Faculty of
Information Technology
King Mongkut's Institute of Technology Ladkrabang

Introduction to Data Structures and Algorithms

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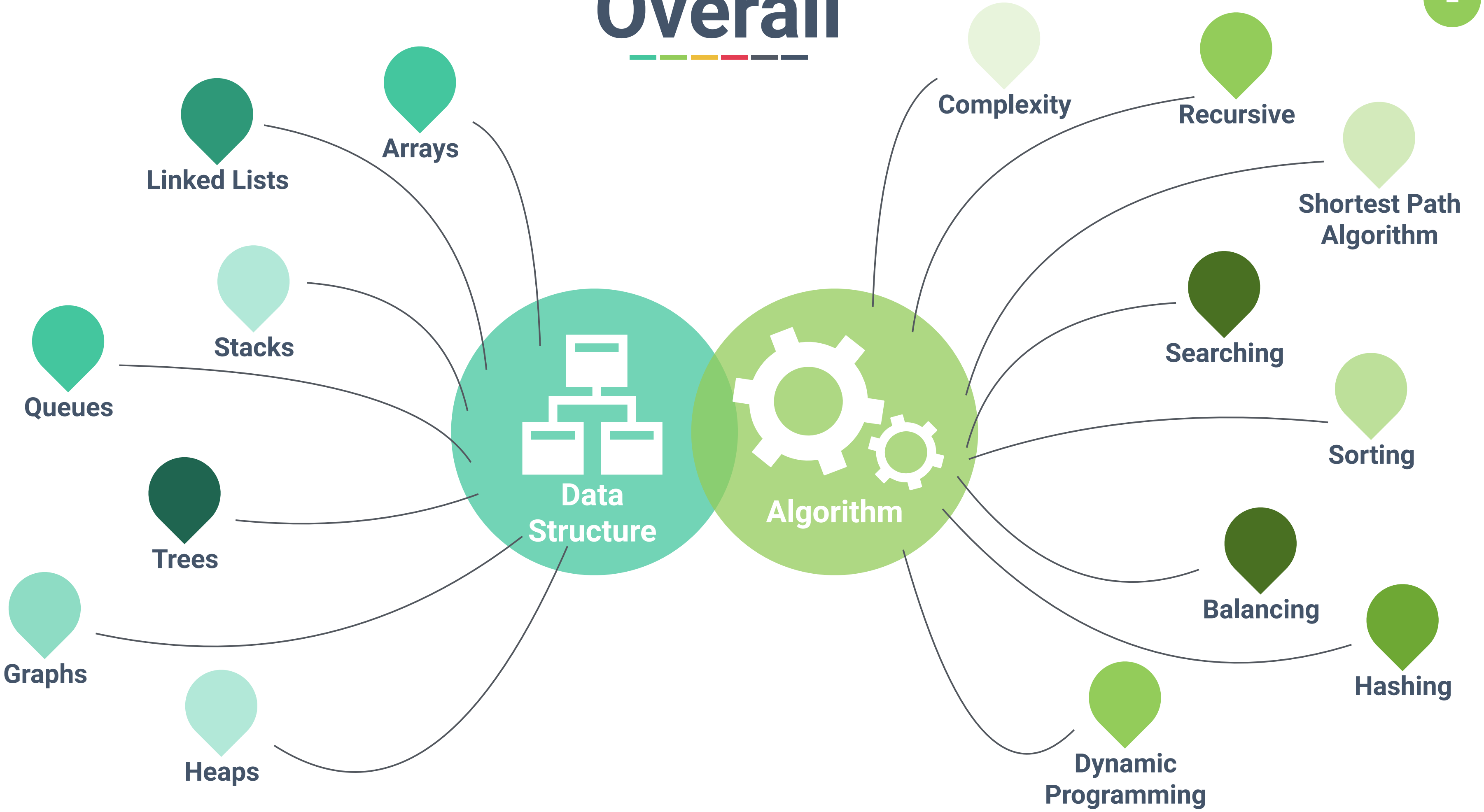
Overall


Linked Lists
Arrays
Stacks
Queues
Trees
Graphs
Heaps
Data Structure
Algorithm
Complexity
Recursive
Shortest Path Algorithm
Searching
Sorting
Balancing
Hashing
Dynamic Programming

Overall

Data Structures

Algorithms

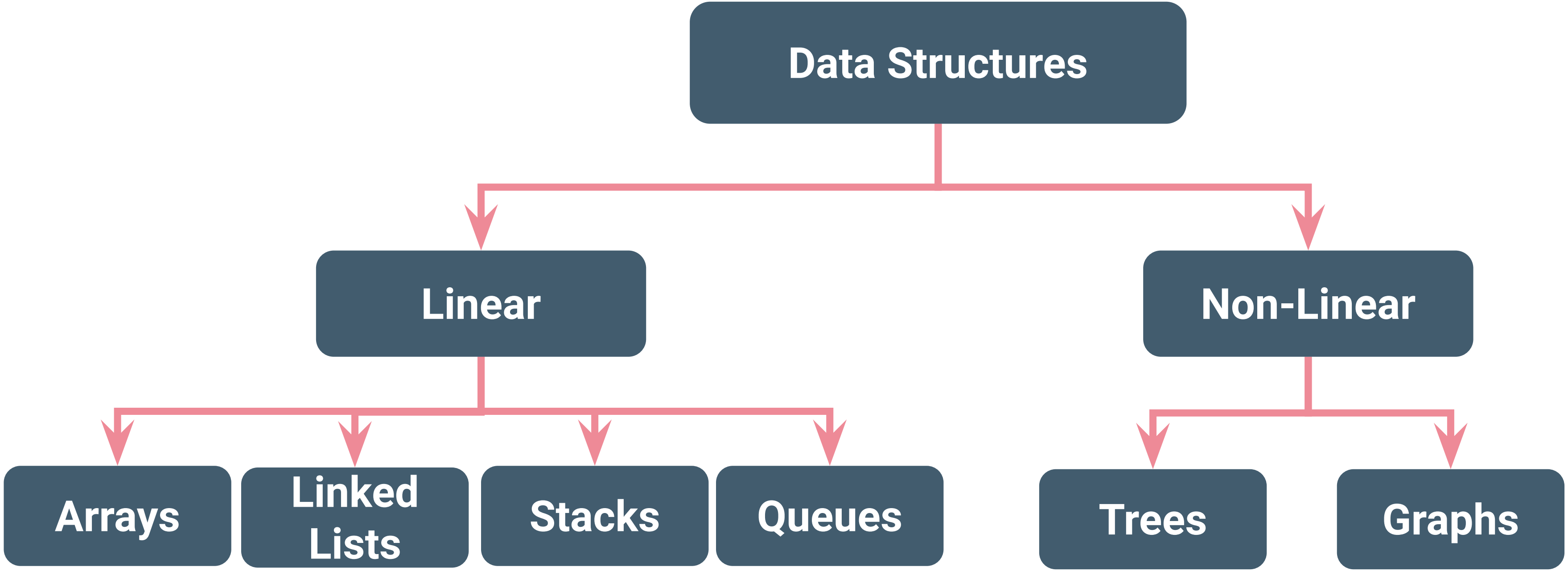
What is “Data Structure” ?

- Way to store and organise data
- Enable efficient access and modification of data
- Designed for a specific algorithm
  - Strengths and limitations
  - Time and space complexity

Abstract Data Type

- A data type, where only behavior is defined but not implementation.
- Similar to a black box where input and output are known, but not how.
- Examples: Array, List, Map, Queue, Set, and etc.

Type of Data Structure



Check out for a comprehensive list of data structures at
https://en.wikipedia.org/wiki/List_of_data_structures

What is "Algorithm" ?

