CODE University 2021 Fall Semester
SE_02 Algorithms and Data Structures
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Data Structure

Analysis of Data Structures

- Data structures are collections of values, the relationships among them, and the functions or operations that canbe applied to the data.
- It's a essential for computer science and each has their own advantages and disadvantages.
- e.g.
  - For map/location data, graph would be the best data structure. (for shortest path/distance/GPS data/coordinates etc)
  - For input job for adding a value at the beginning/end of the ordered list, linked list could be the best case.
  - For scraping nested HTML, tree structure could be the best data structure.

Before get started with Javascript..

Javascript is prototype based language and doesn't have OOP concept per se but there are some syntactic sugar for it since ES2015.

Class

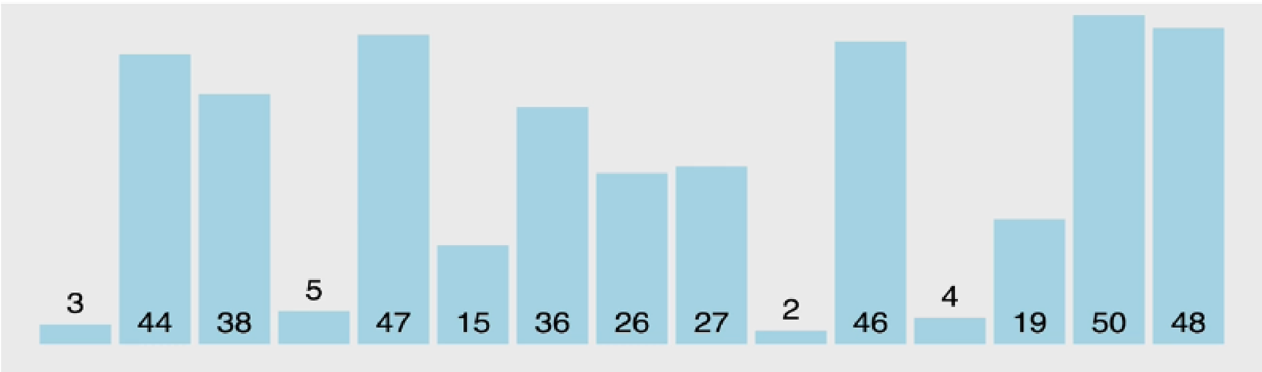
A blueprint for creating objects with pre-defined properties and methods.

```
// define a pattern
class Student {
  constructor(firstName, lastName, point, items) {
    this.firstName = firstName;
    this.lastName = lastName;
    this.point = point;
    this.items = [];
  }
  // method that is.. public to the instances?
  fullName() {
    return `Full name is ${this.firstName} ${this.lastName}.`;
  }
  markPoint(n) {
    this.point += n;
    return `${this.firstName} ${this.lastName} got ${this.point} grade
point.`;
  }
  addItems(item) {
    this.items.push(item);
    return `${this.firstName} got ${this.items}.`;
```

```
  }

  // utility subclass / function
  static enrollStudents(...students) {
    return `${students.length} has enrolled.`;
  }
}

// instantiate an object
let okja = new Student("Okja", "The Cute Dog", 3, "Carrot");

// okja.lastName -> "The Cute Dog"
// okja.fullName(); -> "Full name is Okja The Cute Dog."
// okja.markPoint(-2); -> "Okja got 1 grade point."
// okja.addItems("Carrot"); -> "Okja got Carrot."
// okja.enrollStudents(okja, jongwoo); -> error
// Student.enrollStudents(okja, jongwoo); -> "2 has enrolled."
```

- The method to create new objects **must** be called `constructor`.
- The class keyword create a constant, you can't change the structure of the class.
- Class instances are created with `new` keyword.
- `this` keyword is used to access the properties and methods of the class, it refers to the object created from that class.
- `static` keyword defines a static method or property for a class, which can be called without instantiating an object from the class and can't be called through individual instances. MDN static reference

Arrays



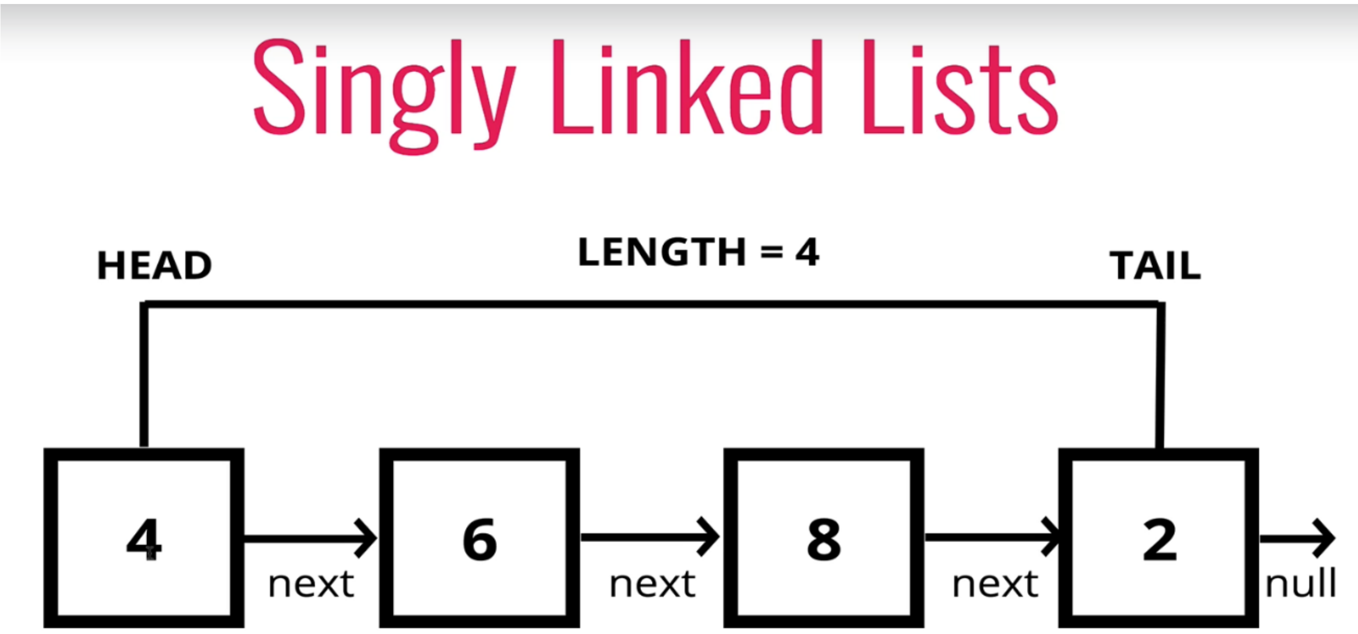
- push: O(1)
- pop: O(1)
  - both are basic accessing
- shift: O(n)
- unshift: O(n)

    - basic accessing with shifting all the indexes afterwards
- concat: O(n)
    - merge two or more array into one
- slice: O(n)
    - returns a shallow copy of a portion of an array into a new array that is selected from begin to end, original array will not be modified
- splice: O(n)
    - changes the content of an array by removing existing elements and/or adding new elements
- sort: O(n*log N)
    - slowest among all the array methods
- forEach/map/filter/reduce: O(n)
    - whatever methods doing, it involves on each element

Linked List

What is a Linked List?

- A data structure that contains a head(beginning), tail(end) and length property.
- Linked lists consist of nodes(each element), and each node has a value and a pointer to another node or null.
- E.g.
    - Singly linked list has each node that is only connected to next node in one direction.
    - Double linked list has each node that is connected to next node in both direction.



Comparisons with Array

- List:
  - There is no indexes.
  - Connected via nodes with a **next** pointer.
  - Raandom access is not possible.
  - Insertion/Deletion is cheap.
- Array:
  - Indexed in order.
  - Insertion and deletion is expensive, every node has to be re-indexed.
  - Node can be accessed quickly with a specific index.

Singly Linked List

- linked list has a pointer to the head of the list and a pointer to the tail.

Push

- push add a value at the end of the list.

Push pseudocode

- this function should accept a value.
- create a new node using the value passed to the function.
- if there is no head property on the list, set the head and tail to be the newly created node.
- otherwise set the next property on the tail to be the new node and set the tail property on the list to be the newly created node.
- increment the length by one.
- return the linked list.

Push implementation

```
// push
class Node {
  constructor(val) {
    this.val = val;
    this.next = null;
  }
}

class SinglyLinkedList {
  constructor() {
    this.head = null;
    this.tail = null;
    this.length = 0;
  }
  push(val) {
    const newNode = new Node(val);
    if (!this.head) {
      this.head = newNode;
```

```
      this.tail = this.head;
    } else {
      this.tail.next = newNode;
      this.tail = newNode;
    }
    this.length++;
    return this;
  }
}

const list = new SinglyLinkedList()
list.push("goodbye");
list.push("cruel");
list.push("world");

consoole.log(list);
// SinglyLinkedList {
//   head: Node { val: 'goodbye', next: Node { val: 'cruel', next: [Node] }
},
//   tail: Node { val: 'world', next: null },
//   length: 3
// }
```

Pop

- pop removes the last element of the list.

Pop pseudocode

- if there are no nodes in the list, return undefined
- loop through the list until you reach the tail
- set the next property of the 2nd to last node to be null.
- set the tail to be the second to last node.
- decrement the length of the list by 1.
- return the value of the node removed.

Pop implementation

```
...SinglyLinkedList

pop() {
  if (!this.head) return undefined;
  let current = this.head;
  let newTail = current;
  while (current.next) {
    newTail = current;
    current = current.next;
  }
  this.tail = newTail;
```

```
    this.tail.next = null;
    this.length--;
    // in case list is empty
    if (this.length === 0) {
      this.head = null;
      this.tail = null;
    }
    return current;
  }

  ...
```

Shift

- shift removes a new node from the beginning of the linked list and return it.

Shift pseudocode

- If there are no nodes, return undefined
- store the current head property in a variable
- update the head property to be the current head's next property
- decrement the length by 1
- return the value of the node removed

Shift implementation

```
  ...SinglyLinkedList
  shift() {
    if (!this.head) return undefined;
    let currentHead = this.head;
    this.head = currentHead.next;
    this.length--;
    if (this.length === 0) {
      this.tail = null;
    }
    return currentHead;
  }
  ...
```

Unshift

- opposite of shift, it adds a anew node to the beginning of the linked list.

Unshift pseudocode

- unshift accepts a value to be put.
- create a new node using the value passed to the function.

  - if there is no head property in the list, set the head and tail to be the newly created node.
- set the newly created node's next property to be the current head property in the list.
- set the head property on the list to be that newly created node.
- increment the length of the list by 1
- return the linked list.

Unshift implementation

```
...SinglyLinkedList
unshift() {
  let newNode = new Node(val);
  if (!this.head) {
    this.head = newNode;
    this.tail = this.head;
  } else {
    newNode.next = this.head;
    this.head = newNode;
  }
  this.length++;
  return this;
}
...
```

Get

- get is a method that takes a number(index) and returns the item in that position.
- i.e. it takes a number and traverse the list n times to get the item at that index.

Get pseudocode

- it should take an index as a argument.
- if the index is less than 0 or greater than or equal to the length of the list, return undefined.
- loop through the list until you reach the index and return the node at that specific index.

Get implementation

```
...SinglyLinkedList
get(index) {
  if(index < 0 || index >= this.length) return undefined;
  let counter = 0;
  let current = this.head;
  while (counter !== index) {
    current = current.next;
    counter++;
  }
  return current;
```

```
}
...
```

Set

- method set is same as get() but it changes to the given value at the given position.

Set pseudocode

- it accepts a value and an index.
- use get() to find the note at the given index.
  - if there is no node, return false.
  - else there is a node, set the node's value to be the given value and return true.

Set implementation

```
...SinglyLinkedList
set(index, val) {
  let foundNode = this.get(index);
  if (foundNode) {
    foundNode.val = val;
    return true;
  }
  return false;
}
...
```

Insert

- similar to set(), it accepts an index and a value but it inserts the value at the given index.

Insert pseudocode

- it accepts an index and a value.
- if the index is less than zero or greather than the length, return false.
- if the index is the same as the length(end of list), just use push() a new node to the end of the list.
- if the index is 0(beginning of list), just use unshift() a new node to the beginning of the list.
- else, use get() to find the node at the given index - 1 to prepare insertion.
  - set the next property on that node to be the new node.
  - set the next property on the new node to be the previous next.
- increment the length of the list by 1.
- return true.

Insert implementation

```
...SinglyLinkedList
insert(index, val) {
  if (index < 0 || index > this.length) return false;
  // double negation to return bool of true in this case
  if (index === this.length) return !!this.push(val);
  if (index === 0) return !!this.unshift(val);

  let newNode = new Node(val);
  let prev = this.get(index-1);
  let temp = prev.next;
  newNode.next = temp;
  this.length++;
  return true;
}
...
```

Remove

- it's a method that removes a node from the linked list at a specific position.

Remove pseudocode

- if the index is less than zero or greater than the length, return undefined.
- if the index is the same as the last(length - 1), pop the last node.
- if the index is 0 at the beginning, shift the note from the beginning of the list.
- otherwise, using get() method, access the node at the index - 1.
  - set the next property on that node to be the next of the next node.
  - decrement the length.
  - return the value of the node removed.

Remove implementation

```
...SinglyLinkedList
remove(index) {
  if (index < 0 || index >= this.length) return undefined;
  if (index === this.length - 1) return this.pop();
  if (index === 0) return this.shift();

  let prev = this.get(index - 1);
  let removed = prev.next;
  prev.next = removed.next;
  this.length--;
  return removed;
}
...
```

Reverse

- Opposite of traverse, it reverses the linked list by replacing heads and tails in an opposite direction.

Reverse pseudocode

- swap the head and tail
- create a variable called next
- create a variable called prev
- create a variable called node and initialize it to the head property
- loop through the list
- set next to be the next property on whataever node is
- set the next property on the node to be whatever prev is
- set prev to be the value of the node variable
- set the node variable to be the value of the next variable

Reverse implementation

```
// 13 -> 27 -> 32 -> 71
// (h to 27)          t

// 13 <- 27 <- 32 <- 71
// (t to 27)          h
```

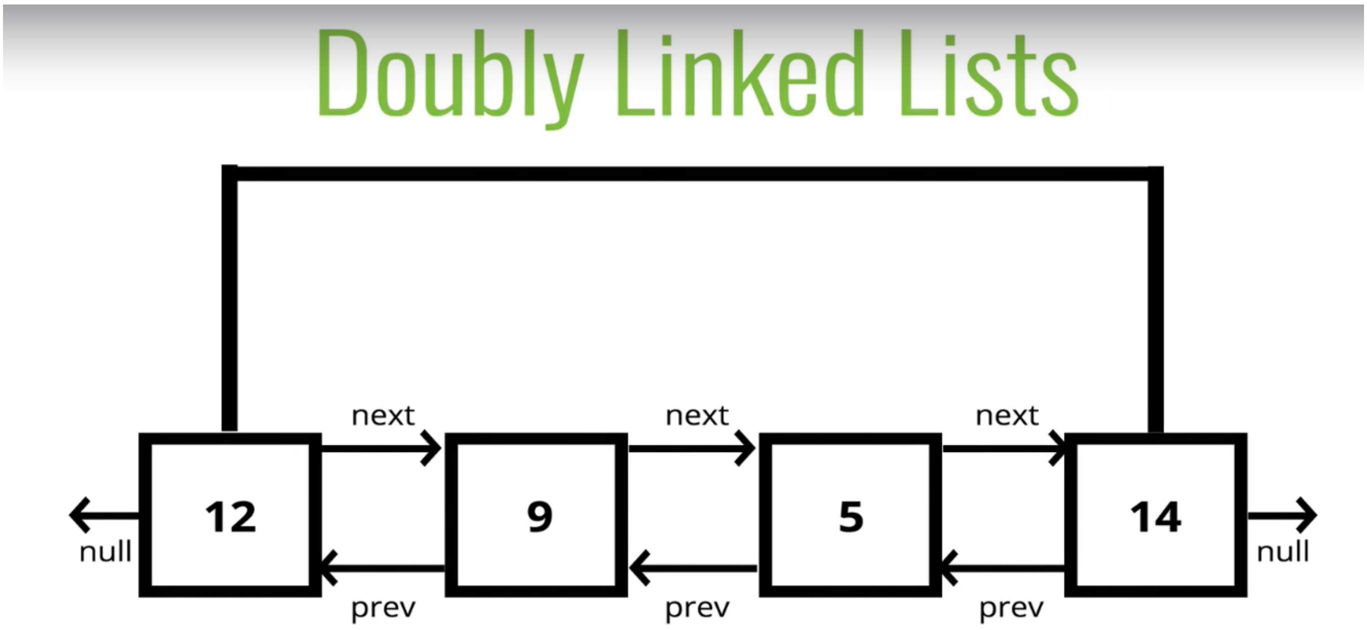
```
...SinglyLinkedList
reverse() {
  let node = this.head;
  this.head = this.tail;
  this.tail = node;

  let next;
  let prev = null;

  for (let i = 0; i < this.length; i++) {
    next = node.next;
    node.next = prev;
    prev = node;
    node = next;
  }
  return this;
}
...
```

Big O of Singly Linked Lists

	Time Complexity	Comparison
Insertion	O(1)	much faster iteration than array O(n)
Removal	O(1) or O(n)	If it's start, it's O(1) but gets difficult if popping is at the end, O(n)
Searching	O(1) or O(n)	
Access	O(n)	

- Singly linked lists excel when **insertion** and **deletion** at the beginning are required.
- The idea of a list data structure that consists of head, tail and nodes is the foundation for other data structures like Stacks and Queues.

