122com Data structures and types

David Croft

Coventry University

david.croft@coventry.ac.uk

2017

Overview

Arrays

C

A series of objects all of the same size and type.

```
array<char,5> arr = {'A', 'B', 'C', 'D', 'E'};
```

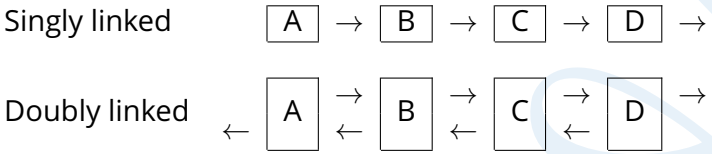
- Stored in contiguous blocks of memory.
- Python lists are functionally closest.
  - But are not arrays.
- Can't be resized.

Linked lists

C

The challenger for array's crown.

- Series of nodes, each of which points to the next element.
  - And to the previous element if it's a doubly linked list.

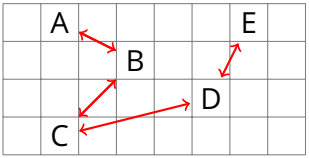


Linked lists II

A

Not in contiguous memory.

- Each node is separate.
- Scattered.
- C++ Dynamic memory (pointers!).
  - Discussed in depth later in module.



- Why would we use linked lists instead of arrays?
  - Can change size.
  - Can quickly insert and delete elements.

```
class Node:
    __prev = None
    __next = None
    value = None
```

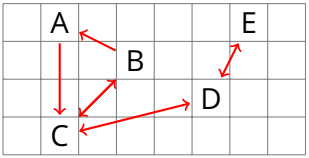
```
class Node
{
private:
    Node *prev;
    Node *next;

public:
    int value;
};
```

Linked lists II

A

Not in contiguous memory.

- Each node is separate.
- Scattered.
- C++ Dynamic memory (pointers!).
  - Discussed in depth later in module.



- Why would we use linked lists instead of arrays?
  - Can change size.
  - Can quickly insert and delete elements.

```
class Node:
    __prev = None
    __next = None
    value = None
```

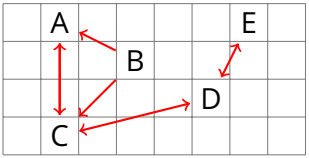
```
class Node
{
private:
    Node *prev;
    Node *next;

public:
    int value;
};
```

Linked lists II

A

Not in contiguous memory.

- Each node is separate.
- Scattered.
- C++ Dynamic memory (pointers!).
  - Discussed in depth later in module.



- Why would we use linked lists instead of arrays?
  - Can change size.
  - Can quickly insert and delete elements.

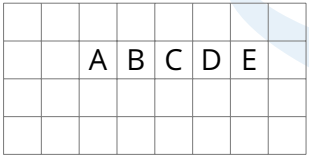
```
class Node:
    __prev = None
    __next = None
    value = None
```

```
class Node
{
private:
    Node *prev;
    Node *next;

public:
    int value;
};
```

Removing array elements

C

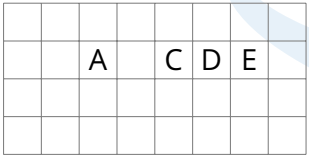
```
temp = ['A', 'B', 'C', 'D', 'E']
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```



- Array in memory, multiple elements in a contiguous block.
- How do we remove elements from the middle?

Removing array elements


```
temp = ['A', 'B', 'C', 'D', 'E']
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```

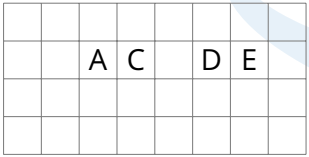


- Array in memory, multiple elements in a contiguous block.
- How do we remove elements from the middle?
  1. Remove element from the array.

