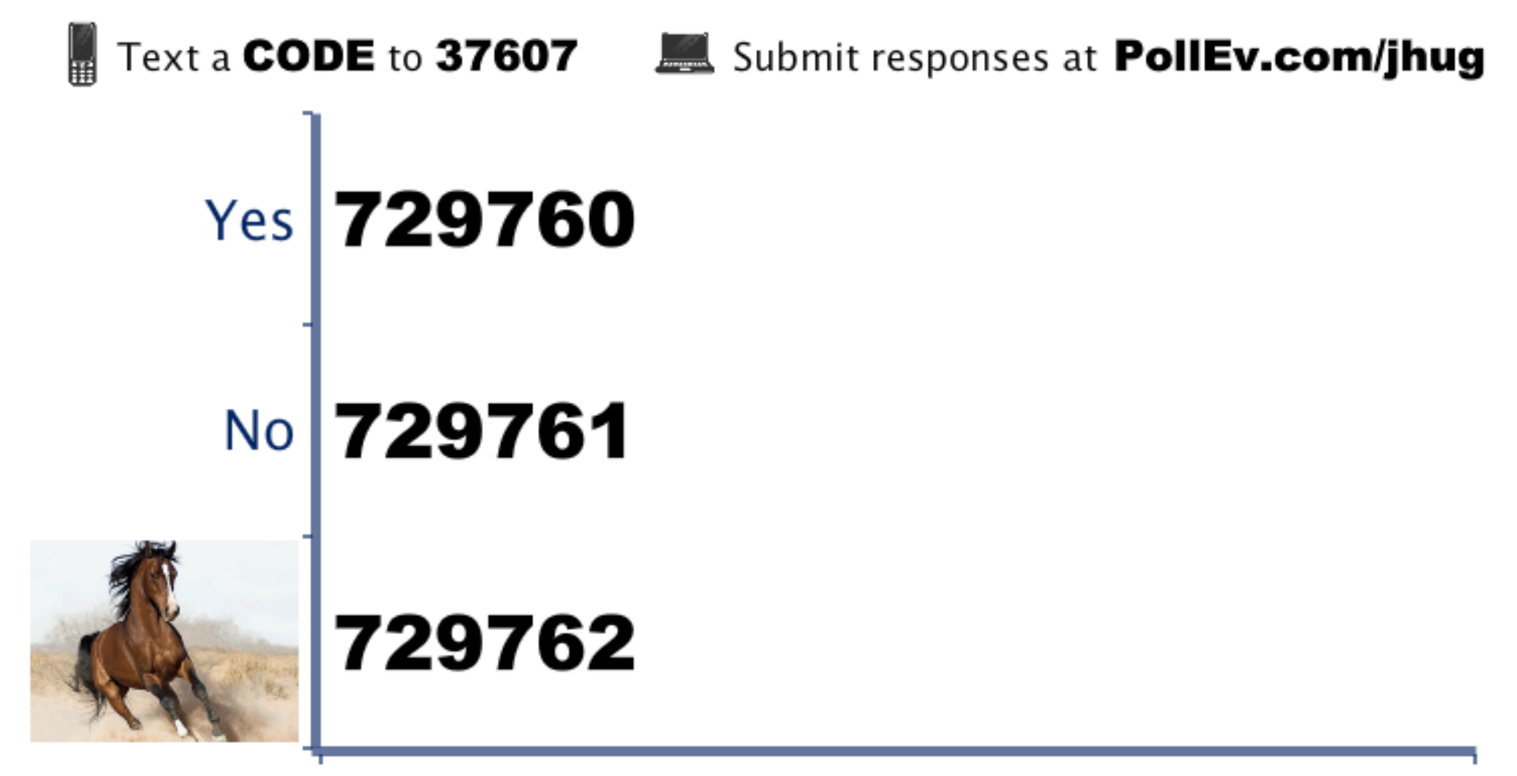
Is Polleverywhere working?



Text a **CODE** to **37607** Submit responses at **PollEv.com/jhug**

Yes	729760
No	729761
	729762

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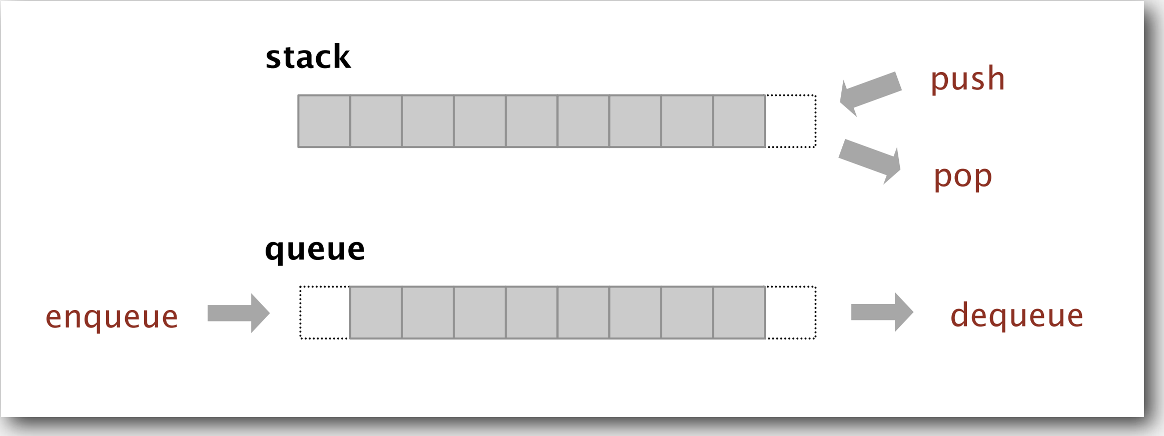
1.3 Bags, Queues, and Stacks

- *stacks*
- *resizing arrays*
- *queues*
- *generics*
- *iterators*
- *applications*

Stacks and queues

Fundamental data types.

- Collections 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"

Client, implementation, interface

Separate interface and implementation.

Ex: stack, queue, bag, priority queue, symbol table, union-find, ….

Benefits.

- Client can't know details of implementation ⇒ client has many implementation from which to choose.
- Implementation can't know details of client needs ⇒ many clients can re-use the same implementation.
- Design: creates modular, reusable libraries.
- Performance: use optimized implementation where it matters.

Client: program using operations defined in interface.

Implementation: actual code implementing operations.

Interface: description of data type, basic operations.

Algorithms

Robert Sedgewick | Kevin Wayne

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1.3 Bags, Queues, and Stacks

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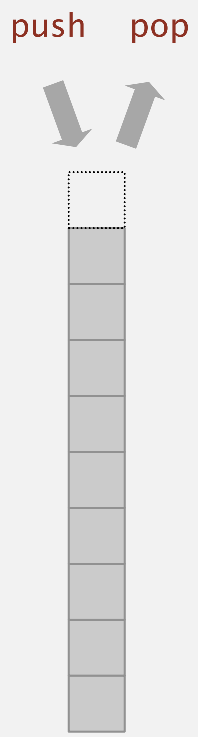
Stack API

Warmup API. Stack of strings data type.

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

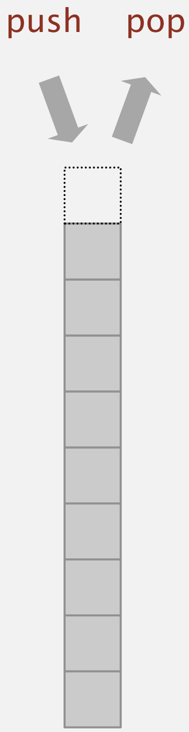


Warmup client. Reverse sequence of strings from standard input.

Stack test client

Read strings from standard input.

- If string equals "-", pop string from stack and print.
- Otherwise, push string onto stack.



```
public static void main(String[] args)
{
   StackOfStrings stack = new StackOfStrings();
   while (!StdIn.isEmpty())
   {
      String s = StdIn.readString();
      if (s.equals("-")) StdOut.print(stack.pop());
      else               stack.push(s);
   }
}
```

```
% more tobe.txt
to be or not to - be - - that - - - is

% java StackOfStrings < tobe.txt
to be not that or be
```

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Q: Which of the following inputs to the stack test client does NOT produce the output 5 4 3 2 1

```
A. 1 2 3 4 5 - - - - -     [740669]
B. 1 2 5 - 3 4 - - - -     [740670]
C. 5 - 1 2 3 - 4 - - -     [740671]
D. 5 - 4 - 3 - 2 - 1 -     [740672]
```

