CS 171: Introduction to Computer Science II

Stacks and Queues

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Announcements/Reminders

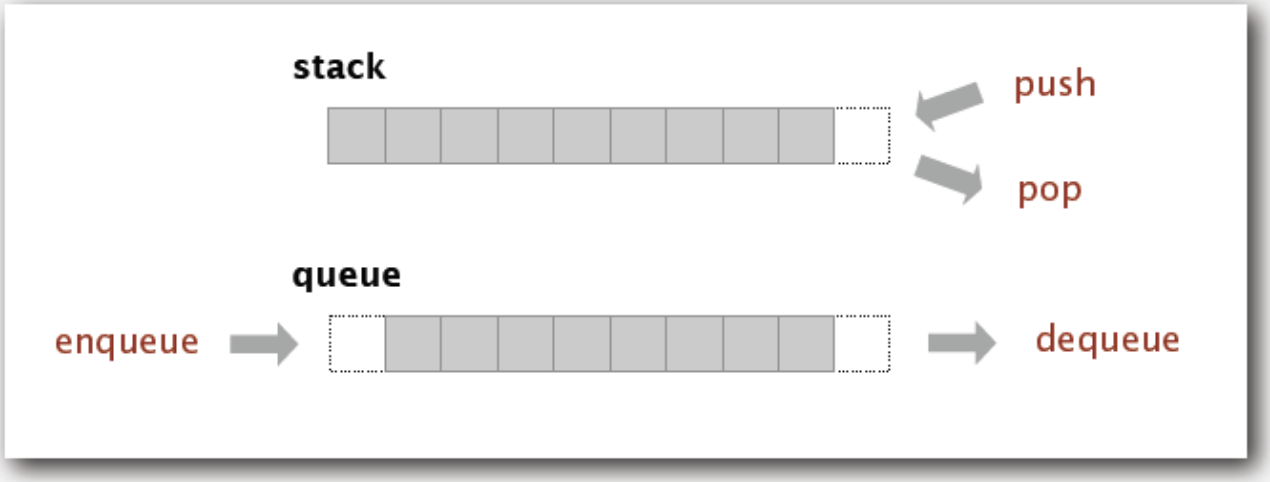
- Last day to turn in Hw1 with 2 late credits
- Hw2 due next Monday
- Hw3 to be assigned next Tuesday
- Midterm 3/29

Today

- Stacks
  - Operations
  - Implementation using resizable array
  - Implementation using generics
- Applications using stacks
- Queues
  - Operations
  - Implementation
  - Applications

Fundamental data types.

- Value: collection of objects.
- Operations: insert, remove, iterate, test if empty.
- Intent is clear when we insert.
- Which item do we remove?



Stack. Examine the item most recently added. ← LIFO = "last in first out"

Queue. Examine the item least recently added. ← FIFO = "first in first out"

Stacks

- A stack stores an array of elements but with only two main operations:

  Push: add an element to the top of the stack

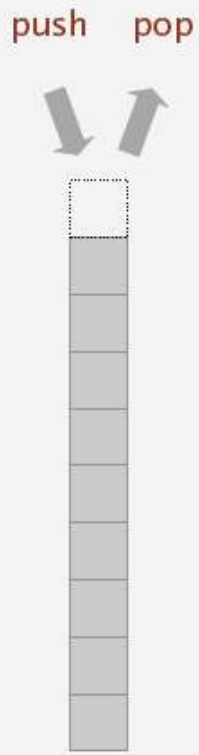
  Pop: remove the top element of the stack.

- Pop always removes the last element that's added to the stack. This is called **LIFO** (Last-In-First-Out).

Stack API

Warmup API. Stack of strings data type.

public class StackOfStrings	
StackOfStrings()	*create an empty stack*
void push(String s)	*insert a new item onto stack*
String pop()	*remove and return the item most recently added*
boolean isEmpty()	*is the stack empty?*
int size()	*number of items on the stack*



Warmup client. Reverse sequence of strings from standard input.

Stack: resizing-array implementation

"repeated doubling"

Q. How to grow array?

A. If array is full, create a new array of twice the size, and copy items.

```
public ResizingArrayStackOfStrings()
{  s = new String[1];  }

public void push(String item)
{
   if (N == s.length) resize(2 * s.length);
   s[N++] = item;
}

private void resize(int capacity)
{
   String[] copy = new String[capacity];
   for (int i = 0; i < N; i++)
      copy[i] = s[i];
   s = copy;
}
```

cost of array resizing is now

$2 + 4 + 8 + \ldots + N \sim 2N$

Consequence. Inserting first N items takes time proportional to N (not N^2).

