Session 1

Introduction to Data Structures

Overview

- Abstract data types and data structures
- Linear data structures
- Arrays
- Stacks
- Queues

Data Type

- Realization of some abstract notion.
- To the system: The way in which a particular memory chunk is interpreted.
- To the user: Data type is identified by its behaviour; the actual storage of data does not alter the behaviour.
- Example
  - Data type int in C++/Java realizes abstract notion of integers and provides operators like +, -, *, / .

Data Structures

- Conceptually similar to a data type.
- Typically, more general purpose and used to organise specific data.
- Defines set of operators and representation.
- Combines more than one simple data items or data structures.
- Relative positions of the data items are of interest.
- Example:
  - Array, matrix, list…

Data Structures

- User of a data structure(DS) is interested only in the operators provided.
- Implementation details hidden from the application program.
- Higher level of abstraction for the programmer.
- Can be used like a data type in the application.

‘Structure’ of a Typical DS

- DS means relative positioning of data items and their access mechanism.
- The positioning can be implicit (as in the case of arrays) or explicit, i.e. each item holds references to its neighbours.
- This gives two parts per node of a DS
  - Data (can be any data type, independent of the DS)
  - Linkages to neighbouring nodes (specific to the DS)

‘Structure’ of a Typical DS

- The access mechanism defines the type of DS
  - Totally ordered (linear)
  - Partially ordered (eg: trees)
  - Non-linear (eg: graphs)
- Actual representation can be different as long as access mechanism is same.

Linear DS

- Data items (or nodes) arranged in linear fashion.
- Every node has a unique next element and a unique previous element.
- Example
  - Array, linked list, stack, queue, vector.

Array

- Ordered collection of objects of same type.
- Contiguous storage allocation: enables random access.
- Linkages to neighbours are implicit - through position in the memory.
- Size is fixed while constructing.
- Insertion of item at specific position may require shifting of existing items. *(why?)*
- Available in Java.

Stack

- An opaque pipe closed at one end.
- Only one element at a time is available, no other information is accessible.
- Addition and deletion of elements only at the open end.
- Last in first out (LIFO) behaviour.

Stack Example

Procedure invocation and return

```
A( )          B( )          C ( )
{             {             {
   B( ) ;        C( );         D( ) ;
   :             :             :
   :             :             :
}             }             }
```

Stack Operations

- clear() – clear/empty the stack
- isEmpty() – check if it is empty
- isFull() – check if it is full?
- push(el) – Put the element *el* on the top of the stack. Note: you can't put it anywhere else!
- pop() - remove the topmost element from the stack. Note: can't remove any other element!
- topEl() - Return the topmost element without removing it.

Stack Operations

- push(item) - item becomes the new top element

  push (3)   (3)

  push (10)   (10, 3)

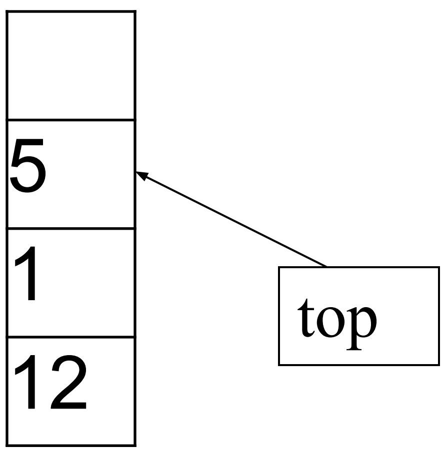
- pop() - top element removed. An error if stack is empty.

  i = pop ()   (3)

  Value of *i* becomes 10

Stack Implementation

- Stack using array
  - Data items stored as an array
  - Position of 'top' maintained by an index



Stack Implementation

```
public class ArrayStack {
    private int top;
   // will point to the topmost element of   the stack
   private Object[] storage;
   public ArrayStack(int n){
         size = n;
         storage = new Object[size];
         top = -1;
   }
```

Stack Implementation

```
 public void clear(){top = -1;}
 public boolean isFull(){
    return (top >= storage.length-1);
 }
public boolean isEmpty(){
   return (top == -1);
}
public void push(Object el){
   if (!isFull())
       {top++; storage[top] = el;}
}
```

Stack Implementation

```
public Object pop(){
      if(!isEmpty()){
         Object tmp = storage[top]; top--;
         return tmp;        }
      else
         throw new Exception("pop on empty stack");
  }
  public Object topEl(){
      if(!isEmpty()){return storage[top];}
       else return null;
  }
}
```

Stack Application

- Many cases of LIFO(last-in first-out) applications in computer science, particularly programming language implementation, algorithms and operating systems.
- We will discuss the bracket matching problem as a case study.

Bracket Matching Problem

- [([ ))] - invalid
- [ ] ( ) ([ ]) - valid
- [{ } ([ ])] - valid

Conditions:

- Every open bracket should be closed by the appropriate close bracket.
- No extra close brackets.
- The last bracket opened should be closed first.