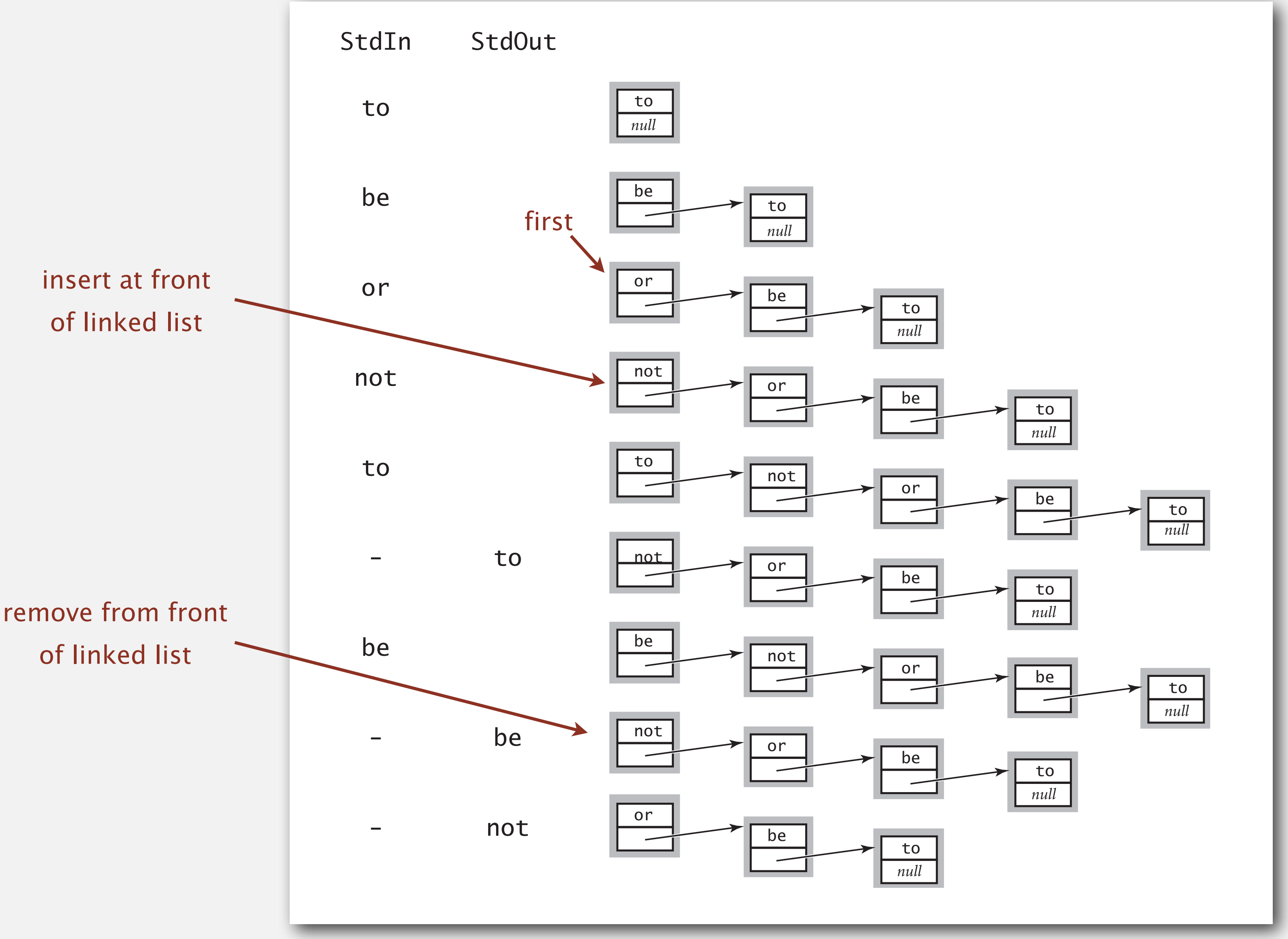
```
public static void main(String[] args)
{
   StackOfStrings stack = new StackOfStrin
   while (!StdIn.isEmpty())
   {
      String s = StdIn.readString();
      if (s.equals("-")) StdOut.print(stack.pop());
      else               stack.push(s);
   }
}
```

```
% more tobe.txt
to be or not to - be - - that - - - is

% java StackOfStrings < tobe.txt
to be not that or be
```

Stack: linked-list representation

Maintain pointer to first node in a linked list; insert/remove from front.



insert at front of linked list

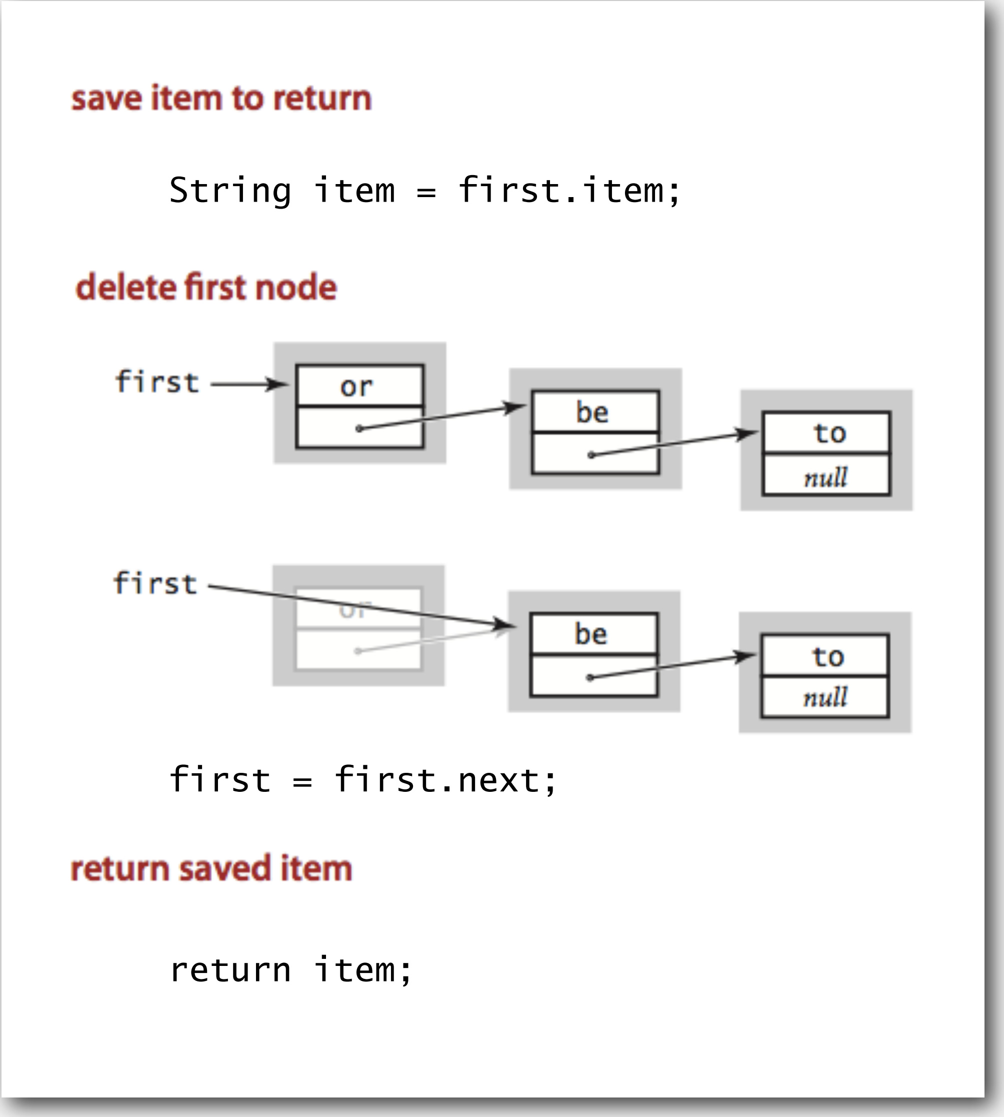
remove from front of linked list

Stack pop: linked-list implementation

inner class

```
private class Node
{
   String item;
   Node next;
}
```

```
public String pop() {
```



save item to return

```
String item = first.item;
```

delete first node

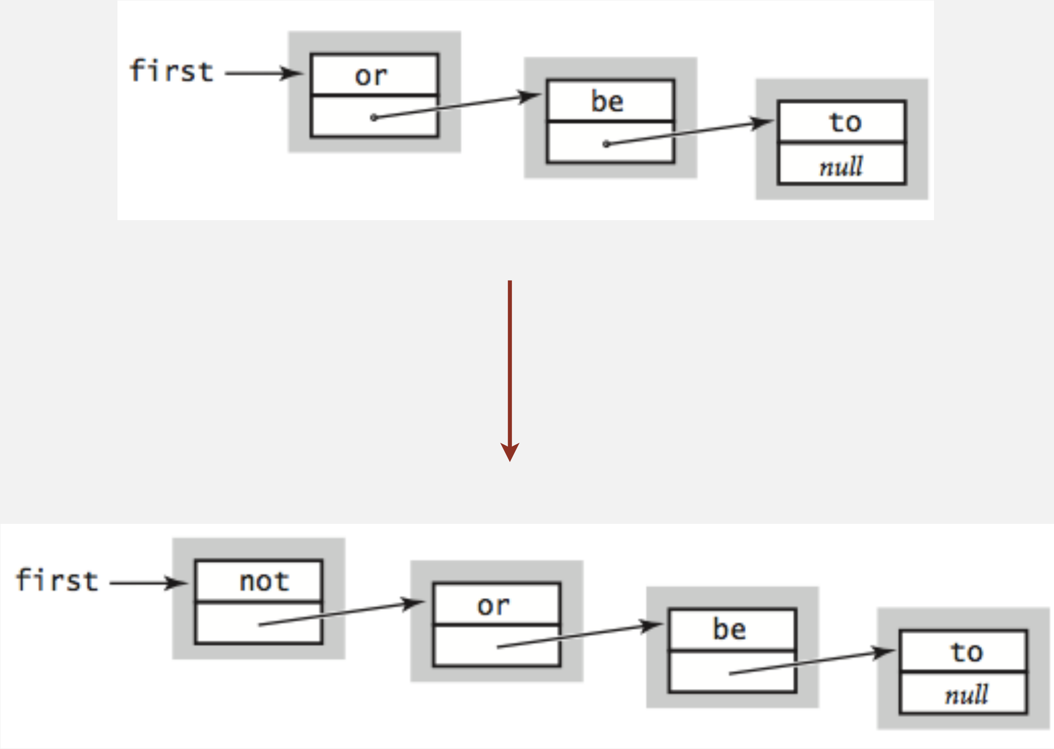
```
first = first.next;
```

return saved item

```
return item;
```

```
}
```

Stack push: linked-list implementation



inner class

```
private class Node
{
   String item;
   Node next;
}
```

```
public void push(String item) {
   Node oldFirst = first;
   first = new Node();
   first.next = oldFirst;
   first.item = item;
}
```

Stack: linked-list implementation in Java

```
public class LinkedStackOfStrings
{
   private Node first = null;

   private class Node
   {
      String item;
      Node next;
   }

   public boolean isEmpty()
   {  return first == null;  }

   public void push(String item)
   {
      Node oldfirst = first;
      first = new Node();
      first.item = item;
      first.next = oldfirst;
   }

   public String pop()
   {
      String item = first.item;
      first = first.next;
      return item;
   }
}
```

private inner class

(access modifiers don't matter)

Stack: linked-list implementation performance

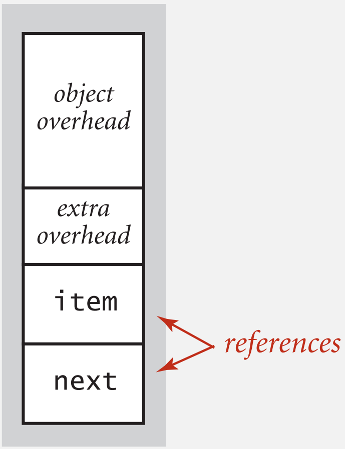
Proposition. Every operation takes constant time in the worst case.

