CX1107
Data Structures and Algorithms

Introduction to Algorithms

College of Engineering

School of Computer Science and Engineering

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Lecturer

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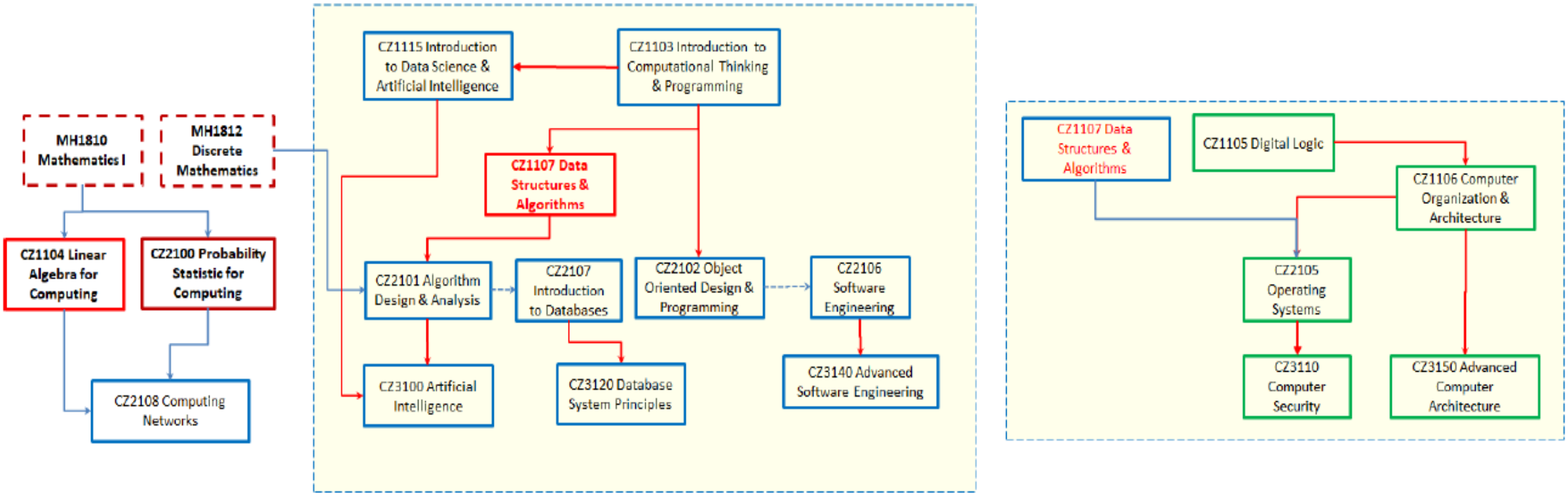
Learning Outcomes

1. Select appropriate data structures
2. Implement algorithms to solver real world problems using C programming
3. Conduct complexity analysis of algorithms

Week	Lecture Topic	Tutorial	Lab	Assignment Deadline
1	Introduction to Data Structure			
	Introduction to Algorithm			
2	Linked List (LL)			
3	Stack and Queue (SQ)	T1 (LL)	Lab 1 (LL)	
4	Stack and Queue (SQ)	T2 (SQ)	Lab 2 (SQ)	A1 (LL)
5	Binary Tree (BT)		Lab 3 (BT)	A2 (SQ)
6	Binary Search Tree (BST)	T3 (BT)	Lab 4 (BST)	A3 (BT)
7	Analysis of Algorithm (AA)			A4 (BST)
	Quiz (Recess Week)			
8	Advanced Data Structure (ADS)			
9	Searching (S)	T4 (AA)	Lab 5 (ADS)	
10	Basic Graph (G)	T5 (S)	Lab 6 (S)	AS 5: ADS
11	BFS, DFS, Topological Sorting		Lab 7 (G-1)	AS 6: Searching
12	Permutation, Matching		Lab 8 (G-2)	AS 7: Graph
13	Revision	T6 (G)		AS 8: Graph 2
14	Lab Test + Quiz			

Part 2 Assessment Components:

Assessments	Weighting
Assignments (W10-13)	20%
Lab Test 2 (Week 14)	20%
Final Quiz (Week 14) Part 1 and Part 2 concepts	20%