Doubly Linked List



- almost identical to singly linked list, except every node has another pointer to the previous node.
- Comparing to singly linked list, it takes more space(memory) but more flexible.

Doubly Linked List Constructor

```
class Node {
  constructor(val) {
    this.val = val;
    this.next = null;
    this.prev = null;
  }
}

class DoublyLinkedList {
  constructor() {
    this.head = null;
    this.tail = null;
    this.length = 0;
```

```
  }
}
// Same as singly linked list but has 'prev' node
```

Push

- it adds a node to the end of the doubly linked list.
- it finds the tail at the end and add a next node with prev property.

Push pseudocode

- Create a new node with the value passed to the function.
- If the head property is null, set the head and tail to be the newly created node.
- if not, set th next property on the tail to be that node.
- set the previous property on the newly created node to be the tail.
- set the tail to be the newly created node.
- increment the length.
- return the doubly linked list.

Push implementation

```
...DoublyLinkedList

push(val) {
    let newNode = new Node(val);
    if (this.length === 0) {
      this.head = newNode;
      this.tail = newNode;
    } else {
      this.tail.next = newNode;
      newNode.prev = this.tail;
      this.tail = newNode;
    }
    this.length++;
    return this;
  }
```

Pop

- it removes a node from the end of the doubly linked list and return it.

Pop pseudocode

- first check if there is no head, return undefined.
- store the current tail in a variable to return later.
- if the length is 1, set the head and tail to be null

- update the tail to be the previous node.
- set the new tail's next to be null.
- decrement the length.
- return the value removed.

Pop implementation

```
pop() {
  if (!this.head) return undefined
  let poppedNode = this.tail;
  if (this.length === 1) {
    this.head = null;
    this.tail = null;
  } else {
    this.tail = poppedNode.prev;
    this.tail.next = null;
    poppedNode.prev = null;
  }
  this.length--;
  return poppedNode;
}
```

Shift

- it removes a node from the beginning of the doubly linked list and return it.
- it finds the head at the beginning and remove it.

Shift pseudocode

- if length is 0, return undefined.
- store the current head property in a variable as an old head.
- if the length is one.
  - set the head to be null.
  - set the tail to be null.
- update the head to be the next of the old head.
- set the head's prev property to be null.
- set the old head's next to null.
- decrement the length.
- return old head.

Shift implementation

```
shift() {
  if (this.length === 0) return undefined;
  let oldHead = this.head;
  if (this.length === 1) {
```

```
      this.head = null;
      this.tail = null;
    } else {
      this.head = oldHead.next;
      // remove the connection between old head and new head
      this.head.prev = null;
      oldHead.next = null;
    }
    this.length--;
    return oldHead
  }
```

Unshift

- It adds a node to the beginning of the doubly linked list and return the list.

Unshift pseudocode

- create a new node with the value passed to the function.
- if the length is 0
  - set the head to be the new node.
  - set the tail to be the new node.
- else
  - set the prev property on the head of the list tobe the new node.
  - set the next property on the new node to be the head property.
  - set the head property to be the new node.
- increment the length.
- return the list.

Unshift implementation

```
unshift(val) {
    let newNode = new Node(val);
    if (this.length === 0) {
      this.head = newNode;
      this.tail = newNode;
    } else {
      this.head.prev = newNode;
      newNode.next = this.head;
      this.head = newNode;
    }
    this.length++;
    return this;
  }
```

Get

- it accesses a node in a doubly linked list by its position.
- it returns the value of the node at the position passed to the function.
- Same as get() in singly linked list, but it can start from the tail, depend on the index provided.

Get pseudocode

- if index is less than 0 or greater or equal to the length, return undefined.
- if index is less than or equal to half of the length
  - loop through the list starting from the **head** and loop towards the middle.
  - return the node once it is found.
- if index is greather than laf of the length
  - loop through the list starting from the **tail** and loop towards the middle.
  - return the node once it is found.

Get implementation

```
get(index) {
  let count, current;
  if (index < 0 || index >= this.length) return undefined;
  if (index <= this.length / 2) {
    count = 0;
    current = this.head;
    while (count !== index) {
      current = current.next;
      count++;
    }
  } else {
    count = this.length - 1;
    current = this.tail;
    while (count !== index) {
      current = current.prev;
      count--;
    }
  }
  return current;
}
```

Set

- it replaces the value of a node in a doubly linked list by its position.
- it works same as get(), but it update the given value of the node at the position passed to the function.

Set pseudocode

- create a variable which is the result of the get() method, at the index passed to the function.
  - if the get() returns a valid result, set the value of that node to be the given value and return true.
  - else, return false.

Set implementation

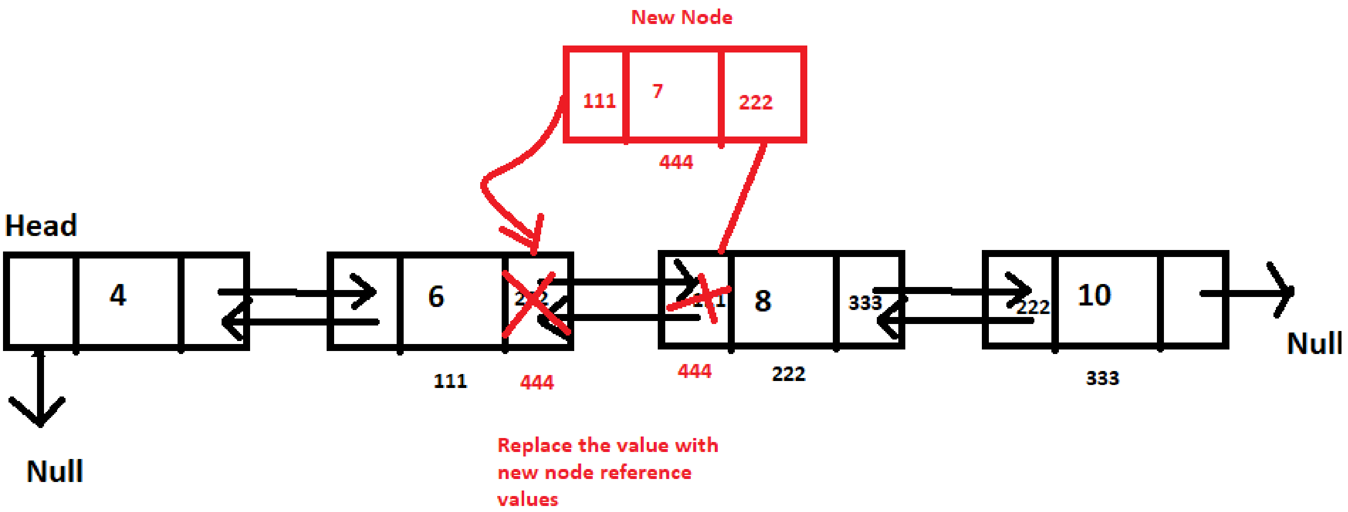
```
set(index, val) {
    let foundNode = this.get(index);
    if (foundNode) {
      foundNode.val = val;
      return true;
    }
    return false;
  }
```

Insert

- it adds a node in a doubly linked list by a certain position and returns the list.
- it accepts an index, value and position and it creates a anew node with that value and adds it at the position to the lengthy list.
- it uses get() to retrieve the node at the index passed to the function.

Insert pseudocode

- if index is less than 0 or greater than or equal to the length, return false.
- if index is 0, unshift.
- if index is the same as the length, push.
- else, use get() to access the index -1.
    - set the next and prev properties on the correct nodes to link everything together
- increment the length.
- return true.



Insert implementation

```
insert(index, val) {
  if (index < 0 || index > this.length) return false;
  if (index === 0) return !!this.unshift(val);
  if (index === this.length) return !!this.push(val);

  let newNode = new Node(val);
  let beforeNode = this.get(index - 1);
  let afterNode = beforeNode.next;

  beforeNode.next = newNode, newNode.prev = beforeNode;
  newNode.next = afterNode, afterNode.prev = newNode;
  this.length++;
  return true;
}
```

Remove

- it takes an index or position as argument and removes a node in a doubly linked list on a certain position and returns the removed item.
- it works similar as get() to check the position from head or tail.

Remove pseudocode

- if index is less than zero or greater than or equal to length, return undefined.
- if index is 0, shift.
- if index is the same as the length - 1, pop.
- otherwise, use get() to retrieve the item to be removed.
- update the next and prev properties to remove the found node from the list.
- set next and prev to null on the found node.
- decrement the length.
- return the removed node.

Remove implementation

```
remove(index) {
  if (index < 0 || index >= this.length) return undefined;
  if (index === 0) return this.shift();
  if (index === this.length - 1) return this.pop();
  let removedNode = this.get(index);
  // connecting in between the nodes before and after the removed node
  let beforeNode = removedNode.prev;
  let afterNode = removedNode.next;
  beforeNode.next = afterNode;
  afterNode.prev = beforeNode;

  // remove the connection of the target node
  removedNode.next = null;
```

```
    removedNode.prev = null;
    this.length--;
    return removedNode;
  }
```

Big O of Doubly Linked Lists

	Big O
Insertion	O(1)
Removal	O(1)
Searching	O(n)
Access	O(n)

- insertion excels with both O(1), singly and doubly linked list.
- removal for doubly linked list is always constant, unlike traversing for same in singly linked list.
- searching is O(n/2) -> O(n) because it starts from start or end of the list to the middle.

Comparison with singly linked list

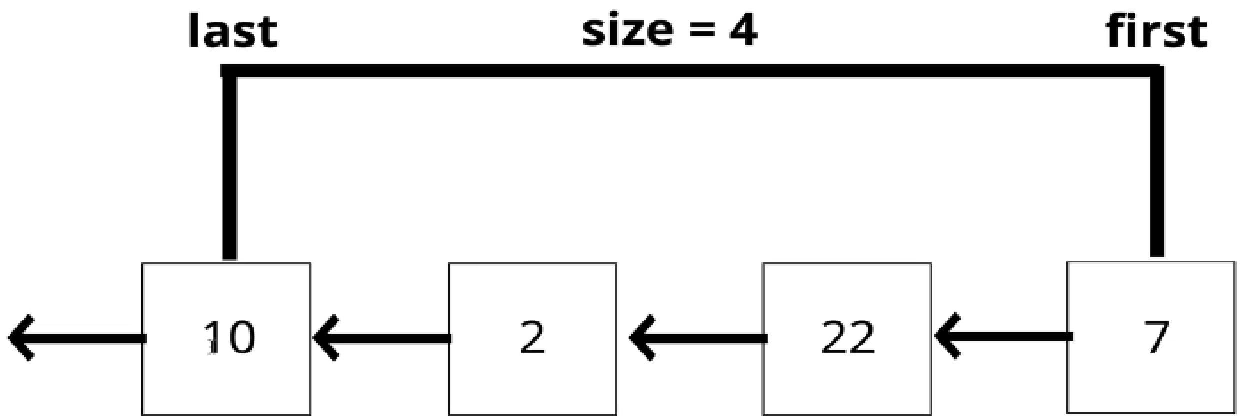
e

- doubly linked lists are almost same as singly linked list, except there is an additional pointer to previous node.
- it fits in a situation where linear backward traversal is needed as much as forward. i.e. history, re/undo, etc.
- it works better than singly linked list for finding nodes and can be done in half the time.
- it takes more (almost twice)space given the extra pointer.

Stacks and Queues

Stack

- it is not a built-in data structure in Javascript.
- it is an abstracted collection of data that abide by LIFO data structure.
  - **LIFO**: Last In First Out i.e. last element added to the stack will be the first element removed from the stack.
  - e.g. STACKS of books, STACKS of plates and so on, as it being piled up, the last thing is what gets removed first.



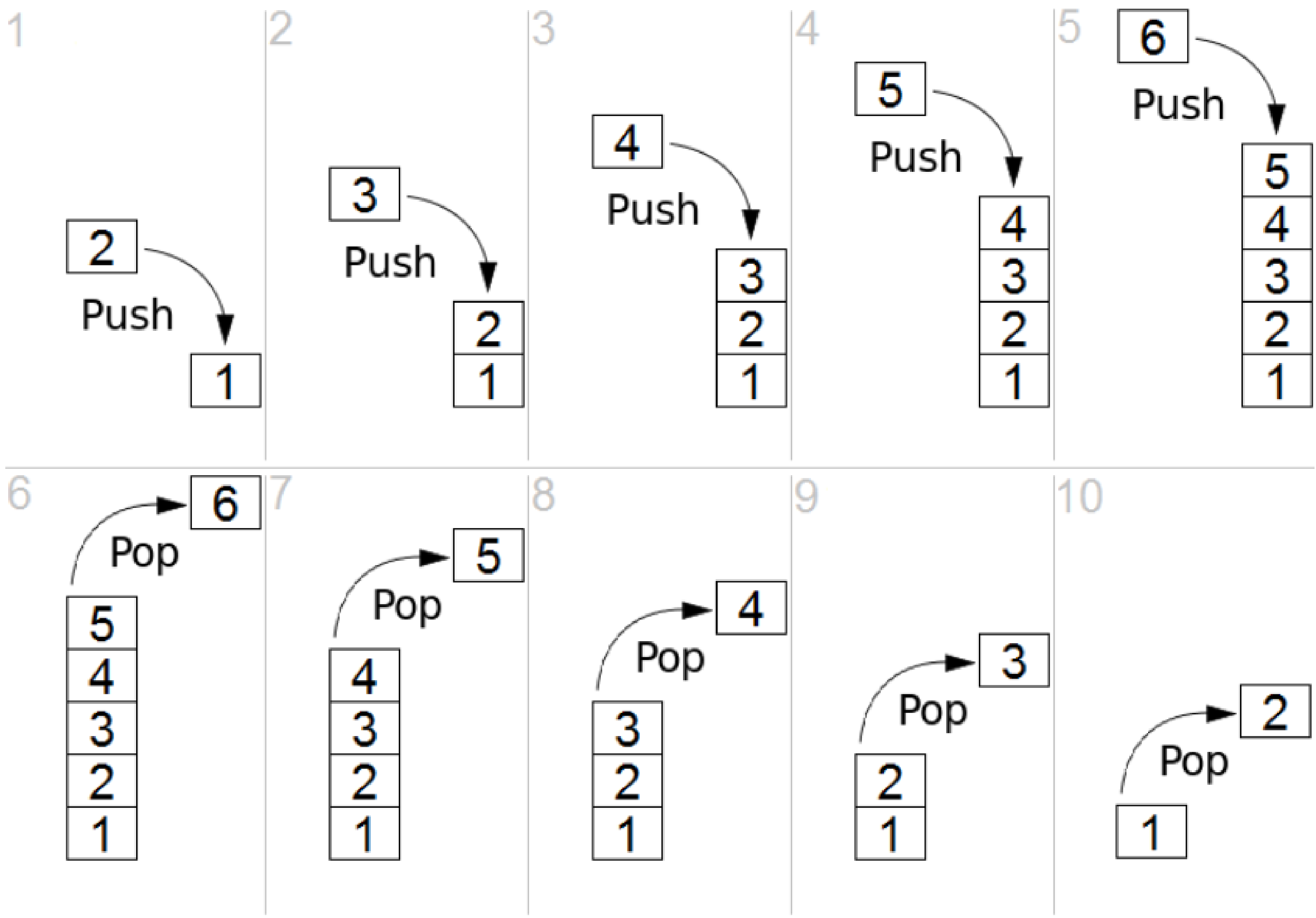
Where Stacks Are Used

- managing function invocations as call stack
- history object: undo/redo, backward/forward, routing

Create Stack

With Array

- push, pop for last and shift, unshift for first node for LIFO can be used but adding node at the beginning with array with shift/unshift is not efficient cause every rest of element need to be reindexed.
- that said, stack with array for shift/unshift might not be a good fit.



