Abstract Data Types and Data Structures

Often, these terms are used as synonyms. But it's better to think of them this way:

- An Abstract Data Type (ADT) represents a particular set of behaviours.
  - → You can formally define (*i.e.*, using mathematical logic) what an ADT is/does.

  e.g., a Stack is a list implements a LIFO policy on additions/deletions.
- A data structure is more concrete. Typically, it is a *technique* or *strategy* for implementing an ADT.
  - → Use a *linked list* or an *array* to implement a stack class.
- Going one level lower, we get into particulars of programming languages and libraries
  - → Use `java.lang.Vector` or `java.util.Stack` or a C++ library from STL.

ADTs and Data Structures

- Some common ADTs that all trained programmers know about:
  - → stack, queue, priority queue, dictionary, sequence, set
- Some common data structures used to implement those ADTS:
  - → array, linked list, hash table (open, closed, circular hashing)
  - → trees (binary search trees, heaps, AVL trees, 2-3 trees, tries, red/black trees, B-trees)

We'll discuss these is some detail.

Revisiting the Stack

Recall our friend the stack, as implemented by an array.

```
class stack {
    private int maxSize, top = -1;
    public static final int DefaultMaxSize = 100;
    private Object [] store;

    public stack () {
        maxSize = DefaultMaxSize;
        store = new Object [maxSize];
    }

    public stack (int desiredMaxSize) {
        maxSize = desiredMaxSize;
        store = new Object [maxSize];
    }

    public void push (Object newVal) {
        if (top < maxSize -1) {
            top++;
            store[top]=newVal;
        } else {
            System.err.println ("Sorry, stack is full.");
        }
    }
    ⋮
}
```


What's Wrong with this Picture?

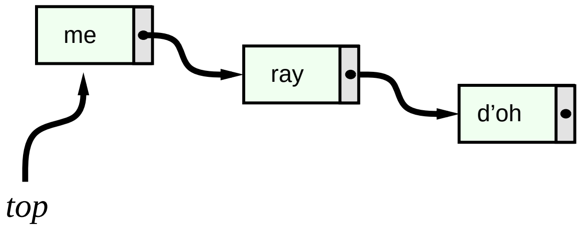
There's something unsatisfying about this implementation.

- We have to state, in advance, exactly how many elements we will need.
  [Or just use the provided default of 100]
  - → If we go over that number of elements at any one point in time, the stack stops working.
  - → If we use a big `desiredMaxSize`, then we waste space most of the time.
    [What if we need several stacks?]
- This approach uses a *static* approach to resource allocation:
  - → We have to decide before creating the object what its size will be.
  - → We are not allowed to change the size during its lifetime.
- Yes, all resources are ultimately finite. But we would like a little more flexibility and reasonable use of resources.

A *Dynamic* Approach to Resource Allocation

- What if we could design a stack that used exactly "enough" storage at any given time?
  - → Sure we will run out of space eventually if we keep adding elements, but only if we really have to, *i.e.*, only if the stack gets really huge.
  - → What are the tradeoffs?
    Are there any disadvantages?
- *Dyanamically* allocated structures can grow and shrink as needed throughout their lifetime.
- A common yin-yang in CS in static vs. dynamic allocation.

A Linked List Approach



- The stack is a set of *nodes* linked together.
  - → Each node has a "value" plus a link variable (a reference to another `node`).
  - → The "value" could be a simple value (*e.g.*, an `int`), a set of values, or a reference to another object (*e.g.*, an employee record).
- When you want to push a new value:
  1. Create a new node via `new`.
  2. Set the value of the new node.
  3. Set its link field to point to the previous top node.
  4. Reset top to point to the new node.


```java
public interface Stack {
    public abstract void push (Object element);
    public abstract Object pop ();
    public abstract boolean isEmpty ();
    public abstract int size ();
}

class Node {
    // Use package-level visibility.
    Object value;
    Node next;

    public Node (Object value, Node next) {
        this.next = next;
        this.value = value;
    }
}

public class LinkedStack implements Stack {
    private int numElements;
    private Node first;

    public LinkedStack () {
        numElements = 0;
        first = null;
    }

    public void push (Object element) {
        Node newNode = new Node (element, first);
        first = newNode;
        numElements++;
    }
```



```java
    // Still inside LinkedStack ...

    public Object pop () {
        Object returnVal;
        if (numElements > 0) {
            returnVal = first.value;
            first = first.next;
            numElements--;
        } else {
            System.out.println ("Sorry, stack is empty.");
            returnVal = null;
        }
        return returnVal;
    }

    public boolean isEmpty () {
        return numElements == 0;
    }

    public int size () {
        return numElements;
    }
```

```
    // Still inside LinkedStack ...

    public static void main (String [] args) {
        LinkedStack s1 = new LinkedStack();
        s1.push ("hello");
        s1.push ("there");
        s1.push ("world");
        System.out.println ("There are now " + s1.size()
                + " elements.");
        String s;
        s = (String) s1.pop();
        System.out.println ("Popped: " + s);
        s = (String) s1.pop();
        System.out.println ("Popped: " + s);
        s = (String) s1.pop();
        System.out.println ("Popped: " + s);
        s = (String) s1.pop();
        System.out.println ("Should be empty now.");
    }
}
```