Proposition. A stack with N items uses $\sim 40\ N$ bytes.

```
public class LinkedStackOfStrings
{
    private Node first = null;

    inner class
    private class Node
    {
       String item;
       Node next;
    }

}
```



16 bytes (object overhead)

8 bytes (inner class extra overhead)

8 bytes (reference to String)

8 bytes (reference to Node)

40 bytes per stack node

Remark. This accounts for the memory for the stack (but not the memory for strings themselves, which the client owns).

Stack: array implementation

Array implementation of a stack.

- Use array `s[]` to store `N` items on stack.
- `push()`: add new item at `s[N]`.
- `pop()`: remove item from `s[N-1]`.

`s[]`	`to`	`be`	`or`	`not`	`to`	`be`	*null*	*null*	*null*	*null*
	0	1	2	3	4	5	6	7	8	9
							`N`			

capacity = 10

Defect. Stack overflows when `N` exceeds capacity. [stay tuned]

Stack: array implementation

a cheat
(stay tuned)

```
public class FixedCapacityStackOfStrings
{
   private String[] s;
   private int N = 0; //# items on stack

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

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

   public void push(String item) {
      s[N++] = item; //some consider this bad style
   }

   public String pop() {
      N--;
      String item = S[N];   //these two lines
      s[N] = null;          //prevent loitering
      return item;          //so do something similar
   }
}
```

Stack considerations

Overflow and underflow.

- Underflow: might want to throw exception if pop from an empty stack.
- Overflow: use resizing array for array implementation. [stay tuned]

Null items. We allow null items to be inserted.

Loitering. Holding a reference to an object when it is no longer needed.

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

loitering

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

this version avoids "loitering":
garbage collector can reclaim memory
only if no outstanding references

Algorithms

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1.3 Bags, Queues, and Stacks

- *stacks*
- ***resizing arrays***
- *queues*
- *generics*
- *iterators*
- *applications*

Stack: resizing-array implementation

Problem. Requiring client to provide capacity does not implement API!

Q. How to grow and shrink array?

First try.

- `push()`: increase size of array `s[]` by `1`.
- `pop()`: decrease size of array `s[]` by `1`.

Too expensive.

- Need to copy all items to a new array.
- Inserting first N items takes time proportional to $1 + 2 + \ldots + N \sim N^2 / 2$.

infeasible for large N

Challenge. Ensure that array resizing happens infrequently.

Stack: resizing-array implementation

Q. How to grow array?

"repeated doubling"

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;
}
```

see next slide

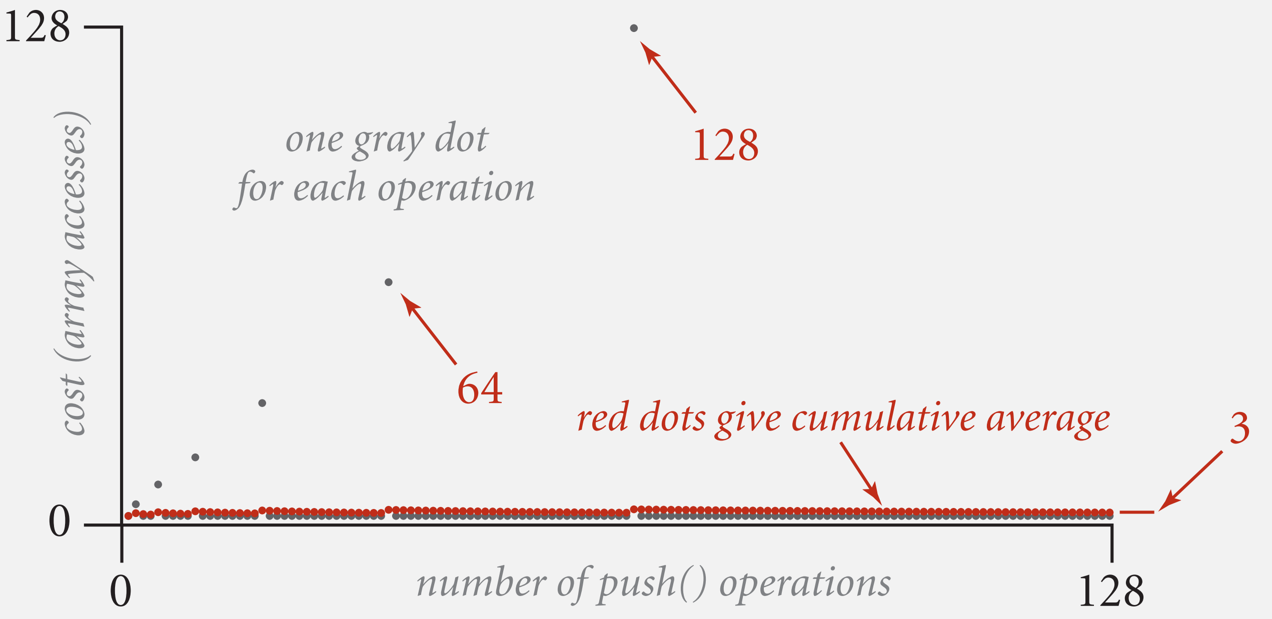
Consequence. Inserting first N items takes time proportional to N (not N^2).

Stack: amortized cost of adding to a stack

Cost of inserting first N items. $N \; + \; (2 + 4 + 8 + \ldots + N) \;\; \sim \;\; 3N.$

1 array access per push

k array accesses to double to size k (ignoring cost to create new array)



Stack: resizing-array implementation

Q. How to shrink array?

First try.

- `push()`: double size of array `s[]` when array is full.
- `pop()`: halve size of array `s[]` when array is one-half full.

Too expensive in worst case.

- Consider push-pop-push-pop-… sequence when array is full.
- Each operation takes time proportional to N.

N = 5	to	be	or	not	to	*null*	*null*	*null*
N = 4	to	be	or	not				
N = 5	to	be	or	not	to	*null*	*null*	*null*
N = 4	to	be	or	not				

Stack: resizing-array implementation

Q. How to shrink array?

Efficient solution.

- push(): double size of array s[] when array is full.
- pop(): halve size of array s[] when array is one-quarter full.

```
public String pop()
{
   String item = s[--N];
   s[N] = null;
   if (N > 0 && N == s.length/4) resize(s.length/2);
   return item;
}
```

Invariant. Array is between 25% and 100% full.

Stack: resizing-array implementation trace

push()	pop()	N	a.length	a[]							
				0	1	2	3	4	5	6	7
		0	1	*null*							
to		1	1	to							
be		2	2	to	be						
or		3	4	to	be	or	*null*				
not		4	4	to	be	or	not				
to		5	8	to	be	or	not	to	*null*	*null*	*null*
–	to	4	8	to	be	or	not	*null*	*null*	*null*	*null*
be		5	8	to	be	or	not	be	*null*	*null*	*null*
–	be	4	8	to	be	or	not	*null*	*null*	*null*	*null*
–	not	3	8	to	be	or	*null*	*null*	*null*	*null*	*null*
that		4	8	to	be	or	that	*null*	*null*	*null*	*null*
–	that	3	8	to	be	or	*null*	*null*	*null*	*null*	*null*
–	or	2	4	to	be	*null*	*null*				
–	be	1	2	to	*null*						
is		2	2	to	is						

Trace of array resizing during a sequence of push() and pop() operations

Stack resizing-array implementation: performance

Amortized analysis. Starting from an empty data structure, average running time per operation over a worst-case sequence of operations.

Proposition. Starting from an empty stack, any sequence of M push and pop operations takes time proportional to M.

	best	worst	amortized
construct	1	1	1
push	1	N	1
pop	1	N	1
size	1	1	1

doubling and halving operations

order of growth of running time for resizing stack with N items

Stack resizing-array implementation: memory

Invariant. Array is between 25% and 100% full.

```
public class ResizingArrayStackOfStrings
{
   private String[] s;
   private int N = 0;
   …
}
```

8 bytes (reference to array)
24 bytes (array overhead)
8 bytes × array size
4 bytes (int)
4 bytes (padding)

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text to **37607**

Q: If the array is completely full, how many bytes does the stack use to store N strings? Give your answer in Tilde notation.

A. ~N bytes	[740928]	D. ~16N bytes	[740931]
B. ~4N bytes	[740929]	E. ~32N bytes	[740932]
C. ~8N bytes	[740930]	F. ~16N + 40 bytes	[740933]

Do not count the memory used to store the actual strings, only count the references.

Stack resizing-array implementation: memory

Invariant. Array is between 25% and 100% full.

