

122com Data structures and types

David Croft

Coventry University

david.croft@coventry.ac.uk

2017

Overview

- 1 Arrays
- 2 Linked lists
 - Array example
 - LL example
- 3 Data structures
- 4 Abstract data types
- 5 Queues
- 6 Stacks
- 7 Sets
- 8 Other
- 9 Trees
- 10 Quiz
- 11 Recap

Arrays

Linked lists

Array example

LL example

Data
structuresAbstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap

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

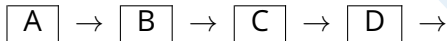
```
array<char,5> arr = {'A', 'B', 'C', 'D', 'E'};
```

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

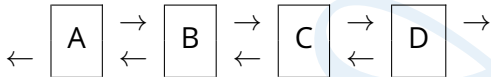
The challenger for array's crown.

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

Singly linked

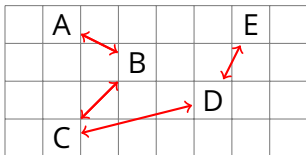


Doubly linked



Not in contiguous memory.

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



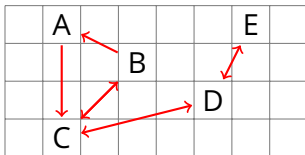
- Why would we use linked lists instead of arrays?
 - Can change size.
 - Can quickly insert and delete elements.

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

```
class Node  
{  
private:  
    Node *prev;  
    Node *next;  
  
public:  
    int value;  
};
```

Not in contiguous memory.

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



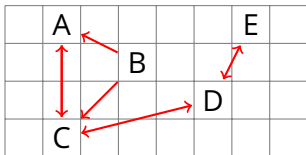
- Why would we use linked lists instead of arrays?
 - Can change size.
 - Can quickly insert and delete elements.

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

```
class Node  
{  
private:  
    Node *prev;  
    Node *next;  
  
public:  
    int value;  
};
```

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'};
```

		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

C

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

		A		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'};
```

		A	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'};
```

		A	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'};
```

		A	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

Arrays

Linked lists

Array example

LL example

Data
structuresAbstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap

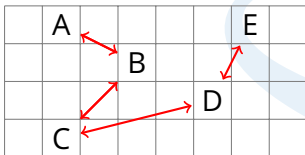
```
temp = ['A', 'B', 'C', 'D', 'E']  
array<char,5> temp {'A', 'B', 'C', 'D', 'E'};
```

		A	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.

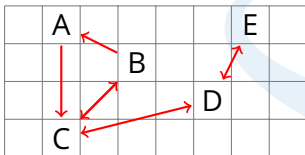
Removing linked list elements

1



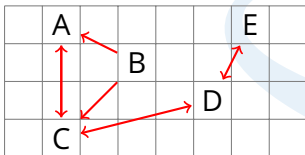
- Linked list, separate elements scattered in memory.
- Each pointing to the next/prev element.
- How do we remove elements?

Removing linked list elements



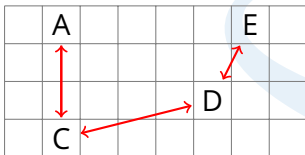
- Linked list, separate elements scattered in memory.
- Each pointing to the next/prev element.
- How do we remove elements?
 - 1 Change pointers.

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.

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 20th 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.

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 will 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 will 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 will 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 will 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 will 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.



Imagine an ADT like a car.

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

Arrays

Linked lists

Array example

LL example

Data

structures

Abstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap



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.

Arrays

Linked lists

Array example

LL example

Data
structures

Abstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap



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.

Arrays

Linked lists

Array example

LL example

Data
structures

Abstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

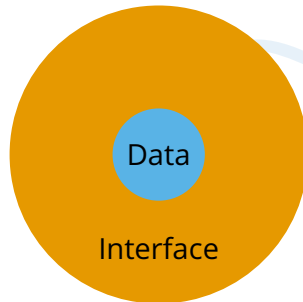
Recap

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



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.

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.

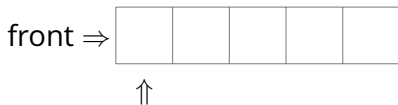
A FIFO ADT.

- 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?

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.

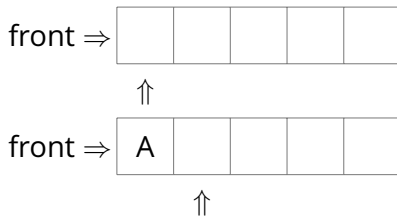
Array as a queue.



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

Array as a queue.

1

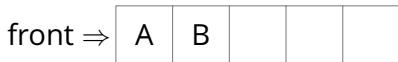


push(A)

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

Array as a queue.

1



push(A)

push(B)

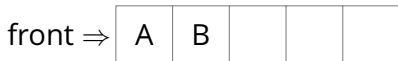
- Very similar to stacks.
 - Keep track of next free space.
 - Limited size.

Array as a queue.

