Stacks and Queues

- stacks
- dynamic resizing
- queues
- generics
- applications

Fundamental data types.

- Values: sets of objects
- Operations: insert, remove, test if empty.
- Intent is clear when we insert.
- Which item do we remove?

LIFO = "last in first out"

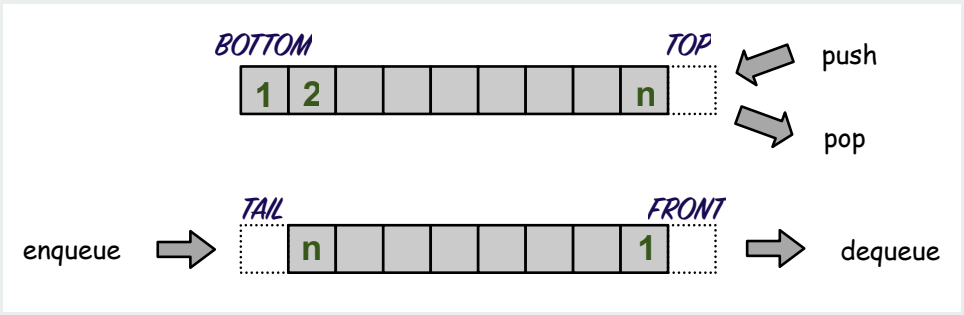
Stack.

- Remove the item most recently added.
- Analogy: cafeteria trays, Web surfing.

FIFO = "first in first out"

Queue.

- Remove the item least recently added.
- Analogy: Registrar's line.



- stacks
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Stacks

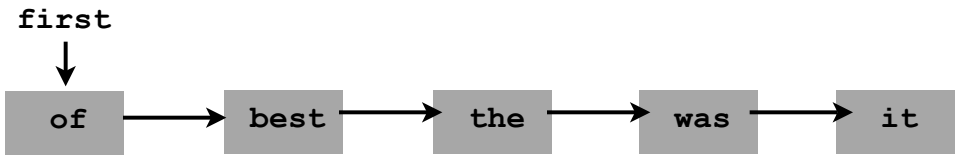
Stack operations.

- `push()` Insert a new item onto stack.
- `pop()` Remove and return the item most recently added.
- `isEmpty()` Is the stack empty?

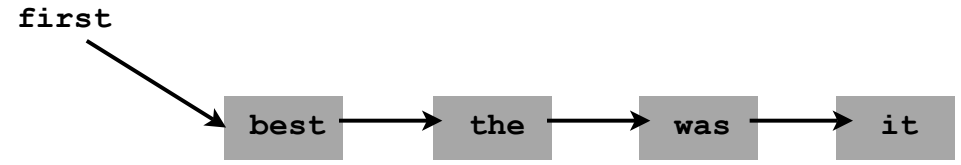

```
public static void main(String[] args)
{
   StackOfStrings stack = new StackOfStrings();
   while(!StdIn.isEmpty())
   {
      String s = StdIn.readString();
      stack.push(s);
   }
   while(!stack.isEmpty())
   {
      String s = stack.pop();
      StdOut.println(s);
   }
}
```

