgggtg tgaccgaaag gtaagatgga gagccttgtc cctggtttca acgagaaaac
 301 acacgtccaa ctcagtttgc ctgttttaca ggttcgcgac gtgctcgtac gtggctttgg
 361 agactccgtg gaggaggtct tatcagaggc acgtcaacat cttaaagatg gcacttgtgg
 421 cttagtagaa gttgaaaaag gcgttttgcc tcaacttgaa cagccctatg tgttcatcaa
 481 acgttcggat gctcgaactg cacctcatgg tcatgttatg gttgagctgg tagcagaact
 541 cgaaggcatt cagtacggtc gtagtggtga gacacttggt gtccttgtcc ctcatgtggg
 601 cgaaatacca gtggcttacc gcaaggttct tcttcgtaag aacggtaata aaggagctgg
 661 tggccatagt tacggcgccg atctaaagtc atttgactta ggcgacgagc ttggcactga
 721 tccttatgaa gattttcaag aaaactggaa cactaaacat agcagtggtg ttacccgtga
 781 actcatgcgt gagcttaacg gaggggcata cactcgctat gtcgataaca acttctgtgg
 841 ccctgatggc taccctcttg agtgcattaa agaccttcta gcacgtgctg gtaaagcttc
 901 atgcactttg tccgaacaac tggactttat tgacactaag aggggtgtat actgctgccg
 961 tgaacatgag catgaaattg cttggtacac ggaacgttct gaaaagagct atgaattgca
1021 gacacctttt gaaattaaat tggcaaagaa atttgacacc ttcaatgggg aatgtccaaa
1081 ttttgtattt ccctttaaatt ccataatcaa gactattcaa ccaagggttg aaaagaaaaa
1141 gcttgatggc tttatgggta gaattcgatc tgtctatcca gttgcgtcac caaatgaatg
1201 caaccaaatg tgcctttcaa ctctcatgaa gtgtgatcat tgtggtgaaa cttcatggca
1261 gacgggcgat tttgttaaag ccacttgcga attttgtggc actgagaatt tgactaaaga
1321 aggtgccact acttgtggtt acttacccca aaatgctgtt gttaaaattt attgtccagc
1381 atgtcacaat tcagaagtag gacctgagca tagtcttgcc gaataccata atgaatctgg
1441 cttgaaaacc attcttcgta agggtggtcg cactattgcc tttggaggct gtgtgttctc
1501 ttatgttggt tgccataaca agtgtgccta ttgggttcca cgtgctagcg ctaacatagg
1561 ttgtaaccat acaggtgttg ttggagaagg ttccgaaggt cttaatgaca accttcttga
1621 aatactccaa aaagagaaag tcaacatcaa tattgttggt gactttaaac ttaatgaaga
```

SARS-CoV-2/human/USA/UNC_200265_2020/2020, complete genome

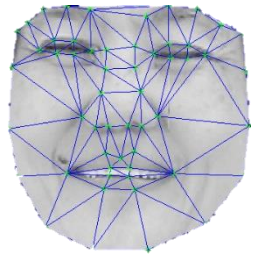
```
   1 aacaaaccaa ccaactttcg atctcttgta gatctgttct ctaaacgaac tttaaaatct
  61 gtgtggctgt cactcggctg catgcttagt gcactcacgc agtataatta ataactaatt
 121 actgtcgttg acaggacacg agtaactcgt ctatcttctg caggctgctt acggtttcgt
 181 ccgtgttgca gccgatcatc agcacatcta ggttttgtcc gggtgtgacc gaaaggtaag
 241 atggagagcc ttgtccctgg tttcaacgag aaaacacacg tccaactcag tttgcctgtt
 301 ttacaggttc gcgacgtgct cgtacgtggc tttggagact ccgtggagga ggtcttatca
 361 gaggcacgtc aacatcttaa agatggcact tgtggcttag tagaagttga aaaaggcgtt
 421 ttgcctcaac ttgaacagcc ctatgtgttc atcaaacgtt cggatgctcg aactgcacct
 481 catggtcatg ttatggttga gctggtagca gaactcgaag gcattcagta cggtcgtagt
 541 ggtgagacac ttggtgtcct tgtccctcat gtgggcgaaa taccagtggc ttaccgcaag
 601 gttcttcttc gtaagaacgg taataaagga gctggtggcc atagttacgg cgccgatcta
 661 aagtcatttg acttaggcga cgagcttggc actgatcctt atgaagattt tcaagaaaac
 721 tggaacacta aacatagcag tggtgttacc cgtgaactca tgcgtgagct taacggaggg
 781 gcatacactc gctatgtcga taacaacttc tgtggccctg atggctaccc tcttgagtgc
 841 attaaagacc ttctagcacg tgctggtaaa gcttcatgca ctttgtccga acaactggac
 901 tttattgaca ctaagagggg tgtatactgc tgccgtgaac atgagcatga aattgcttgg
 961 tacacggaac gttctgaaaa gagctatgaa ttgcagacac cttttgaaat taaattggca
1021 aagaaatttg acatcttcaa tggggaatgt ccaaattttg tatttccctt aaattccata
1081 atcaagacta ttcaaccaag ggttgaaaag aaaaagcttg atggctttat gggtagaatt
1141 cgatctgtct atccagttgc gtcaccaaat gaatgcaacc aaatgtgcct ttcaactctc
1201 atgaagtgtg atcattgtgg tgaaacttca tggcagacgg gcgattttgt taaagccact
1261 tgcgaatttt gtggcactga gaatttgact aaagaaggtg ccactacttg tggttactta
1321 ccccaaaatg ctgttgttaa aatttattgt ccagcatgtc acaattcaga agtaggacct
1381 gagcatagtc ttgccgaata ccataatgaa tctggcttga aaaccattct tcgtaagggt
1441 ggtcgcacta ttgcctttgg aggctgtgtg ttctcttatg ttggttgcca taacaagtgt
1501 gcctattggg ttccacgtgc tagcgctaac ataggttgta accatacagg tgttgttgga
1561 gaaggttccg aaggtcttaa tgacaacctt cttgaaatac tccaaaaaga gaaagtcaac
1621 atcaatattg ttggtgactt taaacttaat gaagagatcg ccattatttt ggcatctttt
```

Severe acute respiratory syndrome coronavirus 2 isolate Wuhan-Hu-1, complete genome.

