CS 171: Introduction to Computer Science II

Stacks and Queues

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Today

- Quick note on running book code
- Stacks
  - Operations
  - Implementations

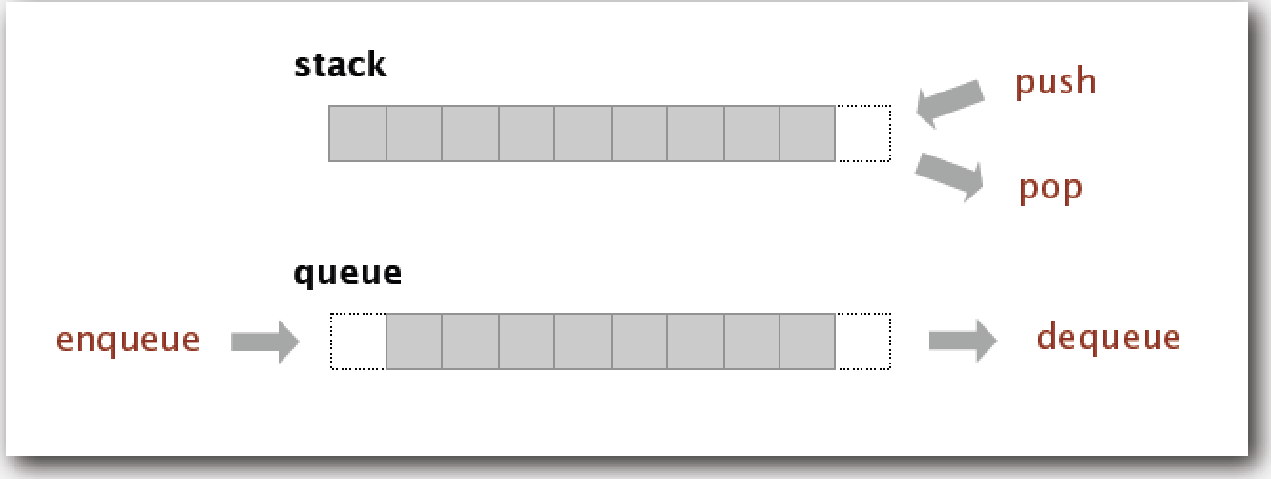
Book code

- All book code are available at
  ~cs171000/share/book
- To go to the directory from a lab machine
  cd ~cs171000/share/book
- To run a program from the directory (classpath include stdlib.jar)
  java -cp .:* Selection < tiny.txt

Stacks and queues

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).

Stacks – A Familiar Example

- A can of tennis balls
  - Imagine the entire can represents an array, and each ball is an element.
  - It only allows access to one element at a time: the last element.
  - If you remove the last element, you can then access the next-to-last element.
  - There is no way to directly access the element at the bottom.

Stacks – Another Example

- A dynamic list of tasks you perform everyday:
  - Imagine you start your day by working on task A.
  - At any time you may be interrupted by a co-worker asking you for temporary help on task B.
  - While you work on B, someone may interrupt you again for help on task C.
  - When you are done with C, you will resume working on B.
  - Then you go back to work on A.
  - Think about the sequence of tasks you perform.

Stacks – Any other examples?

Stack Examples

Stacks

- An element cannot be inserted to or accessed from the middle of the array.
- The only way you modify the elements is through the push and pop operations.

- This capability turns out to be very useful in many programming situations.
- In a computer, the stack is an essential data structure for handling program calls and returns.

Stacks

- Programmer’s tool
  - Arrays are typically used as data storage structures in apps such as a database (e.g. personal records, inventories …)
  - In contrast, stacks are often used as programmer’s tool, and are not typically used for data storage.

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.

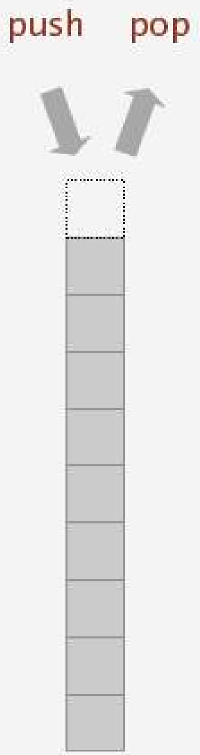
Implementation: actual code implementing operations.

Interface: description of data type, basic operations.

Stack API

Warmup API. Stack of strings data type.