Removing array elements

C

```
temp = ['A', 'B', 'C', 'D', 'E']
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```

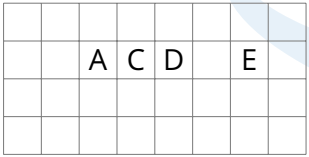


- Array in memory, multiple elements in a contiguous block.
- How do we remove elements from the middle?
  1. Remove element from the array.
  2. Move next element to occupy the empty space.

Removing array elements

C

```
temp = ['A', 'B', 'C', 'D', 'E']
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```

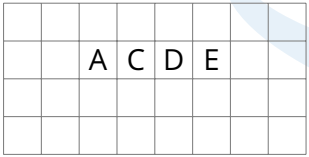


- Array in memory, multiple elements in a contiguous block.
- How do we remove elements from the middle?
  1. Remove element from the array.
  2. Move next element to occupy the empty space.
  3. Repeat.

Removing array elements

C

```
temp = ['A', 'B', 'C', 'D', 'E']
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```

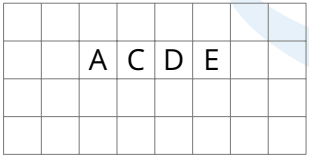


- Array in memory, multiple elements in a contiguous block.
- How do we remove elements from the middle?
  1. Remove element from the array.
  2. Move next element to occupy the empty space.
  3. Repeat.

Removing array elements

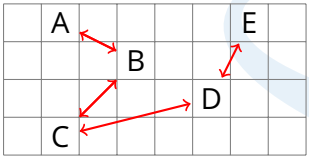
C

```
temp = ['A', 'B', 'C', 'D', 'E']
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```



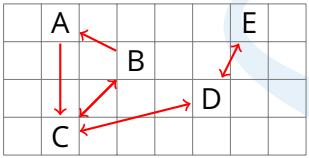
- Array in memory, multiple elements in a contiguous block.
- How do we remove elements from the middle?
  1. Remove element from the array.
  2. Move next element to occupy the empty space.
  3. Repeat.
- Is very slow with large arrays.

Removing linked list elements



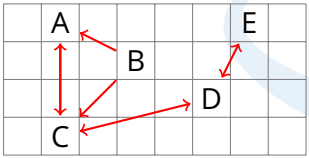
- Linked list, separate elements scattered in memory.
- Each pointing to the next/prev element.
- How do we remove elements?

Removing linked list elements



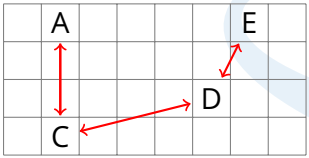
- Linked list, separate elements scattered in memory.
- Each pointing to the next/prev element.
- How do we remove elements?
  1. Change pointers.

Removing linked list elements



- Linked list, separate elements scattered in memory.
- Each pointing to the next/prev element.
- How do we remove elements?
  1. Change pointers.

Removing linked list elements



- Linked list, separate elements scattered in memory.
- Each pointing to the next/prev element.
- How do we remove elements?
  1. Change pointers.
  2. Delete old element.

Linked lists III

Advantages

- Inserting and deleting elements is very fast.
  - $O(1)$.
- No size limits, can keep adding new elements.
- Doesn't waste memory.

Disadvantages

- Not indexed.
  - Can't ask for the 20^{th} element etc.
  - Have to step through the list (slow).
- Needs more memory than an array to store the same number of elements.
  - Have to keep track of where the next/prev nodes are.

Data structures

Arrays and linked lists are data structures.

- A specific way of storing data.
- Can see how the various elements of the structure are laid out in memory.
- Direct access to the underlying memory.

Abstract data types

As we move to storing more complex information in our software we well start to encounter Abstract Data Types (ADTs).

- Software engineering principal.

Abstract data types

As we move to storing more complex information in our software we well start to encounter ADTs.

- Software engineering principal.
- Keep what a data type can do...

Abstract data types

As we move to storing more complex information in our software we well start to encounter ADTs.

- Software engineering principal.
- Keep what a data type can do...

  ...and how it does it separate.

Abstract data types

As we move to storing more complex information in our software we well start to encounter ADTs.

- Software engineering principal.
- Keep what a data type can do...
  ...and how it does it separate.