MH1810 Mathematics I
MH1812 Discrete Mathematics
CZ1104 Linear Algebra for Computing
CZ2100 Probability Statistic for Computing
CZ2108 Computing Networks
CZ1115 Introduction to Data Science & Artificial Intelligence
CZ1103 Introduction to Computational Thinking & Programming
CZ1107 Data Structures & Algorithms
CZ2101 Algorithm Design & Analysis
CZ2107 Introduction to Databases
CZ2102 Object Oriented Design & Programming
CZ2106 Software Engineering
CZ3100 Artificial Intelligence
CZ3120 Database System Principles
CZ3140 Advanced Software Engineering
CZ1107 Data Structures & Algorithms
CZ1105 Digital Logic
CZ1106 Computer Organization & Architecture
CZ2105 Operating Systems
CZ3110 Computer Security
CZ3150 Advanced Computer Architecture

Overview

- What is an algorithm?
- Problem types in computing
- Algorithm design strategies

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 (300B.C.)

algorithm

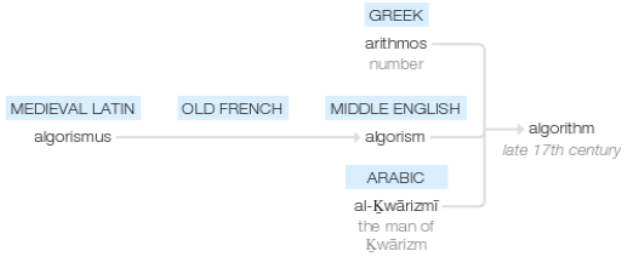
/ˈalgərɪð(ə)m/

noun

noun: **algorithm**; plural noun: **algorithms**

a process or set of rules to be followed in calculations or other problem-solving operations, especially by a computer.
"a basic **algorithm for** division"

Origin



late 17th century (denoting the Arabic or decimal notation of numbers): variant (influenced by Greek *arithmos* 'number') of Middle English *algorism*, via Old French from medieval Latin *algorismus* . The Arabic source, *al-Ḵwārizmī* 'the man of Ḵwārizm' (now Khiva), was a name given to the 9th-century mathematician Abū Jaʻfar Muhammad ibn Mūsa, author of widely translated works on algebra and arithmetic.

Translate algorithm to Choose language

Use over time for: algorithm

Definitions from Oxford Languages Feedback

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

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.

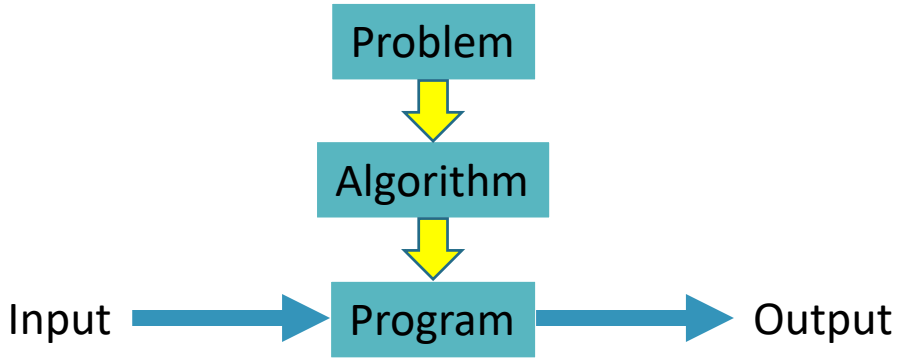
Algorithm

- 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 language.

- 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 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
- Combinatorial Problems
- Sorting (CZ2101)
- String Processing (CZ2101)
- Geometric Problems
- Numerical Problems