```
public class ResizingArrayStackOfStrings
{
   private String[] s;
   private int N = 0;
   …
}
```

8 bytes (reference to array)
24 bytes (array overhead)
8 bytes × array size
4 bytes (int)
4 bytes (padding)

pollEv.com/jhug

text to **37607**

Q: If N is the number of strings in the stack, how much memory does a ResizingArrayStackOfStrings use in the **worst** case as a function of N? Give your answer in Tilde notation.

A. ~N bytes [740966]

B. ~4N bytes [740967]

C. ~8N bytes [740968]

D. ~16N bytes [740969]

E. ~32N bytes [740970]

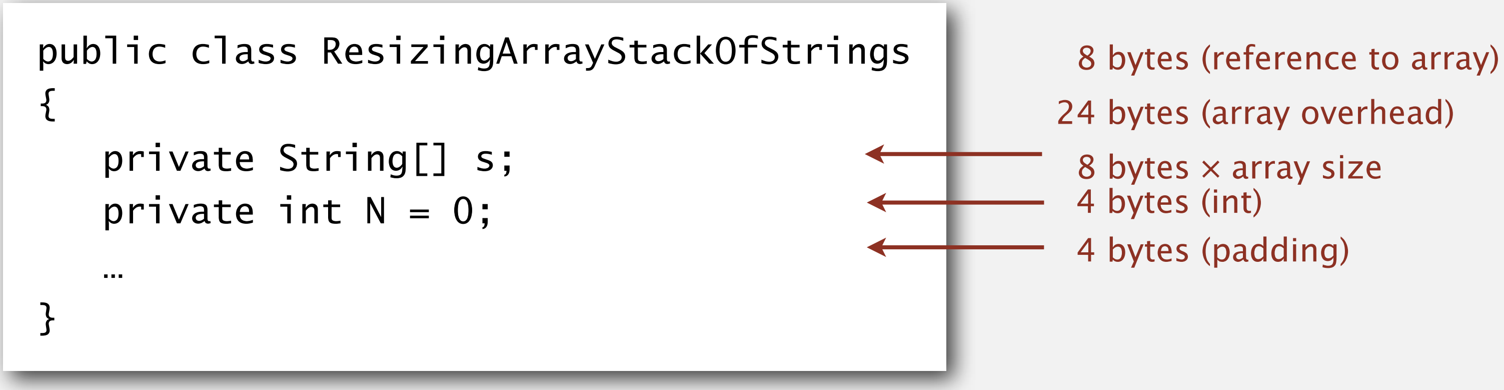
F. ~16N + 40 bytes [740971]

As before, don't count the memory of the actual strings, just references.

Stack resizing-array implementation: memory usage

Proposition. Uses between ~ $8N$ and ~ $32N$ bytes to represent a stack with N items.

- ~ $8N$ when full.
- ~ $32N$ when one-quarter full.



```
public class ResizingArrayStackOfStrings
{
   private String[] s;
   private int N = 0;
   …
}
```

8 bytes (reference to array)

24 bytes (array overhead)

8 bytes × array size

4 bytes (int)

4 bytes (padding)

Invariant. Array is between 25% and 100% full.

Remark. This accounts for the memory for the stack (but not the memory for strings themselves, which the client owns).

Stack implementations: resizing array vs. linked list

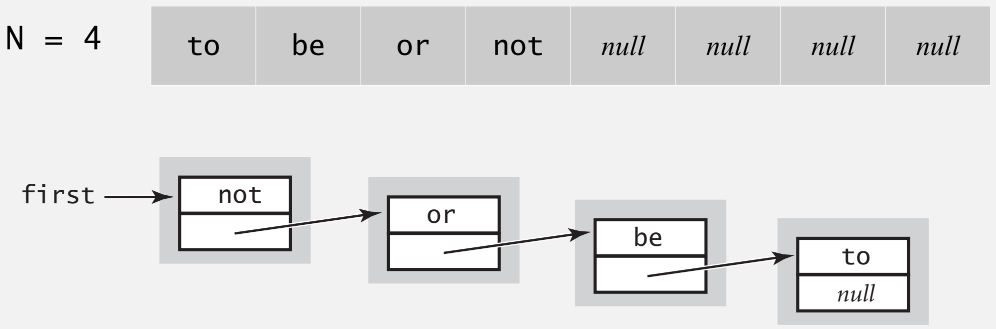
Tradeoffs. Can implement a stack with either resizing array or linked list; client can use interchangeably. Which one is better?

Linked-list implementation.

- Every operation takes constant time in the worst case.
- Uses extra time and space to deal with the links.

Resizing-array implementation.

- Every operation takes constant amortized time.
- Less wasted space.



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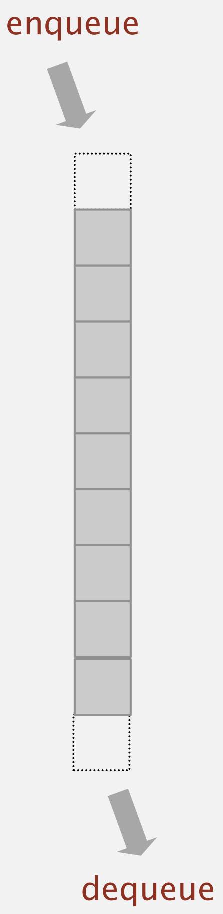
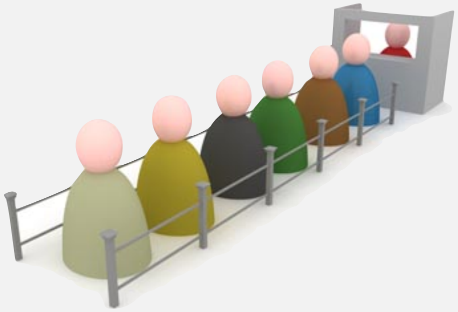
1.3 Bags, Queues, and Stacks

- *stacks*
- *resizing arrays*
- ***queues***
- *generics*
- *iterators*
- *applications*

Queue API

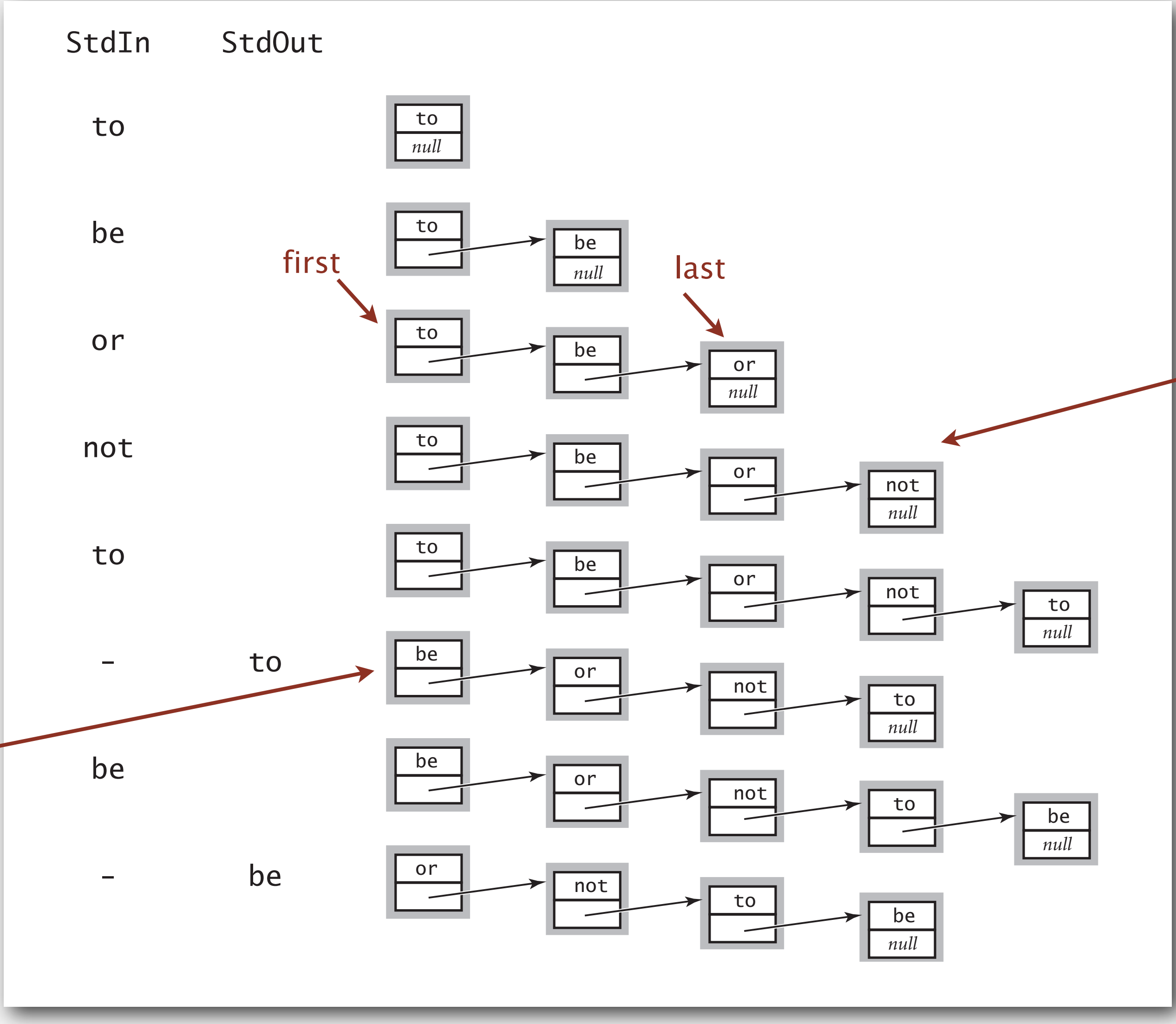
	public class QueueOfStrings	
	`QueueOfStrings()`	*create an empty queue*
`void`	`enqueue(String item)`	*insert a new string onto queue*
`String`	`dequeue()`	*remove and return the string least recently added*
`boolean`	`isEmpty()`	*is the queue empty?*
`int`	`size()`	*number of strings on the queue*





Queue: linked-list representation

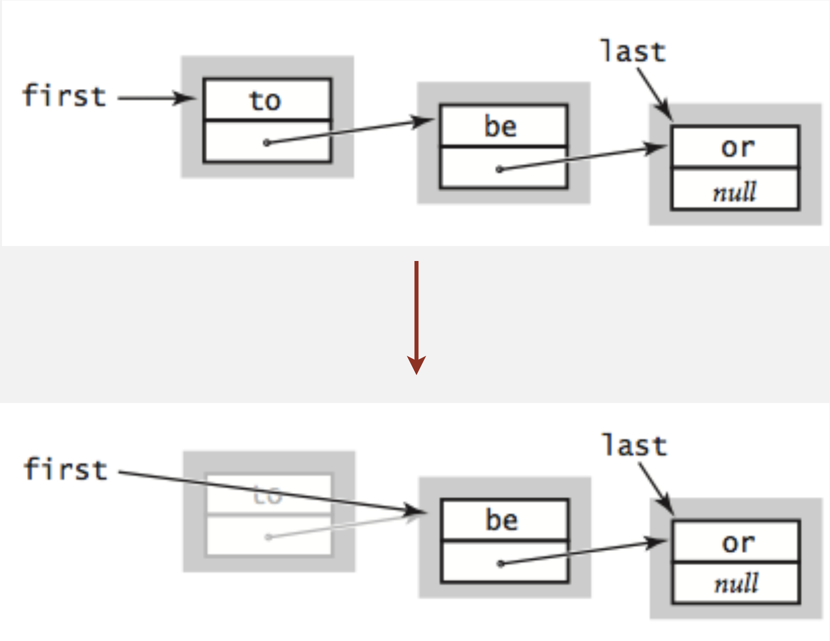
Maintain pointer to first and last nodes in a linked list;
insert/remove from opposite ends.



insert at end of linked list

remove from front of linked list

Queue dequeue: linked-list implementation

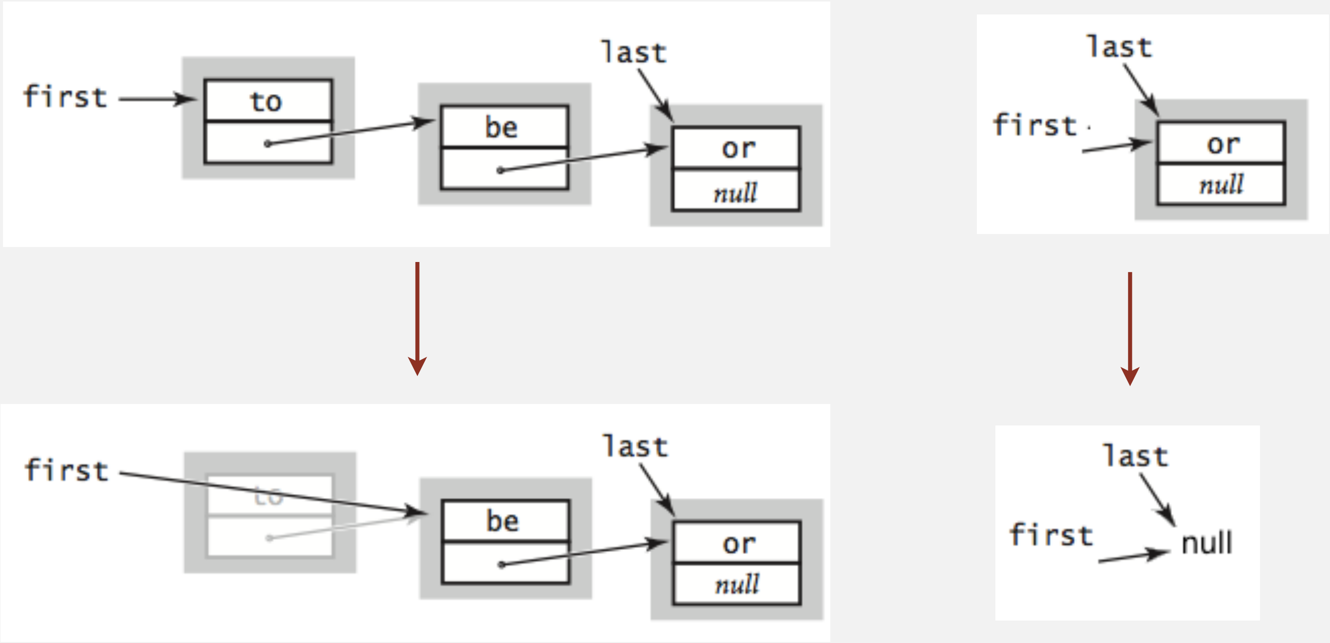


inner class