With Linked List Implementation

- stack is supposed to be constant time but push/pop with array occurs traversing, thus using stack with list makes more sense in this case.
- it uses similar structure of class constructor used above.

```
class Stack {
  constructor() {
    // unlike linked list, terms are for LIFO
    this.first = null;
    this.last = null;
    this.size = 0;
  }
}

class Node {
  constructor(value) {
    this.value = value;
    this.next = null;
  }
}
```

Push pseudocode

- creeate a function push that create a node which accept a value.
- if there are no nodes in the stack, set the first and last property to be the newly create node.
- if there is one node, create a varialble that stores the current first property on the stack.
- reset the first property to be the newly created node.
- set the next property on the node to be the previously created variable. increment the size of the stack by 1.

```
push(val) {
  let newNode = new Node(val);
  if (!this.first) {
    this.first = newNode;
    this.last = newNode;
  } else {
    let temp = this.first;
    this.first = newNode;
    this.first.next = temp;
  }
  return this.size++;
}
```

Pop pseudocode

- if there are no nodes in the stack, return undefined.
- create a temporary variable to store the first property on the stack.
- if there is only one node, set the first and last property to be null.
- otherwise, set the first property to be the next property on the current first.
- decrement the size by 1.
- return the value of the node removed.

```
pop() {
  if (!this.first) return undefined;
  let temp = this.first;
  if (this.first === this.last) {
    this.last = null;
  }
  this.first = this.first.next;
  this.size--;
  return temp.value;
}
```

Big O of Stacks

	Big O
Insertion	O(1)
Removal	O(1)
Searching	O(n)
Access	O(n)

- stack is prioritized on push/pop and both are constant.
- searching/accessing individual node is same as O(n).

Queues

- it's similar to stack but with FIFO data structure.
  - **FIFO**: FIrst In First Out, i.e. first element added to the queue will be the first element removed from the queue.
  - e.g. background task, uploading resources, printing like task processing in general.
- Due to nature of FIFO, handling first elements in array with queue is more costly because of re-indexing every rest of element, thus using shift/unshift with queue is better being done in a customized class in linked list.

Create Queue

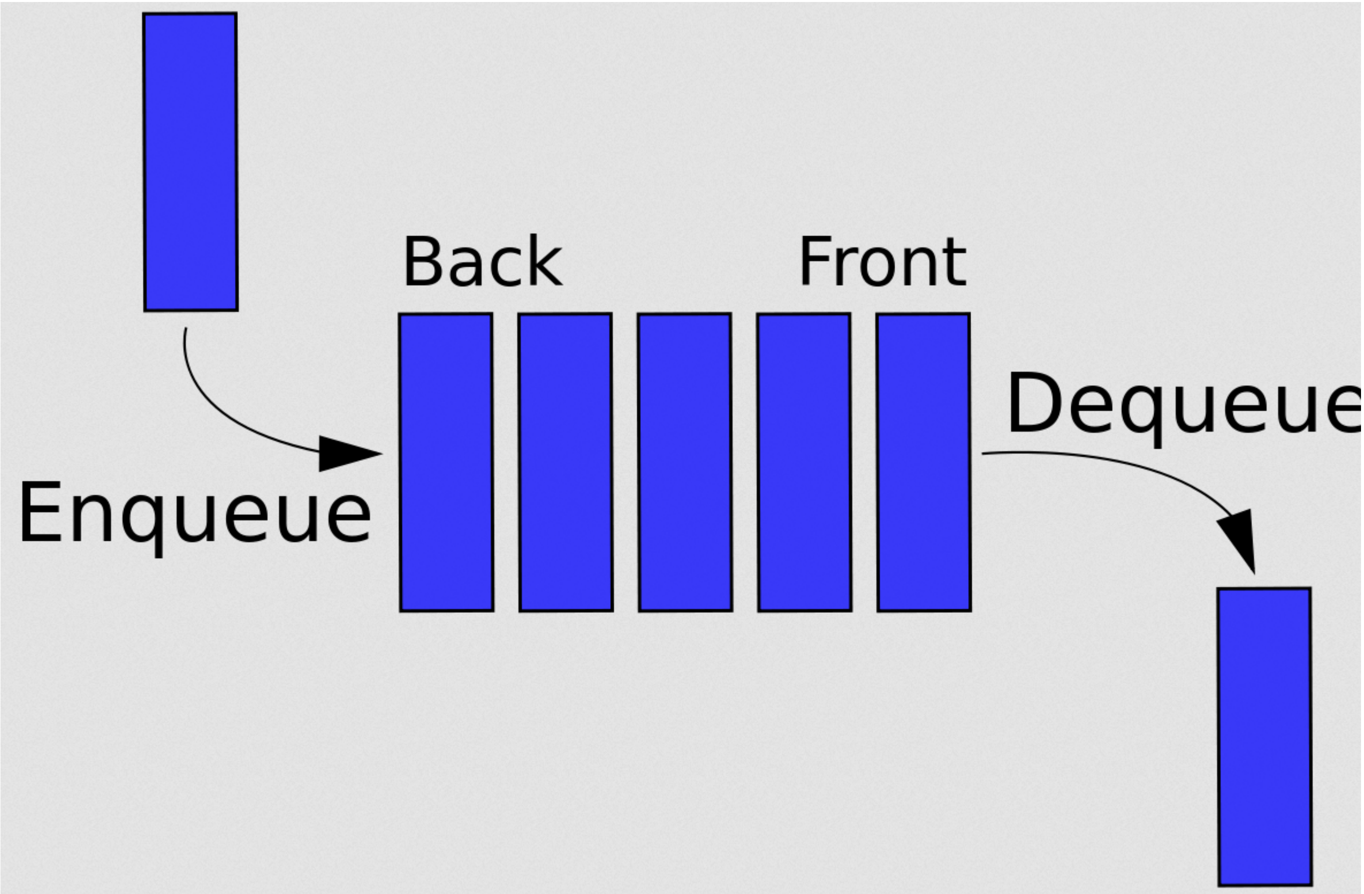
- Queue involves with enqueue and dequeue operations.
  - enqueue: add a new node to the end of the queue.
  - dequeue: remove the first node from the queue.

With Array

- First In could be done with array.unshift() and First Out could be done with array.shift() but it is inefficient because of re-indexing.

With Linked List Implementation

```
class Node {
  constructor(val) {
    this.val = val;
    this.next = null;
  }
}

class Queue {
  constructor() {
    this.first = null;
    this.last = null;
    this.size = 0;
  }
}
```



Enqueue pseudocode

- create a function enqueue that accepts a value.

- create a new node that value passed to the function.

Enqueue implementation

```
enqueue(value) {
  let newNode = new Node(val);
  if (!this.first) {
    this.first = newNode;
    this.last = newNode;
  } else {
    this.last.next = newNode;
    this.last = newNode;
  }
  return this.size++;
}
```

Dequeue psesudocode

- if there is no first property, just return undefined.
- store the first property in a variable.
- see if the first is the same as the last(check if there is only one node).
  - if yes, set the first and last property to be null.
  - else, set the first property to be the next property of first.
- decrement the size by 1.
- return the value of the node dequeued.

Dequeue implementation

```
// almost identical to pop() in linked list
dequeue() {
  if (!this.first) return undefined;
  let temp = this.first;
  if (this.first === this.last) {
    this.last = null;
  }
  this.first = this.first.next;
  this.size--;
  return temp.val;
}
```

Big O of Queues

	Big O
Insertion	O(1)

	Big O
Removal	O(1)
Searching	O(n)
Access	O(n)

- Big O Notation of Insertion and Removal on queue is O(1) because it's constant time but it would be O(n) if array is used.
- Searching and Access is not in a good fit with queue, because of traversing.

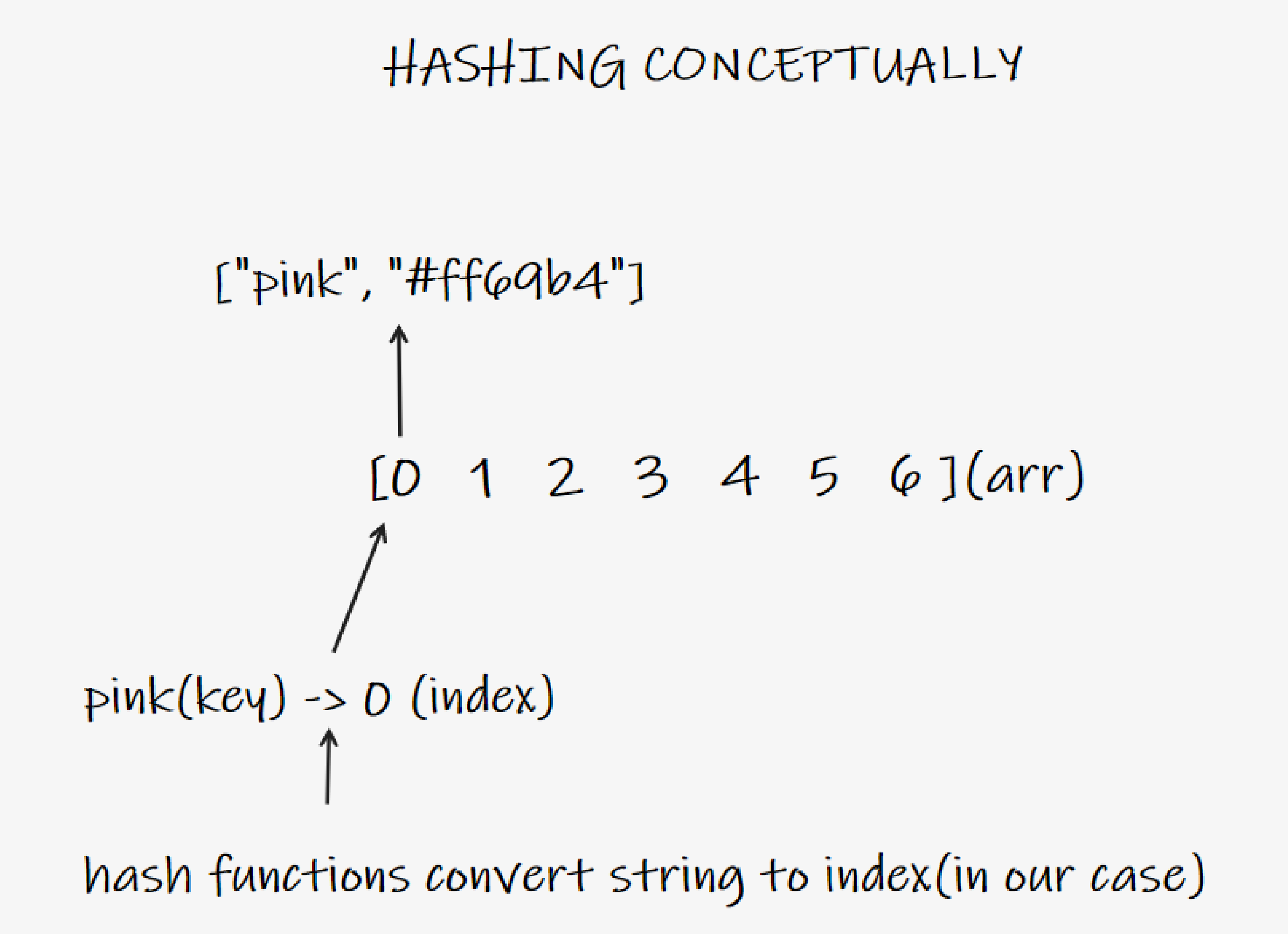
Hash Tables

What is Hash Table?

- it's often called hash maps too.
- hash table is a data structure that stores **key-value** pairs.
- it is like array, but the keys are not ordered.
- Unlike array, hash tables are fast for all of following:
  - finding values
  - adding new values
  - removing values
- it is commonly used because of efficiency.
- it is..
  - dictionary in Python
  - objects and maps in Javascript
  - Maps in Java, Go and Scala
  - Hashes in Ruby
- it gives a human-readable representation of the data.

Hash Function

- to impelement a hash table, array will be used in this case.
- in order to look up the value by key, keys are needed to be converted into valid array index.
  - **hash function** can be performed to convert the key into valid array index.
  - it can takes a string or any type of data and converts it to number or index.



More of Hash Function Basics

- it's a function that takaes data of arbitrary size, and converts it to a number. e.g. hash() in python
- hashed output result cannot be reversed, key cannot be extracted from the output.
- it has to be fast in constant time for its purpose.
- it should not cluster outputs at specific indices, but distributes them evenly.
- it has to be deterministic, reproducible. same input should result same output.

Simple Hash Function Implementation

```
function hash(key, arrayLength) {
  let total = 0;
  for (let char of key) {
    // a = 1, b = 2..
    let value = char.charCodeAt(0) - 96;
    // remainder of total of position num divided by length
    total = (total + value) % arrayLength;
  }
  return total;
}
```

Problems:

- it only works with strings.
- it's a function that takes a string and returns a number within array length range.
- not fast: it has a linear time complexity of array length.
- there is a collision: output's not totally random.

Simple Hash Function Slightly Improved Implementation

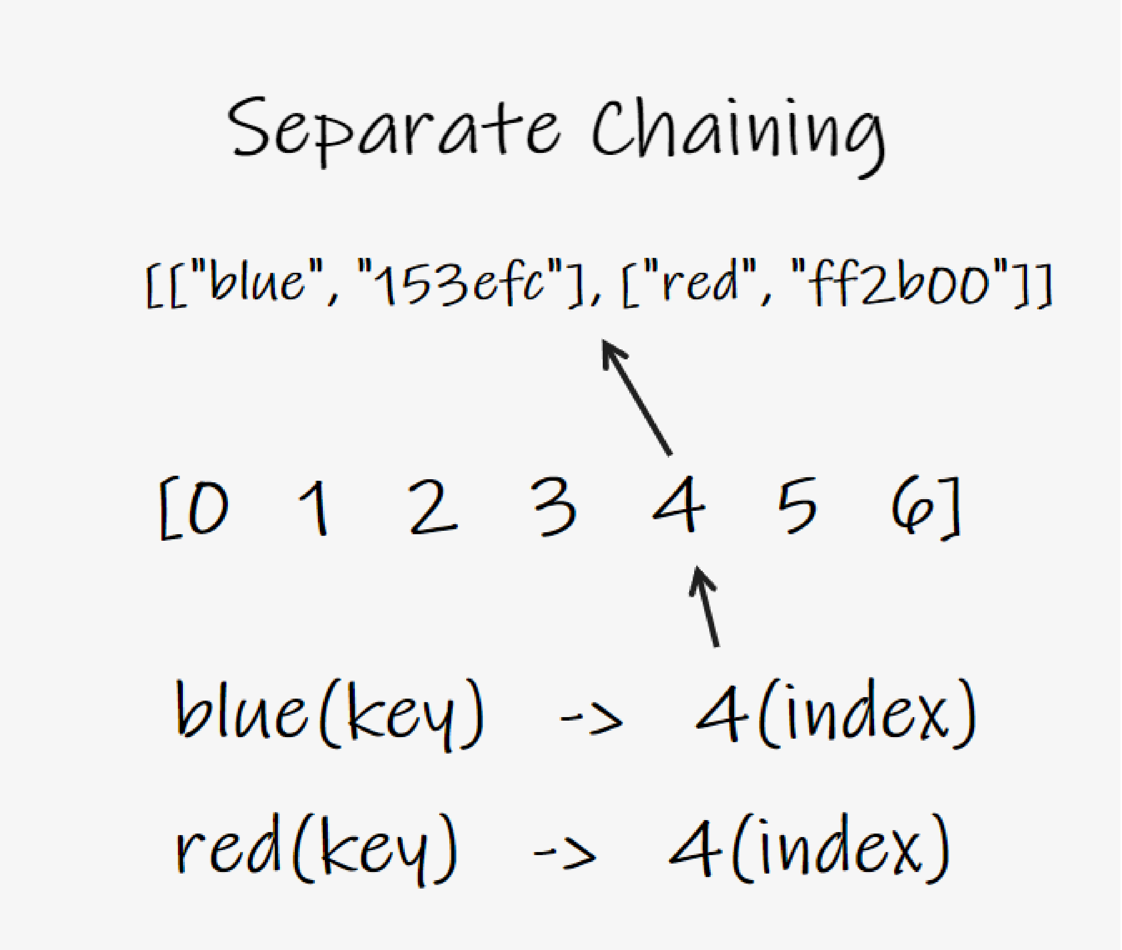
```
function hash(key, arrayLength) {
  let total = 0;
  let WEIRD_PRIME = 31;
  for (let i = 0; i < Math.min(key.length, 100); i++) {
    let char = key[i];
    let value = char.charCodeAt(0) - 96;
    total = (total * WEIRD_PRIME + value) % arrayLength;
  }
}
```

- prime number seed is used for reducing collisions(much less, but still happens)
  - Relation between array length size of prime number and hash table implemenation
- it is conditionally constant time.
- loop runs based smaller value of length of key or 100 for testing purpose.