- Unlike data structure ADTs only concerned with the interface.

Abstract data types

As we move to storing more complex information in our software we well start to encounter ADTs.

- Software engineering principal.
- Keep what a data type can do...
  ...and how it does it separate.

- Unlike data structure ADTs only concerned with the interface.
- Internals of ADTs can vary widely between implementations.

ADT

Imagine an ADT like a car.

- It has a set of supported operations, go faster, go slower, turn left, turn right.

ADT

Imagine an ADT like a car.

- It has a set of supported operations, go faster, go slower, turn left, turn right.
- Don’t care how it achieves these.

ADT

Imagine an ADT like a car.

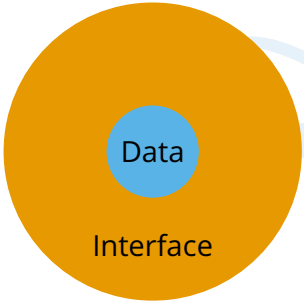
- It has a set of supported operations, go faster, go slower, turn left, turn right.
- Don't care how it achieves these.
- Don't care if, internally, it's using a combustion engine or an electric motor.

ADT

Imagine an ADT like a car.

- It has a set of supported operations, go faster, go slower, turn left, turn right.
- Don't care how it achieves these.
- Don't care if, internally, it's using a combustion engine or an electric motor.
- Only care about the result.
- Keep people away from the internal workings/data.

Programmer



Queues

C

A First In First Out (FIFO) ADT.

- Ends of the queue called the front and back.
- New elements added to back of queue only.
  - Pushing - push(value)
- Old elements removed from front of queue only.
  - Popping - pop()
- No cutting in.

Queues

C

A FIFO ADT.

- Ends of the queue called the front and back.
- New elements added to back of queue only.
  - Pushing - push(value)
- Old elements removed from front of queue only.
  - Popping - pop()
- No cutting in.
- Buffer to hold items for processing in the order in which they arrive.

Queues

A FIFO ADT.

- Ends of the queue called the front and back.
- New elements added to back of queue only.
  - Pushing - push(value)
- Old elements removed from front of queue only.
  - Popping - pop()
- No cutting in.
- Buffer to hold items for processing in the order in which they arrive.

- Which would be better for a queue? An array or a linked list?

Queues

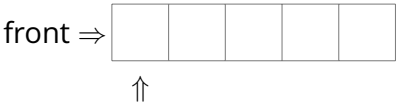
C

A FIFO ADT.

- Ends of the queue called the front and back.
- New elements added to back of queue only.
  - Pushing - push(value)
- Old elements removed from front of queue only.
  - Popping - pop()
- No cutting in.
- Buffer to hold items for processing in the order in which they arrive.

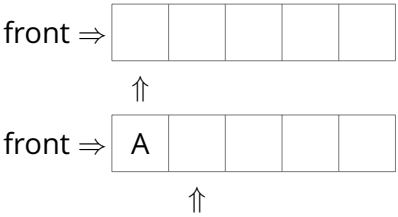
- Which would be better for a queue? An array or a linked list?
  - Linked list.

Array as a queue.



- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.

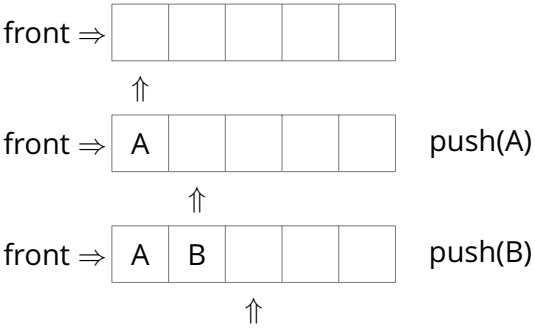
Array as a queue.



push(A)