Pseudo Code

```
valid = true // assume string is valid so far
Stack s = new Stack(); s.clear();
while (valid  & (input not over )){
    read next symbol (symb) ;
    if (symb is '(' or '[' or '{' ){
        s.push(symb);
    }
     else if (symb is ')' or ']' or '}' ){
        if (s.isEmpty()) valid = false // too many closing brackets
        i = s.pop()
        if (i does not match with symb) valid = false
    }
}
```

Pseudo Code

```
if (! s.isEmpty ( ) )
    valid = false ;  //  too many open brackets
if (valid) system.out.println("String is valid");
else system.out.println("String is not valid");
```

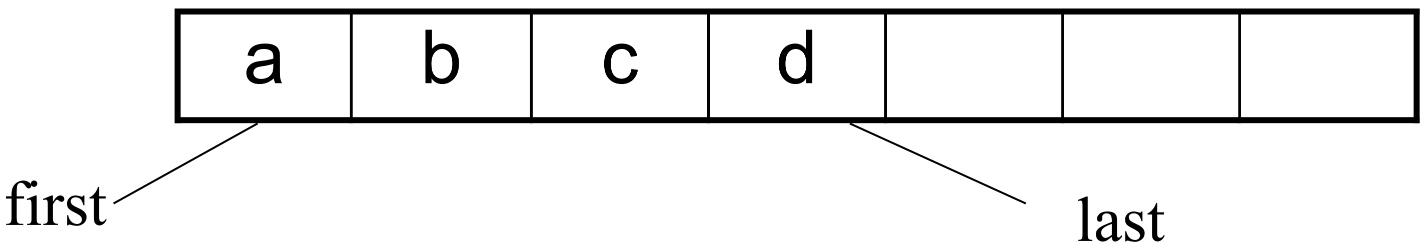
Queue

- Modeled on real queue at counters, service centers, etc.
- When input is to be processed as per arrival, but can’t wait for all input to be ready before processing.
- Insertion at the tail; deletion from the front.
- Unlike real queues, for each deletion we don’t want to move all the elements.

Queue Operations

- clear() – Clear the queue
- isEmpty()
- isFull()
- enqueue(el) – Put element *el* at the end of the queue
- dequeue() – Remove the first element from the queue
- firstEl() – Return the first element in the queue without removing it

Implementation Using Arrays



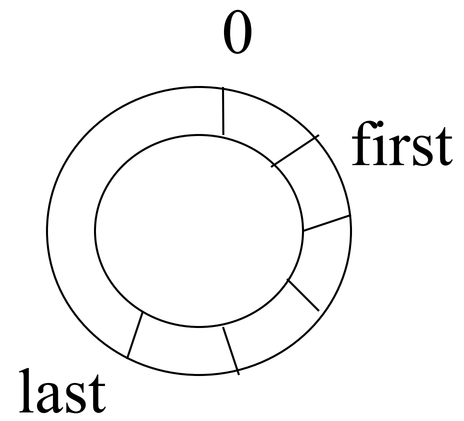
- '*last*' moves right for every addition
- '*first*' moves right for every deletion
- empty when *first* = *last* + 1
- full when *last* = arraysize
- but ...

Implementation Using Arrays

- Queue moves right
- Locations freed by delete not reused
- Queue may be flagged full even with a single element!

Implementation Using Circular Arrays

- View array as circular -
  q[max +1] -> q[0];   q[0 - 1] -> q[max]
- *last* and *first* travels clockwise
- *first* need not be less than *last*



Implementation Using Circular Arrays

```
public class ArrayQueue{
    private int first, last, size, count;
    private Object[] storage;
    public ArrayQueue(int n){
        first = 0;last = -1;count = 0;size = n;
      storage = new Object[n];
     }
    public boolean isFull(){
        return count >= size;
     }
    public boolean isEmpty(){
        return count == 0;
     }
```

Implementation Using Circular Arrays

```
  public void enqueue(Object el){
      last = (last+1)%size; count++;
      storage[last] = el;
     //add suitable error checks
  }
  public Object dequeue(){
     Object tmp = storage[first];
     first = (first+1)%size; count--;
     return tmp;
     //add suitable error checks
}
```

Example

Railway Ticket Reservation

- Ten counters, all identical.
- Customers arrive - Assume only one type of transaction.
- A single queue.
- When a counter falls vacant, the person at the front of the queue goes there.
- Simulate this.

Ticket Counter

- A queue structure will maintain the queue.
- An array serve[1..c] records status of the counters. -1 indicates empty; otherwise expected time of completion.
- For each time tick:
  - if any arrival, insert in the queue.
  - if any counter has serve [i] = timer, set serve[i] = -1
  - if any counter vacant, dequeue a person and send to first available counter, update serve array.
- Can extend to record max queue size, vacant counter time etc.

Summary

- Data Structures: useful abstractions for a programmer
- Arrays, Stacks and Queues: simple linear data structures
- We will discuss “better” representations for these, and introduce more sophisticated DS in subsequent sessions.