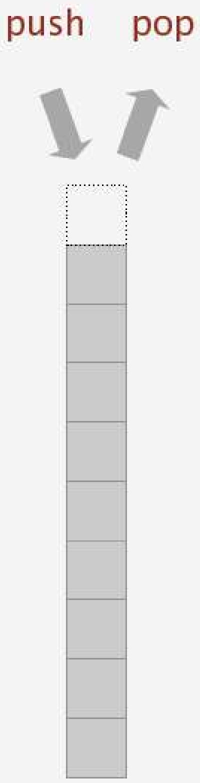
public class StackOfStrings		
	`StackOfStrings()`	*create an empty stack*
`void`	`push(String s)`	*insert a new item onto stack*
`String`	`pop()`	*remove and return the item most recently added*
`boolean`	`isEmpty()`	*is the stack empty?*
`int`	`size()`	*number of items on the stack*



Warmup client. Reverse sequence of strings from standard input.

Stack test client

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

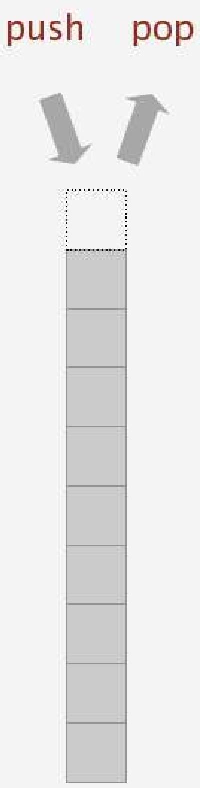


```
% more tobe.txt
to be or not to - be - - that - - - is

% java StackOfStrings < tobe.txt
```

Stack test client

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



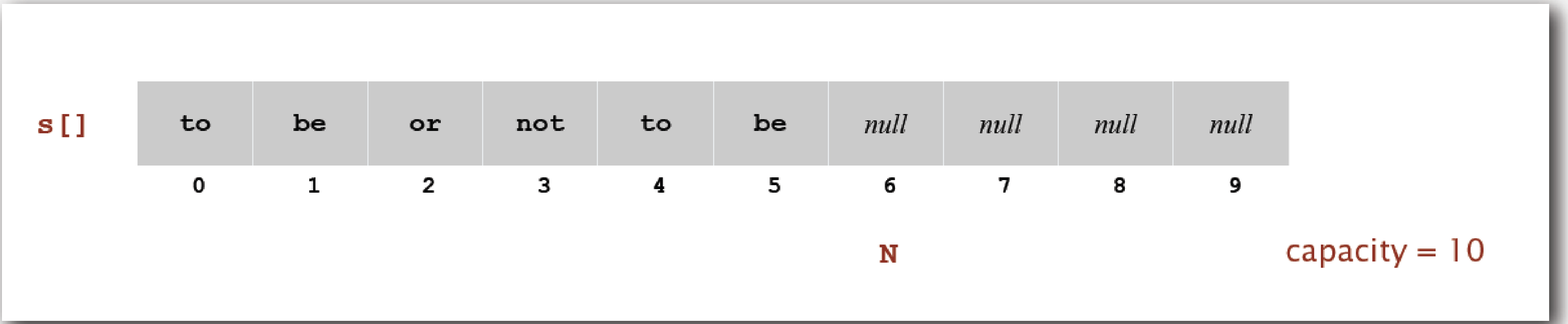
```
% more tobe.txt
to be or not to - be - - that - - - is

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

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

Stack: array implementation

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

   public FixedCapacityStackOfStrings(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];  }
}
```

a cheat (stay tuned)

use to index into array;
then increment N

decrement N;
then use to index into array

Stack: Array implementation

- Underflow: what happens if pop from an empty stack?
  - Throw exception
- Overflow: what happens if push to a full stack?
  - Use resizing array

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.

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 item 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

"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).

