CSCI 1103: Array-based Data Structures

Chris Kauffman

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Logistics

Date	Lecture	Outside
Mon 11/13	Expandable Arrays	Lab 10 on Stacks
Wed 11/15	Stacks/Queues	P4 Due
Fri 11/17	Queues	
Mon 11/20	Review	Lab 10 Due, Review
Wed 11/22	Exam 2	

Reading from Eck

- Ch 5 on Objects/Classes
- Ch 8.3.3 on Throwing exceptions
- Ch 7.4 on ArrayList
- Ch 9.3 on Stacks and Queues

Lab10: Stack Data Structure

- Define a new class for Stacks of Strings
- Fixed and Expandable

Project 4

- Due Wednesday
- Questions?

Exceptions for Errors

- Java's mechanism for indicating errors is to throw exceptions
- There are a wide variety of exception kinds available
- Can also create your own: they are a class
- For simple situations, `RuntimeException` suffices
- Construct one with a `String` error message indicating problem

```
RuntimeException e = new RuntimeException("Ya done mess
```

- Raise the exception with the keyword throw

```
throw e;
```

- Frequently do this in one-liners

```
throw new RuntimeException("Ya done messed up.");
```

Exceptions share `return` semantics

- Uncaught `throw` statements immediately exit a method, similar to `return`
- Control flows up and out, usually crashes program

```
// Divide num by denom and return the quotient.
// Raise a RuntimeException if denom is 0.
public static int divide(int num, int denom){
  if(denom == 0){
    throw new RuntimeException("Divide by 0");  // error: immediately
  }                                             // throw exception
  int quotient = num / denom;
  return quotient;                              // immediately return
}                                               // value
```

Additional Info on Exceptions

- We will work with `RuntimeExceptions` as they are simple sufficient
- Exceptions are a complex topic, include
  - `try/catch` blocks to recover form exceptions
  - method signatures with `throws`
  - inheritance of exception types
- We will revisit some of these topics later when discussing File Input/Output as many methods in I/O involve exception handling

Basic Data Structures

- Information frequently comes/goes in patterns
- To make life easier for programmers and utilize the machine more efficiently, data structures provide a way to organize data for easy use
- The purpose of a creating data structure is to make programming another task easier
- We will discuss some simple data structures
  - Expandable Arrays (today)
  - Stacks built on arrays (lab 10)
  - Queues built on arrays (later in week)
- Textbook discusses some alternatives
  - Linked lists
  - Stacks built from linked nodes
  - Queues built for linked nodes
- You will likely study these in later CS courses

Expandable Data Structures

Standard Array

- Recall Java's standard arrays
  1. Length is fixed at creation
  2. Initially filled with zeroey elements (`0` or `null` or similar)
  3. Random access based on index number using square braces: `arr[i]`
  4. Cannot grow
- Inability to grow is a drag as one frequently wants to add without knowing limit
- The goal of an expandable array or `ArrayList` is to making adding possible

Expandable List

- Independent class created by us (and others)
  1. Length is NOT fixed
  2. Initially empty: size 0
  3. Random access based on index number using methods: `a.get(i)` and `a.set(i,x)`
  4. Can grow: `a.add(y)`
- No magic: a field of the expandable list will be a standard array
- When standard array fills up, make a bigger one, copy over elements

First pass: `FixedList` doesn't grow

Create/Initial Add

```
Welcome to DrJava.
> FixedList f = new FixedList(3);
> f.toString()
[]
> f.size()
0
> f.get(2)
java.lang.RuntimeException:
out of bounds
at FixedList.get(FixedList.java:22)
> f.add("A")
> f.size()
1
> f.toString()
[A]
> f.get(0)
A
> f.get(1)
java.lang.RuntimeException:
out of bounds
at FixedList.get(FixedList.java:22)
```

Further Adds/Set

```
> f.add("B")
> f.toString()
[A, B]
> f.get(1)
B
> f.size()
2
> f.add("C")
> f.toString()
[A, B, C]
> f.size()
3
> f.get(2)
C
> f.set(1,"X")
> f.toString()
[A, X, C]
> f.add("D")
java.lang.RuntimeException:
list array is full
at FixedList.add(FixedList.java:40)
```

Exercise: Accessor/Mutators Methods

Define size()

```
public class FixedList{

  // number of elements
  // that have been added
  private int size;

  // contents of the array
  private String[] data;

  // Create the array backing
  // the fixed list
  public FixedList(int maxSize){
    this.size = 0;
    this.data = new String[maxSize];
  }

  // Return how many elements
  // are in the list
  public int size(){
     // YOUR CODE HERE
  }
```