- Well-defined procedure or set of instructions to accomplish a task

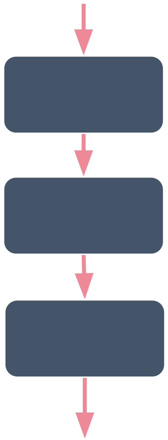
- Sequence of steps that transform input into output

- Tool to solve a well-specified computational problem

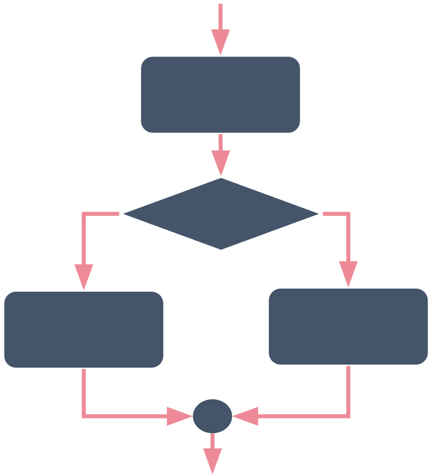
Example: Sorting numbers

1. **Input:**
   - A sequence of n numbers: *<a1, a2, …, an>*
   - <31, 41, 59, 26, 41>
2. **Sorting Algorithms**
3. **Output:**
   - A permutation (reordering) *<a’1, a’2, …, a’n>* of input sequence such that *a’1 <= a’2 <= … <= a’n*
   - <26, 31, 41, 41, 59>

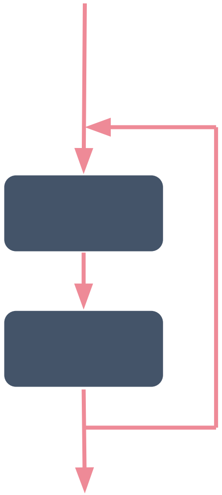
Control Structure



Sequence

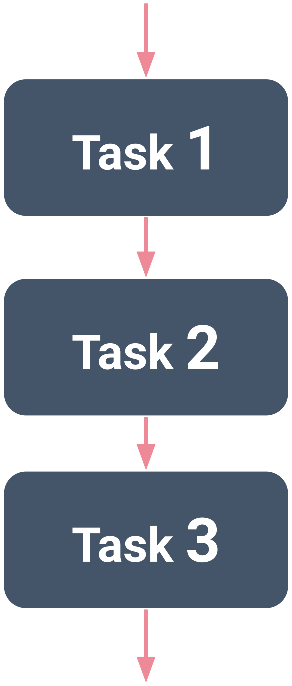


Selection

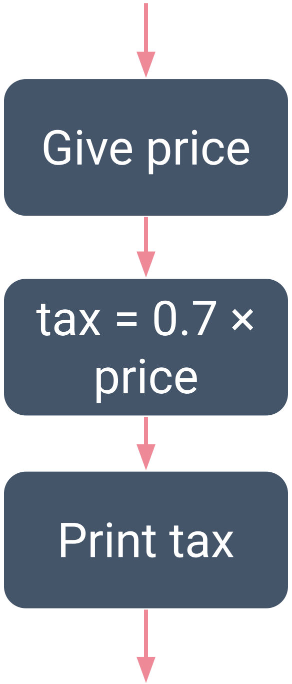


Iteration

Sequence



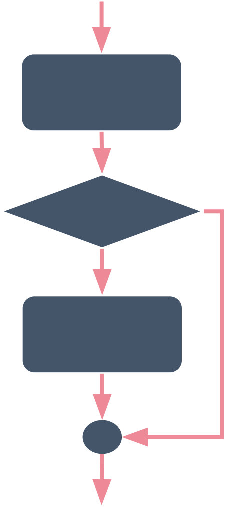
Sequence



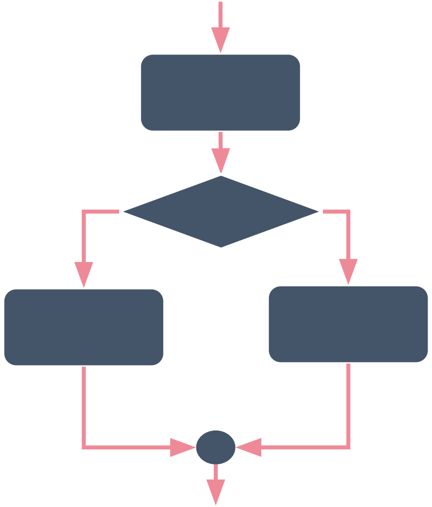
Exercise: Sequence

Write a flowchart that converts **USD currency** to **Thai baht**. At the end of the flowchart, print the **Thai baht**. (Exchange rate USD to Thai baht is 32.00)