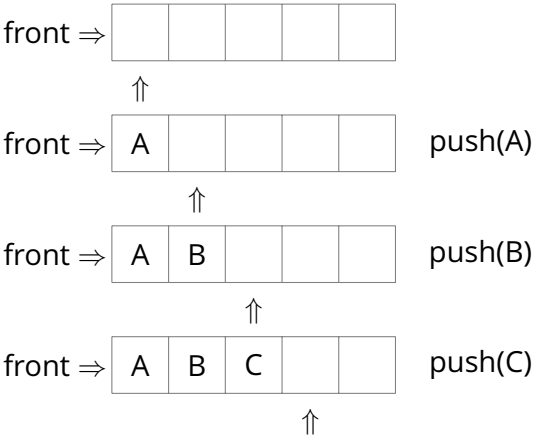
- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.

Array as a queue.



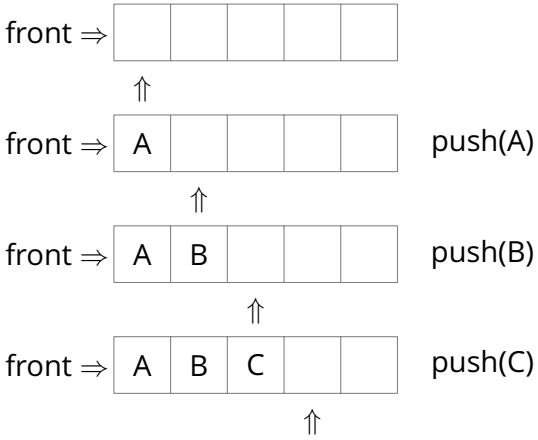
- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.

Array as a queue.



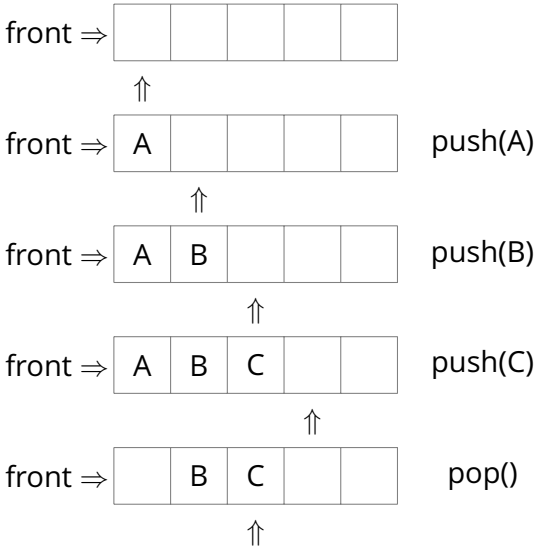
- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.

Array as a queue.



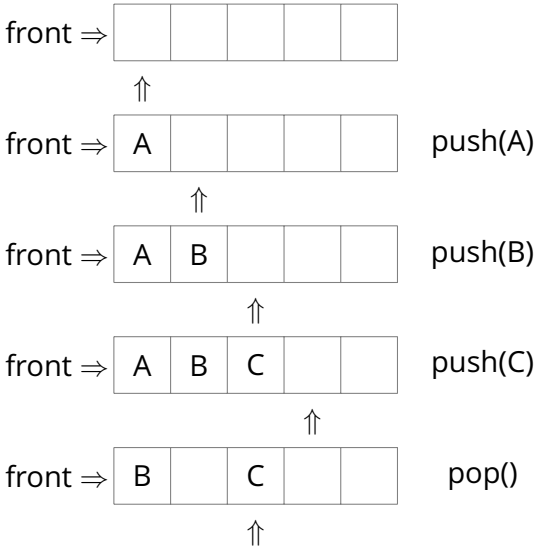
- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.
- What happens when we pop()?
  - Have to shuffle every element forward one space.
  - Inefficient.

Array as a queue.