Computational Geometric Problem



Convex Hull



Delaunay Triangulation

- Finding the convex hull of a set of points
- Finding the closest pair of points in a set of points
- Finding the intersection of two line segments or two circles
- Testing whether a point is inside or outside a polygon
- Finding the Voronoi diagram of a set of points
- Finding the shortest path between two points in a planar graph with obstacles
- Constructing a Delaunay triangulation Computing the area of a polygon or the volume of a polyhedron
- Detecting and resolving collisions between objects in a 2D or 3D space

Numerical Problem and Optimization Problem

- Use numerical approximation for the mathematical analysis
- Widely used for solving problems of engineering and mathematical models
  - Newton's method
  - Gaussian elimination
- Linear programming is an optimization technique for a system of linear constraints and a linear objective function

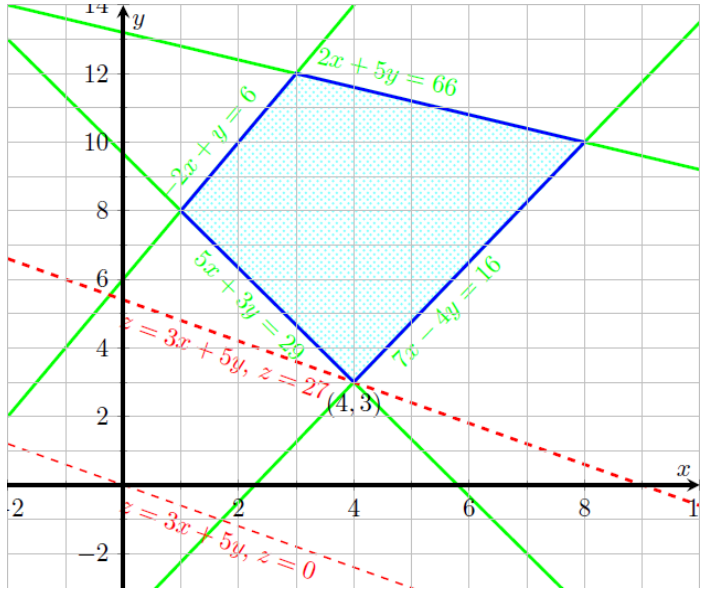
$$\min 3x + 5y$$

$$\text{subject to } 5x + 3y \geq 29$$

$$-2x + y \leq 6$$

$$2x + 5y \leq 66$$

$$7x - 4y \leq 16$$



How do we solve these problems?

How Do We Solve These Problems?

- Select appropriate data structures
  - Arrays
  - Linked Lists
    - Singly linked list, doubly linked list, circular linked list etc.
  - Stack and Queue
  - Trees
  - Table
  - Graphs

Algorithm Design Strategies

A general approach to solving problems algorithmically that is applicable to a variety of problems from different areas of computing

- Brute Force and Exhaustive Search
- Divide-and-Conquer
- Greedy Strategy
- …etc.
- Decrease-and-Conquer
- Transform-and-Conquer
- Iterative Improvement

Summary

- An algorithm is not simply a computer program
- Computing Problems
  - Searching
- Algorithm Design Strategies
  - Brute-force
  - Divide-and-Conquer
  - Decrease-and-Conquer
  - Transform-and-Conquer
    - Infix expression to Postfix expression

- Lectures focus on introduction to concepts
- Tutorials focus on understanding the concepts, discussion and doubt clarification
- Lab Sessions and assignments focus on practice and realization
- Lab Tests and quiz are assessments

Course Schedule

Week	Lecture Topic	Tutorial	Lab	Assignment Deadline
1	Introduction and Memory Management in Python			
2	Linked List (LL)			
3	Linked List: Doubly linked list and circular list			
4	Stacks and Queues	T1(LL)	Lab 1 (LL)	
5	Priority Queues and Arithmetic Expressions		Lab 2 (SQ)	
6	Tree Structure: Binary Tress and Binary Search Tress	T2 (SQ)	Lab 3 (BT)	AS1: LL and SQ (**21/02/2025**)
7	Tree Structure: AVL Tress	T3 (BT & BST)	Lab 4 (BST)	AS2: BT and BST (**28/02/2025**)
	Lab Test 1 (Recess Week: 04/03/2025 – 05/03/2025)			
8	Introduction to Algorithms and Analysis of Algorithms			
9	Analysis of Algorithms			
10	Searching		Lab 5 (AA)	
11	Hash Table	T4 (AA, Searching)	Lab 6 (Searching)	
12	String Search with Trie	T5 (Hash Table)	Lab 7 (Hash Table)	AS3: AA, Searching (**11/04/2025**)
13	Revision	T6 (Trie)	Lab 8 (Trie)	AS6: Hash Table, trie (**27/04/2025**)
14	**Lab Test 2 + Quiz (22/04/2024 – 23/04/2024)**			

Common Questions

- No marks for late submissions of assignments on HackerEarth without valid reasons (supporting documents are required)
- ONLY one make-up session for lab test 2 (April 25, 2025)
- The make-up test will be more difficult than the normal sessions
- Whether 1st half contents will be tested in the 2nd lab test? – Yes