```
private class Node
{
   String item;
   Node next;
}
```

```
public String dequeue() {
   String item = first.item;
   first = first.next;
   return item;
}
```

Queue dequeue: linked-list implementation

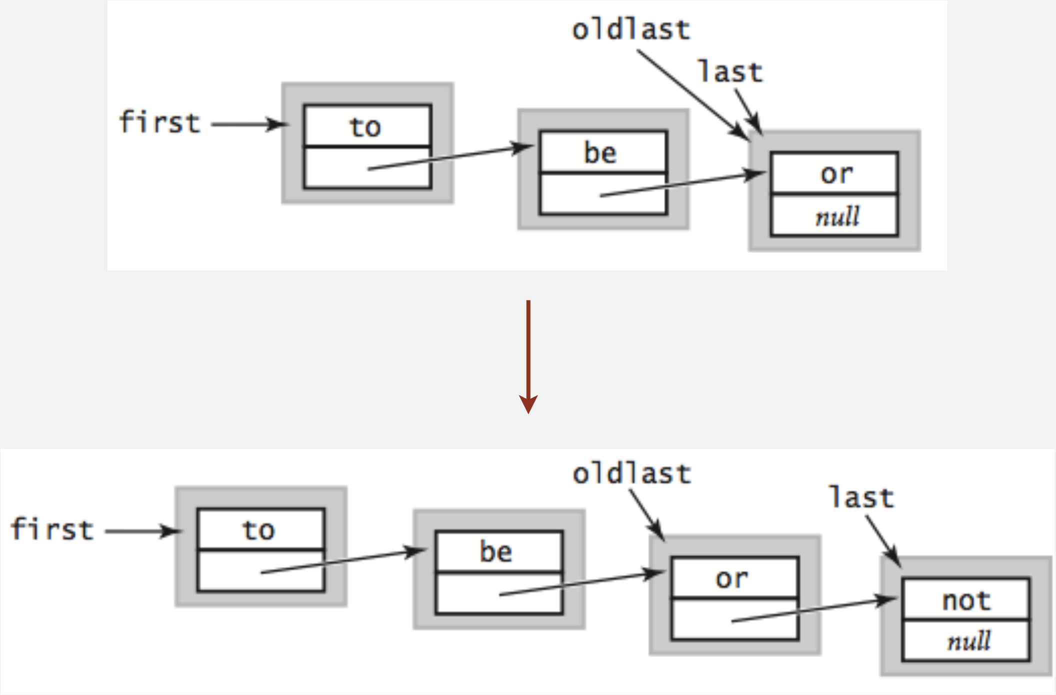


inner class

```
private class Node
{
   String item;
   Node next;
}
```

```
public String dequeue() {
   String item = first.item;
   first = first.next;
   if (first == null)
      last = null;
   return item;
}
```

Queue enqueue: linked-list implementation

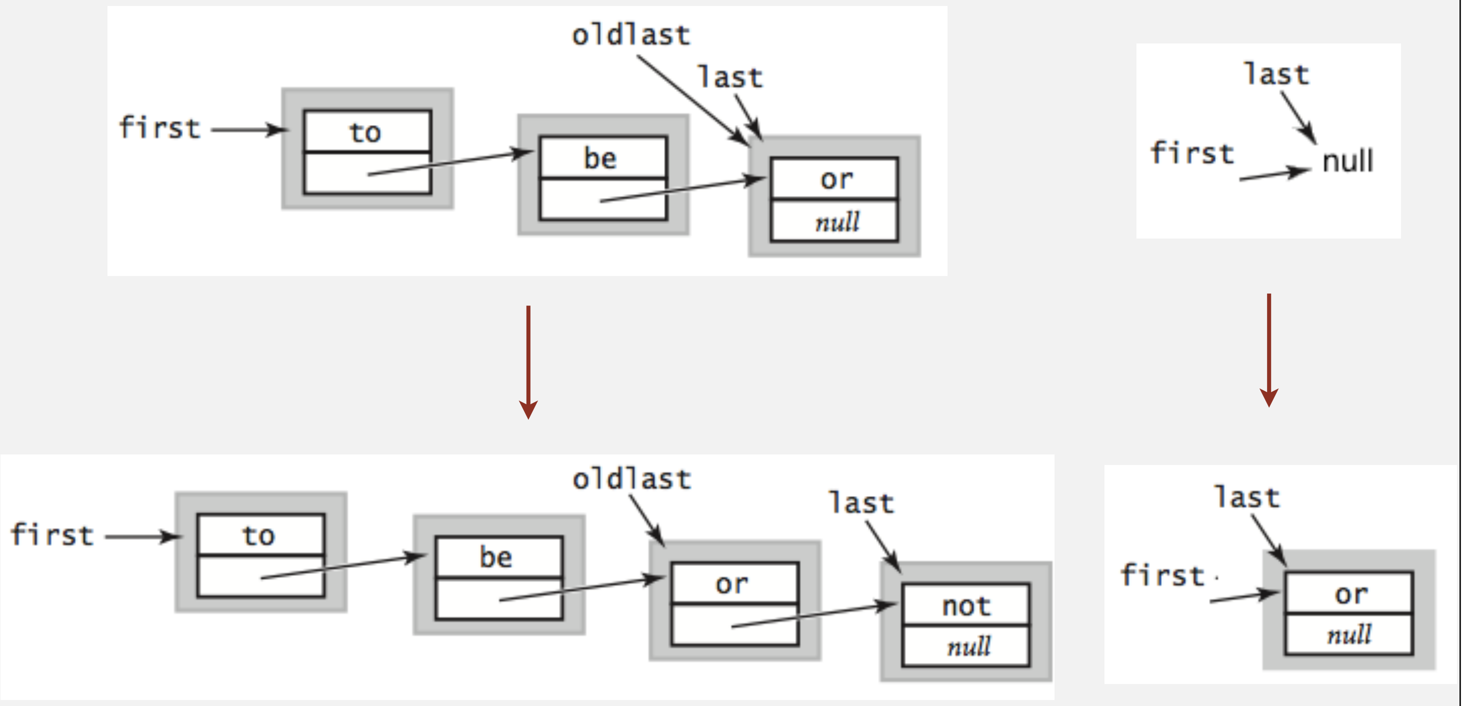


inner class

```
private class Node
{
   String item;
   Node next;
}
```

```
public void enqueue(String item) {
   Node oldLast = last;
   last = new Node();
   last.item = item;
   oldLast.next = last;
}
```

Queue enqueue: linked-list implementation



inner class

