CS211, LECTURE 21
LINEAR SEQUENCE STRUCTURES

ANNOUNCEMENTS:

OVERVIEW:

- Motivation
- What's a sequence structure?
- Stack
- Queue
- Deque

1. Motivation

1.1 Sequence Structure

- want ADT to store and retrieve items
- what do you to create and manipulate a pile of things?
  - **`put`**: store current item
  - **`get`**: retrieve an item
- not interested in search
  - so, order not important
  - need to determine *where* **`put`** puts and **`get`** gets

1.2 Interface to implement

```
interface SeqStructure {

    // stick into sequence structure:
    void put(Object o);

    // extract from sequence structure
    Object get();

    boolean isEmpty();
    int size();
}
```

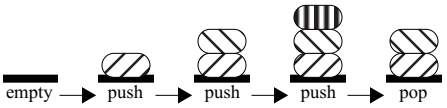
1.3 Linear Sequence Structures

- stack: LIFO
- queue: FIFO
- deque
- priority queue (we'll see a hierarchical version, too, so saving this for later)

2. Stack

2.1 Stack: LIFO

- Last in, first out:
  - push item on top of pile (put)
  - pop itemfrom top of pile (get)
- Visualize process:



2.2 Stack Pointer

- ***SP***: Address of *next* free element
- After pushing, **SP** increments (**SP++**):

2.3 Implementations

- Array: not dynamic, which means…
- List: better, since stack is dynamic

2.4 Stack size

- theoretically infinite
- realistically limited
- heap and stack space is finite for computer
- CS212: **`Runtime`** API and more…

3. Stack as Array

- Fields: array, SP, size
- Methods: see **`SeqStructure`**
- limitations: array size; could change to grow, though costly in terms of space (O(n))

3.1 Stubbed Stack

```
public class StackAsArray implements SeqStructure {

    private class SortedArray { }
    private SortedArray stack; // data in stack
    private int SP; // points to first empty cell
    public StackAsArray(int size) { }
    public void put(Object o) { }
    public Object get() { return null; }
    public int size() { return SP; }
    public boolean isEmpty() { return (SP == 0); }
    public String toString() { return ""; }

}
```


3.2 Member Class

- design: want to store elements in generic array
- could use a field that's an array
- I use an inner class to help keep track of size info

```
private class SortedArray {
    public Object[] a;
    public int MAXSIZE;
    public SortedArray(int n) {
        a = new Object[n];
        MAXSIZE = n;
    }
}
```

3.3 Constructor

```
public StackAsArray(int size) {
    stack = new SortedArray(size);
}
```


3.4 Fields

- Reference to sorted array (could scrap this and directly use an array!)
- **SP**: address in array of first free location
  - 0 is at bottom, which means empty stack
  - **`MAXSIZE`** is at top, which means full stack

```
private SortedArray stack; // data in stack
private int SP; // address of 1st free location
```

3.5 Put

- Algorithm:
  - check if stack is full (SP equals size)
  - if stack not full, add element at current SP and increment SP afterwards
- Code:

```
public void put(Object o) {
    if (SP == stack.MAXSIZE) {
        System.out.println("Stack overflow");
        return;
    }
    stack.a[SP] = o; // insert element
    SP++; // move SP "up"
}
```

- Alternatives?
  - return ***Something*`Exception`** to handle full case
  - syntax trick: **`stack.a[SP++]`**

3.6 Get

- Algorithm:
  - check if stack is empty
  - if not, extract object from top of stack, move SP down, and return the object
- Code:

```
public Object get() {
    if (SP == 0) {
        System.out.println("Empty stack!");
        return null;
    }
    Object temp = stack.a[--SP];
    stack.a[SP] = null;
    return temp;
}
```


3.7 Other operations

```
// size of stack is SP
public int size() {
    return SP;
}

// SP is at bottom:
public boolean isEmpty() {
    return (SP == 0);
}

// Stingify Stack:
public String toString() {
    String s = "LIFO: [";
    for (int i = 0; i < SP; i++) {
        s += stack.a[i];
            if (i < SP-1) s += ",";
    }
    s +="]";
    return s;
}
```


3.8 API `Stack`

- extends **`Vector`**
- has additional methods:
  - empty: is stack empty?
  - peek: inspect top of stack without popping
  - pop: take from top of stack
  - push: add to top of stack
  - search: “returns the 1-based position where an object is on this stack.”