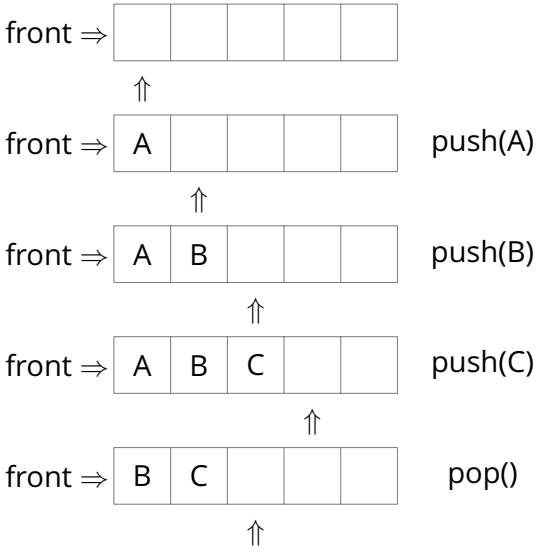
- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.
- What happens when we pop()?
  - Have to shuffle every element forward one space.
  - Inefficient.

Array as a queue.



- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.
- What happens when we pop()?
  - Have to shuffle every element forward one space.
  - Inefficient.

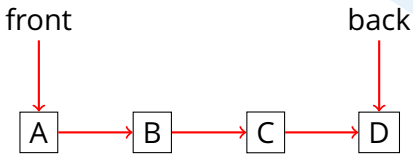
Array as a queue.



- Very similar to stacks.
  - Keep track of next free space.
  - Limited size.
- What happens when we pop()?
  - Have to shuffle every element forward one space.
  - Inefficient.

Linked list as a queue.

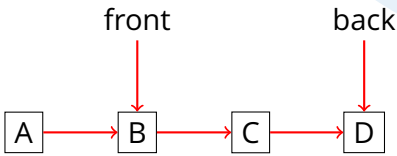
A



Linked list as a queue.

A

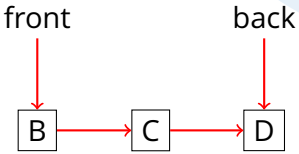
pop()



Linked list as a queue.

A

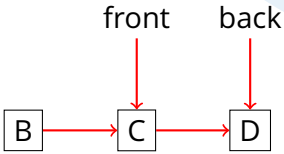
pop()



Linked list as a queue.

A

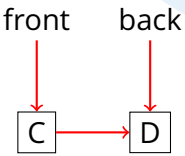
pop() , pop()



Linked list as a queue.

A

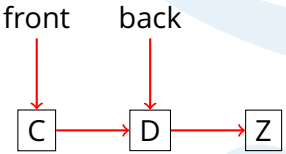
pop() , pop()



Linked list as a queue.

A

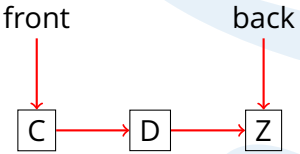
pop() , pop() , push(Z)



Linked list as a queue.

A

pop() , pop() , push(Z)



Stacks

A First In Last Out (FILO) ADT.

- Ends of the stack are called the top and bottom.
- New elements add to top of stack only.
  - Pushing - push(value)
- Old elements removed from top of stack only.
  - Popping - pop()
- No cutting in.

Stacks

C

A FILO ADT.

- Ends of the stack are called the top and bottom.
- New elements add to top of stack only.
  - Pushing - push(value)
- Old elements removed from top of stack only.
  - Popping - pop()
- No cutting in.

- Which would be better for a stack? An array or a linked list?

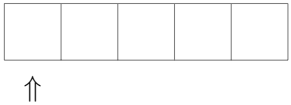
Stacks

A FILO ADT.

- Ends of the stack are called the top and bottom.
- New elements add to top of stack only.
  - Pushing - push(value)
- Old elements removed from top of stack only.
  - Popping - pop()
- No cutting in.

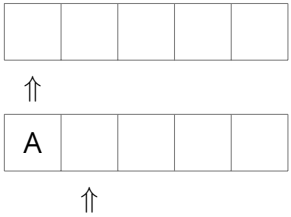
- Which would be better for a stack? An array or a linked list?
  - Doesn't matter performance wise.
  - Linked list if *n* is unknown.

Array as a stack.



