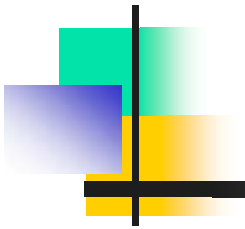
Stacks



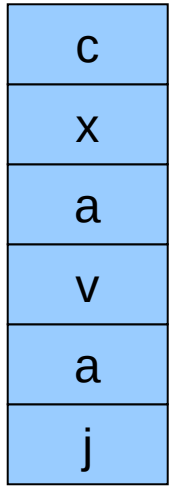
Lists are great, but…

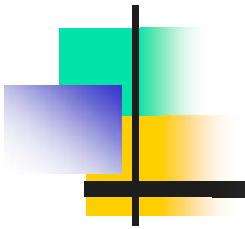
- Lists are simply collections of items
  - Useful, but nice to have some meaning to attach to them
  - Restrict operations to create useful data structures
- We want to have ADTs that actually do something useful
  - Example (from text): collecting characters on a line of text
  - Example: doing math with operator precedence (more on this later)
  - Example: matching braces
- Both of these applications can use a *stack*
  - A stack is also an ADT!
  - Stacks can be based on (abstract) lists!

What is a stack?

- A stack is a data structure that keeps objects in Last-In-First-Out (LIFO) order
  - Objects are added to the *top* of the stack
  - Only the top of the stack can be accessed
- Visualize this like a stack of paper (or plates)
- Example: function call return stack
- What methods does a stack need?

```
j a v a x c
```





What methods are needed for a stack?

- Create a stack
- Determine whether a stack is empty (or how many items are on it)
- Add an object to the top of the stack (push)
- Remove an object from the top of the stack (pop)
  - Does this return the object removed?
- Remove all of the objects from the stack
  - Can be done by repeatedly calling **pop** until the stack is empty
- Retrieve the object from the top of the stack (peek)

Stack example: matching braces and parens

- Goal: make sure left and right braces and parentheses match
  - This can't be solved with simple counting
  - { (x) } is OK, but { (x}) isn't
- Rule: **{ ok string }** is OK
- Rule: **(ok string)** is OK
- Use a stack
  - Place left braces and parentheses on stack
  - When a right brace / paren is read, pop the left off stack
  - If none there, report an error (no match)

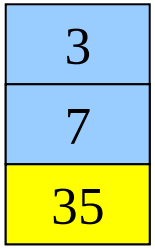
Stack example: postfix notation

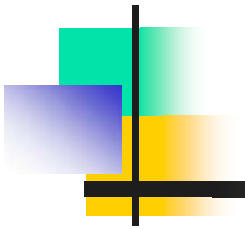
- HP calculators use postfix notation (as do some human languages)
  - Operations are done by specifying operands, then the operator
  - Example: 2 3 4 + * results in 14
    - Calculates 2 * (3 + 4)
- We can implement this with a stack
  - When we see a operand (number), push it on the stack
  - When we see an operator
    - Pop the appropriate number of operands off the stack
    - Do the calcuation
    - Push the result back onto the stack
  - At the end, the stack should have the (one) result of the calculation

More on postfix notation

- Calculate 5 * (4 + 3)
- Numbers orderer 5 4 3
- Operands ordered + *
  - Note reverse order!
  - Must compute + first!
- See example at right


```
5 4  3  +  *
```





Postfix is nice, but infix is more common

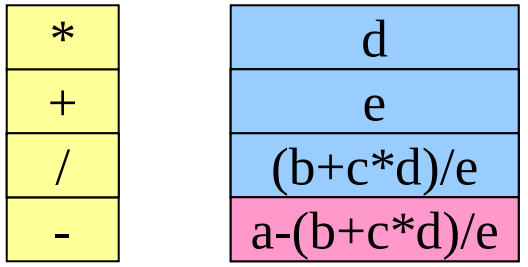
- Postfix works if you're used to HP calculators
- Most people are more used to infix
  - Example: (8*4) + 5
- Can we convert infix to postfix?
  - Yes!
  - Use a stack to do this…
- Observations
  - Operands stay in the same order from infix to postfix
  - Operator *x* moves "to the right" to ensure that *x* precedes any operands that it should

How is this done?