For completeness, here is the array implementation restated slightly as implementing the `Stack` interface:

```
public class ArrayStack implements Stack {
    private int maxSize;
    public static final int DefaultMaxSize = 100;
    private int top = -1;
    private Object [] store;

    public ArrayStack () {
        maxSize = DefaultMaxSize;
        store = new Object [maxSize];
    }

    public ArrayStack (int desiredMaxSize) {
        maxSize = desiredMaxSize;
        store = new Object [maxSize];
    }

    public void push (Object newVal) {
        if (top < maxSize -1) {
            top++;
            store[top]=newVal;
        } else {
            System.err.println ("Sorry, stack is full.");
        }
    }
```



```
    // Still inside ArrayStack ...

    public Object pop () {
        Object ans = null;
        if (top >= 0) {
            ans = store[top];
            top--;
        } else {
            System.err.println ("Sorry, stack is empty.");
        }
        return ans;
    }

    public boolean isEmpty () {
        return size() == 0;
    }

    public int size () {
        return top + 1;
    }
}
```


Array vs. Linked List: Advantages and Disadvantages

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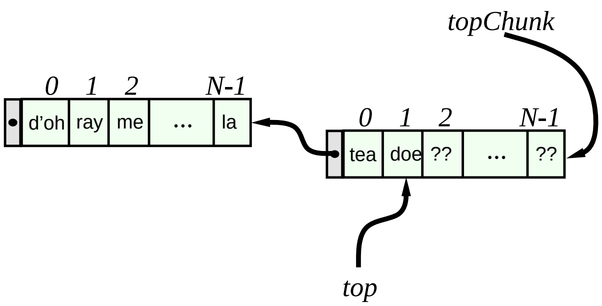
Another Strategy: Split the Difference



- Keep a linked list of arrays (`NodeChunks`):
  - → Each `NodeChunk` has a reference to the one before it.
  - → Keep a reference to the "top chunk", plus a `top` integer that points to the top element in the top chunk.
- Must decide on a good chunk size somehow.
  - → Constructor arg and/or use a default size.

"Splitting the Difference": Advantages and Disadvantages

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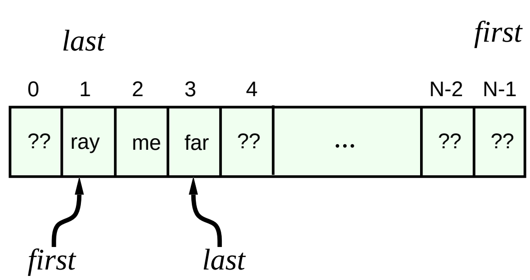
Another ADT: The Queue

- A queue is a list that implements a FIFO (First In is the First Out) policy on insertions and deletions.
  - → Can add elements only to the end of the list.
  - → Can remove elements only from the front of the list.
- "Add" is called `enter`, `enqueue`, or `add`
- "Delete" is called `leave`, `dequeue`, or `remove`
- Misc. extra methods: `isEmpty`, `size`

```
public interface Queue {
    public abstract void enter (Object element);
    public abstract Object leave ();
    public abstract boolean isEmpty ();
    public abstract int size ();
}
```

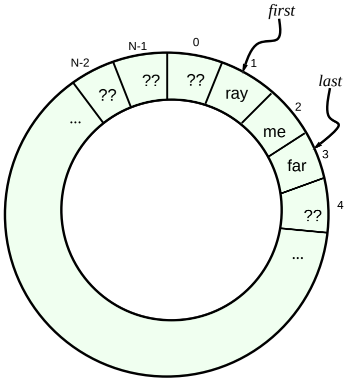

Implementing a Queue with an Array



An `ArrayQueue` is trickier than an `ArrayStack`:

- → There are *two* pointers (`int` indexes into array) to keep track of.
- → When you run out of room, start over at the beginning.
- → Of course, this *static* approach means you are limited to at most `N` elements in your queue at any given moment.

Implementing a Queue with an Array



Think of the array as a circle.

→ Use modular arithmetic to stay in the valid range of indexes. To increment `last` on an enter:

```
last = (last + 1) % N;
```

[Assumes there is space, *i.e.*, element 0 is empty]

→ Items in the range `first` ... `last` are full.