Define set()

```
// Return element i of the
// list. Check that the index is
// in bounds (greater than or
// equalt to 0 and less than the
// list size)
public String get(int i){
  if(i < 0 || i >= this.size){
    // out of bounds
    String msg = "out of bounds";
    throw new RuntimeException(msg);
  }
  return this.data[i];
}

// Change element i of the
// list. Check that the index is
// in bounds (greater than or
// equalt to 0 and less than the
// list size)
public void set(int i, String x){
   // YOUR CODE HERE
}
```

Exercise: add() Method

Define `add(x)` method that allows new elements to be put in the list at the end increasing the size

```
> f.toString()
[]
> f.add("A")
> f.add("B")
> f.toString()
[A, B]
> f.size()
2
```

```
public class FixedList{
  // number of elements that have been added
  private int size;
  // contents of the array
  private String[] data;

  // Add the given string to the list at the end. If there is not
  // sufficient space for the addition, throw an exception
  public void add(String x){
    // YOUR CODE HERE to:
    // Check for space in array, throw exception if none
    // Put x in array
    // Increment size
  }
```

ExpandableList: Grow the Array

A modification to add(x) allows as many additions as memory supports: allocate larger arrays and copy when needed.

- Draw pictures to demonstrate how add(x) works
- How much does the array size increase during expansion?

```
// A class wrapper for a list of Strings. This version grows the
// underlying array when needed.
public class ExpandableList{
  private int size;              // number of elements that have been added
  private String[] data;         // contents of the array

  // Add the given string to the list at the end. If there is not
  // sufficient space for the addition, expand the underlying array to
  // accommodate it.
  public void add(String x){
    if(this.size >= this.data.length){                   // check for space
      String newData[] = new String[this.data.length*2]; // new larger array
      for(int i=0; i<this.data.length; i++){             // copy old elements
        newData[i] = this.data[i];
      }
      this.data = newData;       // point at new array
    }
    this.data[this.size] = x;    // add on element
    this.size++;                 // increase size
  }
```

Exercise: Removal in Lists

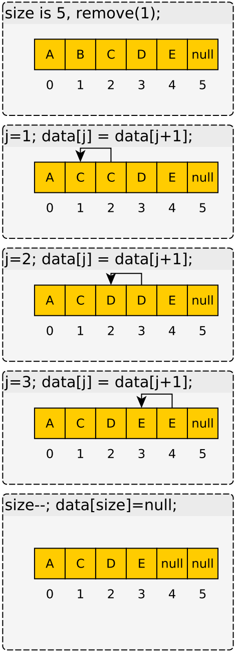
- Another common operation is removal: get rid of an element at a specific index
- List semantics dictate no gaps so much shift elements to account for this change
- Propose how one might write `remove(i)`
  - What fields must change and how?
  - What control structures are needed?

```
> l
[A, B, C, D, E]   // 5 elements
> l.remove(2)     // remove C
> l
[A, B, D, E]      // elements shifted
> l.size()
4                 // size smaller
> l.add("F")
> l
[A, B, D, E, F]   // 5 elements again
> l.remove(0)     // remove A
> l
[B, D, E, F]      // elements shifted
> l.remove(2)     // remove E
> l
[B, D, F]         // elements shifted
> l.size()
3                 // down to 3 elements
```

Answer: Removal in Lists

Removal requires a loop to shift elements left in the array, decrease the size of the list

```
// Remove the element at index i. Shift
// elements to fill in gap and decrease the
// size of the list.
public void remove(int i){
  if(i < 0 || i >= this.size){
    throw
    new RuntimeException("out of bounds");
  }
  // shift elements to overwrite index i
  for(int j=i; j<this.size-1; j++){
    this.data[j] = this.data[j+1];  //
  }
  this.size--;          // fewer elements
  this.data[size]=null; // nullify last element
}
```

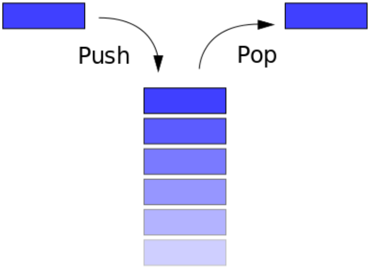


Exercise: Stacks

Another major data structure, covered in Lab 10

Questions

- From lab work, what are the main operations of the stack?
- Where have we seen stacks used so far?
- How are stacks and expandable lists related?
- How are stacks and expandable lists different?
- What options exist when adding into a stack and the backing array is full (at capacity)?