```
private class Node
{
   String item;
   Node next;
}
```

```
public void enqueue(String item) {
   Node oldLast = last;
   last = new Node();
   last.item = item;
   if (first == null)
      first = last;
   else //to avoid null pointer
      oldLast.next = last;
}
```

Queue: linked-list implementation in Java

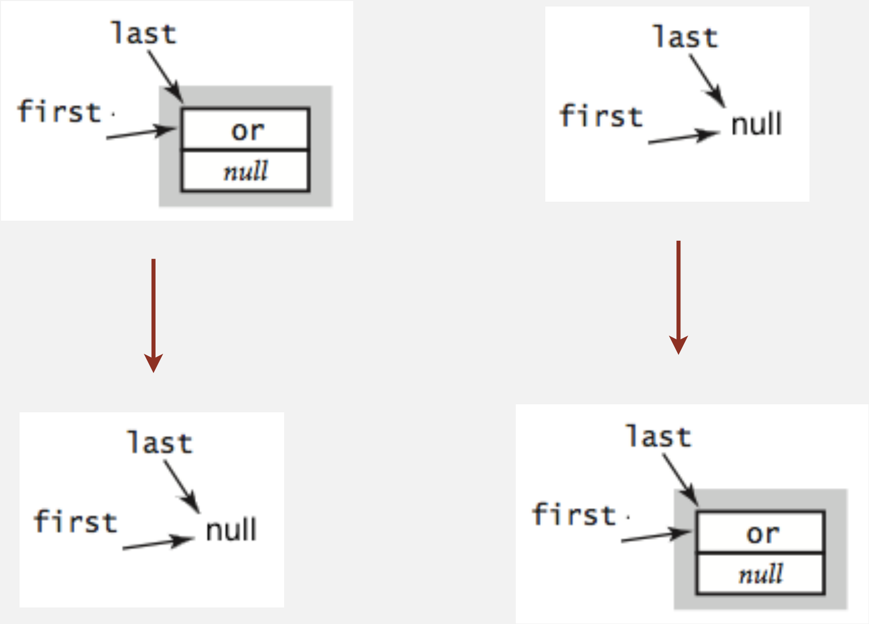
```
public class LinkedQueueOfStrings
{
   private Node first, last;

   private class Node
   {  /* same as in LinkedStackOfStrings */  }

   public boolean isEmpty()
   {  return first == null;  }

   public void enqueue(String item)
   {
      Node oldlast = last;
      last = new Node();
      last.item = item;
      last.next = null;
      if (isEmpty()) first = last;
      else           oldlast.next = last;
   }

   public String dequeue()
   {
      String item = first.item;
      first       = first.next;
      if (isEmpty()) last = null;
      return item;
   }
}
```

special cases for
empty queue

Sentinel nodes

Annoying Cases.

- Enqueueing on an empty list.
- Dequeuing to an empty list.



Solutions

- Write special case code.
- Create a node that can never be removed (sentinel node).
  - Always first in line.
  - Never gets to leave the line.
  - The queue is considered empty if sentinel is the only item.

Sentinel nodes

Annoying Cases.

- Going to/from to empty list.

Solutions

- Use an if statement.
- Never allow an empty list.
  - Create a single dummy node.
  - Null pointer if dequeue on empty list.
- Never allow a null pointer.
  - Create two dummy nodes.
  - Have back dummy node point backwards.
  - “dummy node” returned if dequeue on empty list.

```
public class LinkedQueueOfStrings
{
   private Node sentinel, last;

   public LinkedQueueOfStrings {
      sentinel = new Node();
      sentinel.item = “dummy node”;
      last = sentinel;
   }

   public boolean isEmpty()
   {  return sentinel == last;  }

   public void enqueue(String item)
   {
      Node oldLast = last;
      last = new Node();
      last.item = item;
      oldLast.next = last;
   }

   public String dequeue()
   {
      String item = sentinel.next.item;
      sentinel.next = sentinel.next.next;
      return item;
   }
}
```

Single dummy node example. Two nodes is arguably better.

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.

q[]	*null*	*null*	the	best	of	times	*null*	*null*	*null*	*null*	
	0	1	2	3	4	5	6	7	8	9	
			head				tail				capacity = 10

Q. How to resize?

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1.3 Bags, Queues, and Stacks

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Parameterized stack

We implemented: `StackOfStrings`.

We also want: `StackOfURLs`, `StackOfInts`, `StackOfVans`, ….

Attempt 1. Implement a separate stack class for each type.

- Rewriting code is tedious and error-prone.
- Maintaining cut-and-pasted code is tedious and error-prone.

@#$*! most reasonable approach until Java 1.5.

Parameterized stack

We implemented: StackOfStrings.

We also want: StackOfURLs, StackOfInts, StackOfVans, ….

Attempt 2. Implement a stack with items of type Object.

- Casting is required in client.
- Casting is error-prone: run-time error if types mismatch.

```
StackOfObjects s = new StackOfObjects();
Apple  a = new Apple();
Orange b = new Orange();
s.push(a);
s.push(b);
a = (Apple) (s.pop());
```

run-time error

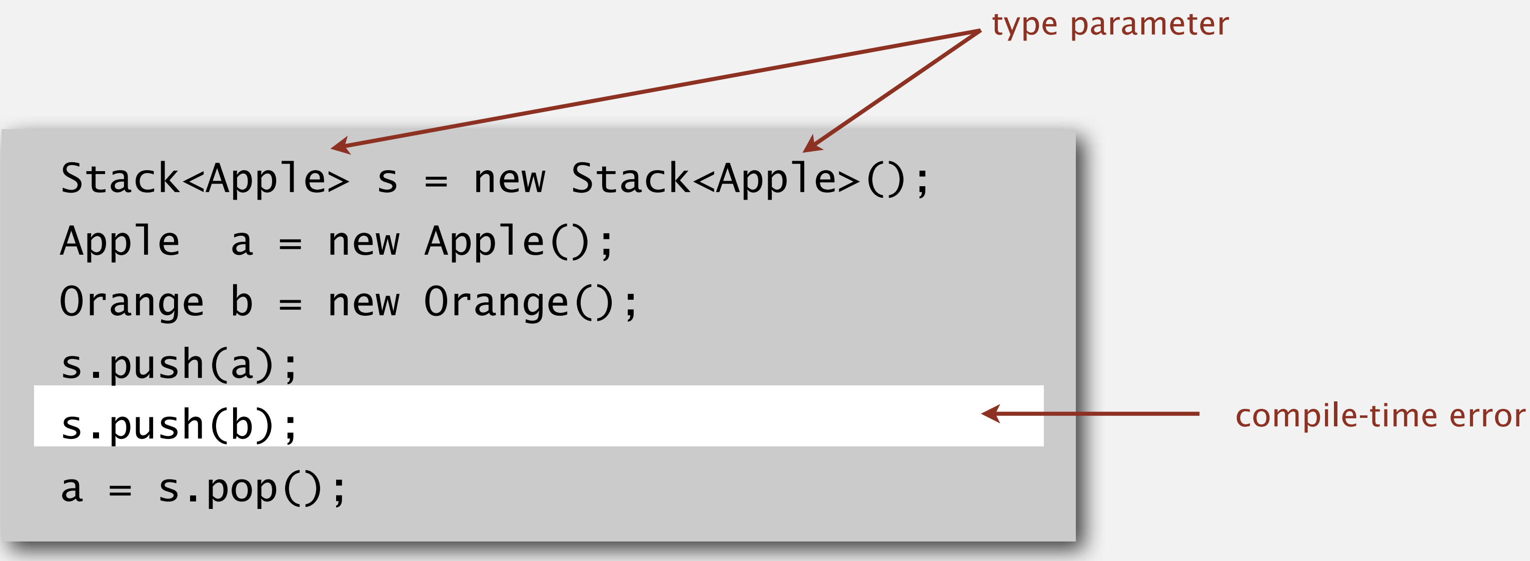
Parameterized stack

We implemented: `StackOfStrings`.

We also want: `StackOfURLs`, `StackOfInts`, `StackOfVans`, ….

Attempt 3. Java generics.

- Avoid casting in client.
- Discover type mismatch errors at compile-time instead of run-time.

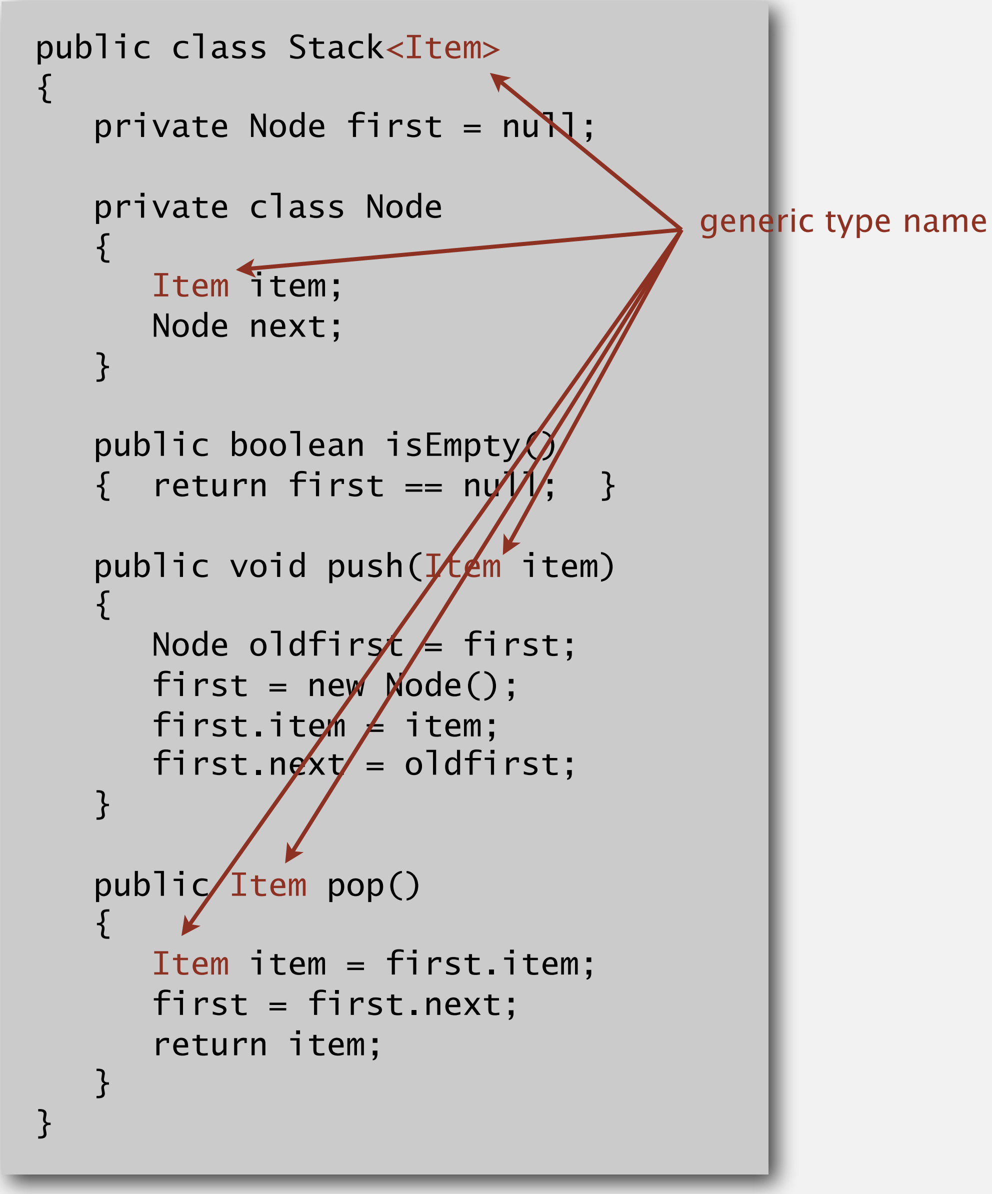