4. Stack As List

4.1 Need to add/change some SLL operations:

```
// help to allow printing of empty stack:
public String toString() {
    if (head==null) return null;
    return head.toString();
}

// Adds element to head of list:
public boolean prepend(Object o) {
    ListNode tmp = new ListNode(o, head);
    if (head == null) tail=tmp;
    head = tmp;
    return true;
}
```

4.2 Implementations

- **`StackAsList`**: uses modified **`SLL`**
- **`TestStackAsListAlt`**: "bury" list into Stack class

4.3 Implementation

```
public class StackAsList implements SeqStructure {
    private SLL list;
    private int SP;
    public StackAsList() { list = new SLL(); }

    public void put(Object o) {
        list.prepend(o); SP++;
    }

    public Object get() {
        if (isEmpty()) {
            System.out.println("Empty list!");
            return null;
        }
        Object result = list.getHead().getItem();
        list.remove(result); // remove head of list
        SP--; // adjust SP
        return result;
    }

    public Object peek() {
        if (isEmpty()) return null;
        return list.getHead();
    }

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

    public String toString() {
        return "LIFO: ["+list+"]";
    }
}
```


4.4 An Alternative Implementation

```
class StackAsListAlt implements SeqStructure{
    private class ListNode {
    } // not shown
    private ListNode list;
    public StackAsListAlt() { }

    public void put(Object o) {
        list = new ListNode(o,list); }

    public Object get() {
        if (! isEmpty()) {
            Object v = list.item;
            list = list.next;
            return v;
        } else {
            System.out.println("Empty!"); return null; }
        }

    public boolean isEmpty() { return (list == null); }

    public int size() {
        int v = 0;
        ListNode finger = list;
        while (finger != null) {
            v++; finger = finger.next;
        }
        return v;
    }

    public String toString() {
    } // not shown
}
```


4.5 Example Session

See **`TestStack.java`**:

```
    System.out.println("Testing list:");
    StackAsList s2 = new StackAsList();
    s2.put("Billy");
    s2.put("Rilly");
    s2.put("Silly");
    s2.put("Willy");
    System.out.println(s2);
    s2.get();System.out.println(s2);
    s2.get();System.out.println(s2);
    s2.get();System.out.println(s2);
    s2.get();System.out.println(s2);
    s2.get();

/* Output:
    Testing list:
    LIFO: [Willy Silly Rilly Billy]
    LIFO: [Silly Rilly Billy]
    LIFO: [Rilly Billy]
    LIFO: [Billy]
    LIFO: [null]
    Empty list!
*/
```

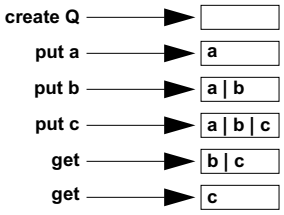
5. Queue

5.1 Singled-Ended Queue

- queue: "a line" (as in "to queue up")
- what we're calling queue
- "what goes in must come out…"
  - put/enqueue: add elements from one end
  - get/dequeue: remove elements from the other end

5.2 FIFO

- queue is FIFO
- ***FIFO***: first in, first out



5.3 Implementations

- array: **`QueueAsArray`**
- list: **`QueueAsList`**
- testing: **`TestQueue`**

6. Queue As Array

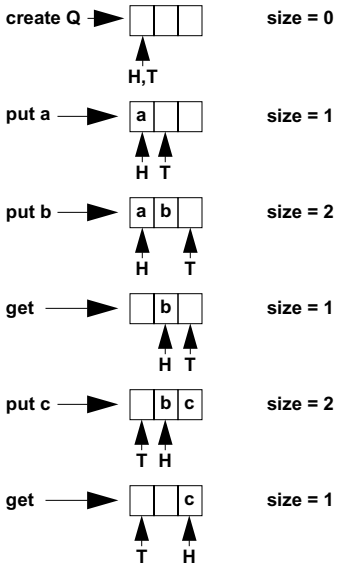
6.1 Design

- need to account for array filling…options:
  - allow only elements to fit from front to end
  - add space to array as needed
  - use circular array
- use circular array because of more flexibility and less wasted space
- what's a ***circular array***?

6.2 Circular Array and Queue

- keep track of head and tail of queue
  - head: first element to take
  - tail: first place to put an element
- In terms of FIFO:
  - get first element, which is stored at head
  - put element into first free position, which is tail
- tail and head move left to right and wrap around…

6.3 Circular Array Design



6.4 Fields

- **`Object a[]`**: store the elements
- **`head`**
- **`tail`**

6.5 Constructor

- create array of an input size (**`MAXSIZE`**)
- number of elements (**`size`**) must not exceed **`MAXSIZE`**
- ensure that **`head`** and **`tail`** are properly set, though they do not need to start at front of array

```
public class QueueAsArray implements SeqStructure {

    private int head; // points to element for deQ
    private int tail; // points to empty slot for enQ
    private Object[] a; // array of objects
    private int size;   // current # of objects in Q
    private final int MAXSIZE;  // max number of objects

    public QueueAsArray(int size) {
        a = new Object[size];
        MAXSIZE = size;
        head = 0;
        tail = 0;
        this.size = 0;
    }
    // methods: put, get, others
}
```