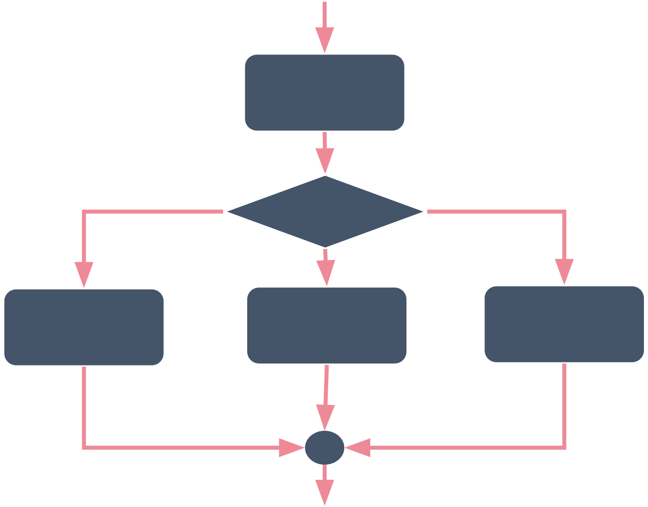
Selection



Single Selection

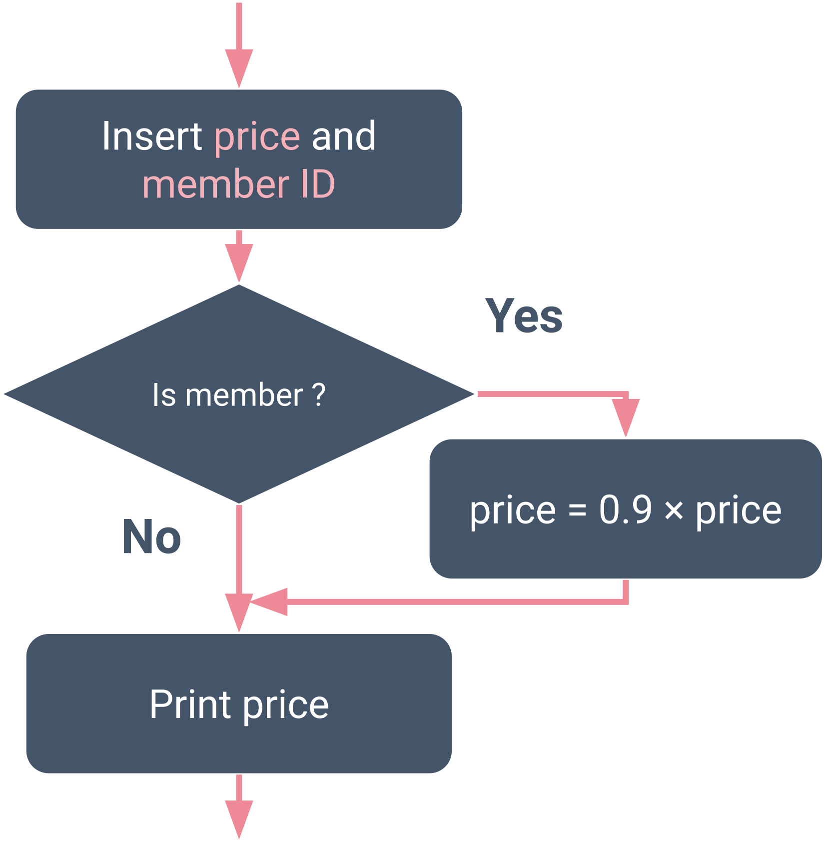


Double Selection

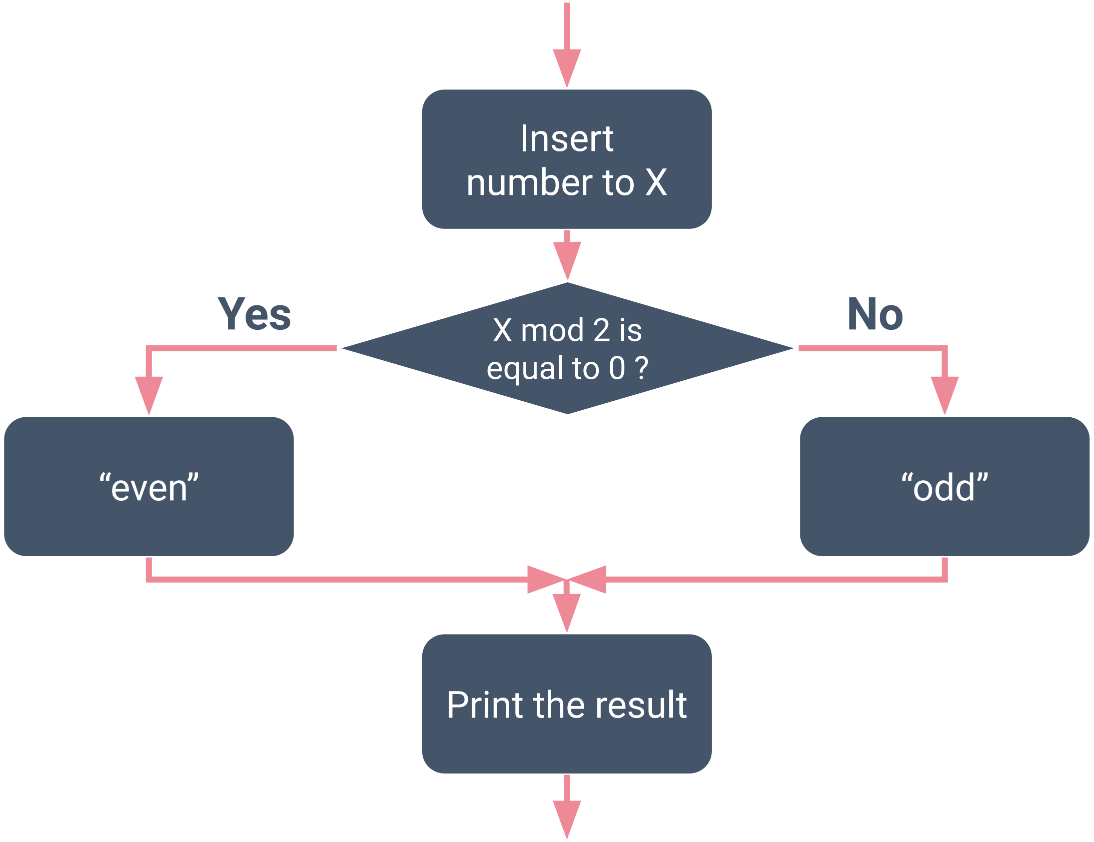


Multiple Selection

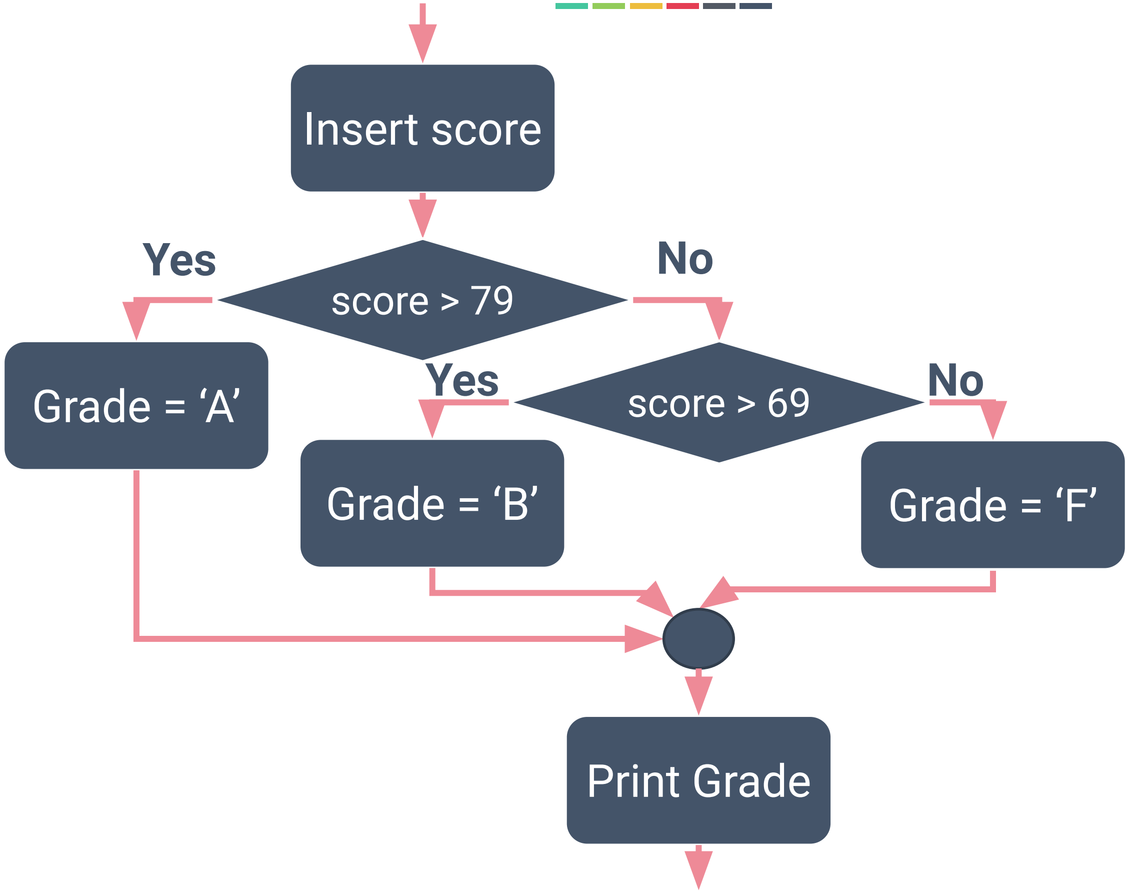
Selection


Insert price and member ID
Is member ?
Yes
No
price = 0.9 × price
Print price

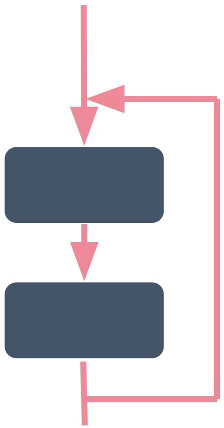
Selection


Insert number to X
X mod 2 is equal to 0 ?
Yes
No
"even"
"odd"
Print the result

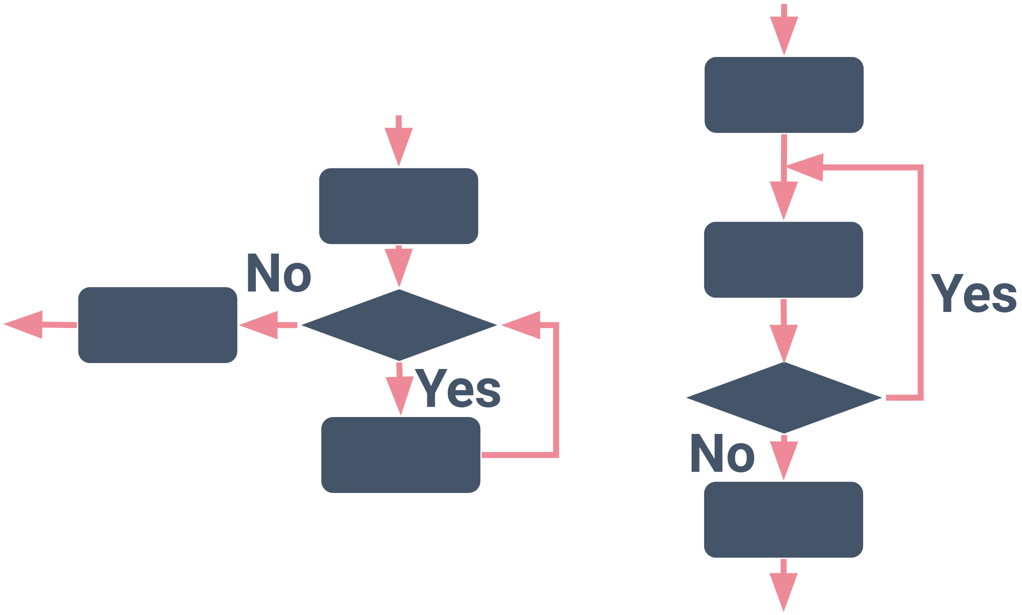
Selection


Insert score
score > 79
Yes
No
Grade = 'A'
score > 69
Yes
No
Grade = 'B'
Grade = 'F'
Print Grade

Iteration



Infinite Loop



Finite Loop

Exercise: Control Flow

Write a flowchart describing the logic of factorial function.