```
Stack<Apple> s = new Stack<Apple>();
Apple  a = new Apple();
Orange b = new Orange();
s.push(a);
s.push(b);
a = s.pop();
```

Guiding principles. Welcome compile-time errors; avoid run-time errors.

Generic stack: linked-list implementation

```
public class LinkedStackOfStrings
{
   private Node first = null;

   private class Node
   {
      String item;
      Node next;
   }

   public boolean isEmpty()
   {  return first == null;   }

   public void push(String item)
   {
      Node oldfirst = first;
      first = new Node();
      first.item = item;
      first.next = oldfirst;
   }

   public String pop()
   {
      String item = first.item;
      first = first.next;
      return item;
   }
}
```



```
public class Stack<Item>
{
   private Node first = null;

   private class Node
   {
      Item item;
      Node next;
   }

   public boolean isEmpty()
   {  return first == null;   }

   public void push(Item item)
   {
      Node oldfirst = first;
      first = new Node();
      first.item = item;
      first.next = oldfirst;
   }

   public Item pop()
   {
      Item item = first.item;
      first = first.next;
      return item;
   }
}
```

generic type name

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

```
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 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

Unchecked cast

```
% javac FixedCapacityStack.java
Note: FixedCapacityStack.java uses unchecked or unsafe operations.
Note: Recompile with -Xlint:unchecked for details.

% javac -Xlint:unchecked FixedCapacityStack.java
FixedCapacityStack.java:26: warning: [unchecked] unchecked cast
found   : java.lang.Object[]
required: Item[]
        a = (Item[]) new Object[capacity];
                     ^
1 warning
```

Generic data types: autoboxing

Q. What to do about primitive types?

Wrapper type.

- Each primitive type has a wrapper object type.
- Ex: `Integer` is wrapper type for `int`.

Autoboxing. Automatic cast between a primitive type and its wrapper.

```
Stack<Integer> s = new Stack<Integer>();
s.push(17);        // s.push(Integer.valueOf(17));
int a = s.pop();   // int a = s.pop().intValue();
```

Bottom line. Client code can use generic stack for any type of data.

Algorithms

Robert Sedgewick | Kevin Wayne

http://algs4.cs.princeton.edu

1.3 Bags, Queues, and Stacks

- *stacks*
- *resizing arrays*
- *queues*
- *generics*
- *iterators*
- *applications*

Iteration

Question. How would you print out the contents of the stack without destroying it?

```
public class StackOfStrings
{
   public boolean isEmpty()
   public void push()
   public String pop()
}
```

```
public void printStackOfStrings(StackOfStrings sos) {

}
```

Iteration

Question. How would you print out the contents of the stack without destroying it?

```
public class StackOfStrings
{
   public boolean isEmpty()
   public void push()
   public String pop()
}
```

```
public void printStackOfStrings(StackOfStrings sos) {
   StackOfStrings sos2;
   while (sos.isEmpty() == false) {
      String s = sos.pop();
      StdOut.println(s);
      sos2.push(s);
   }
   while (sos2.isEmpty() == false) {
      String s = sos2.pop();
      sos.push(s);
   }
}
```

Iteration

Question. How would you print out the contents of the stack without destroying it?

```
public class StackOfStrings
{
   public boolean isEmpty()
   public void push()
   public String pop()
}
```

Alternate Approach. Extend the API to support iteration.

```
public class StackOfStrings
{
   public boolean isEmpty()
   public void push()
   public String pop()
   public int startIterating()
   public String getNextString()
   public boolean hasNextString()
}
```

```
StackOfStrings sos = ...;
sos.startIterating();
while (sos.hasNextString())
   System.out.println(
         sos.getNextString());
```

API above doesn’t allow nested iteration!

Iteration

Question. How would you print out the contents of the stack without destroying it?

```
public class StackOfStrings
{
   public boolean isEmpty()
   public void push()
   public String pop()
}
```

Java Approach. Extend the API to support iteration using Iterable interface.

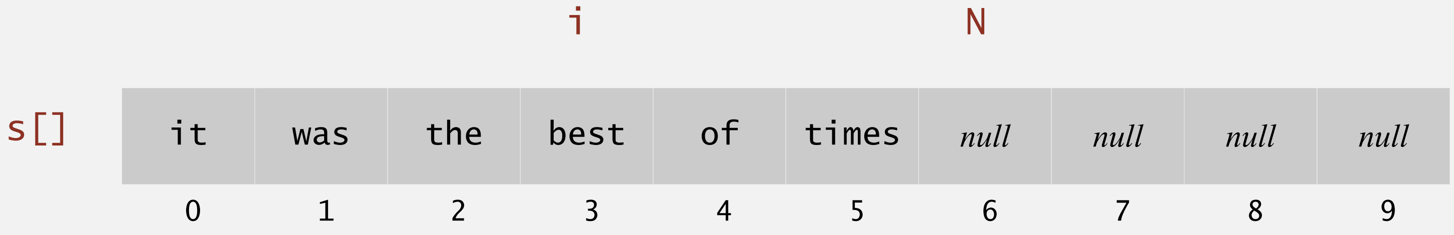
```
public class StackOfStrings
{
   public boolean isEmpty()
   public void push()
   public String pop()
   public Iterator<String> iterator()
}
```

“foreach” statement (shorthand)

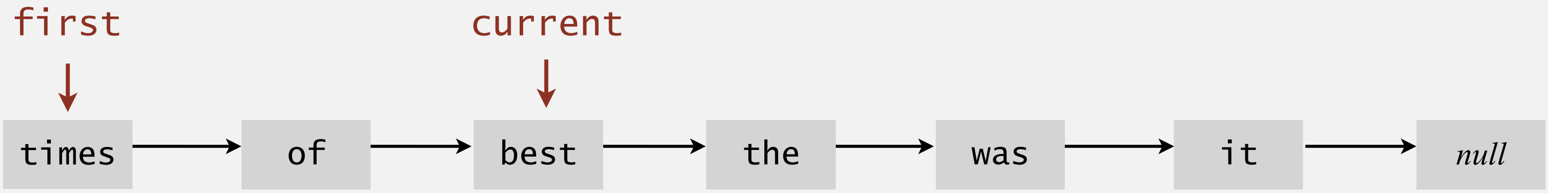
```
for (String s : stack)
   StdOut.println(s);
```

Iteration

Design challenge. Support iteration over stack items by client, without revealing the internal representation of the stack.



0	1	2	3	4	5	6	7	8	9
it	was	the	best	of	times	*null*	*null*	*null*	*null*



"foreach" statement (shorthand)

```
for (String s : stack)
   StdOut.println(s);
```

Java solution. Make stack implement the `java.lang.Iterable` interface.

Iterators

Q. What is an `Iterable` ?

A. Has a method called iterator() that returns an `Iterator`.

Iterable interface

```
public interface Iterable<Item>
{
   Iterator<Item> iterator();
}
```

Q. What is an `Iterator` ?

A. Has methods `hasNext()`, `next()` (and `remove()`).

Iterator interface

```
public interface Iterator<Item>
{
   boolean hasNext();
   Item next();
   void remove(); ⟵
}
```

optional; use at your own risk

Q. Why make data structures `Iterable` ?

A. Java supports elegant client code.

“foreach” statement (shorthand)

```
for (String s : stack)
   StdOut.println(s);
```

equivalent code (longhand)

```
Iterator<String> i = stack.iterator();
while (i.hasNext())
{
   String s = i.next();
   StdOut.println(s);
}
```