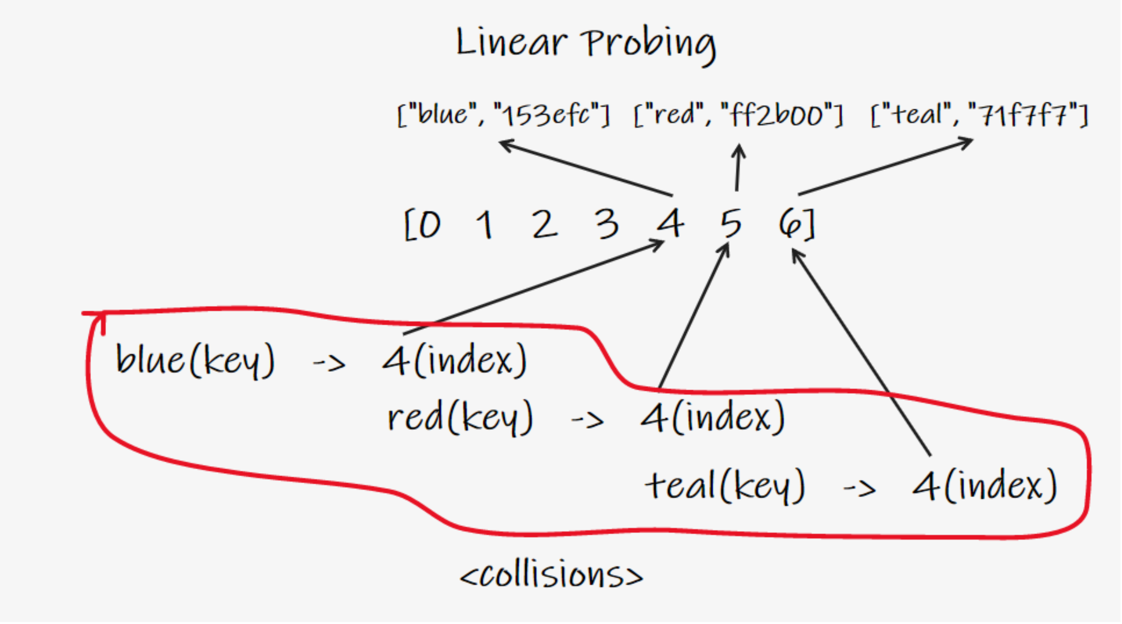
Dealing with Collisions

- collisions are inevitable even with greater array and prime number seed but it can be reduced via:
  - separate chaining
    - it stores value using a more nested data structure at each index in array with an array or linked list.

- this allows for storing multiple key-value pairs at the same index.



- linear probing
  - data is only stored at each index unlike separate chaining.;
  - when collision is found, it search through the array to find the next empty slot.
  - but it has a limitted number of key as array length.



Hash Table Implementation

- Hash Table class

```
class HashTable {
  // arbitrary small size array for test
  constructor(size = 5) {
    this.keyMap = new Array(size);
  }

  _hash(key) {
    let total = 0;
    let WEIRD_PRIME = 31;
    for (let i = 0; i < Math.min(key.length, 100); i++) {
      let char = key[i];
      let value = char.charCodeAt(0) - 96;
      total = (total * WEIRD_PRIME + value) % this.keyMap.length;
    }
    return total;
  }
}
```

Set

- it accepts a key and a value
- it hashes the key.
- it stores the key-value pair in the hash table array via separate chaianing.

```
set(key, value) {
  let index = this._hash(key);
  // if empty, set new array
  if (!this.keyMap[index]) {
    this.keyMap[index] = [];
  }
  // or set nested key value pair
  this.keyMap[index].push([key, value]);
  return index;
}

// intantiate hash table
let ht = new HashTable();
ht.set("Hello World", "Good World");
ht.set("color", "brown");
ht.set("name", "okgu");
ht.set("attr", "cute");

/*
ht.keyMap = [
  [
    ["Hello World", "Good World"],       -> nested array at index 0
    ["color", "brown"]
  ],
  [
```

```
      ["name", "okgu"]
    ],
    [
      ["attr", "cute"]
    ]
  ]
  */
```

Get

- it accepts a key.
- it hashes the key.
- retrieves the key-value pair in the given index(possibly more than one).
  - return the value of exact match in sub array.
- if key is not found, returns undefined.

```
get(key) {
  let index = this._hash(key);
  if (this.keyMap[index]) {
    // traverse the array to fiind the index
    for (let i = 0; i < this.keyMap[index].length; i++) {
      // look for exact match in sub array
      if (this.keyMap[index][i][0] === key) {
        // return the value of exact match
        return this.keyMap[index][i][1];
      }
    }
  }
  return undefined;
}

// ht.get("name") -> okgu
```

Hash Table Keys and Values Method

- key:

  - it loops through the hash table array and returns an array of keys in the table.
  - it is unique.

- value:

  - it loops through the hash table array and returns an array of values in the table.
  - it is often not unique.

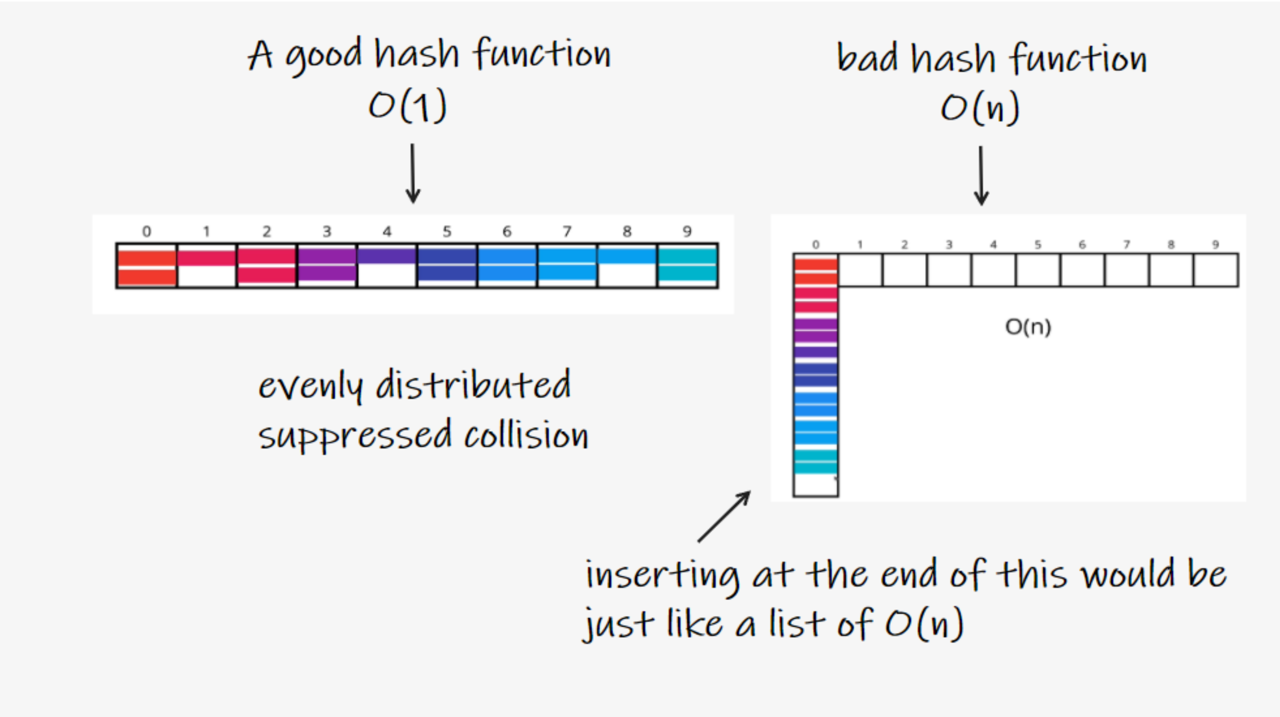
```
values() {
  let valuesArr = [];
  for (let i = 0; i < this.keyMap.length; i++) {
```

```
      if (this.keyMap[i]) {
        for (let j = 0; j < this.keyMap[i].length; j++) {
          // filter duplicate values
          if (!valuesArr.includes(this.keyMap[i][j][1])) {
            // push each second item(value) in array into values arr
            valuesArr.push(this.keyMap[i][j][1]);
          }
        }
      }
      return valuesArr;
    }
  }
```

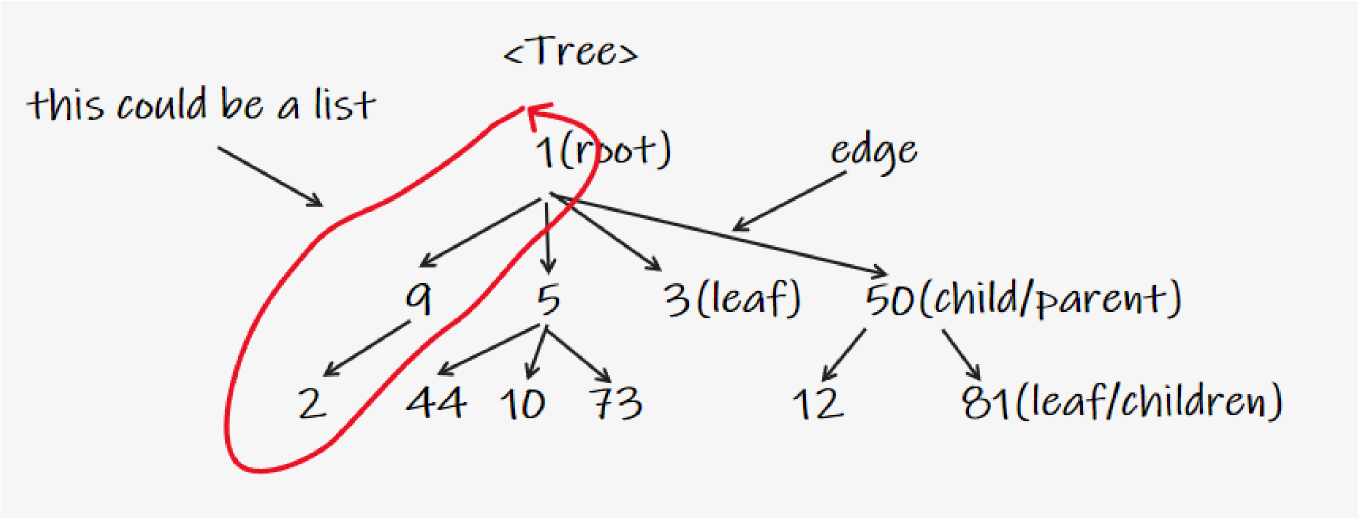
Big O of Hash Tables

	avg
Insert	O(1)
Delete	O(1)
Access	O(1)

- with hash table, insertion, deletion and access of average and best case are constant time.
- but it depends on
  - how fast hash function it self is.
  - how evenly it distributes keys.
  - how suppressed collisions are.
- that said, hash function still depends on input size, traverse the array.
- if searching keys/values of every each item, it would be O(n).



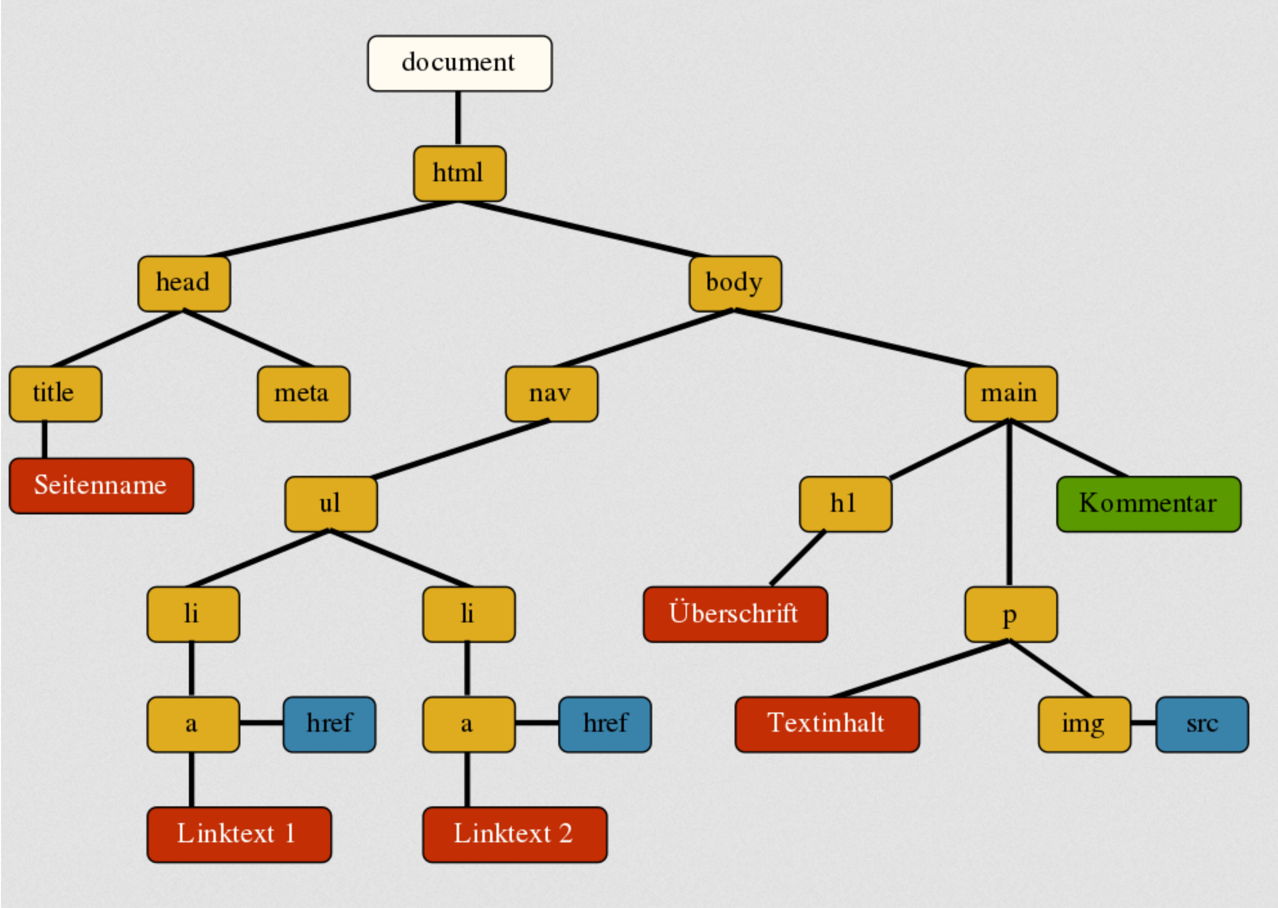
Trees



- it's a top-down data structure that consists of nodes in a parent/child relationship with branching structure.
- Unlike linear behavior in lists, trees are non-linear.
- Tree is consist of
    - root: the top node in a tree.
    - child: a node directly connected to another node when moving away from the root.
    - parent: the converse notion of a child.
    - siblings: a group of nodes with the same parent.
    - leaf: a node with no children.
    - edge: the connection between one node and another.
- Tree node can only point to the child node.
- Tree node can only have one root.

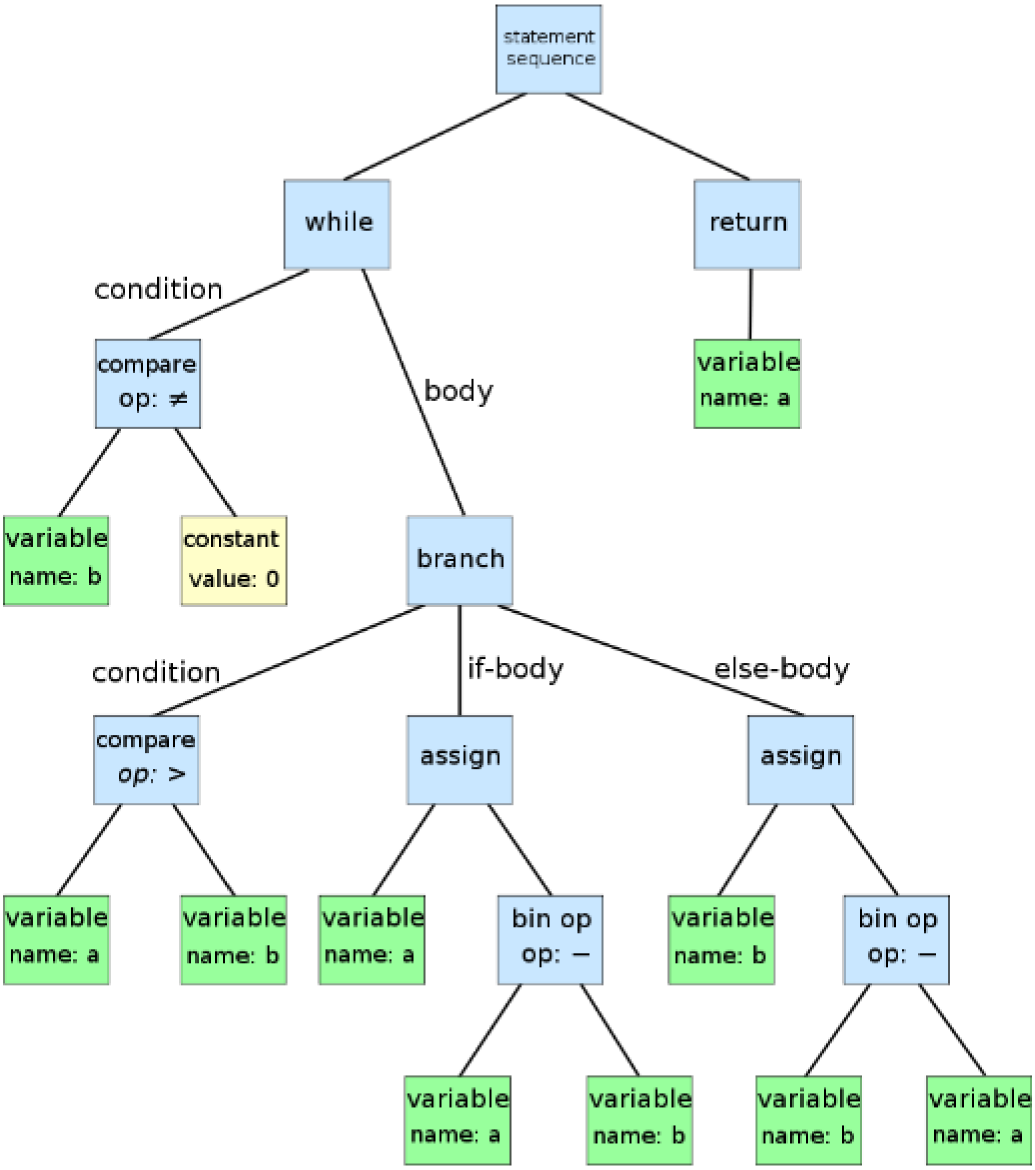
What is Tree For?