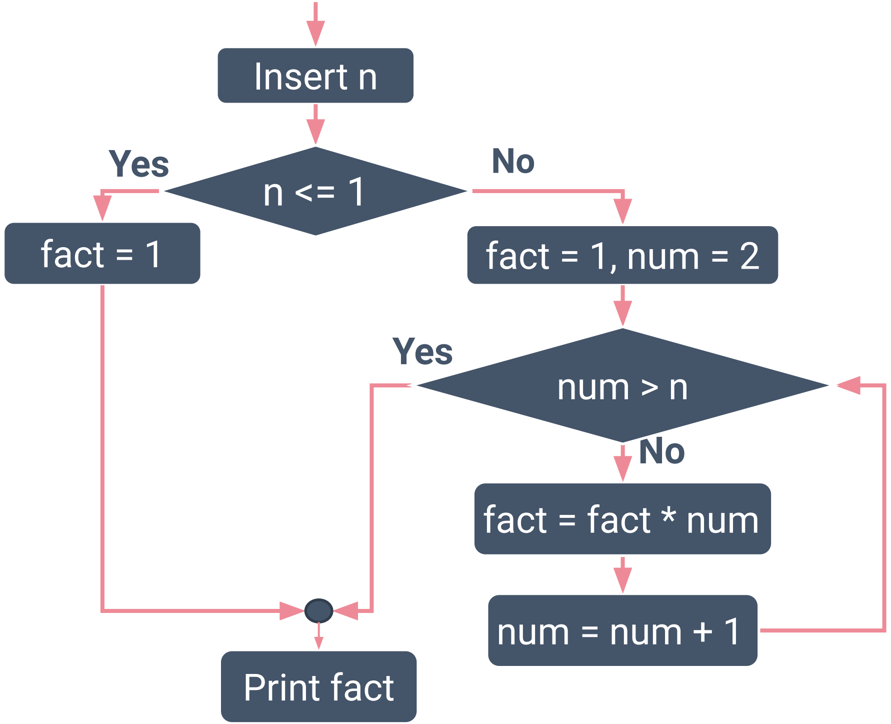
Hint: The factorial n!, is the product of all positive integers less than or equal to n.

For example: 5! = 5 * 4 * 3 * 2 * 1 = 120

Exercise: Control Flow

Write a flowchart describing the logic of factorial function.

Hint: The factorial n!, is the product of all positive integers less than or equal to n.




```python
def factorial1(n):
  if n <= 1:
    return 1
  else:
    fact = 1
    for num in range(2,n+1):
      fact *= num
    return fact
```

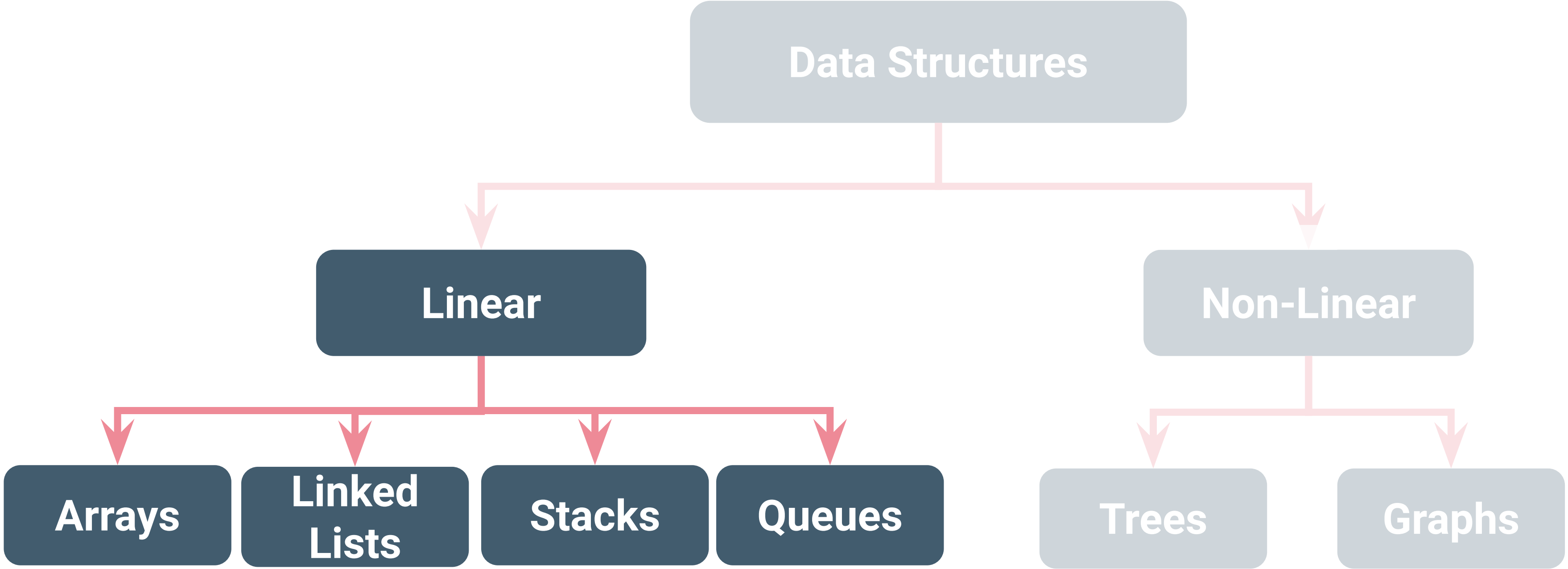
What kind of problems are solved by algorithms?

- Human Genome Project
  - identifying all genes of human beings
- Internet: Routing, searches, and security
  - Shortest path, search engines, encrypted communication
- E-commerce
  - Ads, recommendations, authentications
- Commercial enterprises
  - Resource allocation:
    - crew assignment on flights, package delivery route

Data Structures and Algorithms

- Data Structures
  - Way to store and organise data
- Algorithms
  - Sequence of steps performed on data structures to perform a task