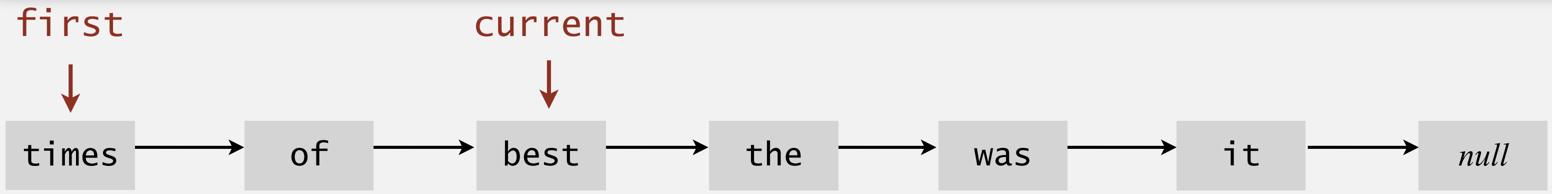
Stack iterator: linked-list implementation

```
import java.util.Iterator;

public class Stack<Item> implements Iterable<Item>
{
    ...

    public Iterator<Item> iterator() { return new ListIterator(); }

    private class ListIterator implements Iterator<Item>
    {
        private Node current;

        public ListIterator()     {  current = first;         }
        public boolean hasNext()  {  return current != null;  }
        public void remove()      {  /* not supported */      }
        public Item next()
        {
            Item item = current.item;
            current   = current.next;
            return item;
        }
    }
}
```

throw UnsupportedOperationException

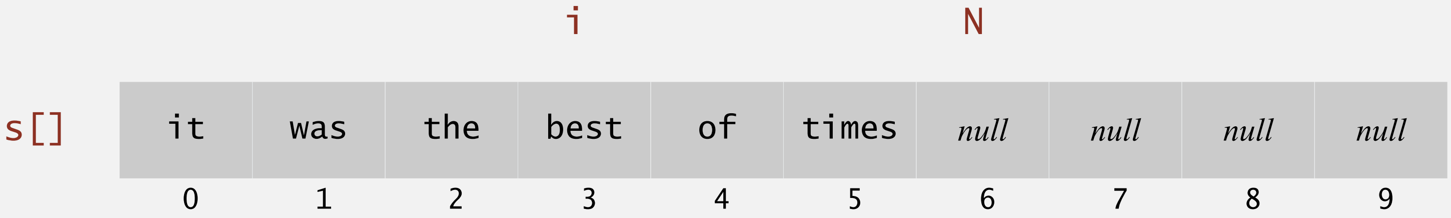
throw NoSuchElementException

if no more items in iteration



Stack iterator: array implementation

```
import java.util.Iterator;

public class Stack<Item> implements Iterable<Item>
{
    …
    public Iterator<Item> iterator()
    { return new ReverseArrayIterator(); }

    private class ReverseArrayIterator implements Iterator<Item>
    {
        private int i;

        public ReverseArrayIterator()
        public boolean hasNext()
        public void remove()     {  /* not supported */  }
        public Item next()
    }
}
```



				i			N			
s[]	it	was	the	best	of	times	*null*	*null*	*null*	*null*
	0	1	2	3	4	5	6	7	8	9

http://algs4.cs.princeton.edu

1.3 Bags, Queues, and Stacks

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- *resizing arrays*
- *queues*
- *generics*
- *iterators*
- ***applications***

Java collections library

List interface. `java.util.List` is API for an sequence of items.

```
public interface List<Item> implements Iterable<Item>
```

	`List()`	*create an empty list*
`boolean`	`isEmpty()`	*is the list empty?*
`int`	`size()`	*number of items*
`void`	`add(Item item)`	*append item to the end*
`Item`	`get(int index)`	*return item at given index*
`Item`	`remove(int index)`	*return and delete item at given index*
`boolean`	`contains(Item item)`	*does the list contain the given item?*
`Iteartor<Item>`	`iterator()`	*iterator over all items in the list*
`...`		

Implementations. `java.util.ArrayList` uses resizing array; `java.util.LinkedList` uses linked list.

caveat: only some operations are efficient

Java collections library

java.util.Stack.

- Supports push(), pop(), and and iteration.
- Extends java.util.Vector, which implements java.util.List interface from previous slide, including get() and remove().
- Bloated and poorly-designed API (why?)

Java 1.3 bug report (June 27, 2001)

> The iterator method on java.util.Stack iterates through a Stack from the bottom up. One would think that it should iterate as if it were popping off the top of the Stack.

status (closed, will not fix)

> It was an incorrect design decision to have Stack extend Vector ("is-a" rather than "has-a"). We sympathize with the submitter but cannot fix this because of compatibility.

Java collections library

java.util.Stack.

- Supports `push()`, `pop()`, and and iteration.
- Extends `java.util.Vector`, which implements `java.util.List` interface from previous slide, including `get()` and `remove()`.
- Bloated and poorly-designed API (why?)

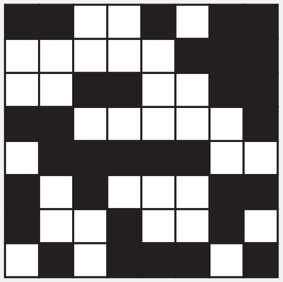
java.util.Queue. An interface, not an implementation of a queue.

Best practices. Use our implementations of `Stack`, `Queue`, and `Bag`.

War story (from Assignment 1)

Generate random open sites in an N-by-N percolation system.

- Jenny: pick (i, j) at random; if already open, repeat.
  Takes ~ $c_1 N^2$ seconds.
- Kenny: create a `java.util.ArrayList` of N^2 closed sites.
  Pick an index at random and delete.
  Takes ~ $c_2 N^4$ seconds.



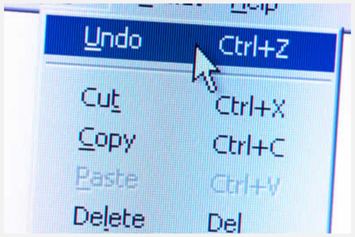
Kenny

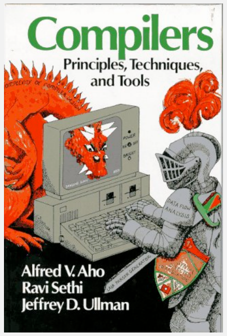
Lesson. Don't use a library until you understand its API!

This course. Can't use a library until we've implemented it in class.

Stack applications

- Parsing in a compiler.
- Java virtual machine.
- Undo in a word processor.
- Back button in a Web browser.
- PostScript language for printers.
- Implementing function calls in a compiler.
- ...





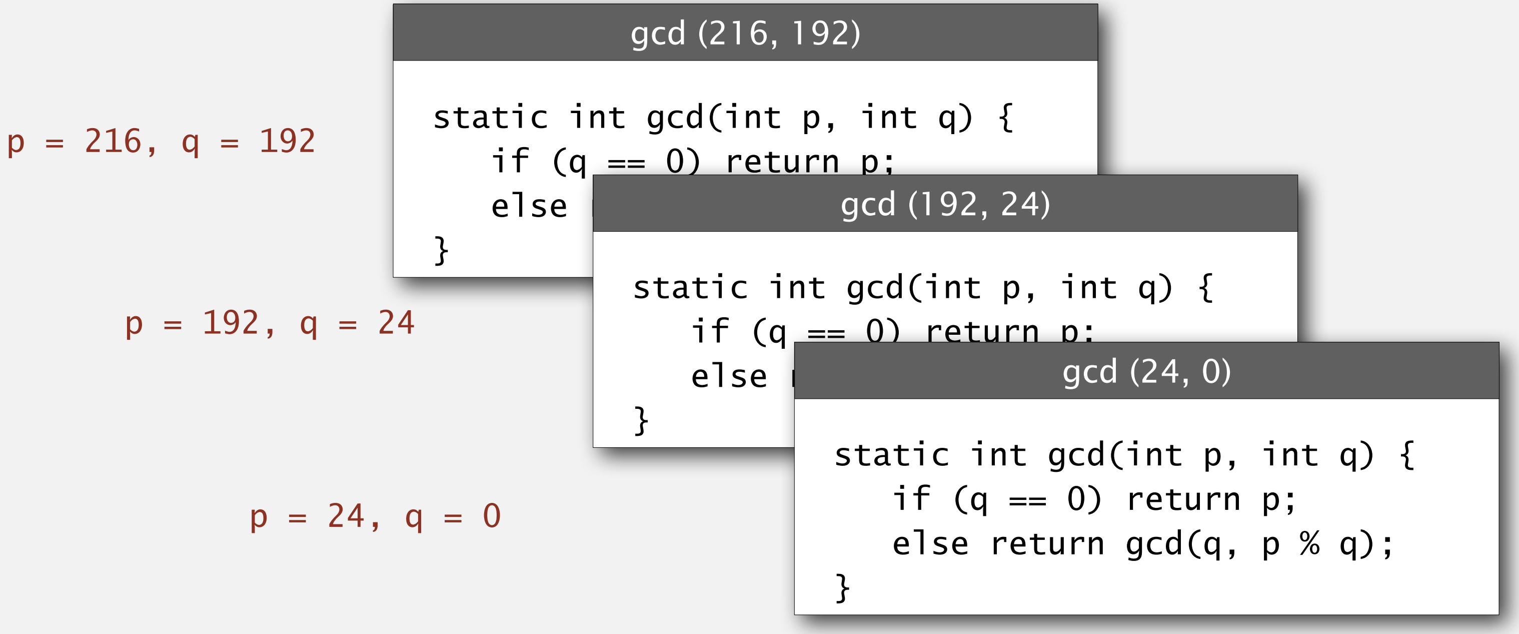
Function calls

How a compiler implements a function.

- Function call: push local environment and return address.
- Return: pop return address and local environment.

Recursive function. Function that calls itself.

Note. Can always use an explicit stack to remove recursion.



p = 216, q = 192

gcd (216, 192)

```
static int gcd(int p, int q) {
   if (q == 0) return p;
   else
}
```

p = 192, q = 24

gcd (192, 24)

```
static int gcd(int p, int q) {
   if (q == 0) return p;
   else
}
```

p = 24, q = 0

gcd (24, 0)

```
static int gcd(int p, int q) {
   if (q == 0) return p;
   else return gcd(q, p % q);
}
```

Assignment 2

Implementation of two data types

- Randomized queue.
- Deque (double-ended queue).

Important choice to be made

- Linked list vs. resizing array.
- Think carefully about whether your choice allows you to obey timing constraints!

Extra credit

- Complete the checkout line simulator.
- Report anything interesting you discover.
- OK to do alone, even if you had a partner.
- Tiny amount of extra credit (1 point).
- No support in office hours.
- OK to ask questions on Piazza or to me directly by email.