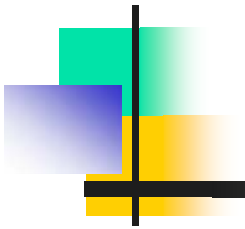
- Use two stacks
  - One for operators being reordered
  - One for the actual postfix operations
- Rules are
  - Operands always pushed onto the postfix stack
  - "(" pushed onto reorder stack
  - For each operator
    - Pop off reorder stack and push onto postfix stack until empty or "(" or lower precedence operator
    - Push operator onto postfix stack
  - On ")", pop off reorder stack until "(" is found
    - Delete "(": postfix needs no parentheses
  - At end of string, pop all off reorder stack and onto postfix stack

Example reordering: a-(b+c*d)/e

- Operands always pushed onto the postfix stack
- "(" pushed onto reorder stack
- For each operator
  - Pop off reorder stack and push onto postfix stack until empty or "(" or lower precedence operator
  - Push operator onto postfix stack
- On ")", pop off reorder stack until "(" is found
  - Delete "(": postfix needs no parentheses
- At end of string, pop all off reorder stack and onto postfix stack
- Here, do operations rather than push operators onto postfix stack

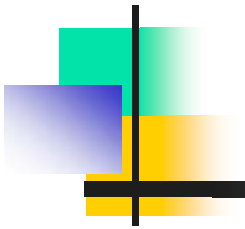


Reorder stack Postfix stack



Using interfaces to declare a stack

- Java has good support for abstract data types
  - An *interface* is a Java class without any methods
  - Classes may *implement* interfaces
- Example: StackInterface
  - May be implemented by array, linked list, etc.
  - We'll go over implementation on Friday
- For now, useful to see how to declare functions using interfaces

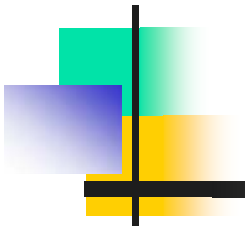


Interfaces and ADTs

```
public interface StackADT {
  public int length ();
  public void popAll ();
  public void push (Object o);
  public Object pop ()
    throws StackException;
  public Object peek ()
    throws StackException;
}

public class StackException
  extends RunTimeException {
   ...
}
```

```
public class StackArray
  implements StackADT {
  final int MAX_STACk = 50;
  private Object items[];
  private int top;
  public StackArray () {
    // constructor
  }
  public int length () {
    return (top+1);
  }
   ...
}
```



OK, so stacks are useful

- Stacks have many uses
  - Arithmetic
  - Language parsing
  - Keeping track of recursion (more in this in a week or so)
- How can stacks be implemented?
  - Using a generic List class
    - Works fine, easy to do
    - May not be as efficient
  - Using an array directly
  - Using a linked list
- Tradeoff between generic and tailored implementations
  - Generic implementation: simple, quick
  - Tailored implementation: often more efficient

Review: methods needed for stacks

- Stacks need six methods
  - Create: make a new stack
  - Push: add an element to the top of the stack
  - Pop: remove an element from the top of the stack
  - Peek: examine the element on the top of the stack
  - PopAll: remove all the elements from the stack
  - IsEmpty: return **true** if the stack has no elements
- Implement these methods using
  - Methods existing for a list
  - Operations on an array
  - Linked list operations directly

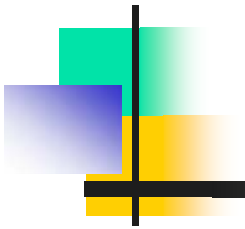
Stack using a (generic) list

```
public class StackList {
  private List l;
  int size;
  public StackList () {
    l = new List();
    size = 0;
  }
  public void push (Object item) {
    l.insert (item, 0);
    size++;
  }
  public Object pop () {
     Object item = l.index (0);
    l.delete (0);
    size--;
    return (item);
  }
```

```
  public Object peek () {
    return (l.index(0));
  }
  public boolean isEmpty () {
    return (size == 0);
  }
  public void popAll () {
    while (!isEmpty()) {
      pop();
    }
  }
}
```

Issue: what about empty lists?

- All this works well if we call pop() with things on the stack
- What if we call pop() on an empty stack?
  - This has no reasonable result!
  - Need to indicate an error somehow
- Solution #1: return a special value
  - Return **null** if there's an error
  - Problem: always checking for **null**!
  - This approach usually taken in C
- Solution #2: generate an exception



What's an exception?