- Keep track of position of the next free space in the array.
- Arrays have a fixed size.
  - Can't hold more values than we have space for.

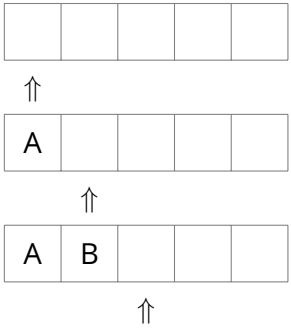
Array as a stack.



push(A)

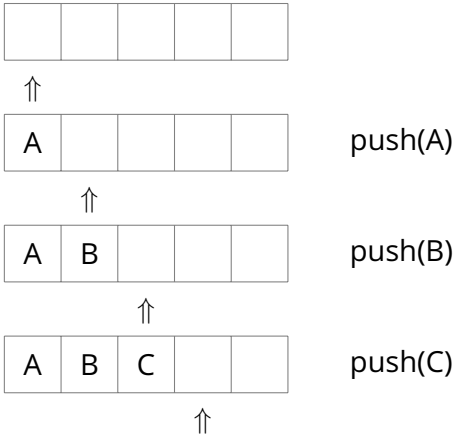
- Keep track of position of the next free space in the array.
- Arrays have a fixed size.
  - Can't hold more values than we have space for.

Array as a stack.



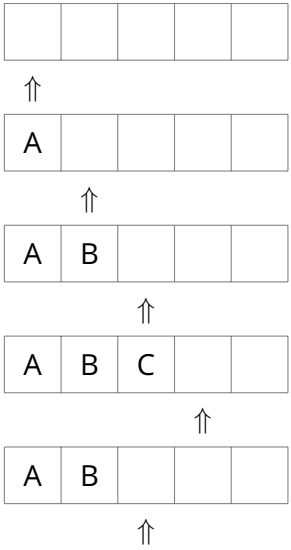
- Keep track of position of the next free space in the array.
- Arrays have a fixed size.
  - Can't hold more values than we have space for.

Array as a stack.



- Keep track of position of the next free space in the array.
- Arrays have a fixed size.
  - Can't hold more values than we have space for.

Array as a stack.



- Keep track of position of the next free space in the array.
- Arrays have a fixed size.
  - Can't hold more values than we have space for.

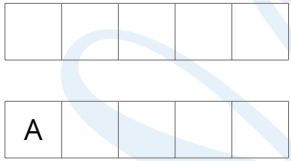
Sets

- An unordered ADT.
  - Items ordered by the set.
  - You have no control over it.
- Sets contain unique elements.
  - Can't contain duplicates.

- Can add items to a set.
- Can remove items from a set.
- Can see if an item is in a set.
- Can't get the n^{th} element.
  - It's unordered remember.

Sets

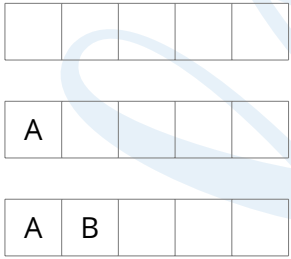
- An unordered ADT.
  - Items ordered by the set.
  - You have no control over it.
- Sets contain unique elements.
  - Can't contain duplicates.



- Can add items to a set.
- Can remove items from a set.
- Can see if an item is in a set.
- Can't get the n^{th} element.
  - It's unordered remember.

Sets

- An unordered ADT.
  - Items ordered by the set.
  - You have no control over it.
- Sets contain unique elements.
  - Can't contain duplicates.

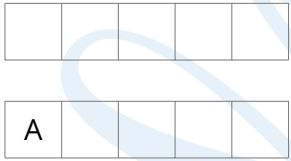


- Can add items to a set.
- Can remove items from a set.
- Can see if an item is in a set.
- Can't get the n^{th} element.
  - It's unordered remember.

Sets

- An unordered ADT.
  - Items ordered by the set.
  - You have no control over it.
- Sets contain unique elements.
  - Can't contain duplicates.