6.6 Put

- Algorithm:
  - prevent overfilling array (**`size`** > **`MAXSIZE`**)
  - insert item at **`tail`** location
  - increment **`tail`** to next element
  - if **`tail`** goes past end of queue, move to front (index 0)
  - increment count of items (**`size`**)
- Code:

```
public void put(Object o) {
    if (size == MAXSIZE) {
        System.out.print("Overflow!");
        return;
    }
    // queue isn't full,
    // so tail must point to an empty slot

    // insert item at end of Q and move tail up:
    a[tail++] = o;

    // if tail at end, move to front:
    if (tail == MAXSIZE) tail = 0;

    // increment count of items in Q:
    size++;
}
```


6.7 Get

- Algorithm:
  - prevent accessing empty array (**`size == 0`**)
  - get element from **`head`** (first element)
  - reset that location and increment head
  - if **`head`** goes past end of queue, move to front
  - decrease count of items (**`size`**)
- Code:

```
public Object get() {
    if (size == 0) {
        System.out.print("Empty!");
        return null;
    }
    // Since size is not 0,
    // we know head must point to a valid item

    // get item from head of Q (FIFO):
    Object temp = a[head];

    // reset that location and move head pointer:
    a[head++] = null;

    // wrap-around: if head at end move to front:
    if (head == MAXSIZE) head = 0;

    // decrease count of items in Q and return elem:
    size--;
    return temp;
}
```


6.8 Other Operations

```
// elements in queue:
public int size() {
    return size;
}

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

// Strigify queue:
public String toString() {
    String s = "FIFO: [";
    // there is at least one item in queue:
    if (size!=0) {
        int index = head;
        do {
            s += a[index++];
            if (index == MAXSIZE) index = 0;
            if (index != tail) s+=" | ";
        } while (index != tail);
    }
    s +="]";
    return s;
}
```

7. Queue As List

7.1 Use SLL

- no need to preallocate space because list is dynamic
- many operations already defined in **`SLL.java`**

7.2 Fields

- **`SLL list`**, which maintain most everything else
- **`size`**: help to keep track of Q

7.3 Operations

- **`put`**:
  - append to end of list, which automatically sets tail pointer
  - no need to check for maxsize
- **`get`**:
  - get head of list, then remove current head to move head pointer to next element
  - need to handle empty queue

7.4 Implementations

- **`QueueAsList`**
- **`TestQueueAsListAlt`**

7.5 Code

```
public class QueueAsList implements SeqStructure{

    private SLL list;
    private int size;

    public QueueAsList() { list = new SLL(); }

    public void put(Object o) {
        list.add(o);
        size++;
    }

    public Object get() {
        if (isEmpty()) {
            System.out.print("Empty!");
            return null;
        }
        Object o = list.getHead().getItem();
        list.remove(o);
        size--;
        return o;
    }

    public boolean isEmpty() { return list.isEmpty(); }

    public int size() { return size; }

    public String toString() {
        return "FIFO: ["+list+"]";
    }

}
```


7.6 Implementation

```
System.out.println("Test QueueAsList");
QueueAsList QAL = new QueueAsList();
System.out.println(QAL);
for (int i = 0; i <= 3; i++) {
      String item = "a"+i;
      System.out.print("Attempt to enqueue "+item+": ");
      QAL.put(item);
      System.out.println(" "+QAL);
}
System.out.println("Done putting!");
System.out.print("Get: "+QAL.get()+" ");
System.out.println(QAL);
System.out.print("Get: "+QAL.get()+" ");
System.out.println(QAL);
System.out.print("Get: "+QAL.get()+" ");
System.out.println(QAL);
System.out.print("Get: "+QAL.get()+" ");
System.out.println(QAL);
System.out.println("Done with lists!");

/* Output:
      Test QueueAsList
      FIFO: [null]
      Attempt to enqueue a0:  FIFO: [a0]
      Attempt to enqueue a1:  FIFO: [a0 a1]
      Attempt to enqueue a2:  FIFO: [a0 a1 a2]
      Attempt to enqueue a3:  FIFO: [a0 a1 a2 a3]
      Done putting!
      Get: a0 FIFO: [a1 a2 a3]
      Get: a1 FIFO: [a2 a3]
      Get: a2 FIFO: [a3]
      Get: a3 FIFO: [null]
      Done with lists!
*/
```


7.7 API Queue

- sorry, it's not there
- use **`LinkedList`** and your knowledge of FIFO

8. Deque

8.1 Double-Ended Queue (deque)

- remove items from both ends
- get and put for both head and tail
- see DS&A 6.3

9. Exercises

- Rewrite **`StackAsArray`** to issue a **`MyStackOverFlow`** exception if the memory is exceeded.
- Rewrite **`StackAsArray`** such that the array "grows" if the space is exhausted instead of issuing a complaint.
- Write a stack iterator for both the list and array implementations.
- Can you use head and tail in a queue to compute the size of the queue?
- Use mod (**`%`**) to assist with the head and tail updates in the **`QueueAsArray`** methods.
- Implement a queue with a circular list. Normally, this would be pointless, but it might make for good practice.