Searching: Find a search key in a given set

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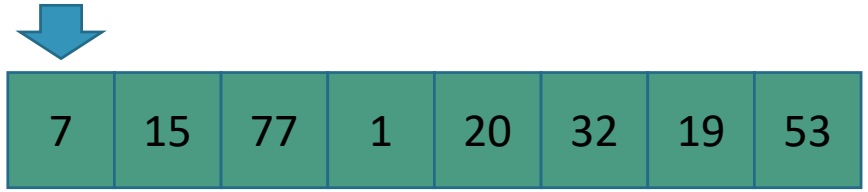
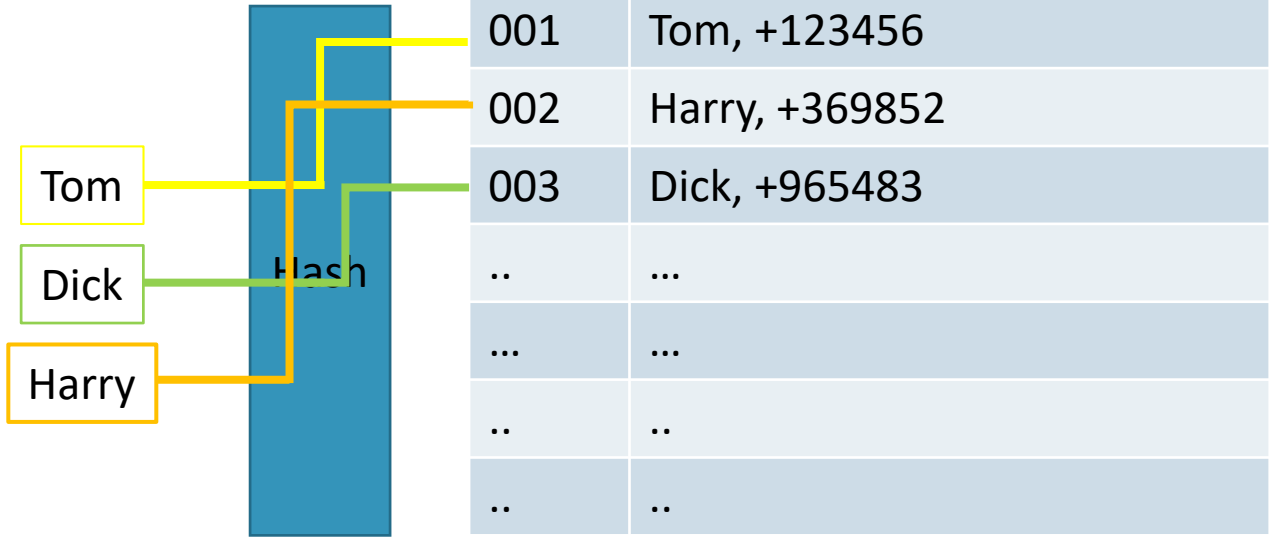