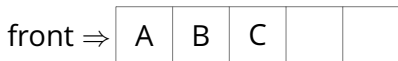
1



push(A)



push(B)



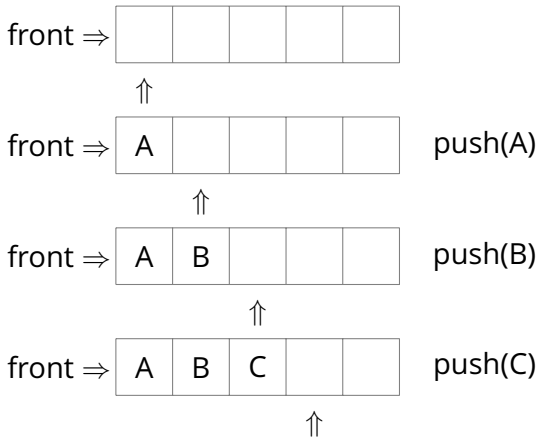
push(C)



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

Array as a queue.

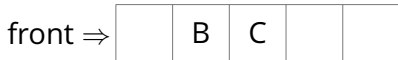
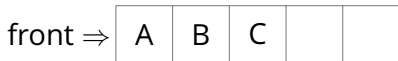
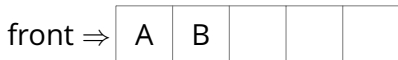
1



- 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.

1



push(A)

push(B)

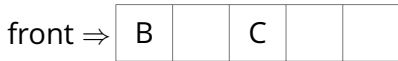
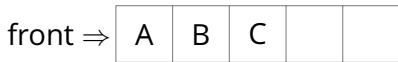
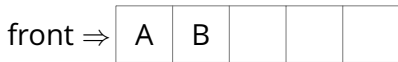
push(C)

pop()

- 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.

1



push(A)

push(B)

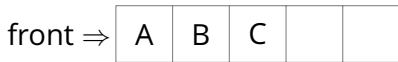
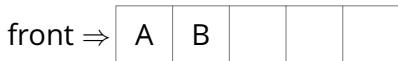
push(C)

pop()

- 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.

1



push(A)

push(B)

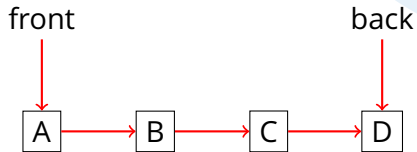
push(C)

pop()

- 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.

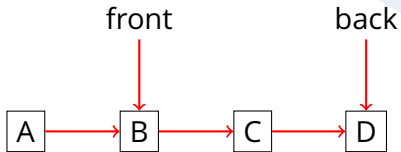
A



Linked list as a queue.

A

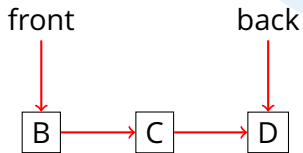
pop()



Linked list as a queue.

A

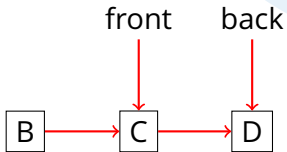
pop()



Linked list as a queue.

A

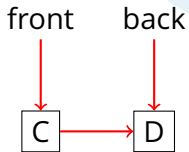
pop() , pop()



Linked list as a queue.

A

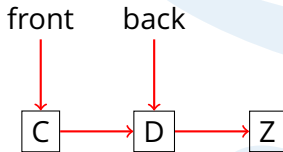
pop() , pop()



Linked list as a queue.

A

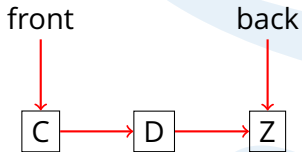
pop() , pop() , push(Z)



Linked list as a queue.

A

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



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.

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?

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.

1



push(A)



push(B)



- 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.

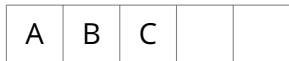
1



push(A)



push(B)



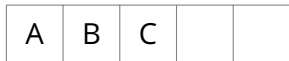
push(C)



- 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.

1



push(A)

push(B)

push(C)

pop()

- 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.

Arrays

Linked lists

Array example

LL example

Data
structuresAbstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap

- 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.



- 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.



add(A)

Arrays

Linked lists

Array example
LL exampleData
structuresAbstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap

- 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.



add(A)



add(B)

Arrays

Linked lists

Array example
LL exampleData
structuresAbstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap

- 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.



add(A)



add(B)



add(A)

- 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.



add(A)



add(B)



add(A)



remove(A)

- Lots of other ADTs.
- Different names in different languages.
- Lists.
- Circular lists.
- Associative arrays.
 - Dictionaries/Maps.
- Double-ended queues.
- Trees.
- Graphs.