- Html DOM

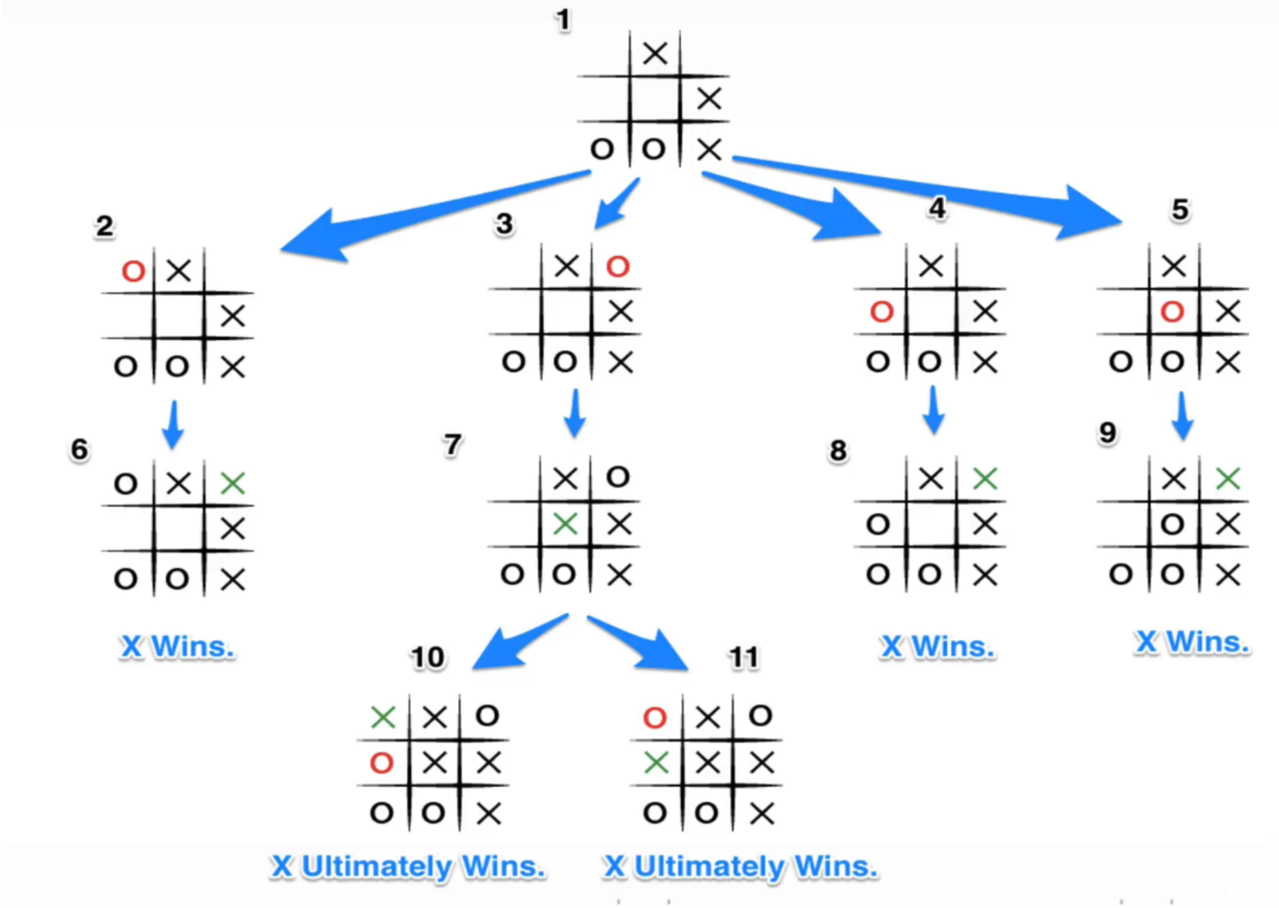


- network routing

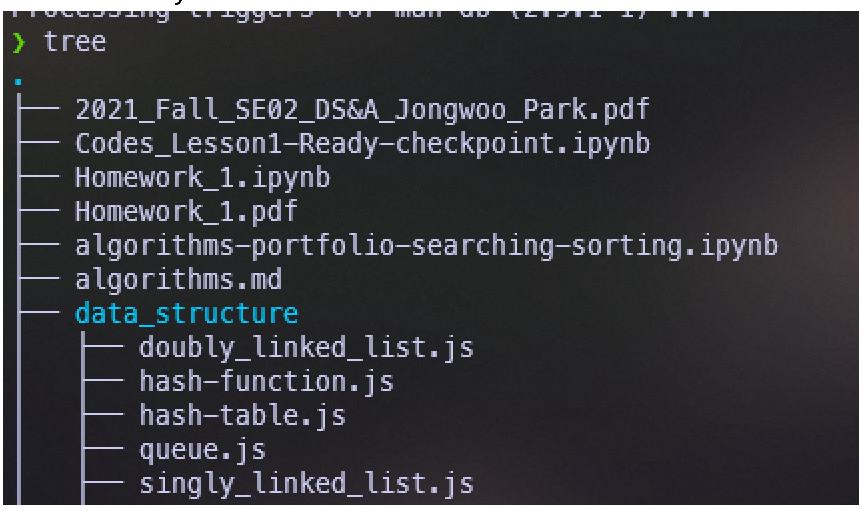
- abstract syntax tree



- artificial intelligence/machine learning decision tree



- folder/directory file structure in OS

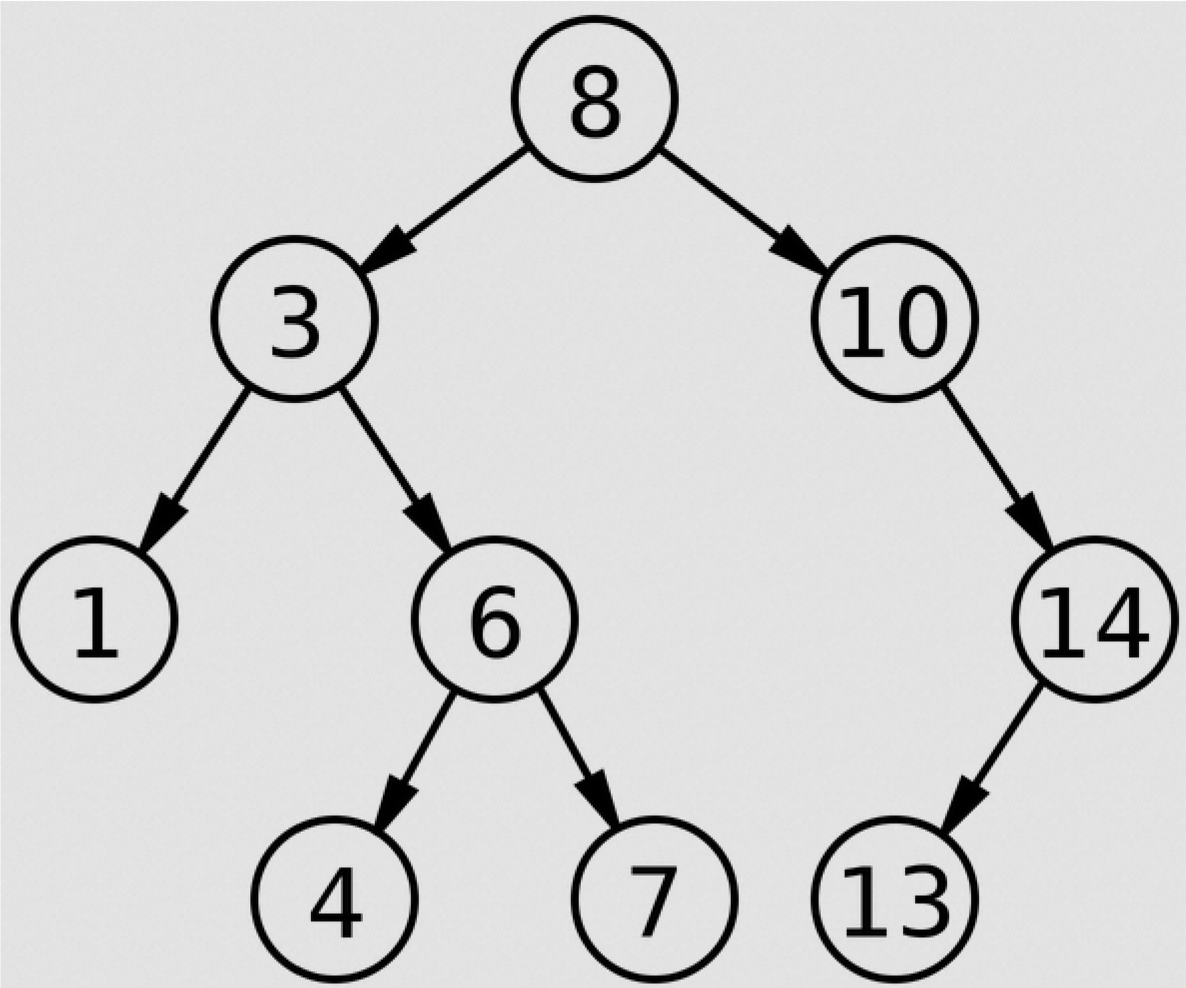


- JSON

Binary Tree

- it has a special condition that it can only have two children at most.(0, 1 or at most 2 children)

Binary Search Tree



- it's similar with binaray tree but property must be kept in order.
- it is used to store data that can be compared that is sortable.
- left side of children of binary search tree are always less than the parent.
- right side of children of binary search tree are always greater than the parent.

Binary Search Tree Implementation

- binary search tree and node class

```
class BinarySearchTree {
  constructor() {
    this.root = null;
  }
}

class Node {
  constructor(value) {
    this.value = value;
    this.left = null;
    this.right = null;
  }
}
```

insertion pseudocode

- create a new node.
- starting at the root,
  - if no root, new node becomes the root.
  - if root, check if new node value is greater or less than the value of root.
  - if new value is greater,
    - check if there is a child node on the right
      - if there is, move to that node and repeat the process
      - if not, add that node as a right property
  - if new value is smaller,
    - check if there is a node on the left
      - if there is, move to that node and repeat the process.
      - if not, add that node as a left property.
- return the result.

insertion implementation

```
insert(value) {
  let newNode = new Node(value);
  // if no root, set root to new node
  if (this.root === null) {
    this.root = newNode;
    return this;
  } else {
    let current = this.root;
    while (true) {
      // duplicate values
      if (value === current.value) return undefined;
      // if value is less than current node, go left
      if (value < current.value) {
        if (current.left === null) {
          current.left = newNode;
          return this;
        } else {
          // if left node, set current to left node
          current = current.left;
        }
      } else {
        if (current.right === null) {
          current.right = newNode;
          return this;
        } else {
          current = current.right;
        }
      }
    }
  }
}
```

find pseudocode

- start at the root.
  - check if there is root,
    - if not, return undefined.
    - if root, check if value of new node is equal to the value of root.
      - if equal, return the value of root.
      - if not, check to see if value is greater than or less than the value of the root.
        - if greater,
          - check if there is a right node.
            - if there is, move to that node and repeat the process.
        - if less,
          - check if there is a left node.
            - if there is, move to that node and repeat the process.
  - if neither, return undefined.

find implementation

```
find(value) {
  if (this.root === null) return undefined;
  let current = this.root,
    found = false;
  while (current && !found) {
    if (value < current.value) {
      current = current.left;
    } else if (value > current.value) {
      current = current.right;
    } else {
      found = true;
    }
  }
  if (!found) return undefined;
  return current;
}
```

Big O of Binary Search Tree

	Best and avg	Worst
Insertion	O(log n)	O(n)
Searching	O(log n)	O(n)

- In best and average case,

n of nodes	extra step

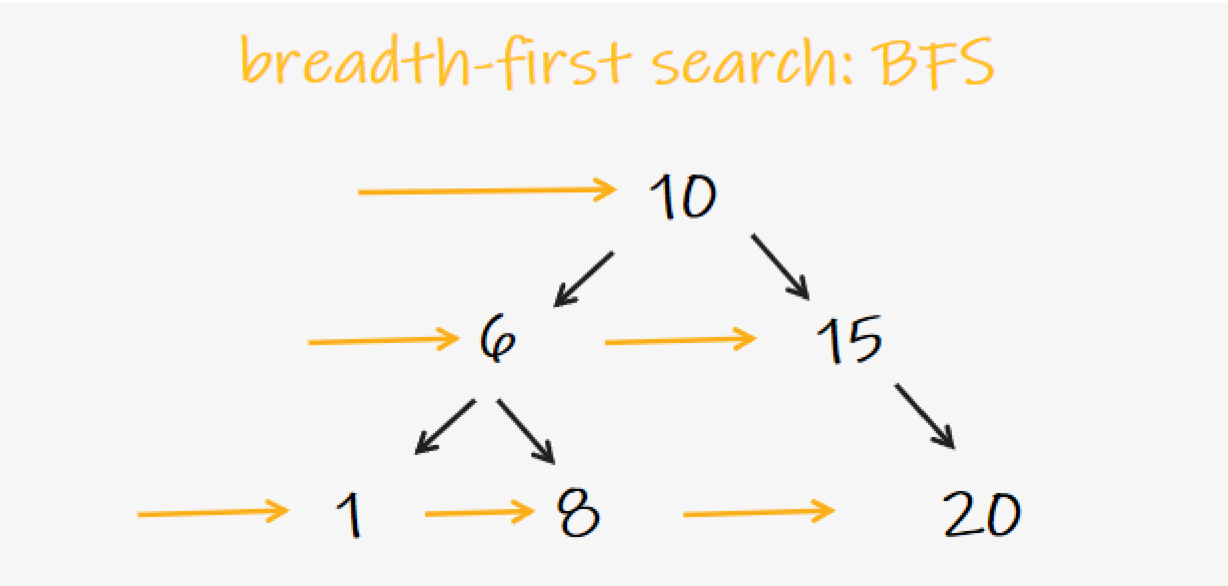
n of nodes	extra step
2	1
4	2
8	3

- insertion and search are both logarithmic.
    - even if the size is doubling, it only increases the number of process to insert/find by 1.
    - it is not always guaranteed. if tree structure resembles with one sided linked list, it could be O(n).
- if the tree isn't sorted, it needs to be traverse all the node and could be O(n).

Tree Traversal

- unlike linked list, traversing every node in tree structure is much more complicated.
- there are two ways to archieve this:
    - breadth-first search
        - it goes horizontally first, then vertically.
    - depth-first search
        - it goes vertically first, then horizontally.

Breadth-First Search



- general approach of BFS is, it looks for every sibling nodes before looking at a child node regardless of tree structure.
- in this case, it would be `[10, 6, 15, 1, 8, 20]` in order.

BFS pseudocode

- initiate a queue/array and a variable to store the values of nodes visited.
- place the root node in the queue
- loop as long as there is anything in the queue

    - dequeue a node from the queue and push the value of the node into the variable that stores the node.
    - if there is a left property on the node dequeued, add it to the queue.
    - if there is a right property on the node dequeued, add it to the queue.
- return the variable that stores the node values.