Stacks are a LIFO:
Last In First Out

Answers: Stacks

- Stack Operations:
  - `s.getTop()`: return whatever is on top
  - `s.push(x)`: put `x` on top
  - `s.pop()`: remove whatever is on top
  - `s.isEmpty()`: `true` when nothing is in it, `false` o/w
- Where have we seen stacks used so far?
  - Function call stack, contains data for running methods
- How are stacks and expandable arrays related?
  - Both backed by an array, `arr.add(x)` like `stack.push()`
- How are stacks and expandable arrays different?
  - Array allows get/set of any element, stack can only change top
- What options exist when pushing into a stack and the backing array is full (at capacity)?
  1. Throw an exception and ignore request
  2. Allocate a larger array, copy elements, proceed with push

Get in Line

Queues are pervasive in computing and life

- Examples?
- Semantics?

Source: kittylittered

Queue Data Structure

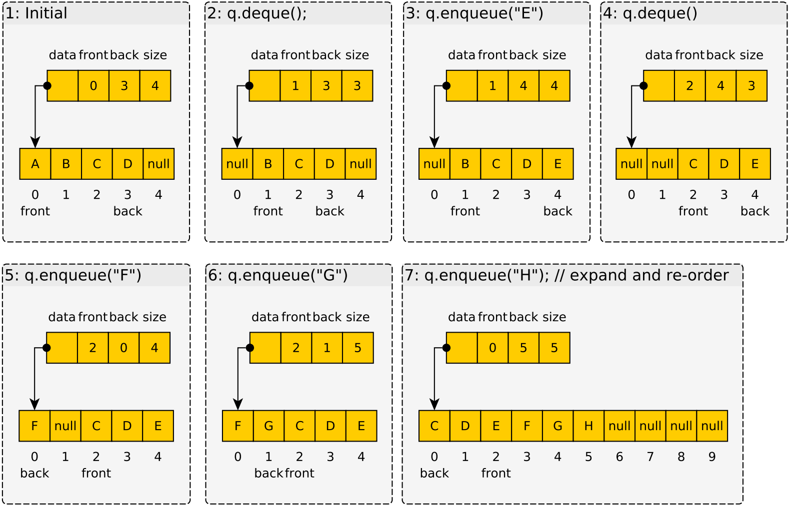
Operations

- `enqueue(x)`: `x` enters at the back
- `dequeue()`: front leaves
- `getFront()`: return who's in front
- `isEmpty()`: `true` when nothing is in it, `false` o/w

Implementation with arrays: seems easy...

- Enqueue elements at low indices like `list.add(x)`
- Dequeue elements by removing at index 0 like `list.remove(0)`
- Leads to a lot of shifting
- For efficiency, never shift
- Move front/back in a ring-like fashion

Efficient Array Queue in Pictures



Tricky to Implement

- Must wrap `front/back` around as they move off end of array
- On expansion must copy elements carefully and wrap around
- `toString()` must also account for wrap-around effect

```
public class ArrayQueue{

  // Produce a string representation of the queue with the front
  // element leftmost followed by other elements to the right
  public String toString(){
    if(this.size==0){
      return "[]";
    }
    String str = "[" + this.data[this.front];
    for(int i=1; i<this.size; i++){
      int index = (this.front+i) % this.data.length;
      str += ", " + this.data[index];
    }
    str += "]";
    return str;
  }
```

Data Typing and Generics

- Notice our expandable list, stack, and queue all use `String`
- If you want a queue of integers, must recode: lots of redundancy
- In old Java (version 1.0-1.4) had bad set of choices for data structures and containers due to type problems
- Java 1.5 introduced *generics*, lifted from C++
- Allows containers to work with any type of item
- Used extensively in Java's standard library

```
ArrayList<String> als = new ArrayList<String>();
als.add("A");                    // add a string to expandable array
als.add("B");
ArrayList<Integer> ali = new ArrayList<Integer>();
als.add(1);                      // add an integer to expandable array
als.add(2);
ArrayDeque<Double> ard = new ArrayDeque<Double>();
ard.addLast(1.23);               // add double to expandable queue
ard.addLast(4.56);
```

Inheritance: Sharing Code between Classes

- Notice that the code for `FixedList` and `ExpandableList` is almost identical
- Created `FixedList` then copied all methods to `ExpandableList`, made a small change to the `add()` method to allow expansion
- This situation is well-suited for inheritance

```
public class FixedList { .. }

public class ExpandableList extends FixedList{
  @Override
  public void add(String x){
    // do this method a little differently
  }
}
```

- `ExpandableList` implicitly inherits all methods and fields of `FixedList` : don't need to be copy them
- Method `add()` is overridden to have a different behavior than the version in the parent class