- An *exception* is an abnormal condition
  - Null reference dereferenced
  - File not found
  - Stack is empty when pop() called
- Exceptions can be dealt with in two ways
  - Handle exception locally
  - Pass it to the calling method
- Pass to calling method
  - Must declare that method can cause an exception: public Object pop() throws StackException {…}
  - Calling method must deal with it now!

How can an exception be “caught”?

- Often useful to “catch” an exception
  - Deal with the problem
  - Try an alternate way of doing things
- Exceptions can be caught with a “try…catch” block
  - Different exceptions can be caught separately
  - Not all exceptions need be caught
- Exceptions are objects
  - May have methods
  - May carry information about the error condition

```
try {
  mystack.pop ();
}
catch (StackException e) {
  println (“Empty stack!”);
}
```

```
while (true) {
  try {
    f = new FileReader (name);
    break;
  }
  catch (IOException e) {
    print (“Enter a new name:”);
    // get another name
  }
}
```

Stacks with exceptions

```
public class StackList {
  private List l;
 int size;
  public StackList () {
    l = new List();
    size = 0;
  }
 public Object peek () {
    if (isEmpty()) {
      throw new StackException
        ("Stack empty");
    }
    return (l.index(0));
  }
  public void popAll () {
    while (!isEmpty()) {
      pop();
    }
  }
```

```
  public void push (Object item) {
    l.insert (item, 0);
    size++;
  }
  public Object pop ()
    throws StackException {
    if (isEmpty()) {
      throw new StackException
        ("Stack empty");
    }
    Object item = l.index (0);
    l.delete (0);
    size--;
    return (item);
  }
  public boolean isEmpty () {
    return (size == 0);
  }
}
```

Implementing stacks with arrays

```
public class StackArray {
  private Object arr[];
  int size;
  private final int max = 20;
  public StackList () {
    arr = new Object[max];
    size = 0;
  }
  public Object peek () {
    if (isEmpty()) {
      throw new StackException
        ("Stack empty");
    }
    return (arr[size-1]);
  }
  public void popAll ();
  public boolean isEmpty();
```

```
  public void push (Object item)
    throws StackException {
    if (size >= max) {
      throw new StackException
        ("Stack full");
    }
    arr[size++] = item;
  }
  public Object pop ()
    throws StackException {
    if (isEmpty()) {
      throw new StackException
        ("Stack empty");
    }
    return (arr[--size]);
  }
}
```

Issues with arrays for stacks

- Arrays are good for stacks because
  - Pop and push are easy to implement
    - Unlike general lists, only need to insert/delete at end
  - Very space efficient
    - Only require space for object references
    - No need for extra links
  - Fast
    - Some CPUs can do these operations in a single instruction
- Downside of using arrays
  - Stack has a limited size: hard to grow beyond that
  - Entire stack must be allocated even if it's never used
    - May be inefficient if maximum size is 1000, but stack never exceeds 10 elements
- Arrays for stacks are *very* common

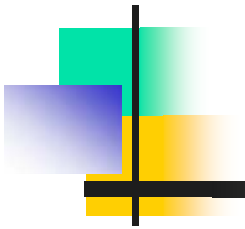
Implementing stacks with linked lists

```
public class StackArray {
  private StackArrayNode head;
  int size;
  public StackList () {
    head = null;
    size = 0;
  }
  public Object peek () {
    if (isEmpty()) {
      throw new StackException
        ("Stack empty");
    }
    return (head.val);
  }
  public void push (Object x) {
    head = new StackArrayNode
      (x, head);
    size++;
  }
```

```
public Object pop ()
    throws StackException {
    if (isEmpty()) {
      throw new StackException
        ("Stack empty");
    }
    Object obj = head.val;
    head = head.next;
    return (obj);
  }
  private class StackArrayNode {
    public Object val;
    public StackArrayNode next;
    public StackArrayNode
      (Object x, StackArrayNode n) {
      val = x;
      next = n;
  }
}
```

Issues with using linked lists as stacks

- Easier to do specific implementation rather than using generic linked lists
  - Only need to insert / delete at head
  - No need to move through the list
- Implementation is efficient, but not as efficient as arrays
  - More space per object (**next** reference)
  - Slower operations
- No preset limit on stack size



Example

- Let’s implement a stack