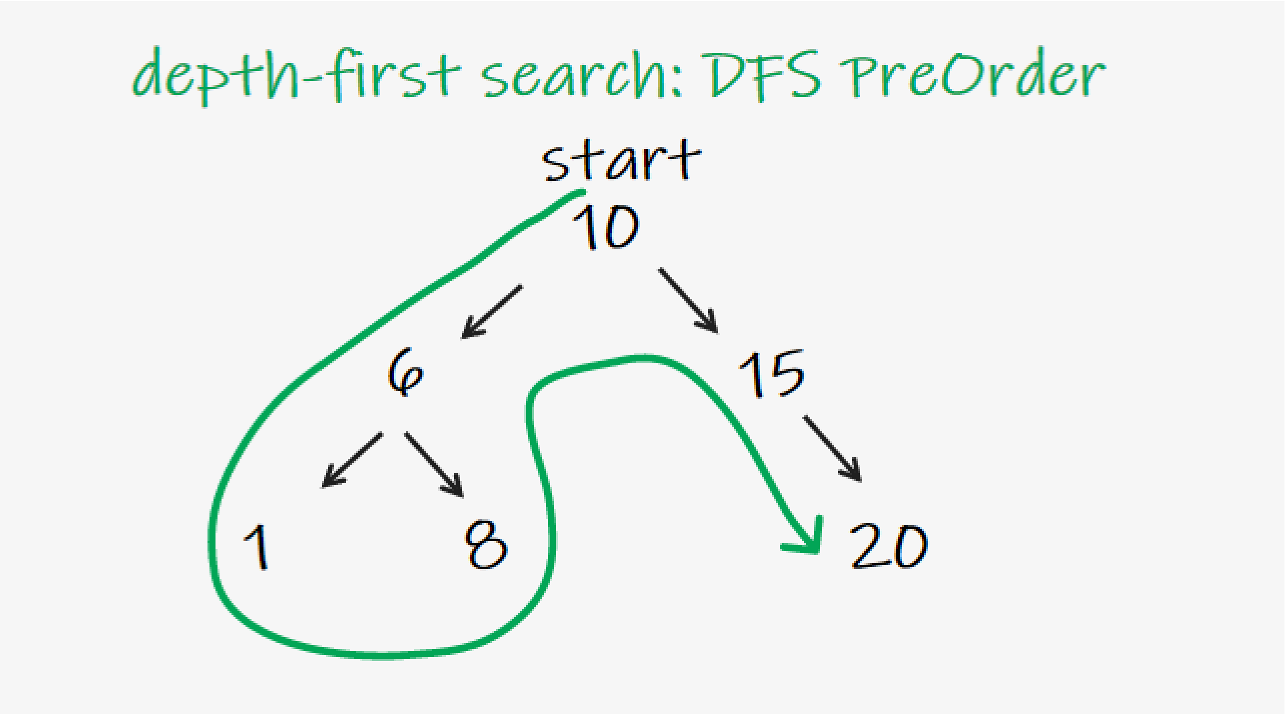
BFS implementation

```
BFS() {
  let node = this.root;
  let visited = [];
  let queue = [];
  queue.push(node);

  while (queue.length) {
    node = queue.shift();
    visiited.push(node.value);
    if (node.left) queue.push(node.left);
    if (node.right) queue.push(node.right);
  }
  return visited;
}
```

Depth-First Search

- it traverse nodes vertically down to the end of the tree before visiting sibling nodes.

DFS PreOrder



- DFS PreOrder has three steps: visit the node first, traverse to the left and then right.

- in this case, it would be `[10, 6, 1, 8, 15, 20]`.

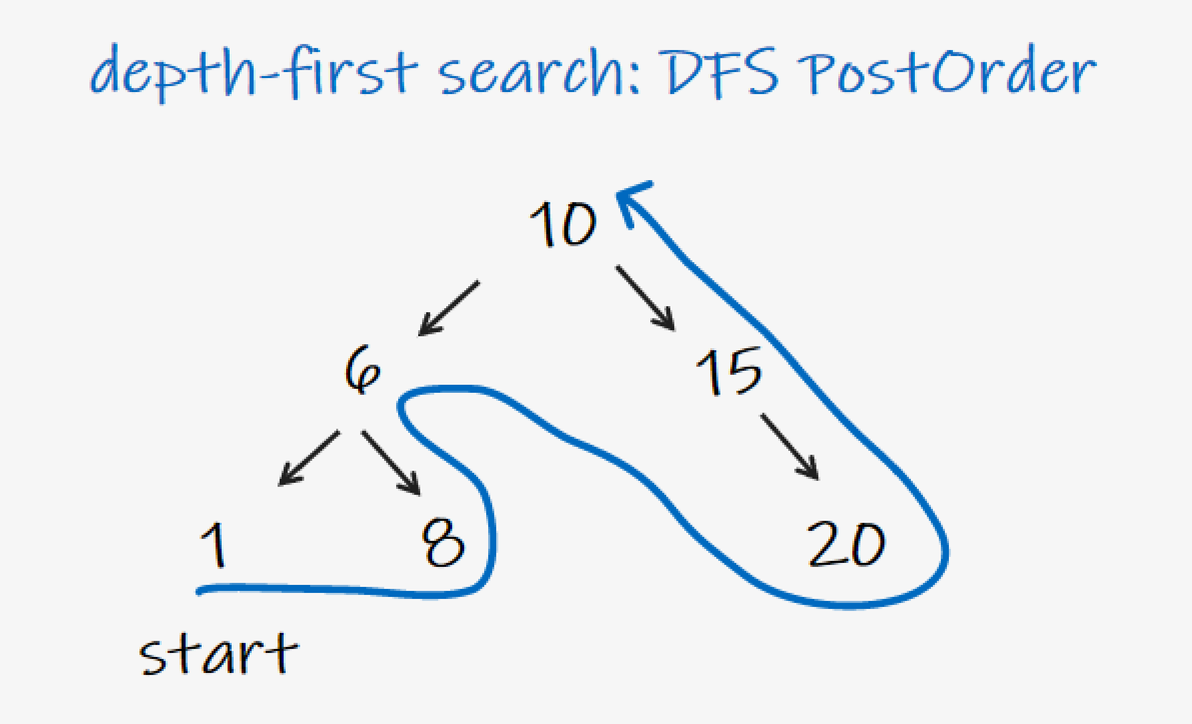
DFS PreOrder pseudocode

- create a variable to store the values of nodes visited.
- store the root of the BST in a variable called current.
- write a helper function which accepts a node
  - push the value of the node to the variable that stores the values.
  - if the node has a left property, call the helper function with the left property on the node.
  - if the node has a right property, call the helper function with the right property on the node.
- call the helper function with current variable.
- return the array of visited.

DFS PreOrder implementation

```
DFSPreOrder() {
  // visited
  let data = [];
  let current = this.root;

  function traverse(node) {

    // check left and right and push to data recursively until empty
    data.push(node.value);
    if (node.left) traverse(node.left);
    if (node.right) traverse(node.right);

  }
  traverse(current);
  return data;
}
```

DFS PostOrder



- it's similar with DFS PreOrder, but it traverses the left, right nodes **first** and then visiting the node.
- root is the last node visited.
- in this case, it would be `[1, 8, 6, 20, 15, 10]`.

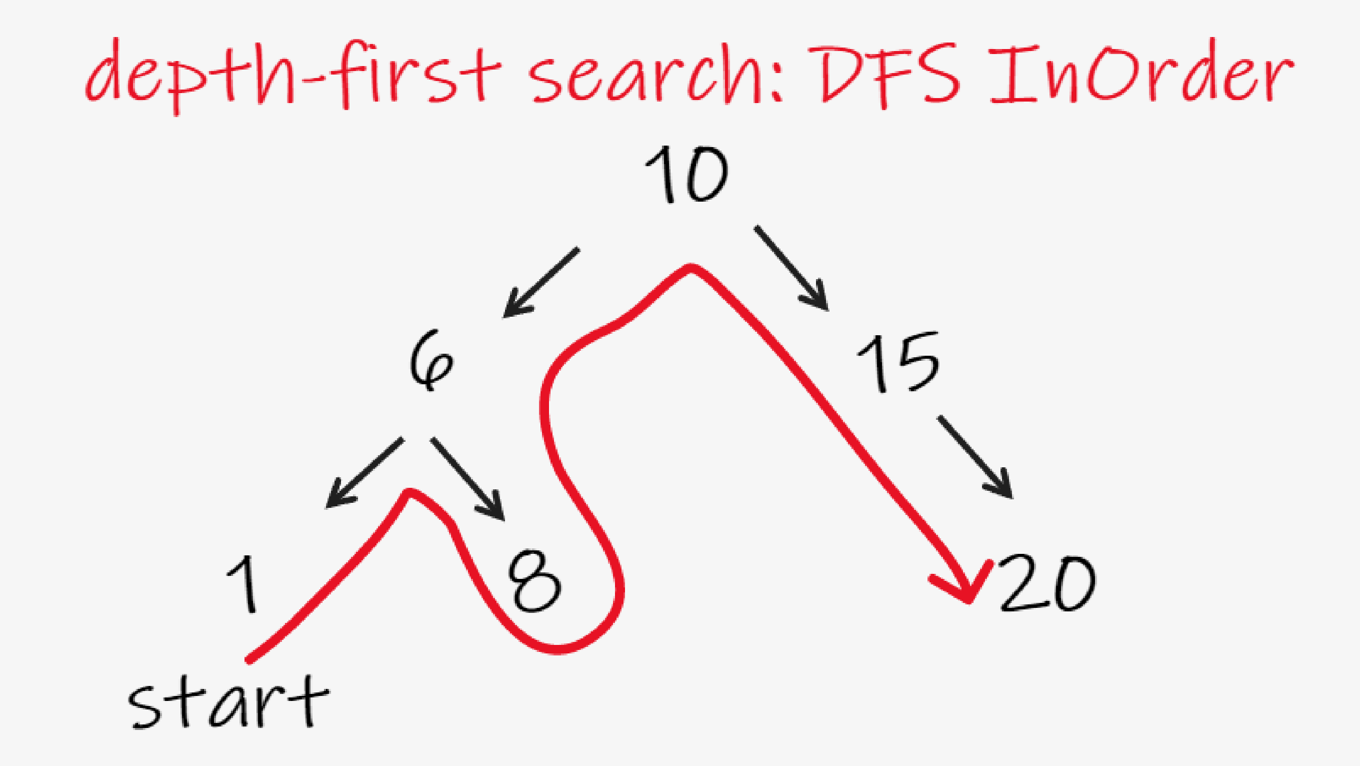
DFS PostOrder pseudocode

- it's similar with DFS PreOrder but slightly different order in recursive helper function as it looks for left, right and the node.

DFS PostOrder implementation

```
DFSPostOrder() {
  let data = [];
  let current = this.root;
  function traverse(node) {

    if (node.left) traverse(node.left);
    if (node.right) traverse(node.right);
    data.push(node.value);

  }
  traverse(current);
  return data;
}
```

DFS InOrder



- it traverses the entire left side first, visit the node, and then traverse the right side.
- in this case, it would be `[1, 6, 8, 10, 15, 20]`.

DFS InOrder pseudocode

- it's same pseudo code as other DFS search method except helper function, it traverse the left and push the value to the array and then traverse the right recursively.

DFS InOrder implementation

```
DFSInOrder() {
   let data = [];
   let current = this.root;
   function traverse(node) {

     if (node.left) traverse(node.left);
     data.push(node.value);
     if (node.right) traverse(node.right);

   }
   traverse(current);
   return data;
 }
```

BFS or DFS Comparison

- time complexity in general is the same.
- space complexity could vary depend on wide or deep tree structure.

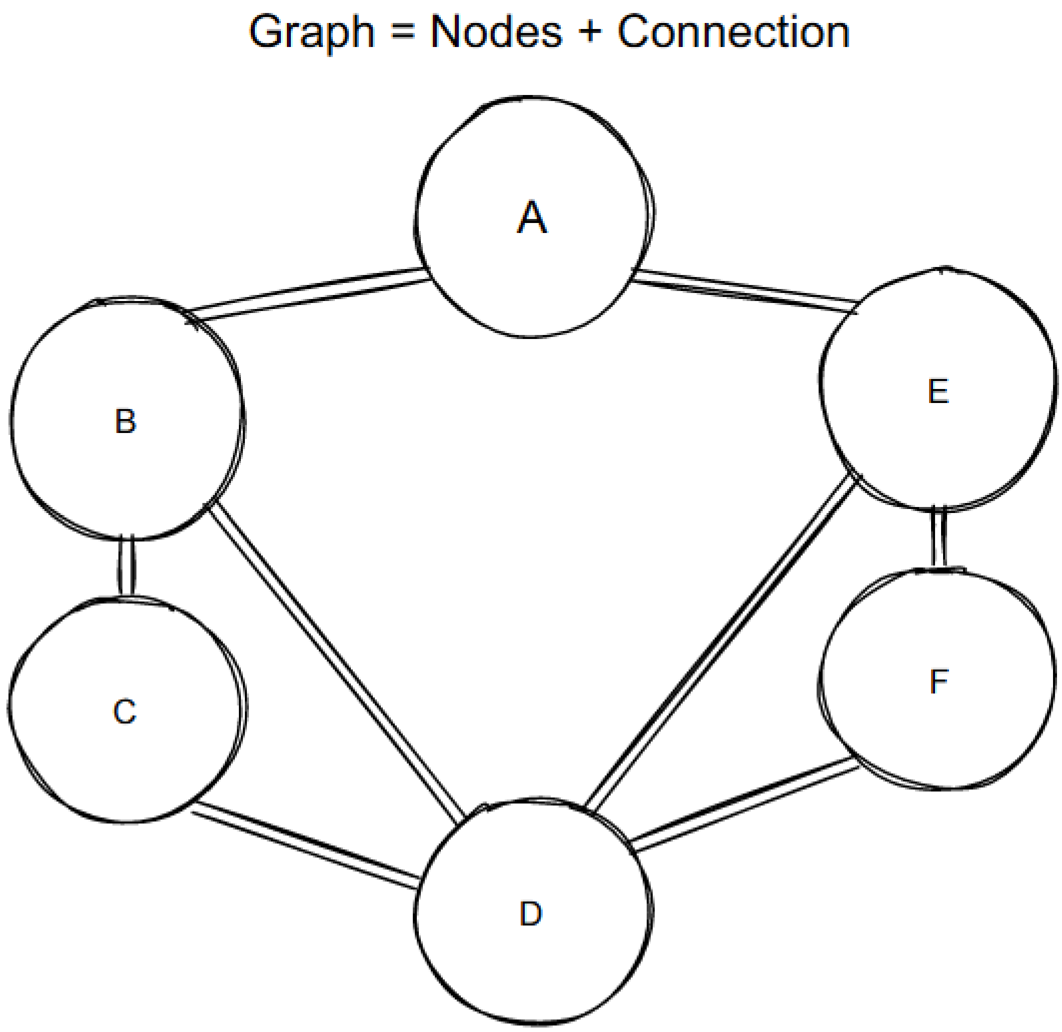
  - in wide tree, BFS could take up more space.
  - in deep tree, DFS could take up more space.
- if tree structure is sad one that looks like a one sided list, queue takes only one item at each level and space doesn't matter in this case but it's inefficient.

DFS Variants Comparison

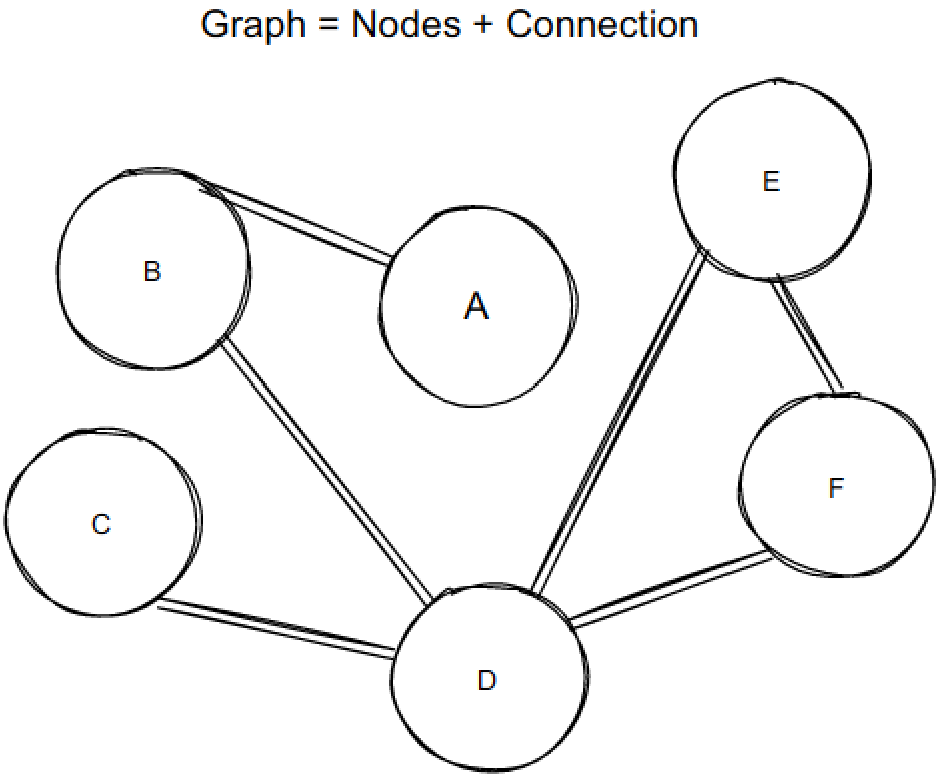
- DFS InOrder returns an ordered result.
- DFS PreOrder can be used to be exported so that it can be easily reconstructed or copied because tree structure can be replicated easily based on order.
- At the end of the day, it can be switched each other easily and result may depend on the target data structure itself.

Graphs

- a graph data structure consists of a finite(and possibly mutable) set of vertices or nodes or points, together with a set of unordered pairs of these vertices for an undirected graph or a set of ordered pairs for a directed graph.
- i.e. it is a collection of nodes and edges(connections).



- node position doesn't matter but connection between nodes is important.