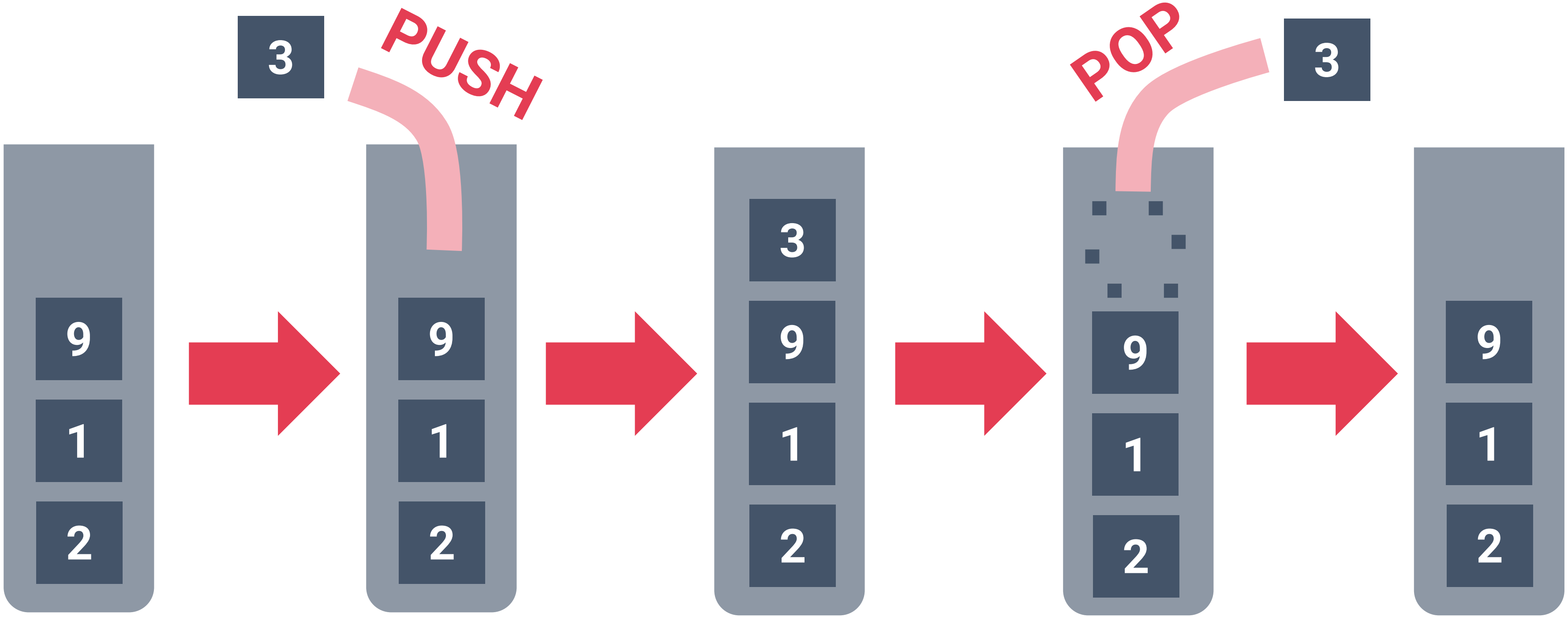
Type of Data Structure



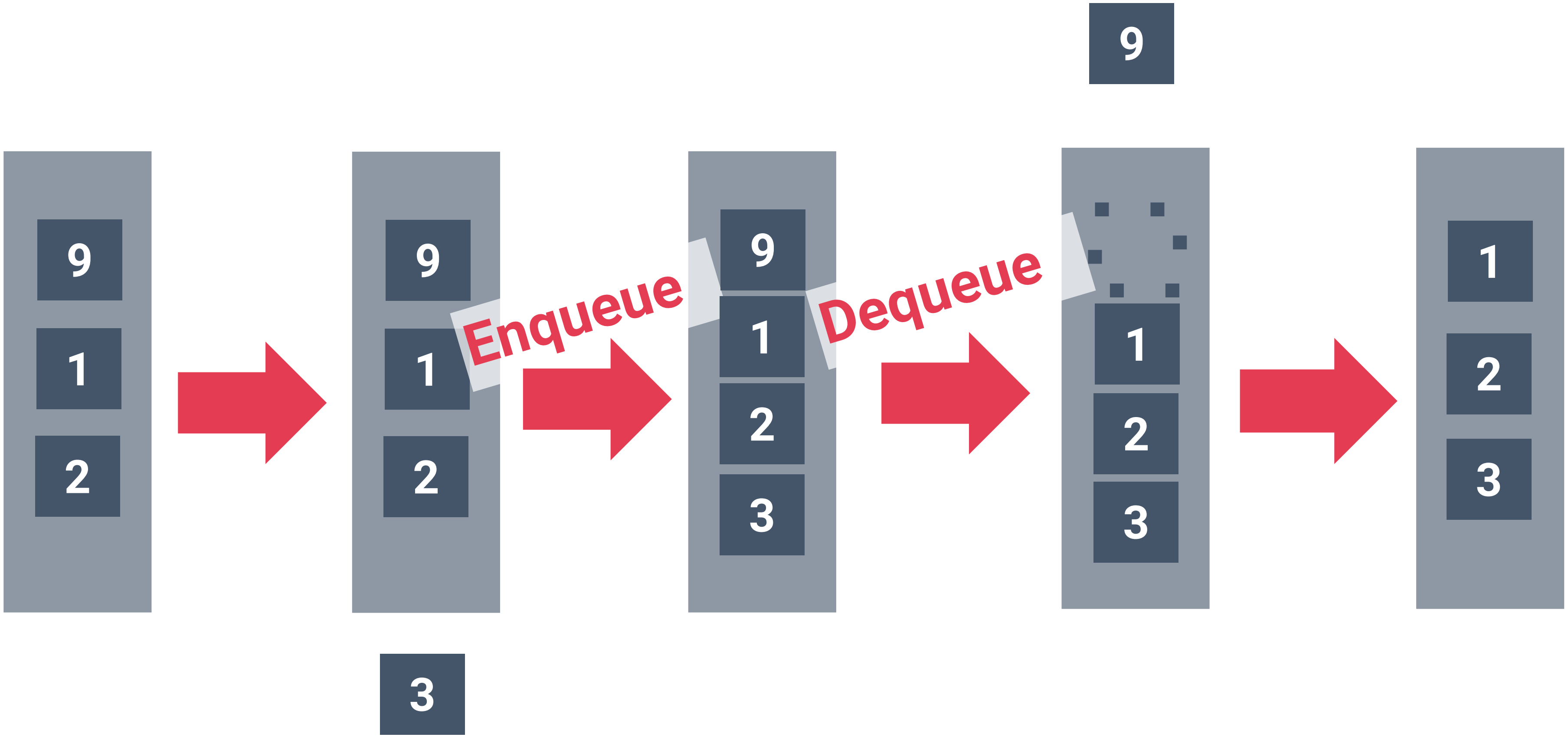
Check out for a comprehensive list of data structures at
https://en.wikipedia.org/wiki/List_of_data_structures