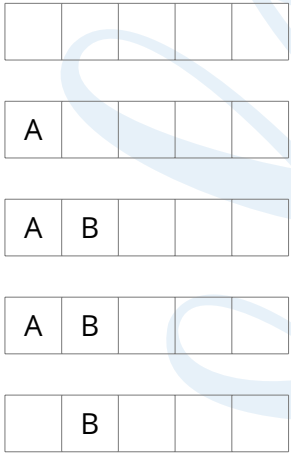
- Can add items to a set.
- Can remove items from a set.
- Can see if an item is in a set.
- Can't get the n^{th} element.
  - It's unordered remember.



Sets

- An unordered ADT.
  - Items ordered by the set.
  - You have no control over it.
- Sets contain unique elements.
  - Can't contain duplicates.

- Can add items to a set.
- Can remove items from a set.
- Can see if an item is in a set.
- Can't get the n^{th} element.
  - It's unordered remember.



...and the others

- Lots of other ADTs.
- Different names in different languages.

- Lists.
- Circular lists.
- Associative arrays.
  - Dictionaries/Maps.
- Double-ended queues.
- Trees.
- Graphs.

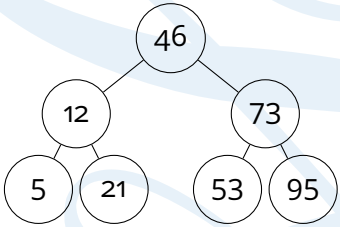
Trees

A

Variation on linked lists.

- Made of nodes and relationships.
- Root node at top.
- Each node can have $\geq$ 0 children.

- Binary search tree.
  - Very common type.
  - Ordered.
  - Max two children.
  - Binary searching.
  - Very good for sets.

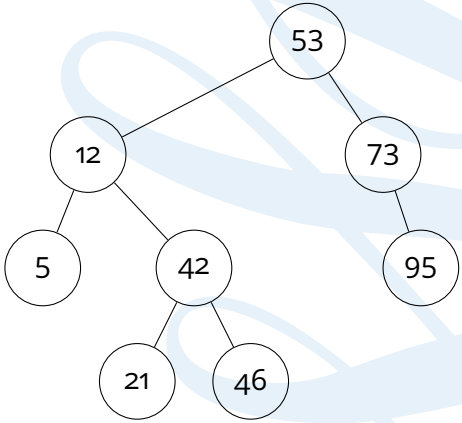


Balance

A

- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.

- Unbalanced because more than a one node difference between the two halves.

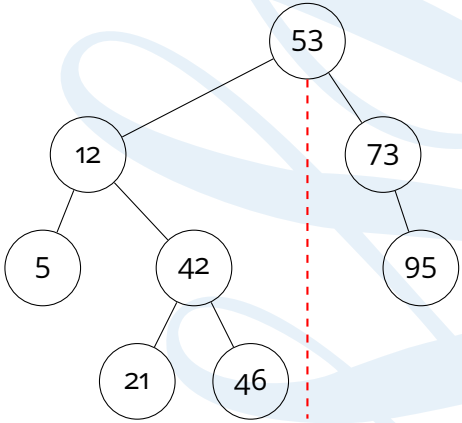


Balance

A

- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.

- Unbalanced because more than a one node difference between the two halves.
  - For the whole tree...

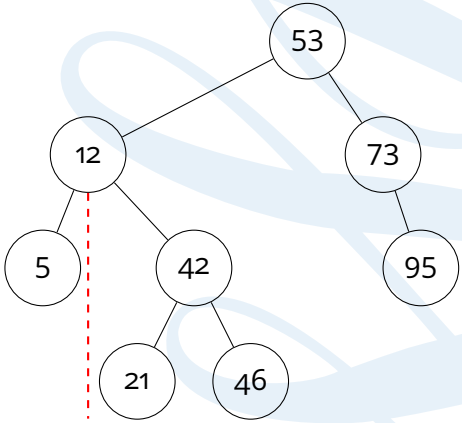


Balance

A

- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.