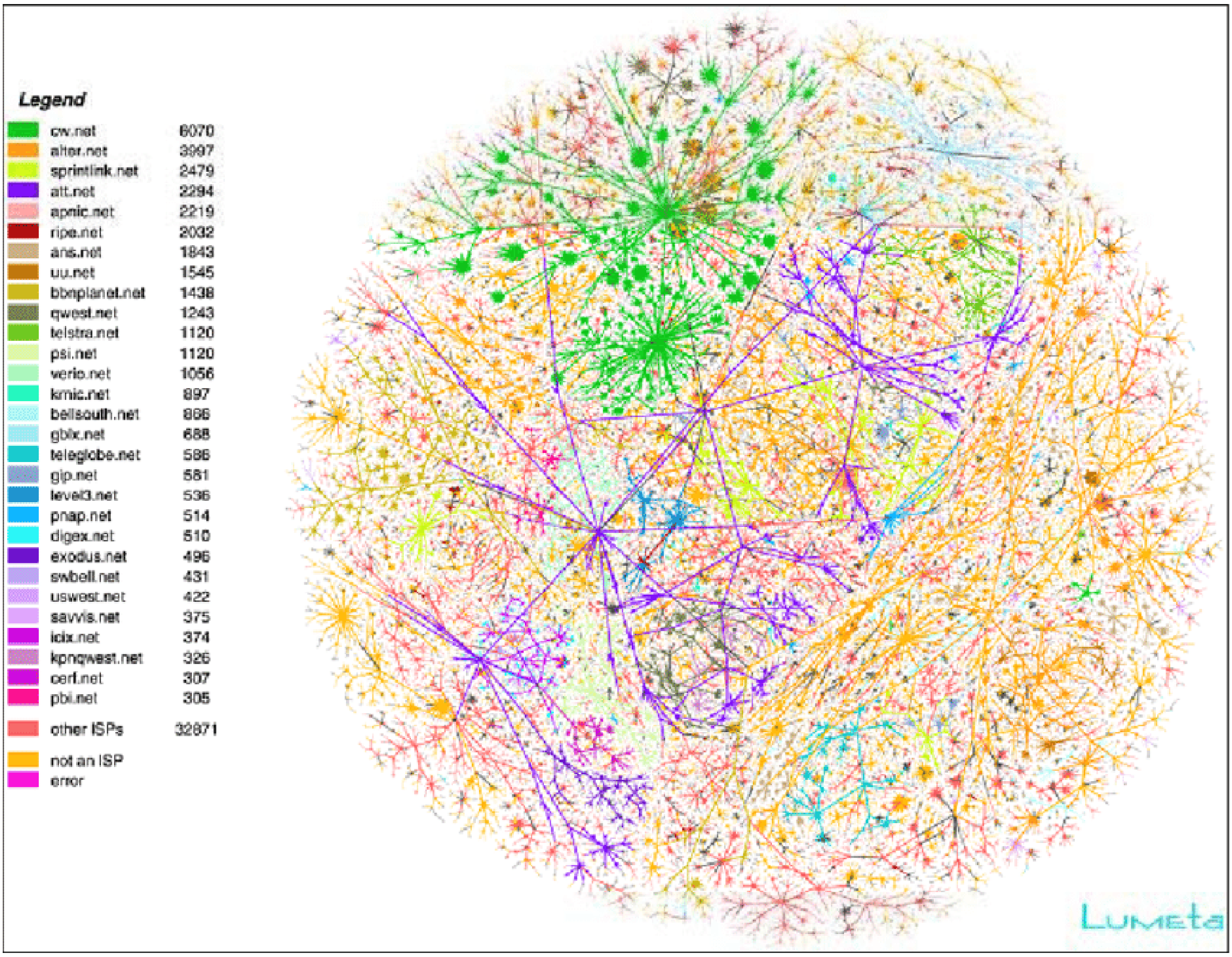
- this graph is also valid one.
- list and tree can be a type of graph.

Use Case of Graphs

- location/Mapping
- routing algorithms

each point of interest represents a node and routing between nodes is represented by edges.

- visual hierarchy



tiny part of internet map hierarchy

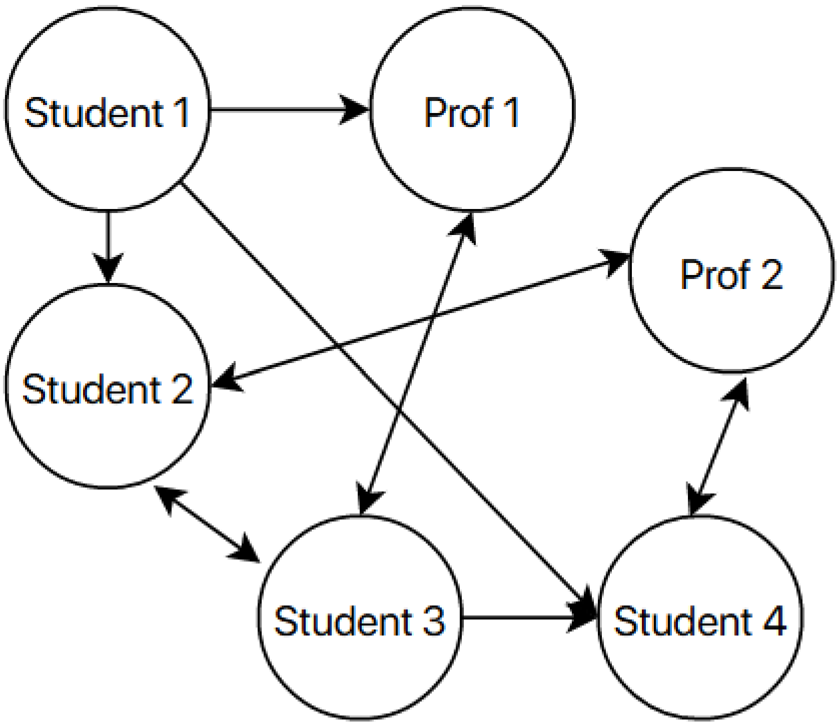
- file system optimizations
- recommendation engine
- any structure that requires complex relationships

Terminology of Graphs

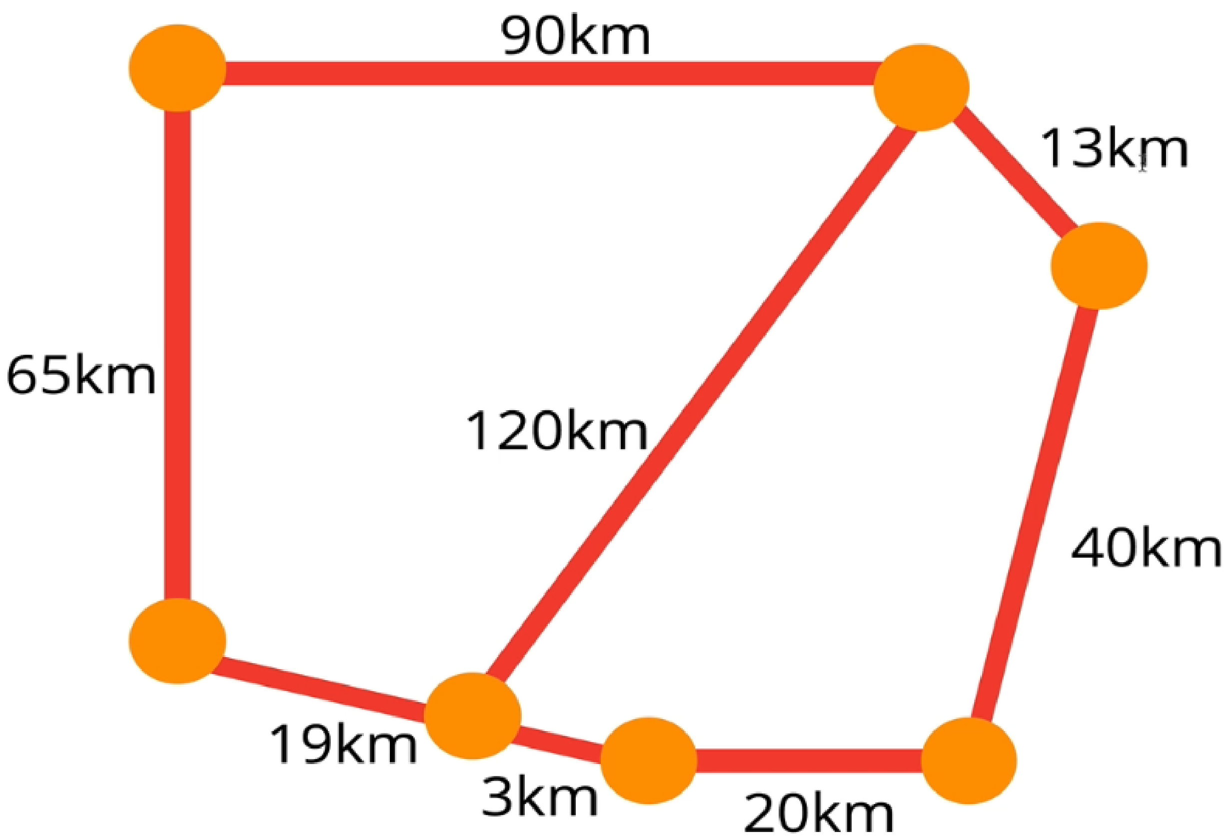
- vertex: a node in a graph.
- edge: a connection between two nodes.
- directed/undirected graph:
  - directed graph:
    - edges have direction or polarity.
      - e.g. instagram one-way follower graph
  - undirected graph:
    - edges have no direction or polarity, it goes either way.
      - e.g. facebook two-way friend graph
- weighted/unweighted graph:
  - unweighted graph:

  - edges have no weight. there is no information in the connection itself.
- weighted graph:
  - edges have weight. there is a information about the connection itself.

Examples



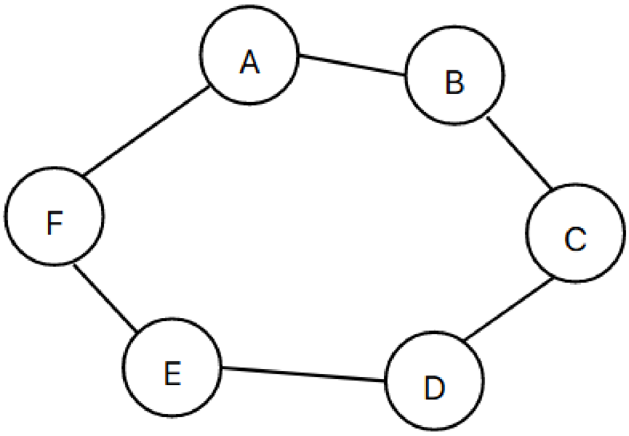
Unweighted directed graph of relationships between people



Weighted undirected graph of map

Breakdown of Graphs

adjacency matrix

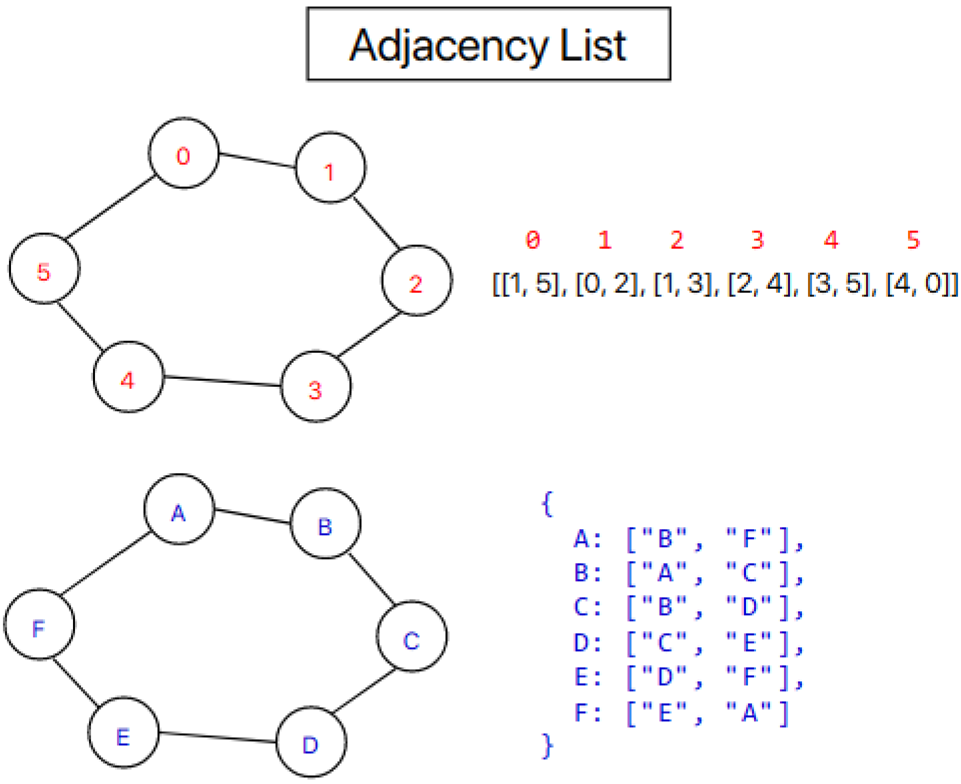


Adjacency Matrix

	A	B	C	D	E	F
A	0	1	0	0	0	1
B	1	0	1	0	0	0
C	0	1	0	1	0	0
D	0	0	1	0	1	0
E	0	0	0	1	0	1
F	1	0	0	0	1	0

- in adjacency matrix, edges are represented as a boolean in rows/columns in matrix.
  - matrix: two dimensional structure that usually implemented with nested array

adjacency list



- in adjacency list, data can be represented as a array based on index or hash table based on key value.

Big O of Adjacency Matrix and List

- |V|: number of vertices
- |E|: number of edges

Operation	Adjacency List	Adjacency Matrix
Add vertex	O(1)	O(|V^2|)
Add edge	O(1)	O(1)
Remove Vertex	O(|V| + |E|)	O(|V^2|)
Remove edge	O(|E|)	O(1)
Query	O(|V| + |E|)	O(1)
Storage	O(|V| + |E|)	O(|V^2|)

- adjacency list time complexity grows more linearly depend on the number of vertices and edges because its structure - array based on index.
  - it can take less space in sparse graphs.
  - it's fster to iterate over all edges. (it skips the vertices that don't have any edges)
  - it can be slower to look u[the specific edge.
- adjacency matrix time complexity grows more exponentially based on the number of vertices because its structure - square matrix.
  - it doesn't matter much how many connections are in adjacency matrix.
  - it takes up more space in sparse graphs.
  - it's slower to iterate over all edges. (it looks over every single one)
  - it's faster to look up specific edge.
  - if data is sparse, don't have many edges, it's better not to use adjacency matrix.
- real world data generally tends to be sparse(lots of node, relationship but not everything is connected), it's better to use adjacency list.
- if data is dense and relationship is strong, it's better to use adjacency matrix.

Creating Graph

```
class Graph {
  constructor() {
    this.adjacencyList = {};
  }
}
```

Adding Vertex pseudocode

- write a method called addVertex that accepts a name of a vertex.

- it should add a key to the adjacency list wit thhe name of the vertex and set its value to be an empty array.

Adding Vertex implementation

```
  addVertex(vertex) {
    if (!this.adjacencyList[vertex]) {
      this.adjacencyList[vertex] = [];
    }
  }
```

Adding Edge pseudocode

- it should accept two vertices as argument, call it vertex1 and vertex2.
- the function should find in the adjacency list the key of vertex 1 and push vertex 2 to the array.
- it should find in the adjacency list the key of vertex2 and push vertex1 to the array.

Adding Edge implementation

```
addEdge(v1, v2) {
  this.adjacencyList[v1].push(v2);
  this.adjacencyList[v2].push(v1);
}

/*
// init
{
  "berlin": [],
  "paris": [],
  "amsterdam": [],
}

g.addEdge("berlin", "paris");

{
  "berlin": ["paris"],
  "paris": ["berlin"],
  "amsterdam": [],
}
*/
```

Removing Edge pseudocode

- it should accept two vertices as v1 and v2.
- it should reassign the key of v1 to be an array that does not contain v2.
- it should reassign the key of v2 to be an array that does not contain v1.

Removing edge implementation

```
removeEdge(v1, v2) {
  this.adjacencyList[v1] = this.adjacencyList[v1].filter(
    v => v !== v2
  );
  this.adjacencyList[v2] = this.adjacencyList[v2].filter(
    v => v !== v1
  );
}
```

Removing Vertex pseudocode

- it should accept a vertex to remove.
- it should loop as long as there are any other vertieces in the adjency list for that vertex.
  - inside of the loop, call removeEdge() with the vertex to remove and any values in the adjacency list for that vertex.
- delete the key in the adjacency list.