Arrays

Linked lists

Array example

LL example

Data
structures

Abstract data
types

Queues

Stacks

Sets

Other

Trees

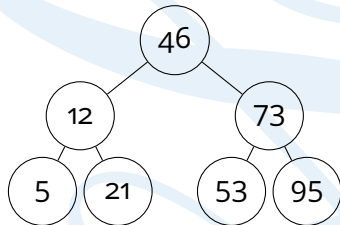
Quiz

Recap

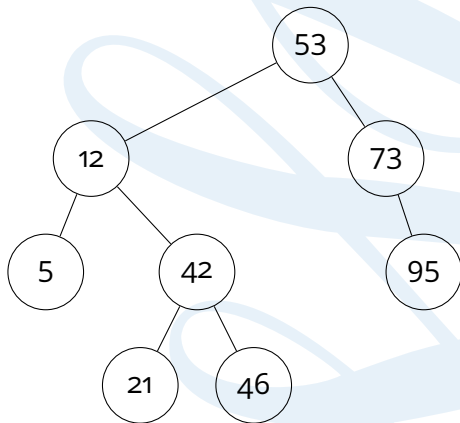
Break

Variation on linked lists.

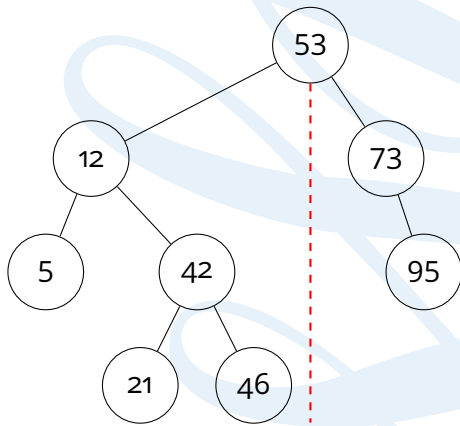
- Made of nodes and relationships.
- Root node at top.
- Each node can have ≥ 0 children.
- Binary search tree.
 - Very common type.
 - Ordered.
 - Max two children.
 - Binary searching.
 - Very good for sets.



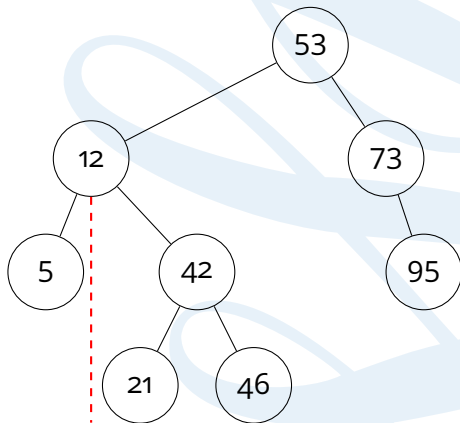
- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.
- Unbalanced because more than a one node difference between the two halves.



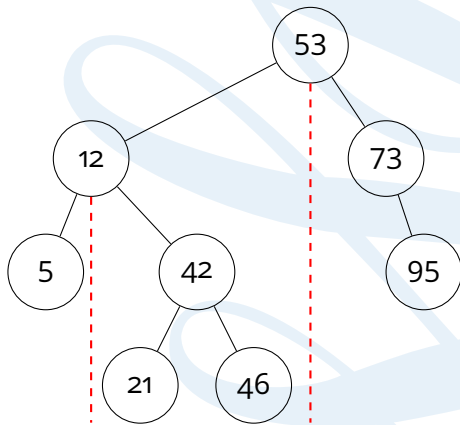
- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.
- Unbalanced because more than a one node difference between the two halves.
 - For the whole tree...



- 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.

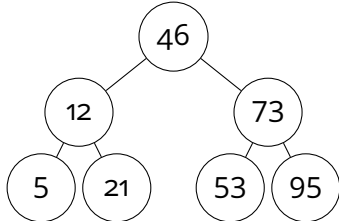


- Trees can be balanced or unbalanced.
- Not required for all trees.
- Going to be talking about BSTs from here on.
- Unbalanced because more than a one node difference between the two halves.
 - For the whole tree...
 - ...and one of the subtrees.

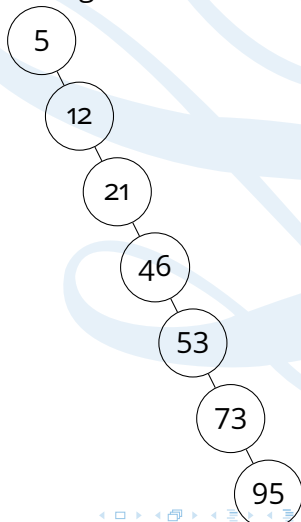


Important that you keep your BSTs balanced.

Perfect tree.



Degenerate tree.



Arrays

Linked lists

Array example

LL example

Data
structures

Abstract data
types

Queues

Stacks

Sets

Other

Trees

Quiz

Recap

Quiz

Stacks and queues are examples of _____

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

Stacks and queues are examples of _____

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

One advantage of linked lists over arrays is that _____

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

One advantage of linked lists over arrays is that _____

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

Stacks are a _____ type.

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

Stacks are a _____ type.

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

The elements of a set can't _____

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

The elements of a set can't _____

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

ADTs separate the ____ of the type.

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

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