a sample stack client

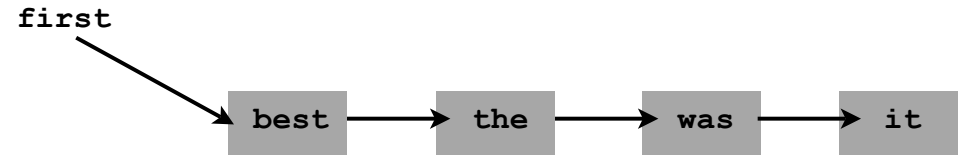
Stack pop: Linked-list implementation




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

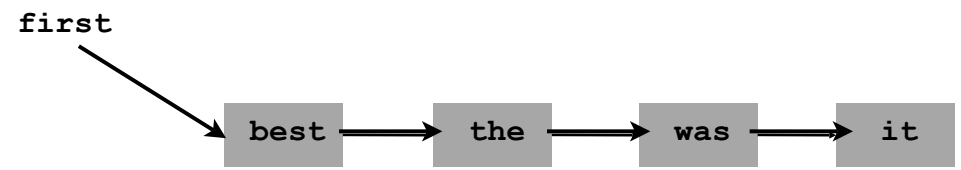


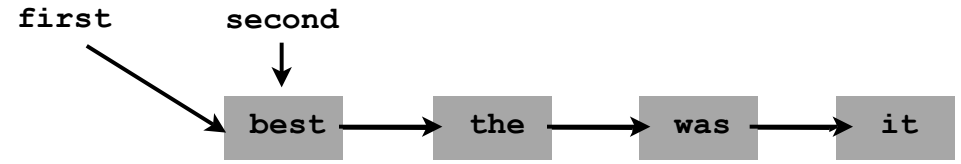

```
first = first.next;
```



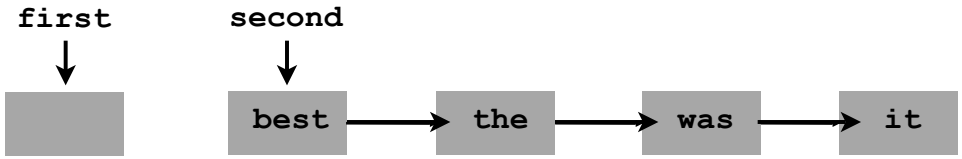

```
return item;
```

Stack push: Linked-list implementation

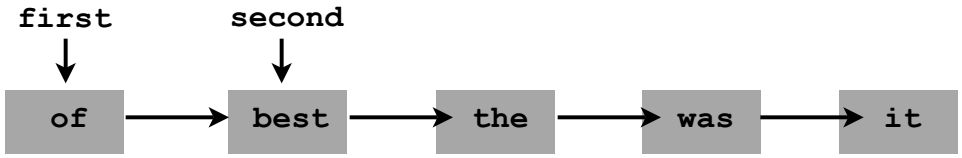





```
second = first;
```




```
first = new Node();
```




```
first.item = item;
first.next = second;
```

Stack: Linked-list implementation

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

   private class Node
   {
      String item;
      Node next;
   }

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

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

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

"inner class"

Error conditions?

Example: pop() an empty stack

COS 217: bulletproof the code

COS 226: first find the code we want to use

- stacks
- dynamic resizing
- **queues**
- generics
- applications

Queues

Queue operations.

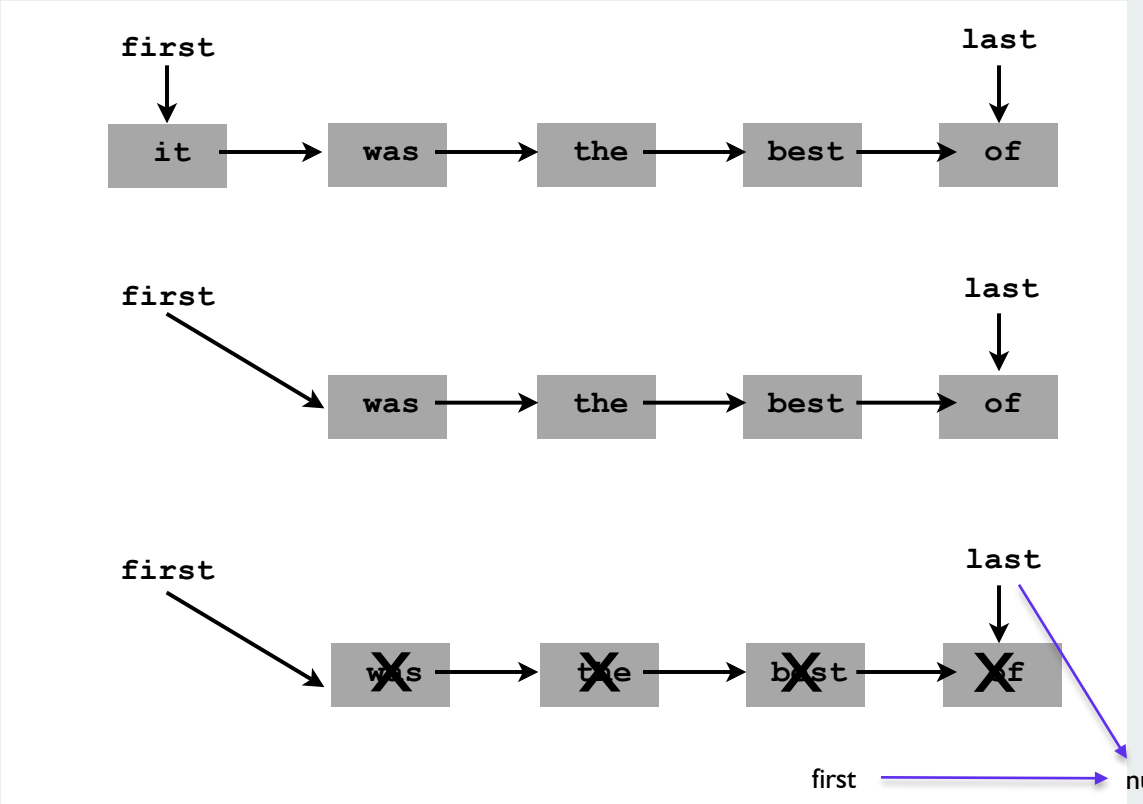
- `enqueue()` Insert a new item onto queue.
- `dequeue()` Delete and return the item least recently added.
- `isEmpty()` Is the queue empty?

```
public static void main(String[] args)
{
   QueueOfStrings q = new QueueOfStrings();
   q.enqueue("Vertigo");
   q.enqueue("Just Lose It");
   q.enqueue("Pieces of Me");
   q.enqueue("Pieces of Me");
   System.out.println(q.dequeue());
   q.enqueue("Drop It Like It's Hot");

   while(!q.isEmpty()

      System.out.println(q.dequeue());
}
```