Removing Vertex implementation

```
removeVertex(vertex) {
    while (this.adjacencyList[vertex].length) {
      const adjacentVertex = this.adjacencyList[vertex].pop();
      this.removeEdge(vertex, adjacentVertex);
    }
    delete this.adjacencyList[vertex];
  }
```

Graph Traversal

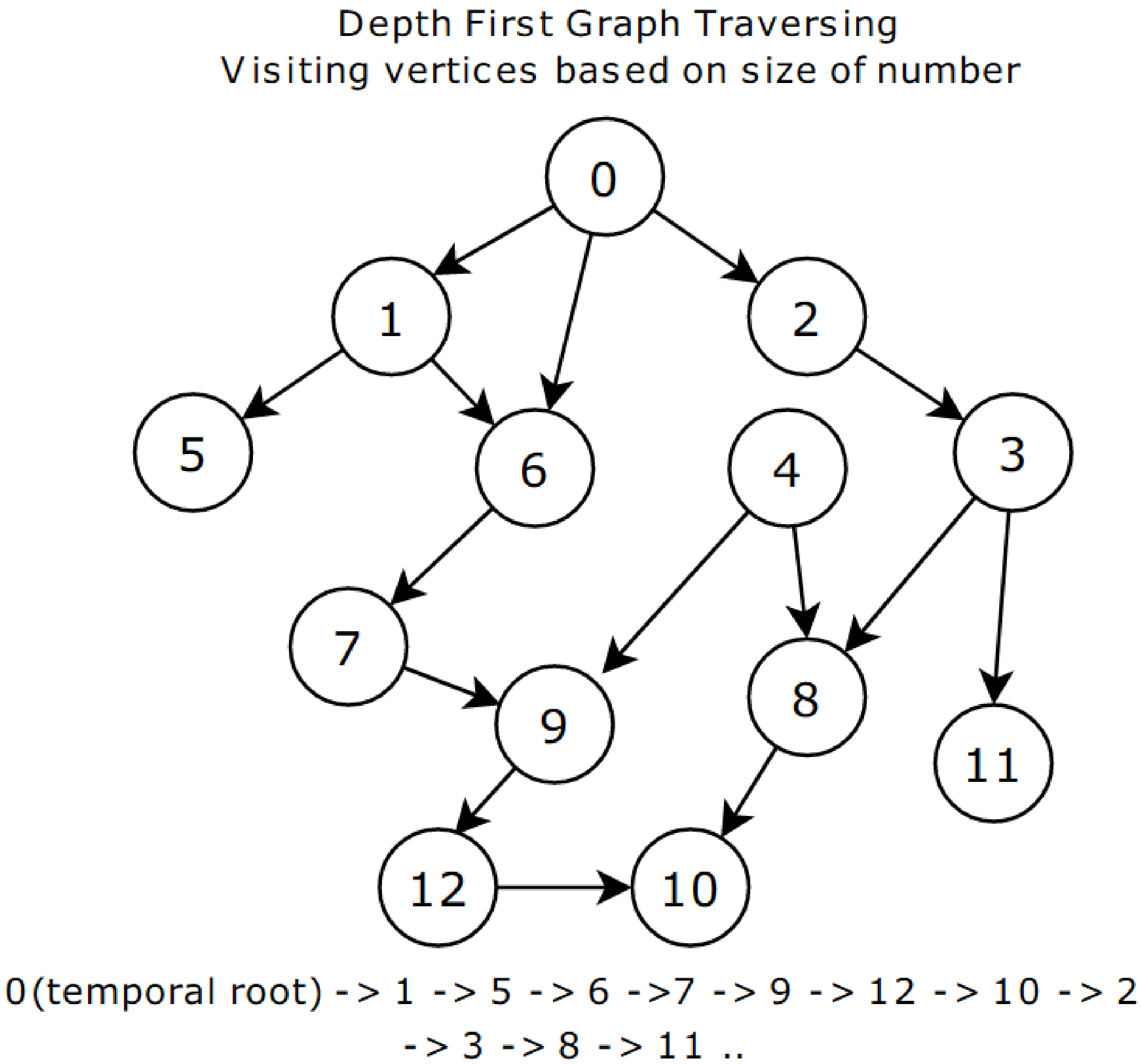
- graph traversal is a process of visiting all vertices connected to a starting vertex.
- unlike tree with root, graph can start from anywhere, so it has to have a starting vertex.

Graph Traversal Uses

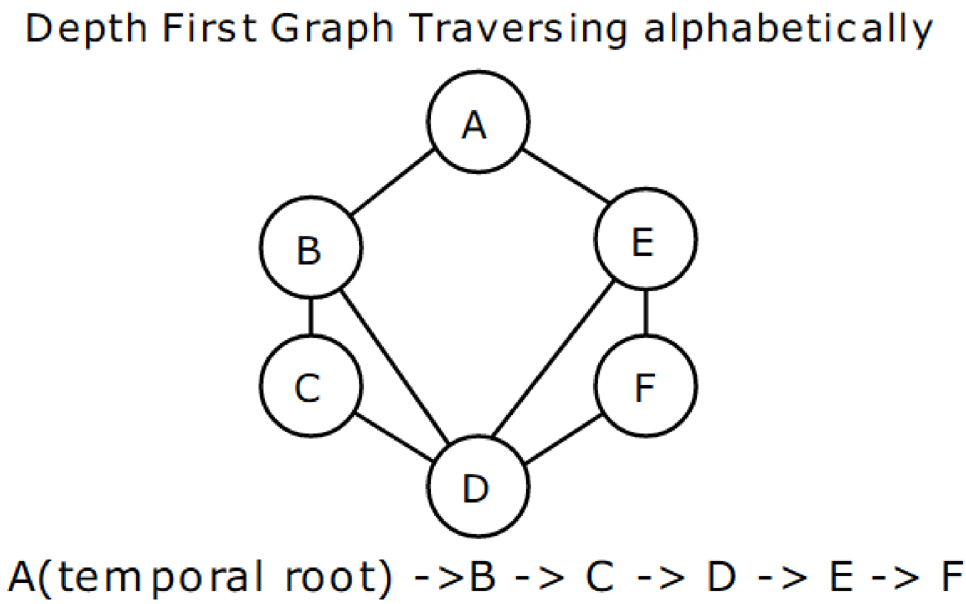
- peer to peer networking
- web crawlers
- finding the closed matches/recommendations
- routing for shorted path
  - GPS navigation
  - solving mazes
  - AI (shorted path to win the game)

Depth First Graph Traversal

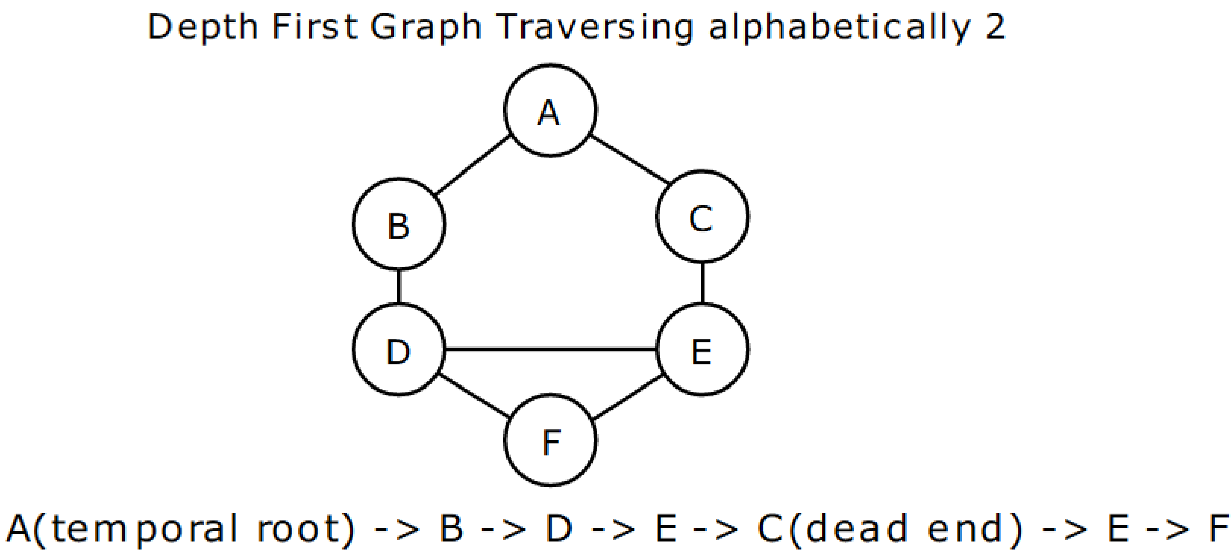
1


Depth First Graph Traversing
Visiting vertices based on size of number
0
1
2
5
6
4
3
7
9
8
11
12
10
0(temporal root) -> 1 -> 5 -> 6 ->7 -> 9 -> 12 -> 10 -> 2
-> 3 -> 8 -> 11 ..

2



3




```
// adjacency list of graph 3
{
  "A": ["B", "C"],
  "B": ["A", "D"],
  "C": ["A", "E"],
  "D": ["B", "E", "F"],
  "E": ["C", "D", "F"],
  "F": ["D", "E"],
}
```

- it priortizes deepening of the traversal rather than widening it out to the siblings in tree. (but it doesn't actually look like deepening because of shape of the graph structure..)
- it's done by following one neighbor at a time.

- it explores as far as possible down one branch before 'backtracking'.
- order of visiting vertices can be different on situations - it can be random, it can be topological, alphabetical or any other order.
- vertices can be removed after being traversed in the adjacency list.

DFS Graph Recursively pseudocode

- it should accept a starting vertex.
- create a list to store the visited vertices.
- create a helper function that accepts a vertex.
  - the helper function should return early if vertex is empty.
  - the helpfer function should place the vertex in the visited list.
  - loop over every neighbors for that vertex.
  - if any of the neighbors is not in the visited list, recursively call the helpfer function with that vertex.

DFS Graph Recursively implementation

```
depthFirstRecursive(start) {
  const result = [];
  let visited = {};

  // context of this would change in helper function
  const adjacencyList = this.adjacencyList;

  (function dfs(vertex) {
    if (!vertex) return null;
    visited[vertex] = true;
    result.push(vertex);
    adjacencyList[vertex].forEach(neighbor => {
      if (!visited[neighbor]) {
        return dfs(neighbor);
      }
    })
  }(start)); // IIFE

  return result;
}
```

DFS Graph Iteratively pseudocode

- it should accept a starting vertex.
- create a stack to help use keep track of vertices using array.
- create a list that stores the end result, to be returned at the end.
- create an object to store visited vertices.
- add the starting vertex to the stack, and mark it visited.
- while stack is not empty:
  - pop the next vertex from the stack

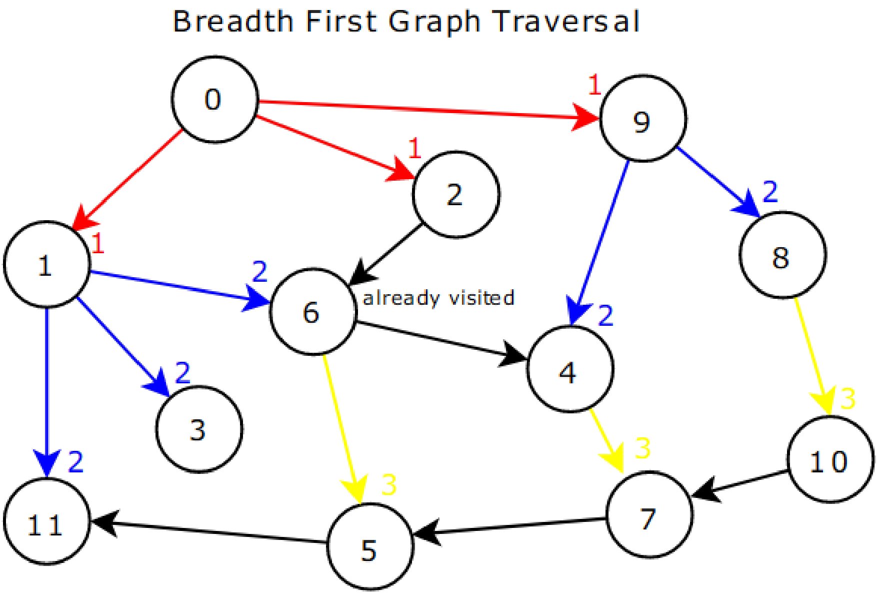
- if the vertax is not visited
  - mark it as visited.
  - add it to the result list.
  - push all of its neighbors onto the stack.
- return the result array.

DFS Graph Iteratively implementation

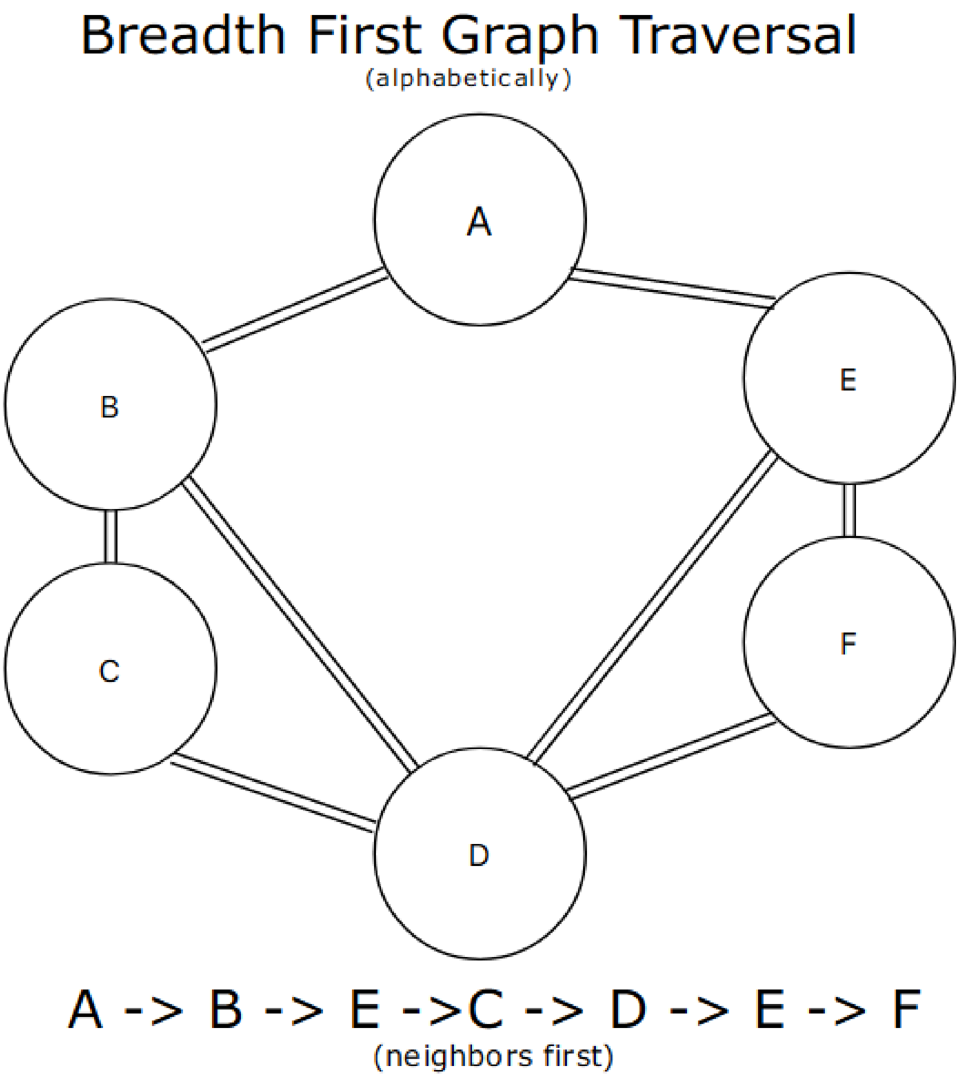
```
depthFirstIterative(start) {
  // init start at the stack and mark it as visited
  const stack = [start];
  const result = [];
  const visited = {};

  let currentVertex;
  visited[start] = true;
  while (stack.length) {
    currentVertex = stack.pop();
    result.push(currentVertex);
    // accessing neighbor
    this.adjacencyList[currentVertex].forEach(neighbor => {
      if (!visited[neighbor]) {
        // mark and push visited
        visited[neighbor] = true;
        stack.push(neighbor);
      }
    })
  }
  return result;
}
```

Breadth First Graph Traversal

BFS Graph with height map



BFS Graph with alphabetical order



- it visites neighbors at current depth first.
- i.e. it visits vertices at the same height horizontally.

Breadth First Graph Traversal pseudocode

- it should accept a starting vertex.
- create a queue or array and initiate the starting vertex in it.
- create an array to store the verticex visited.
- create an object to store the vertices visited.
- mark the starting vertex as visited.
- while there is anything left in the queue,
  - remove the first vertex from the queue and push it into the array that stores vertices visited.
  - loop over each vertex in the adjacency list for the vertex youo are visiting.
  - if it's not inside the object that stores vertices visited, mark it as visited and enqueue the vertex.
- return the array of visited verticies.

Breadth First Graph Traversal implementation

```
breadthFirst(start) {
  // init start at the stack and mark it as visited
  const queue = [start];
  const result = [];
  const visited = {};
  visited[start] = true;

  let currentVertex;
  while (queue.length) {
    // remove the first vertex in the queue
    currentVertex = queue.shift();
    // and push it into result
    result.push(currentVertex);
    this.adjacencyList[currentVertex].forEach(neighbor => {
      if (!visited[neighbor]) {
        visited[neighbor] = true;
        queue.push(neighbor);
      }
    })
  }
  return result;
}
```