Stack: Array Implementation

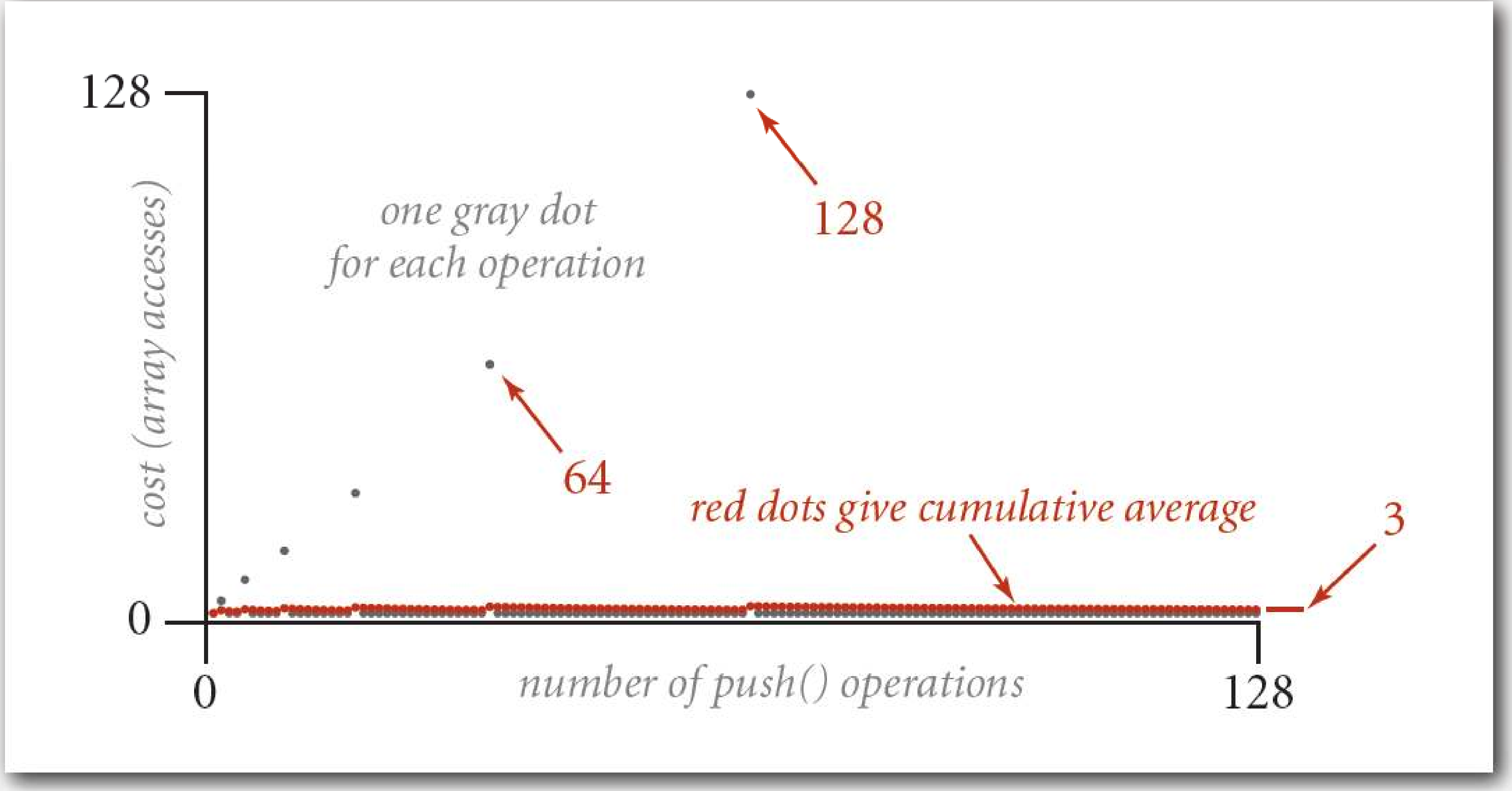
- What’s the cost of pushing/adding to a stack of size N?
  - Case 1: array resizing not required
  - Case 2: array resizing required

Stack: amortized cost of adding to a stack

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

1 array accesses 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.