Linear Search/ Sequential Search

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

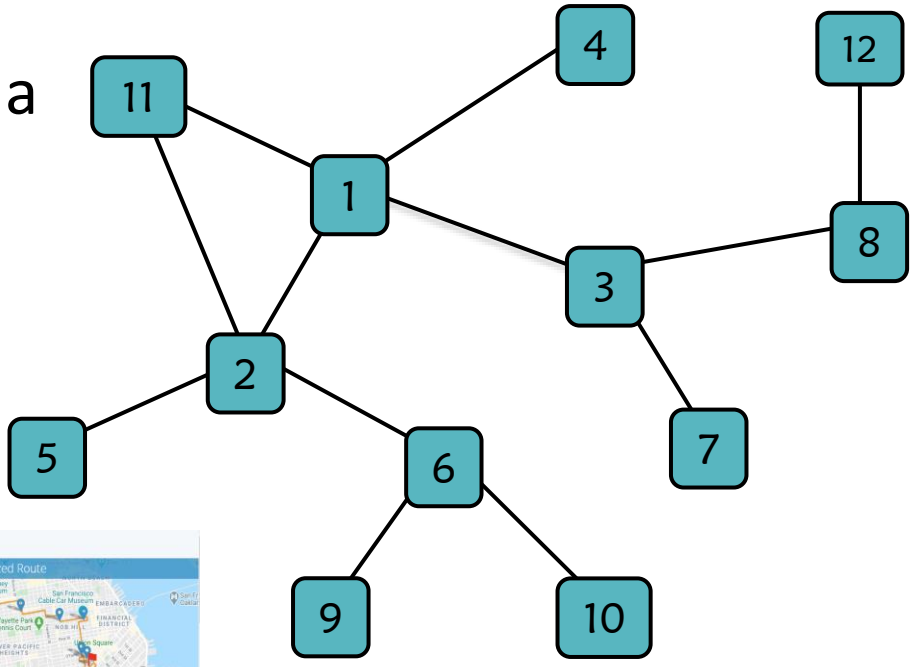


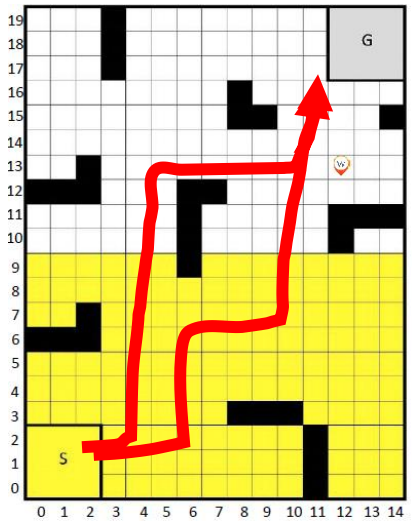
Index	Data
001	Tom, +123456
002	Harry, +369852
003	Dick, +965483
..	…
…	…
..	..
..	..

Graph Problems

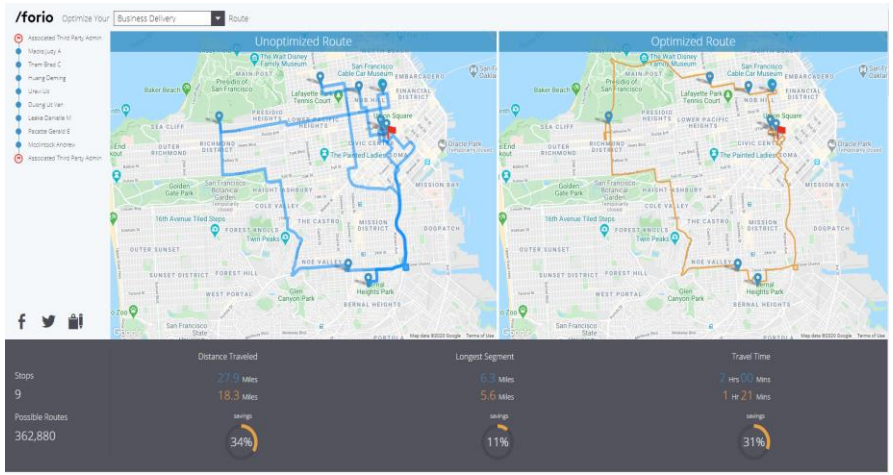
A graph is a mathematical structure consisting of a collection of vertices and edges.

Each edge has one or two vertices associated to it.





