Topic 15
Implementing and Using Stacks

"stack n. The set of things a person has to do in the future. "I haven't done it yet because every time I pop my stack something new gets pushed." If you are interrupted several times in the middle of a conversation, "My stack overflowed" means "I forget what we were talking about."

- The Hacker's Dictionary

Friedrich L. Bauer
German computer scientist who proposed "stack method of expression evaluation" in 1955.

Stacks

- Access is allowed only at one point of the structure, normally termed the top of the stack
  - access to the most recently added item only
- Operations are limited:
  - push (add item to stack)
  - pop (remove top item from stack)
  - top (get top item without removing it)
  - isEmpty
- Described as a "Last In First Out" (LIFO) data structure

Stack Operations

Assume a simple stack for integers.
Stack<Integer> s = new Stack<Integer>();
s.push(12);
s.push(4);
s.push( s.top() + 2 );
s.pop();
s.push( s.top() );
//what are contents of stack?
Stack Operations

Write a method to print out contents of stack in reverse order.

Uses of Stacks

- The runtime stack used by a process (running program) to keep track of methods in progress
- Search problems
- Undo, redo, back, forward

What is Output?

Stack<Integer> s = new Stack<Integer>();
// put stuff in stack
for(int i = 0; i < 5; i++)
    s.push( i );
// Print out contents of stack
// while emptying it.
// Assume there is a size method.
for(int i = 0; i < s.size(); i++)
    System.out.print( s.pop() + " ");
A 0 1 2 3 4  D 2 3 4
B 4 3 2 1 0      E No output due
C 4 3 2          to runtime error

Corrected Version

Stack<Integer> s = new Stack<Integer>();
// put stuff in stack
for(int i = 0; i < 5; i++)
    s.push( i );
// print out contents of stack
// while emptying it
int limit = s.size();
for(int i = 0; i < limit; i++)
    System.out.print( s.pop() + " ");
//or
// while(!s.isEmpty())
// System.out.println( s.pop() );
Implementing a stack

- need an underlying collection to hold the elements of the stack
- 2 obvious choices
  - array (native or ArrayList)
  - linked list
- Adding a layer of abstraction. A big idea.
- array implementation
- linked list implementation

Mathematical Calculations

- What does 3 + 2 * 4 equal?
  2 * 4 + 3?  3 * 2 + 4?
- The precedence of operators affects the order of operations.
- A mathematical expression cannot simply be evaluated left to right.
- A challenge when evaluating a program.
- Lexical analysis is the process of interpreting a program.

What about 1 - 2 - 4 ^ 5 * 3 * 6 / 7 ^ 2 ^ 3

Applications of Stacks

Infix and Postfix Expressions

- The way we are use to writing expressions is known as infix notation
- Postfix expression does not
  - require any precedence rules
- 3 2 * 1 + is postfix of 3 * 2 + 1
- evaluate the following postfix expressions and write out a corresponding infix expression:
  - 2 3 2 4 * + *
  - 1 2 3 4 ^ * +
  - 1 2 - 3 2 ^ 3 * 6 / +
  - 2 5 ^ 1 -
Clicker Question 2

- What does the following postfix expression evaluate to?
  \[ 6 \ 3 \ 2 \ + \ * \]
  A. 18  
  B. 36  
  C. 24  
  D. 11  
  E. 30

Evaluation of Postfix Expressions

- Easy to do with a stack
- Given a proper postfix expression:
  - get the next token
  - if it is an operand push it onto the stack
  - else if it is an operator
    - pop the stack for the right hand operand
    - pop the stack for the left hand operand
    - apply the operator to the two operands
    - push the result onto the stack
  - when the expression has been exhausted the result is the top (and only element) of the stack

Infix to Postfix

- Convert the following equations from infix to postfix:
  \[ 2 \ ^ \ 3 \ ^ \ 3 \ + \ 5 \ * \ 1 \]
  \[ 11 \ + \ 2 \ - \ 1 \ * \ 3 \ / \ 3 \ + \ 2 \ ^ \ 2 \ / \ 3 \]

Problems:
  - Negative numbers?
  - Parentheses in expression

Infix to Postfix Conversion

- Requires operator precedence parsing algorithm
  - Parse & To determine the syntactic structure of a sentence or other utterance

Operands: Add to expression
Close parenthesis: Pop stack symbols until an open parenthesis appears

Operators:
  - Have an on stack and off stack precedence
  - Pop all stack symbols until a symbol of lower precedence appears. Then push the operator
End of input: Pop all remaining stack symbols and add to the expression
### Simple Example

**Infix Expression:** \(3 + 2 \times 4\)

**PostFix Expression:**

**Operator Stack:**

---

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Off Stack Precedence</th>
<th>On Stack Precedence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>^</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>(</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

---

### Simple Example

**Infix Expression:** \(+ 2 \times 4\)

**PostFix Expression:** 3

**Operator Stack:**

---

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Off Stack Precedence</th>
<th>On Stack Precedence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>^</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>(</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

---

### Simple Example

**Infix Expression:** \(2 \times 4\)

**PostFix Expression:** 3

**Operator Stack:** +

---

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Off Stack Precedence</th>
<th>On Stack Precedence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>^</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>(</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

---

### Simple Example

**Infix Expression:** \(* 4\)

**PostFix Expression:** 3 2

**Operator Stack:** +

---

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Off Stack Precedence</th>
<th>On Stack Precedence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>^</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>(</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>
Simple Example

Infix Expression: 4
PostFix Expression: 3 2
Operator Stack: + *

Precedence Table

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Off Stack Precedence</th>
<th>On Stack Precedence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>^</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>(</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>

Simple Example

Infix Expression: 3 2 4 *
PostFix Expression: 3 2 4 *
Operator Stack: + *

Precedence Table

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Off Stack Precedence</th>
<th>On Stack Precedence</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>-</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>*</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>/</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>^</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>(</td>
<td>20</td>
<td>0</td>
</tr>
</tbody>
</table>
Example
1 - 2^3^3 - (4 + 5 * 6) * 7
Show algorithm in action on above equation

Balanced Symbol Checking
› In processing programs and working with computer languages there are many instances when symbols must be balanced 
\{\}, [], ( )

A stack is useful for checking symbol balance. When a closing symbol is found it must match the most recent opening symbol of the same type.
› Applicable to checking html and xml tags!

Algorithm for Balanced Symbol Checking
› Make an empty stack
› read symbols until end of file
  – if the symbol is an opening symbol push it onto the stack
  – if it is a closing symbol do the following
    • if the stack is empty report an error
    • otherwise pop the stack. If the symbol popped does not match the closing symbol report an error
› At the end of the file if the stack is not empty report an error

Algorithm in practice
› list[i] = 3 * ( 44 - method( foo( list[ 2 * ( i + 1 ) + foo( list[i - 1] ) ] ) / 2 * ) - list[ method(list[0])]);

› Complications
  – when is it not an error to have non matching symbols?

› Processing a file
  – Tokenization: the process of scanning an input stream. Each independent chunk is a token.
  – Tokens may be made up of 1 or more characters