Dequeue: Linked List Implementation




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

item = “of”

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

```
return item;
```

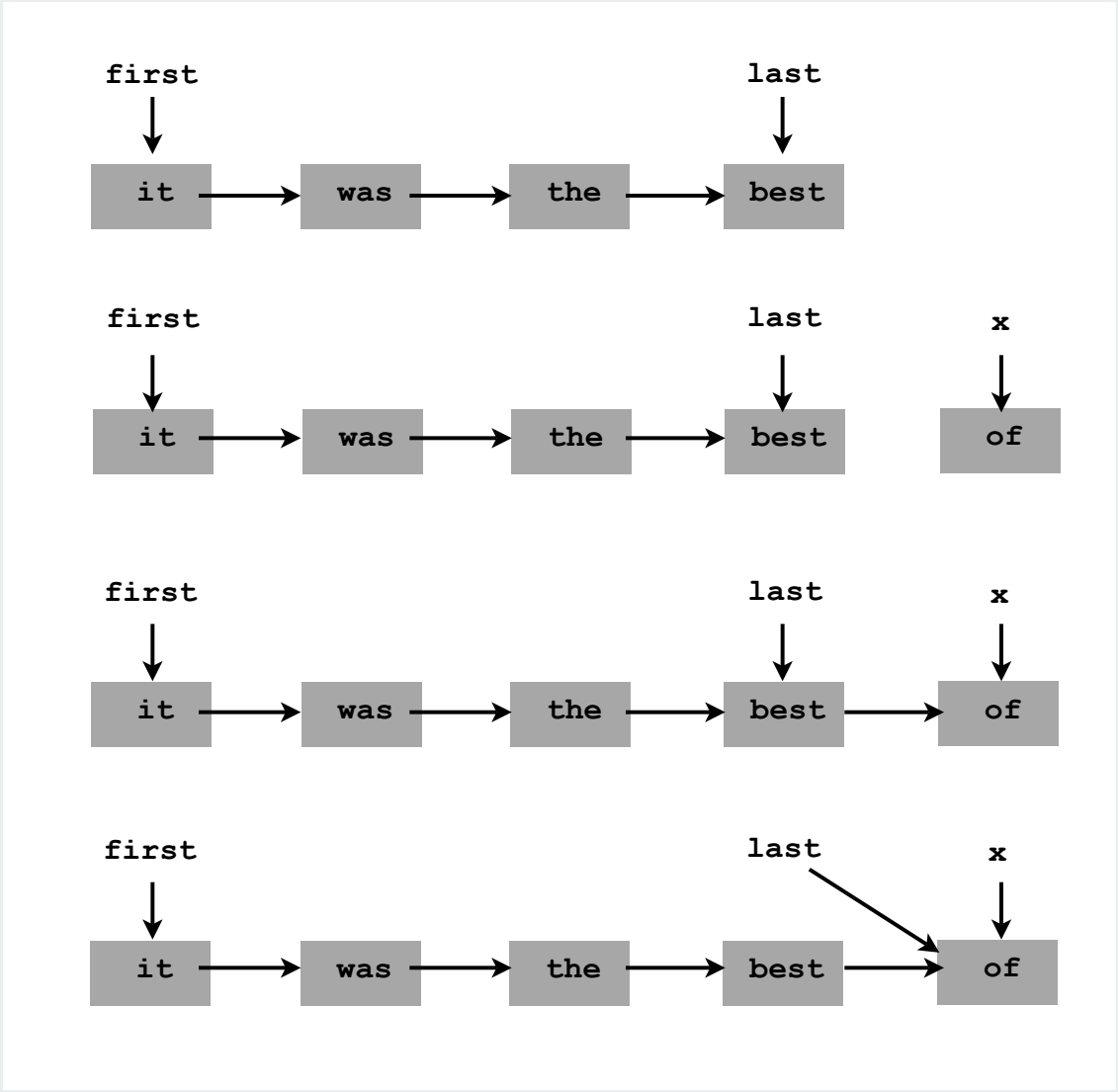
En el ultimo dqueue(), last queda apuntando todavia al ultimo nodo → if (isEmpy() last = null;