Arrays

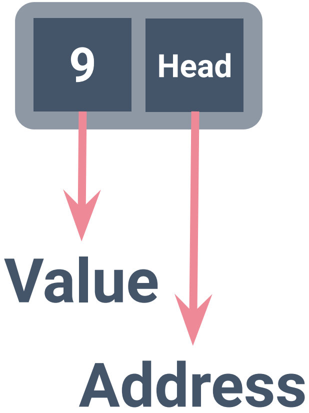
Stacks



Queues

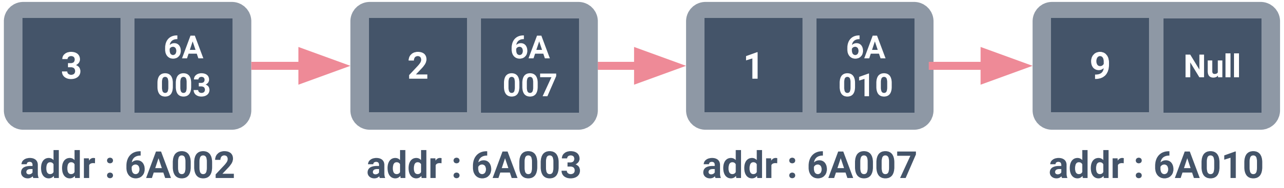


Linked Lists



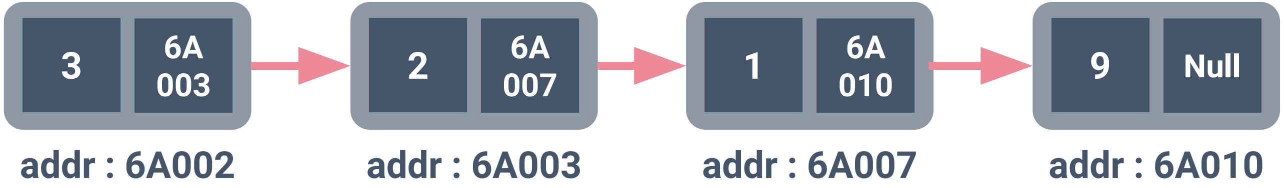
Linked Lists

- **Linked Lists**

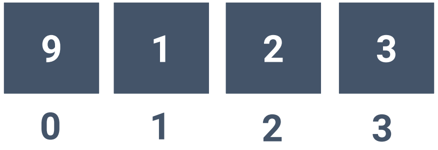


Linked Lists VS Arrays

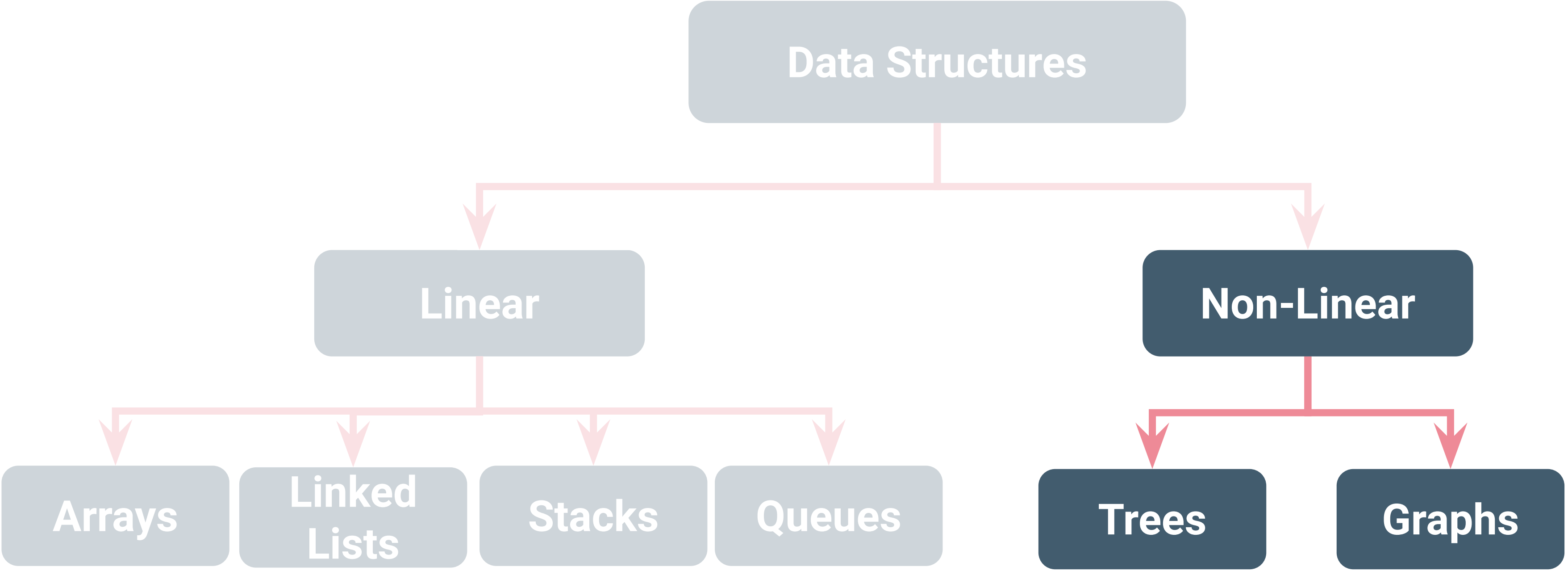
- **Linked Lists**



- **Arrays**



Type of Data Structure



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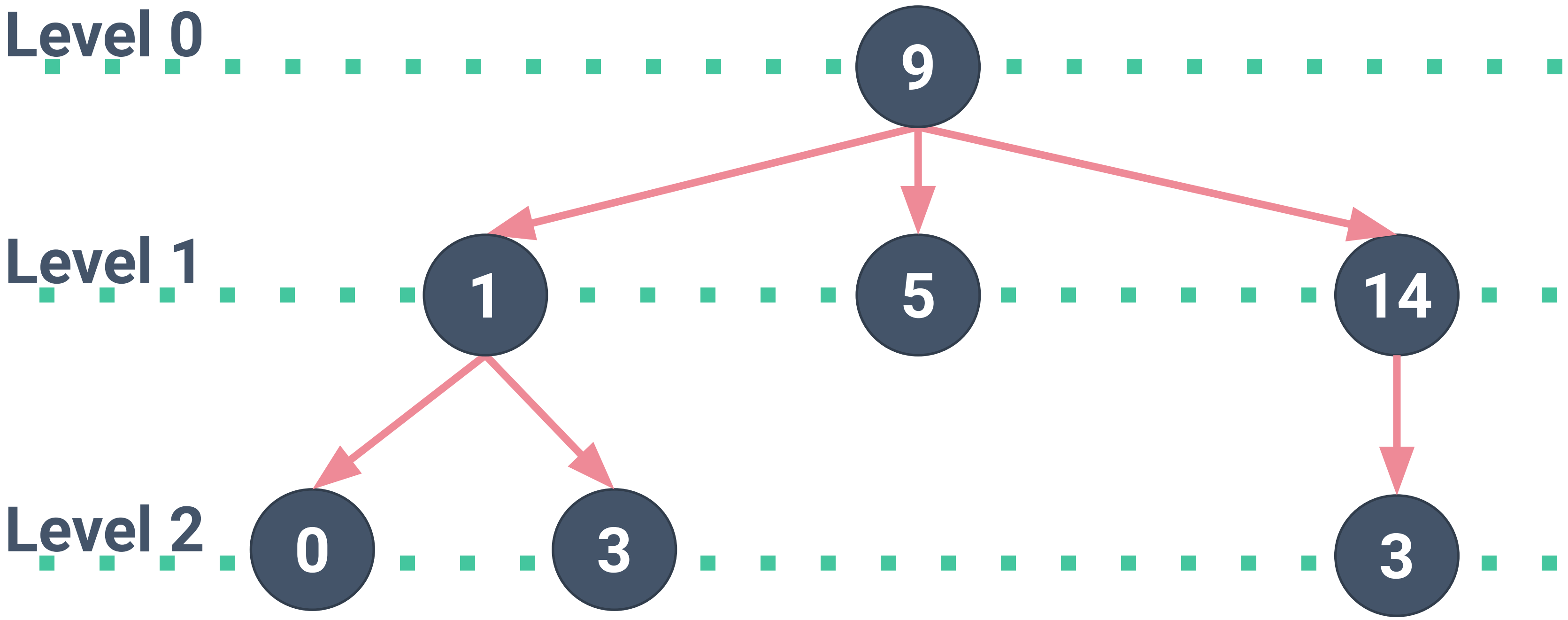
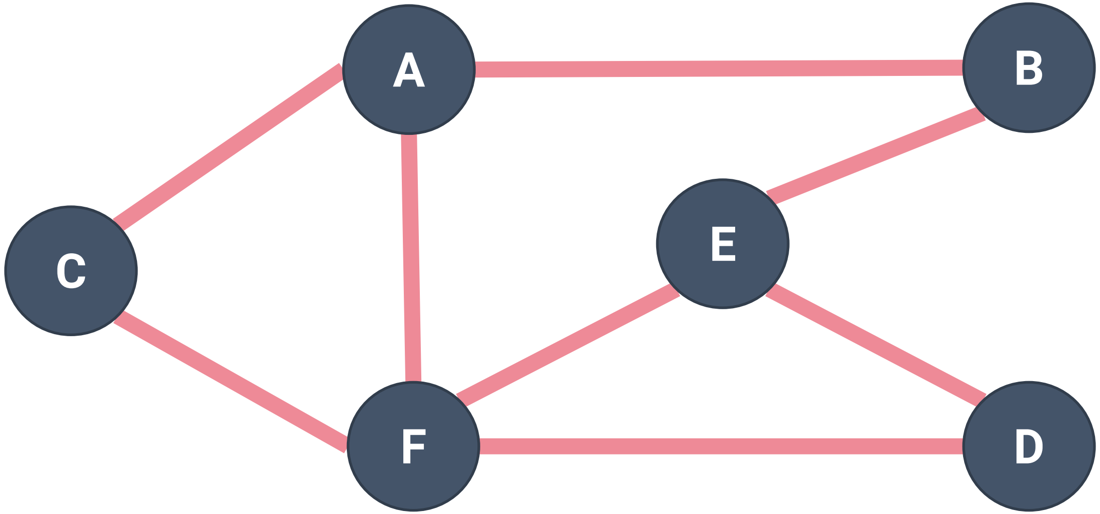
Trees



Graphs



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Algorithm Analysis

- If computers were infinitely fast, **any correct method** for solving a problem would do.
- Computing time and space in memory are a limited resource.
- The solution should run as fast as possible.
- For the same problem, it can be solved by different algorithms but they are often differ in their efficiency.
- **Algorithms that are efficient in terms of time or space are preferred.**

Algorithm Analysis

- How do we measure algorithm **efficiency** or **performance**?
    - Use running time as an indicator.