Generic stack: array implementation

```
public class FixedCapacityStackOfStrings
{
   private String[] s;
   private int N = 0;

   public ..StackOfStrings(int capacity)
   {  s = new String[capacity];  }

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

   public void push(String item)
   {  s[N++] = item;  }

   public String pop()
   {  return s[--N];  }
}
```

the way it should be

```
public class FixedCapacityStack<Item>
{
   private Item[] s;
   private int N = 0;

   public FixedCapacityStack(int capacity)
   {  s = new Item[capacity];  }

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

   public void push(Item item)
   {  s[N++] = item;  }

   public Item pop()
   {  return s[--N];  }
}
```

@#$*! generic array creation not allowed in Java

Generic stack: array implementation

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public class FixedCapacityStackOfStrings
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   {  s = new String[capacity];  }

   public boolean isEmpty()
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   public void push(String item)
   {  s[N++] = item;  }

   public String pop()
   {  return s[--N];  }
}
```

the way it is

```
public class FixedCapacityStack<Item>
{
   private Item[] s;
   private int N = 0;

   public FixedCapacityStack(int capacity)
   {  s = (Item[]) new Object[capacity]; }

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

   public void push(Item item)
   {  s[N++] = item;  }

   public Item pop()
   {  return s[--N];  }
}
```

the ugly cast

Stack: Implementations

- Stack of strings using fixed-capacity array: FixedCapacityStackOfStrings.java
- Generic stack using fixed-capacity array: FixedCapacityStack.java
- Generic stack using a resizing array: ResizingArrayStack.java
- Generic stack using a linked list (next lecture): Stack.java

Stack: Applications

- Application 1: Reverse a list of integers
- Application 2: Delimiter matching
- Application 3: Expression evaluation
- Other applications
  - Undo/redo history
  - Browsing history (back button in browser)
  - Call stack

Application 1: Reverse a list of integers

- Reads a sequence of integers, prints them in reverse order

Application 1: Reverse a list of integers

- Reads a sequence of integers, prints them in reverse order
  - Push the integers to a stack one by one
  - pop and print them one by one

  Reverse.java

Application 2 – Delimiter Matching

- You want to make sure if the parentheses in an mathematical expression is balanced:

  (w * (x + y) / z – (p / (r – q)))
- It may have several different types of delimiters: braces{}, brackets[], parentheses().
  - Each opening on the left delimiter must be matched by a closing (right) delimiter.
  - Left delimiters that occur later should be closed before those occurring earlier.

Application 2 – Delimiter Matching

- Examples:

```
c[d]
a{b[c]d}e
a{b(c]d}e
a[b{c}d]e}
a{b(c)
```

Application 2 – Delimiter Matching

- Examples:

```
c[d]          // correct
a{b[c]d}e     // correct
a{b(c]d}e     // not correct; ] doesn't match (
a[b{c}d]e}    // not correct; nothing matches final }
a{b(c)        // not correct; nothing matches opening {
```

Application 2 – Delimiter Matching

- It's easy to achieve matching using a stack:
  - Read characters from the string.
  - Whenever you see a left (opening) delimiter, push it to the stack.
  - Whenever you see a right (closing) delimiter, pops the opening delimiter from the stack and match.
  - If they don't match, report error.

Application 2 – Delimiter Matching

- It's easy to achieve matching using a stack:
  - Read characters from the string.
  - Whenever you see a left (opening) delimiter, push it to the stack.
  - Whenever you see a right (closing) delimiter, pops the opening delimiter from the stack and match.
  - If they don't match, report error.
  - What happens if the stack is **empty** when you try to match a closing delimiter?
  - What happens if the stack is **non-empty** after all characters are read?

Application 2 – Delimiter Matching

- Example:

  a{b(c[d]e)f}

- Code: ~cs171000/share/code/Brackets/brackets.java
- Why does this work?
  - Delimiters that are opened last must be closed first.
  - This conforms exactly with the LIFO property of the stack.

```
public void check()
    {
    int stackSize = input.length();      // get max stack size
    StackX theStack = new StackX(stackSize);  // make stack

    for(int j=0; j<input.length(); j++)  // get chars in turn
      {
      char ch = input.charAt(j);         // get char
      switch(ch)
        {
        case '{':                        // opening symbols
        case '[':
        case '(':
          theStack.push(ch);             // push them
          break;

