"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

Clicker 1 - What is Output?

Stack<Integer> s = new Stack<>();
// 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
B 4 3 2 1 0
C 4 3 2
D 2 3 4
E No output due 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
  - native array
  - a list!!!
- Adding a *layer of abstraction*. A HUGE idea.
- array implementation
- linked list implementation

https://xkcd.com/2347/

Applications of Stacks

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

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. 11
  B. 18
  C. 24
  D. 30
  E. 36

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 v. 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>
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Precedence Table

Simple Example
Infix Expression: $+ 2 \times 4$
PostFix Expression: $3$
Operator Stack:

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Precedence Table

Simple Example
Infix Expression: $2 \times 4$
PostFix Expression: $3$
Operator Stack: $+$

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Precedence Table

Simple Example
Infix Expression: $\times 4$
PostFix Expression: $3 2$
Operator Stack: $+$

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Precedence Table
Simple Example

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

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Simple Example

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

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Example
11 + 2 ^ 4 ^ 3 - ((4 + 5) * 6 ) ^ 2
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