Path Finding

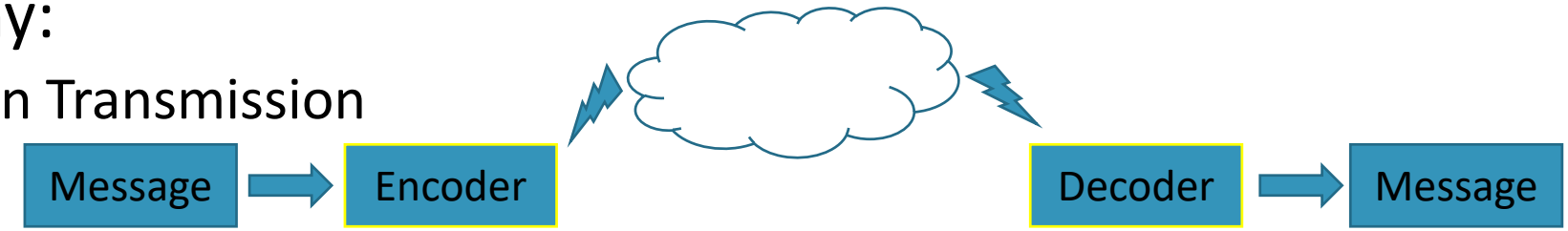


https://forio.com/app/showcase/route-optimizer/

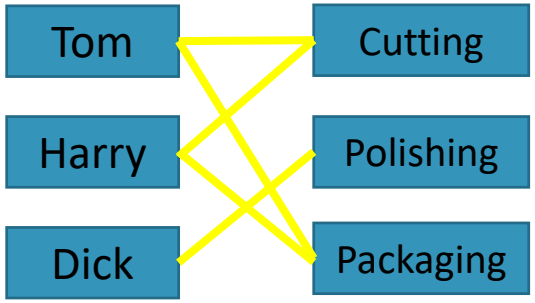
Traveler Salesman Problem

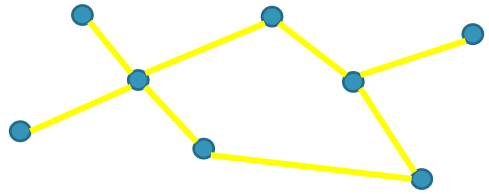
Combinatorial Problems

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



- Matching and Covering Problem





Minimum Vertex Cover Problem

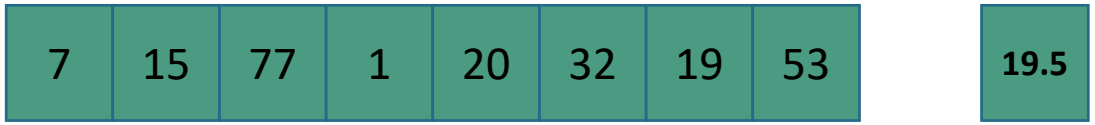
Sorting Problems

- 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



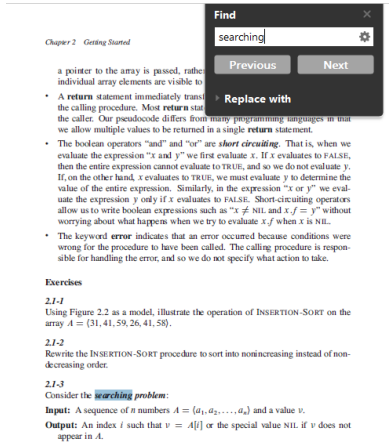
- **Stability:** Stable sorting algorithms sort repeated elements in the same order that they appear in the input.

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 ccctaaattc 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
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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
```
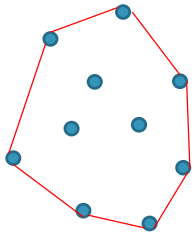

Severe acute respiratory syndrome coronavirus 2 isolate Wuhan-Hu-1, complete genome.

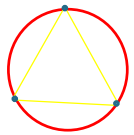
Computational Geometric Problem

- Convex hull problem: Given a set of points, find the smallest convex polyhedron/polygon containing all the points

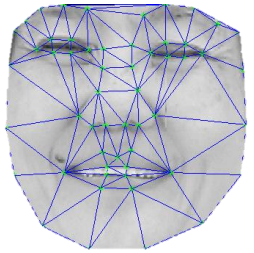
- Delaunay triangulation: for a given set P of discrete points in a plane is a triangulation such that no point in P is inside the circumcircle of any triangle



Convex Hull



circumcircle



Delaunay Triangulation

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

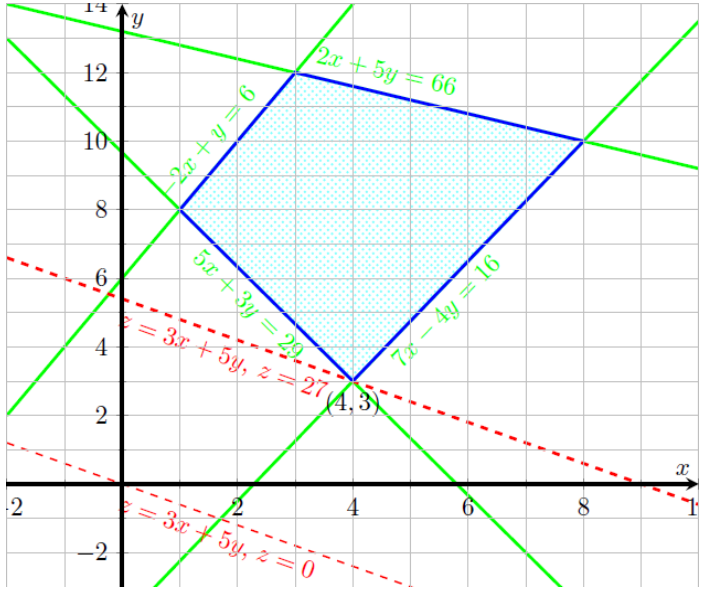
$$\min 3x + 5y$$

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

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

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

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



How do we solve these problems?

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
  - Graph Problems etc.
- 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
- Lab Sessions focus on practice and realization
- Assignments and Lab Tests are assessments

Assessments	Weighting
Assignments (W10-13)	20%
Lab Test 2 (Week 14)	20%
Quiz (Week 14)	20%