        case '}':                        // closing symbols
        case ']':
        case ')':
          if( !theStack.isEmpty() )   // if stack not empty,
            {
            char chx = theStack.pop();  // pop and check
            if( (ch=='}' && chx!='{') ||
                (ch==']' && chx!='[') ||
                (ch==')' && chx!='(') )
               System.out.println("Error: "+ch+" at "+j);
            }
          else                           // prematurely empty
            System.out.println("Error: "+ch+" at "+j);
          break;
        default:    // no action on other characters
          break;
        }  // end switch
      }  // end for
    // at this point, all characters have been processed
    if( !theStack.isEmpty() )
      System.out.println("Error: missing right delimiter");
    }  // end check()
```

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```

Application 3 – Arithmetic Expression Evaluation

- Task: evaluate arithmetic expressions.
- Familiar arithmetic expressions:

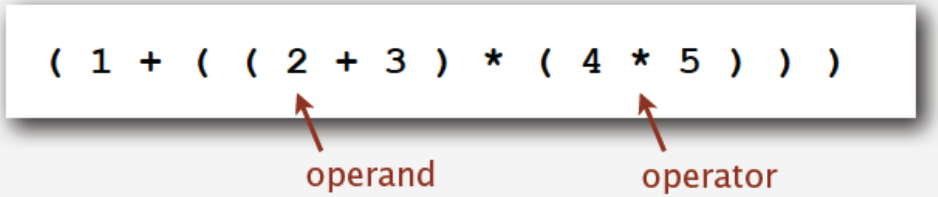
  2+3

  2*(3+4)

  …
- The **operators** are placed between two **operands**. This is called **infix** notation.

Arithmetic expression evaluation

Goal. Evaluate infix expressions.



Arithmetic expression evaluation

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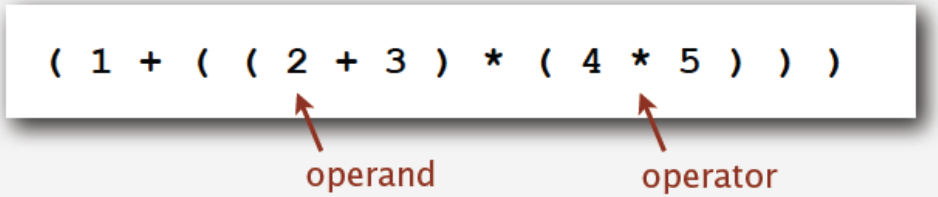


Two-stack algorithm. [E. W. Dijkstra]

- Value: push onto the value stack.
- Operator: push onto the operator stack.
- Left parenthesis: ignore.
- Right parenthesis: pop operator and two values; push the result of applying that operator to those values onto the operand stack.

Application 3 – Arithmetic Expression Evaluation

- Code

  Evaluate.java
- Demo

Postfix (RPN) Notation

- For computers to parse the expressions, it's more convenient to represent expressions in **postfix** notation, also known as reverse polish notation (RPN)
- **Operators** are placed after **operands**.

  23+

  AB/

- Postfix notation is parenthesis-free as long all operators have fixed # operands

Evaluating Postfix Expressions

- Example: **345+*612+/-**
- This is equivalent to the infix expression:
  3*(4+5) - 6 / (1+2)

How do we evaluate this postfix expression?

Implementation Idea

- Whenever we encounter an **operator**, we apply it to the **last two operands** we've seen.

Item Read from Postfix Expression	Action
Operand	Push it onto the stack.
Operator	Pop the top two operands from the stack and apply the operator to them. Push the result.

345+*612+/-

Summary

- **Stack**: a useful abstraction
- **Implementation**: can be done with arrays
- Key operations: **push**, **pop**
- Applications: reversing, matching, expression evaluation

Today

- Stacks
  - Operations
  - Implementation using resizable array
  - Implementation using generics
- Applications using stacks
- Queues
  - Operations
  - Implementation
  - Applications

Queues

- The word *Queue* is British for *Line*.
  - The first person that enters the queue gets served

Queue Data Structure

- Queue is *usually*
  stored as a continuous list of elements.
- The Queue data structure is similar to the Stack data structure, except it's

  First-in-First-Out (**FIFO**)
- The first element is referred to as the **Front** (or **head**)
- The last element is referred to as the **Rear** (or **tail**)

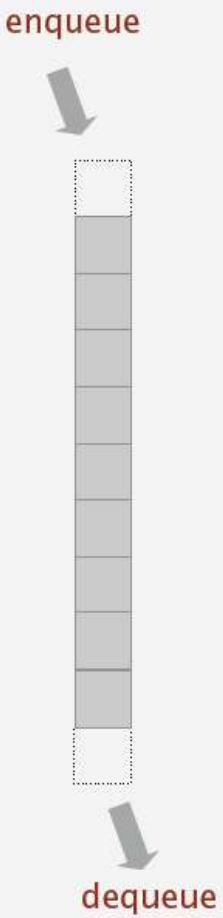
Queue Applications

- Queues are very useful in a computer:

1. Printer queue
2. Keyboard buffer
3. Network buffer
4. …

Queue API

public class QueueOfStrings	
QueueOfStrings()	*create an empty queue*
void enqueue(String s)	*insert a new item onto queue*
String dequeue()	*remove and return the item least recently added*
boolean isEmpty()	*is the queue empty?*
int size()	*number of items on the queue*



Queue: resizing array implementation

Array implementation of a queue.

- Use array `q[]` to store items in queue.
- `enqueue()`: add new item at `q[tail]`.
- `dequeue()`: remove item from `q[head]`.
- Update `head` and `tail` modulo the `capacity`.
- Add resizing array.

Queue: Implementations

- Generic Queue using resizing array

  ResizingArrayQueue.java
- Generic queue using linked list (next lecture)

  Queue.java

Queue: applications

- Josephus problem

  N people agree to the following strategy to reduce the population. They arrange themselves in a circle (at positions numbered from 0 to N-1) and proceed around the circle, eliminating every Mth person until only one person is left.

  Print out the order in which people are eliminated

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