Stack: resizing-array implementation

Q. How to shrink array?

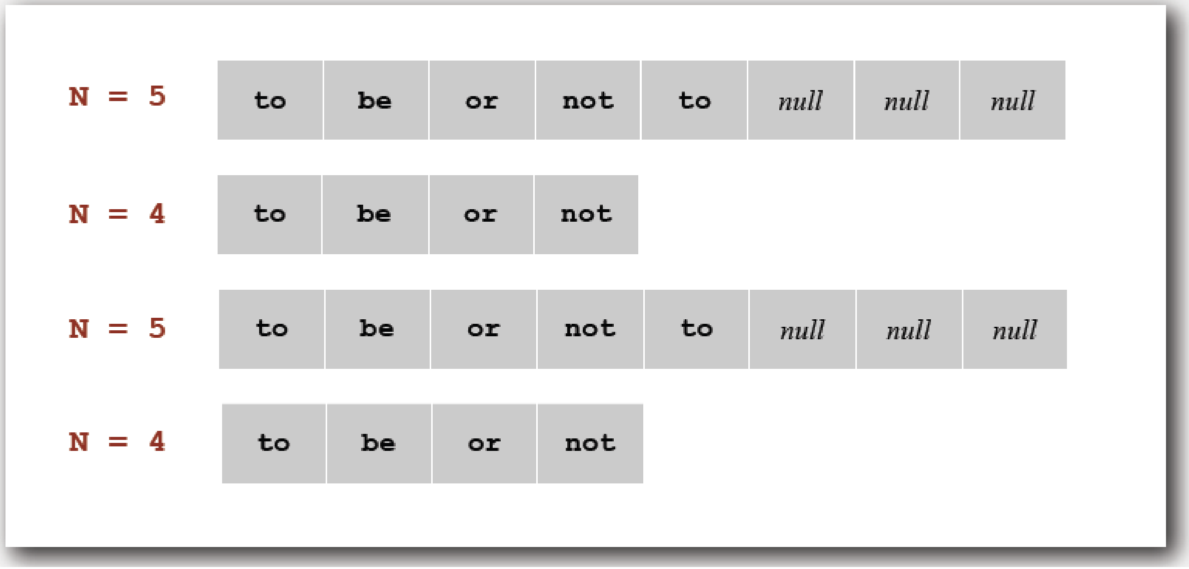
First try.

- `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.

"thrashing"

- 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: performance

Amortized analysis. 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

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

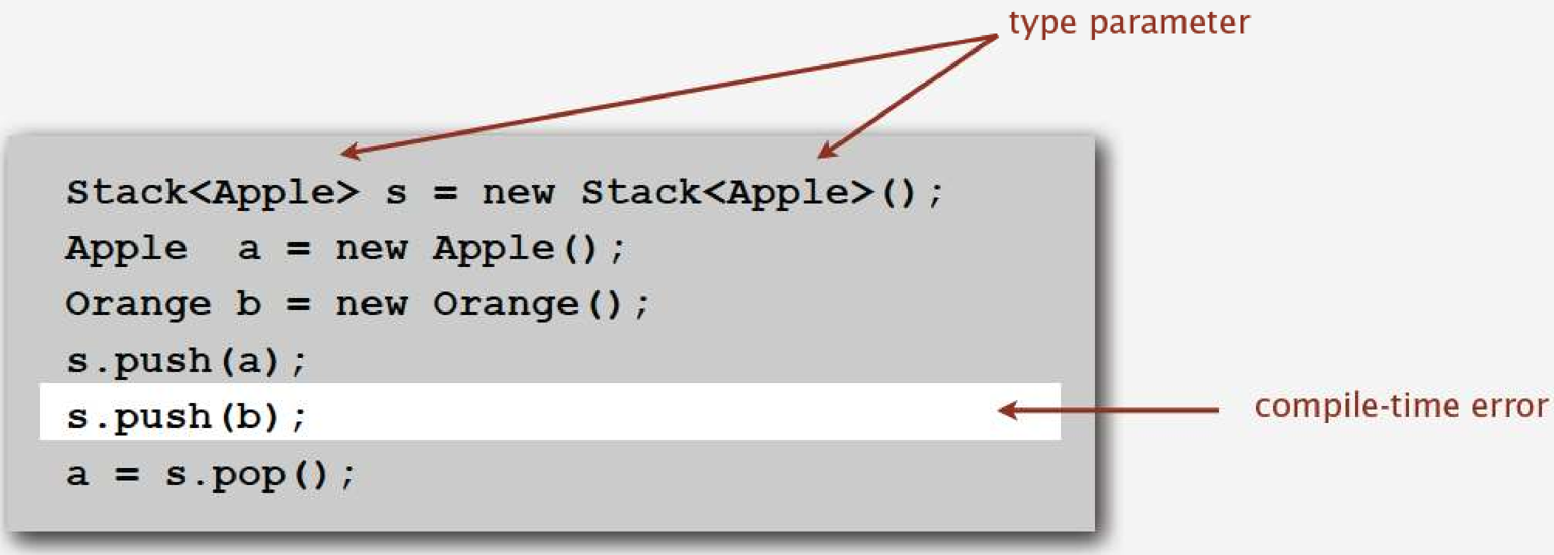
Parameterized stack

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.



type parameter

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

compile-time error

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

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

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.

Syntactic sugar. Behind-the-scenes casting.

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

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

Stack: Resizing Array Implementation

- ResizingArrayStack.java

Today

- Quick note on running book code
- Stacks

- Coming up
  - Applications using stack
  - Queues