Benchmark Analysis

- Example: Summation of *n* integers
  - Time required for the iterative solution seems to increase as we increase the value of *n*.
- Running time depends on many factors
  - Hardware (CPU, RAM, etc.)
  - Software (OS, Programming language, etc.)
- Need an alternative way for analysing algorithms with respect to running time

Algorithm Analysis

- How do we measure algorithm **efficiency** or **performance**?
  - Use running time as an indicator.

- Running time can be expressed as the number of operations or steps executed.
  - theSum = 0 -> 1 step/time
  - for i in range(1,n+1):

    theSum = theSum + i -> n steps/times

Time complexity
T(n) = 1+n

Algorithm Analysis

- The parameter ***n*** is often referred as "**size of the problem**" or **input size**
- The running time of an algorithm or data structure operation **increases** with the input size.
- Running time as a function of the input size - f(n)
- As *n* gets larger, the constant will become less significant.
- Order of magnitude/growth describes the running time that is most important.

Asymptotic Notation

- Example:
  - Suppose an algorithm runs on an input size n.
  - Times required to execute is $T(n) = 2n^2 + n + 1$
  - The $\mathbf{n^2}$ terms become larger when **n** gets larger.
  - The running time of this algorithm grows as $\mathbf{n^2}$.
- Asymptotic notation represents algorithm’s complexity
  - Ignores constant factors and slower growing terms.
  - Focus on the main components that affect the growth.
  - Big-O notation

Big-O notation

- **Big-*O* notation (Order)**
  - Example:
    - Given T(n) = 1+n, then T(n) = O(n)
    - Given T(n) = $2n^2 + n + 1$, then T(n) = $O(n^2)$

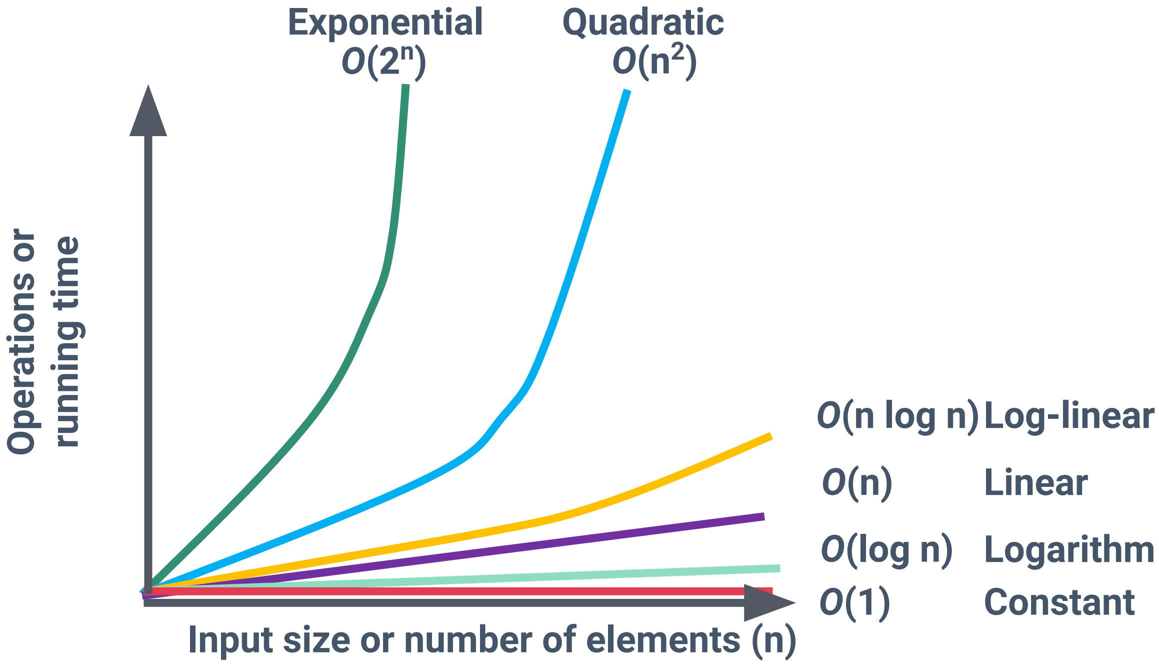
- **O(n) means time complexity will never exceed n.**

Big-O notation

- **Big-*O* notation (Order)**
  - Common f(n):
    - O(1): constant
    - O(log n): logarithm
    - O(n): Linear
    - O(n log n): Log linear
    - $O(n^2)$: Quadratic
    - $O(2^n)$: Exponential
    - O(n!): Factorial

Time Complexity

In general, the standard functions of input size n are shown in figure.

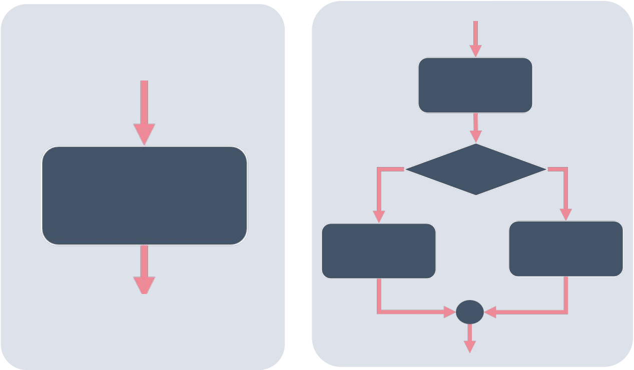


Calculating Time Complexity

Mathematic

$f(n) = 3$

Computer



- Simple statements (read, write, assign)
- Simple operations (+ - * / == > >= < <=)

Big-O

$O(1)$

Constant

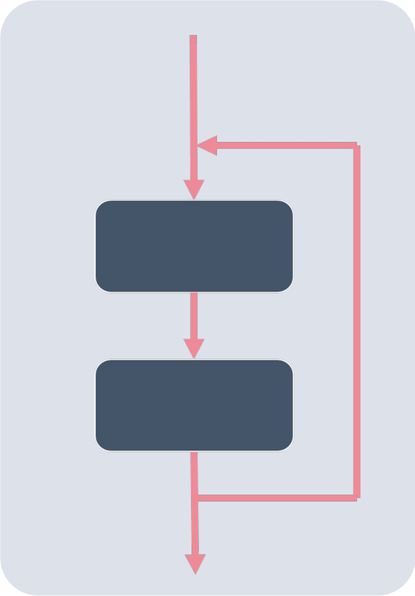
Calculating Time Complexity

Mathematic

$f(n) = n-3$

Computer

Linear loop



Big-O

$O(n)$

Linear

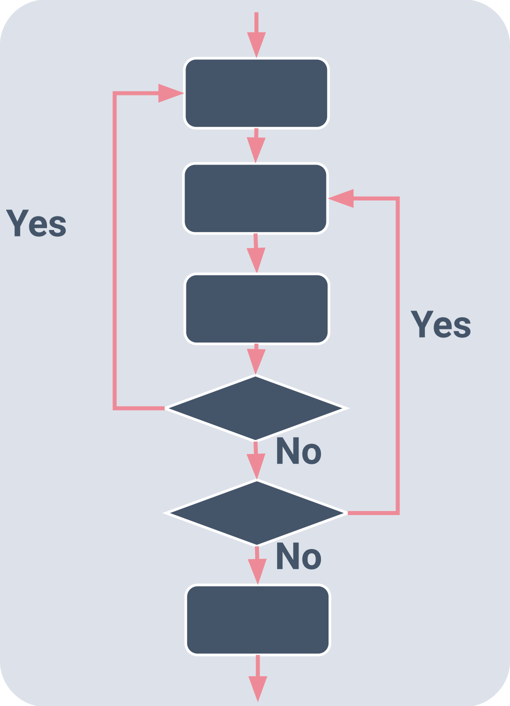
Calculating Time Complexity

Mathematic

$f(n) = n^2 + n + 7$

Computer

Nested loop



Big-O

$O(n^2)$

Quadratic

Loops

	Python Code	Time complexity
Linear	for i in range (0,n): do something	$T(n) = n, O(n)$
Linear	for i in range (0,n,2): do something	$T(n) = n/2, O(n)$