- Unbalanced because more than a one node difference between the two halves.
  - For the whole tree...
  - ...and one of the subtrees.

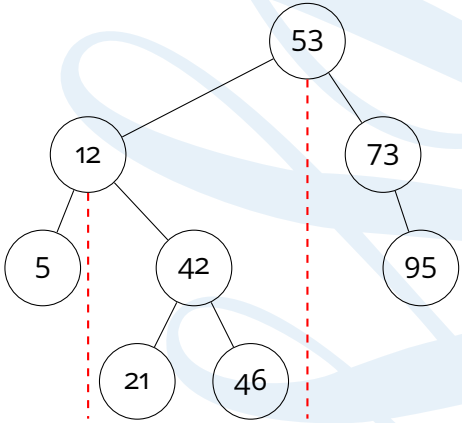


Balance

A

- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.

- Unbalanced because more than a one node difference between the two halves.
  - For the whole tree...
  - ...and one of the subtrees.

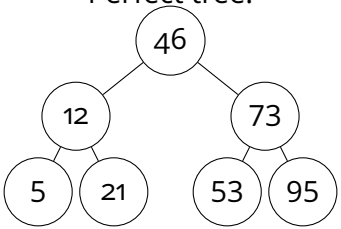


Balance

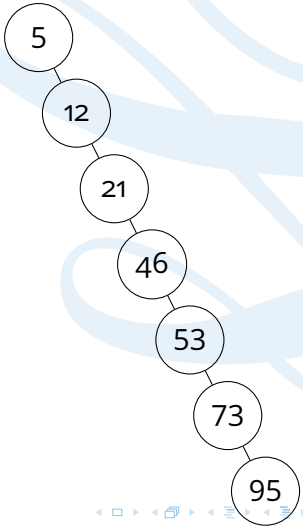
A

Important that you keep your BSTs balanced.

Perfect tree.



Degenerate tree.



Quiz

Q1

Stacks and queues are examples of ____

- Data structures.
- Linked lists.
- Arrays.
- Abstract Data Types.

Q1

Stacks and queues are examples of ____

- Data structures.
- Linked lists.
- Arrays.
- Abstract Data Types.

Q2

One advantage of linked lists of arrays is that ____

- They use less memory.
- They don't waste memory.
- They can be used for queues.
- They are faster to search though.

Q2

One advantage of linked lists of arrays is that ____

- They use less memory.
- They don't waste memory.
- They can be used for queues.
- They are faster to search though.

Q3

Stacks are a ____ type.

- FIFO.
- FOFI.
- FILO.
- FIDO.

Q3

Stacks are a ____ type.

- FIFO.
- FOFI.
- FILO.
- FIDO.

Q4

The elements of a set can't ____

- Contain duplicates.
- Be sequences, ie. lists, strings.
- Be out of order.
- Be removed.

Q4

The elements of a set can't ____

- Contain duplicates.
- Be sequences, ie. lists, strings.
- Be out of order.
- Be removed.

Q5

ADTs separate the ____ of the type.

- Input and output.
- Attributes and methods.
- Implementation and interface.
- Code and software.

Q5

ADTs separate the ____ of the type.

- Input and output.
- Attributes and methods.
- Implementation and interface.
- Code and software.

Why do I care?

Everyone

- Need to understand the structures before we can pick the right one.
- Different data structures have very different characteristics.
- Huge effect on efficiency of your code.
- If you pick the right ADT it can save you a lot of code.
  - E.g. why write code to check for duplicates? Use a set and they can't exist.
  - E.g. why write code to find the most recent addition to a list, use a stack.

Recap

- Arrays.
  - Advantages/disadvantages.
- Linked lists .
  - Advantages/disadvantages.
  - How to insert/delete.
- Difference between data structure and ADTs.
- Stack.
  - FILO.
  - Using an array as one.
  - Using a LL as one.
- Queue.
  - FIFO.
  - Using an array as one.
  - Using a LL as one.
- Sets.
  - No duplicates.
  - Unordered.
- Trees.
  - Balanced/unbalanced.

The End