Aside:

dequeue (pronounced “DQ”) means “remove from a queue”

deque (pronounced “deck”) is a data structure (see PA 1)

Enqueue: Linked List Implementation




```
x = new Node();
x.item = item;
x.next = null;
```

```
last.next = x;
```

```
last = x;
```

Queue: Linked List Implementation

```
public class QueueOfStrings
{
   private Node first;
   private Node last;

   private class Node
   { String item; Node next; }

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

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

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

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Generics (parameterized data types)

We implemented: `StackOfStrings`, `QueueOfStrings`.

We also want: `StackOfURLs`, `QueueOfCustomers`, etc?

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 [hence, used in AlgsJava]

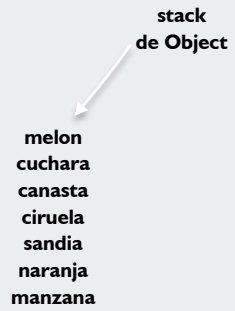
Stack of Objects

We implemented: `StackOfStrings`, `QueueOfStrings`.

We also want: `StackOfURLs`, `QueueOfCustomers`, etc?

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.



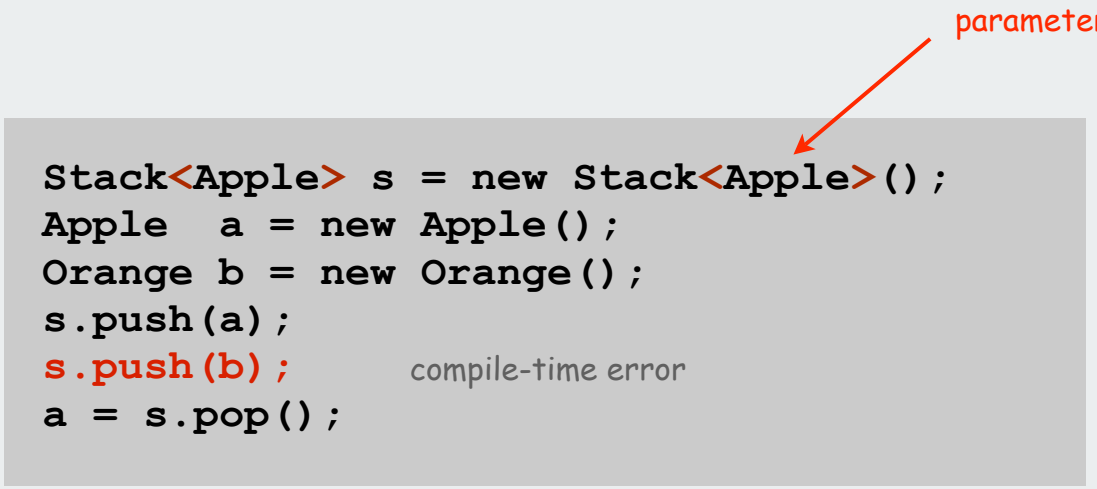