Nested	for i in range (0,n):
	    for j in range (0,n):
	        do something
		$T(n) = n^2, O(n^2)$

Loops

Python Code

Time complexity

n=1000

Logarithmic

```
i = 1              Start
while i < n:       Stop
    do something
    i = i * 2      Step
```

1
2
4
8
16
32
64
128
256
512

T(n) = log n, O(log n)

Logarithmic

```
i = n              Stop
while i >= 1:      Start
    do something
    i = i // 2     Step
```

1000
500
250
125
62
31
15
7
3
1

T(n) = log n, O(log n)

Loops

Python Code

Time complexity

Linear logarithmic

```
for i in range (0,n):    n
    j = 1
    while j < n:         log n
        do something
        j = j*2
```

$T(n) = n\log n, O(n\log n)$

Loops

Python Code

Time complexity

Dependent Nested

```
for i in range (0,n):  n
    for j in range(0, i+1):(n+1)/2
        do something
```

$T(n) = n(n+1)/2,\ O(n^2)$

Number of iterations of the inner loop depends on the outer loop

For the inner loop, the number of iterations is (n+1)/2

For example, n = 3, i = 0 then j = [0],
i = 1 then j = [0, 1],
i = 2 then j = [0 , 1, 2]

Exercise

Time complexity

- $n^2 + 100n$
- $n^2 * n + 100n^2 \log n$
- $123 + \log 657$
- $(n + \log n)^3$
- $n(2 + \log n)$
- $1 + 2 + 3 + ... + n$

→

O(?)
O(?)
O(?)
O(?)
O(?)
O(?)

Exercise

Time complexity

- $n^2 + 100n$
- $n^2 * n + 100n^2 \log n$
- $123 + \log 657$
- $(n + \log n)^3$
- $n(2 + \log n)$
- $1 + 2 + 3 + \dots + n$

$O(n^2)$

$O(n^3)$

$O(1)$

$O(n^3)$

$O(n \log n)$

$O(n)$

Calculating Time Complexity

Python Code: Factorial

```python
def factorial1(n):
  if n <= 1:
    return 1
  else:
    fact = 1
    for i in range(2,n+1):
      fact *= i
    return fact
```

Number of steps

→ 1

→ 1

→ n

→ 1

$T(n) = 2 + n + 1 = n + 3$

Complexity: $O(n)$

Calculating Time Complexity

Python Code: Simple nested loops

```
def simple(n):
  for i in range(n):
    for j in range(n):
      print("i: {0}, j: {1}".format(i,j))
```

Number of steps

→ **n**

→ **n**

$T(n) = n*n$

Complexity: $O(n^2)$

Calculating Time Complexity

Python Code: Element uniqueness v1

```
def unique1(s):
    for i in range(len(s)):
        for j in range(i+1, len(s)):
            if s[i] == s[j]:
                return False  # Found duplicate pair
    return True          # All elements are unique
```

Number of steps

→ n

→ n

$T(n) = n(n-1)/2$

Complexity: $O(n^2)$

Calculating Time Complexity

Python Code: Element uniqueness v2

```
def unique2(s):
  temp = sorted(s) # create a sorted copy of s
  for i in range(1, len(temp)):
    if temp[i-1] == temp[i]:
      return False    # Found duplicate pair
  return True         # All elements are unique
```

Number of steps

→ n log n

→ n

T(n) = n log n + n

Complexity: O(n log n)

Calculating Time Complexity

Python Code: Prefix averages v1

```
def prefix_average1(s):
  n = len(s)
  a = [0] * n              # create list of n zeros
  for i in range(n):
    total = 0              # compute each element
    for j in range(i+1):
      total += s[j]
    a[i] = total / (i+1)   # record the average
  return a
```

Number of steps

→ 1

→ n

→ n

→ 1

→ (n+1)/2

→ 1

$T(n) = 1 + n + 2n + n(n+1)/2$

Complexity: $O(n^2)$

Calculating Time Complexity

Python Code: Prefix averages v2

```python
def prefix_average2(s):
  n = len(s)
  a = [0] * n                    # create list of n zeros
  for i in range(n):
    a[i] = sum(s[0:i+1])/(i+1)  # record the average
  return a
```

Number of steps

- → 1
- → n
- → n
- → (n+1)/2

$T(n) = 1 + n + n(n+1)/2$

Complexity: $O(n^2)$

Calculating Time Complexity

Python Code: Prefix averages v3

```
def prefix_average3(s):
  n = len(s)
  a = [0] * n           # create list of n zeros
  total = 0
  for i in range(n):
    total += s[i]      # update total sum to include s[i]
    a[i] = total / (i+1) # compute average based on
current sum
  return a
```

Number of steps

1
n
1
n
1
1

$T(n) = 2 + n + 2n$

v3 is asymptotically better than v2 and v1

Complexity: $O(n)$

Exercise 1

Python Code

```
def example1(s):
  n = len(s)
  total = 0
  for i in range(n):     # loop from 0 to n-1
    total += s[i]
  return total
```

T(n) = ?

Complexity: *O*(?)

Exercise 2

Python Code

```
def example2(s):
  n = len(s)
  total = 0
  for i in range(0,n,2):  # Increment of 2
    total += s[i]
  return total
```

T(n) = ?

Complexity: *O*(?)

Exercise 3

Python Code

```
def example3(s):
  n = len(s)
  total = 0
  for i in range(n):        # loop from 0 to n-1
    for k in range(1+i):    # loop from 0 to i
      total += s[k]
  return total
```

T(n) = ?

Complexity: *O*(?)

Exercise 4

Python Code

```python
def example4(s):
  n = len(s)
  prefix = 0
  total = 0
  for i in range(n):
    prefix += s[i]
    total += prefix
  return total
```

T(n) = ?

Complexity: *O*(?)

Exercise 5

Python Code

```
# Assume that A and B have equal length of n
def example5(A,B):
  n = len(A)
  count = 0
  for i in range(n):          # loop from 0 to n-1
    total = 0
    for j in range(n):        # loop from 0 to n-1
      for k in range(1+j):    # loop from 0 to j
        total += A[k]
    if B[i] == total:
      count += 1
  return count
```

T(n) = ?

Complexity: *O*(?)

Exercise 2: Sequence

1) Write a flowchart that converts the **Buddhist** calendar to the **Anno Domini** calendar. At the end of the flowchart, print the Anno Domini calendar.

Best, average, or worst case?

- Example: Sequential search
- Suppose a sequence of numbers: <10, 20, 30, 40, 50>
  - Find number 10 = 1 step = Best case
  - Find number 50 = 5 steps = Worst case

- We are interested in worst-case running time, that is, the longest running time for any input of size n.
- With any input size, it guarantees that the algorithm will never take any longer.

Example 10

Write your answer in the box

1. n^2+n
2. $3n+4n^2+n^3-12$
3. 8
4. n^4+8
5. $9n^2+3n-4n^2-6$
6. $6n+2$
7. $9+10n^2+3n-10n^2$
8. $2n+12+4n^3$

การวัดประสิทธิภาพอัลกอริทึม

$f(n)$	Asymptomic
c	$\Theta(1)$
$\Sigma_{i=1}^{k} c_i n^i$	$\Theta(n^k)$
$\Sigma_{i=1}^{n} i$	$\Theta(n^2)$
$\Sigma_{i=1}^{n} i^2$	$\Theta(n^3)$
$\Sigma_{i=1}^{n} i^k$	$\Theta(n^{k+1})$
$\Sigma_{i=0}^{n} r^i$	$\Theta(r^n)$
$n!$	$\Theta(n(n/e)^n)$
$\Sigma_{i=1}^{n} 1/i$	$\Theta(\log n)$