→ Items in the range `last+1` ... `first-1` are empty.


```
class ArrayQueue implements Queue {
    private int first=0, last=-1;
    private final int DefaultMaxSize = 100;
    private int maxSize, numElements = 0;
    private Object [] store;

    public ArrayQueue () {
        this.maxSize = DefaultMaxSize;
        store = new Object[maxSize];
    }

    public ArrayQueue (int maxSize) {
        this.maxSize = maxSize;
        store = new Object[maxSize];
    }

    public void enter (Object newElt) {
        if (size() < maxSize) {
            last = (last + 1) % maxSize;
            store[last] = newElt;
            numElements++;
        } else {
            System.err.println ("Sorry, queue is full.");
        }
    }
```

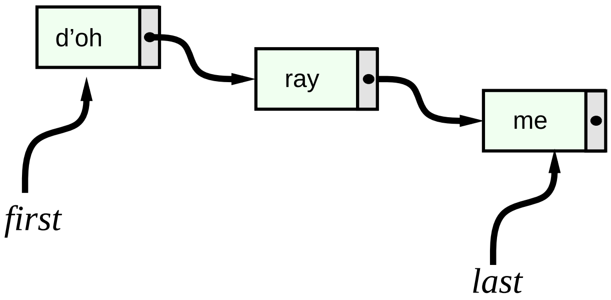


```
    public Object leave () {
        if (size() > 0) {
            Object ans = store[first];
            first = (first + 1) % maxSize;
            numElements--;
            return ans;
        } else {
            System.err.println ("Sorry, queue is empty.");
            return null;
        }
    }

    public void print () {
        System.out.println("Printing the queue: "
                + size() + " elements.");
        int j = first;
        for (int i=0; i< size(); i++) {
            System.out.println (store[j]);
            j = (j + 1)%maxSize;
        }
    }

    public int size () {
        return numElements;
    }

    public boolean isEmpty () {
        return size() == 0;
    }
```



```
    public static void main (String[] args) {
        ArrayQueue q1 = new ArrayQueue(5);
        q1.enter ("do");
        q1.enter ("re");
        q1.enter ("mi");
        q1.enter ("fa");
        q1.enter ("so");
        q1.print();
        System.out.println ("Queue should be full now.");
        q1.enter ("la");
        System.out.println ("Removed " + q1.leave());
        System.out.println ("Removed " + q1.leave());
        System.out.println ("Removed " + q1.leave());
        System.out.println ("Removed " + q1.leave());
        System.out.println ("Removed " + q1.leave());
        System.out.println ("Removed " + q1.leave());
        q1.print();
        q1.enter ("la");
        q1.enter ("ti");
        q1.print();
        q1.enter ("doh");
        q1.enter ("ray");
        q1.enter ("me");
        q1.print();
        q1.enter ("far");
        q1.enter ("sew");
        q1.print();
        System.out.println ("Removed " + q1.leave());
    }
}
```

Implementing a Queue as a Linked List



- Pretty straightforward to implement.
- Only caveat: watch out on enter
  - → If queue empty, adjust `first` to point to new node.
  - → Otherwise reset `last.next` to new node.
- Can also implement using a `NodeChunk`
  [Each `NodeChunk` contains an array of values.]


```
public class LinkedQueue implements Queue {
    private int numElements=0;
    private Node first=null, last=null;

    public void enter (Object element) {
        Node newNode = new Node (element, null);
        if (numElements == 0) {
            first = newNode;
        } else {
            last.next = newNode;
        }
        last = newNode;
        numElements++;
    }

    public Object leave () {
        Object returnVal;
        if (numElements > 0) {
            returnVal = first.value;
            first = first.next;
            numElements--;
        } else {
            System.out.println ("Sorry, queue is empty.");
            returnVal = null;
        }
        return returnVal;
    }

    // Obvious definitions for isEmpty and size omitted.
}
```


Misc. Notes

- We have decided to declare the `Node` fields `value` and `next` as package-level visible.
  - → This means that other classes in the same package, such as `LinkedQueue`, can directly manipulate the instance variables of each `Node` instance.
- Also, we can use more interesting objects than `String`s and `Integer`s in our stacks and queues.
  - → Could have a list of `Figure`s or `EmployeeRecord`s

This program:

```
class FigureQueueTest {
    public static void main (String[] args) {
        Queue q = new LinkedQueue();
        Circle c1, c2;
        c1 = new Circle();
        c1.setSize(50);
        c1.setLoc(25,30);
        c2 = new Circle();
        Square s1 = new Square();
        s1.setSize (75);
        q.enter(c1);
        q.enter(c2);
        q.enter(s1);
        while (!q.isEmpty()) {
            Figure f = (Figure) q.leave();
            f.draw();
        }
    }
}
```

Produces this output:

```
Circle at x = 25 y = 30 with radius = 50
Circle at x = 0 y = 0 with radius = 0
Square at x = 0 y = 0 with width = 75 and height = 75
```