```
Stack  s = new Stack();
Apple  a = new Apple();
Orange b = new Orange();
s.push(a);
s.push(b);
a = (Apple) (s.pop());
```

run-time error

Generics

Generics. Parameterize stack by a single type.

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



Guiding principles.

- Welcome compile-time errors
- Avoid run-time errors

Why?

Generic Stack: Linked List Implementation

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

   private class Node
   {
      String item;
      Node next;
   }

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

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

   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 second = first;
      first = new Node();
      first.item = item;
      first.next = second;
   }

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

Generic type name

Generic data types: autoboxing

Generic stack implementation is object-based.

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 = ((int) s.pop()).intValue();
```

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

- stacks
- dynamic resizing
- queues
- generics
- **applications**

Stack Applications

Real world 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.

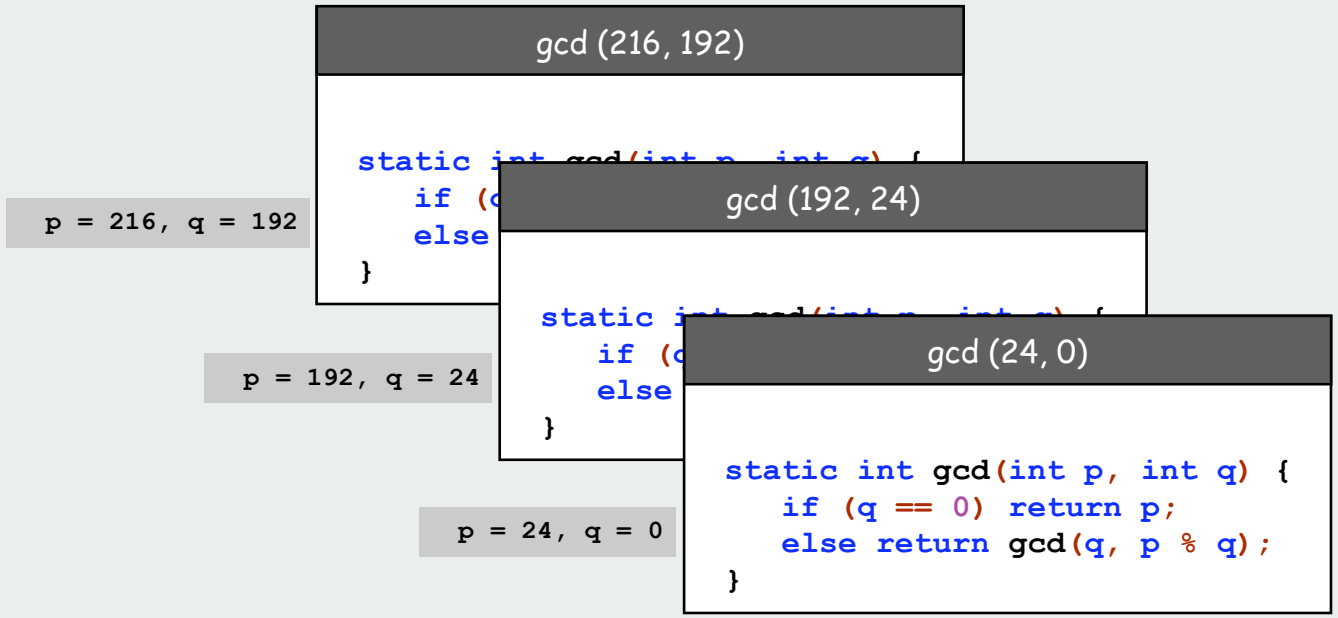
Function Calls

How a compiler implements functions.

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

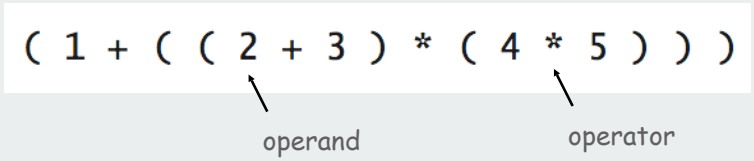
Recursive function. Function that calls itself.

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



Arithmetic Expression Evaluation

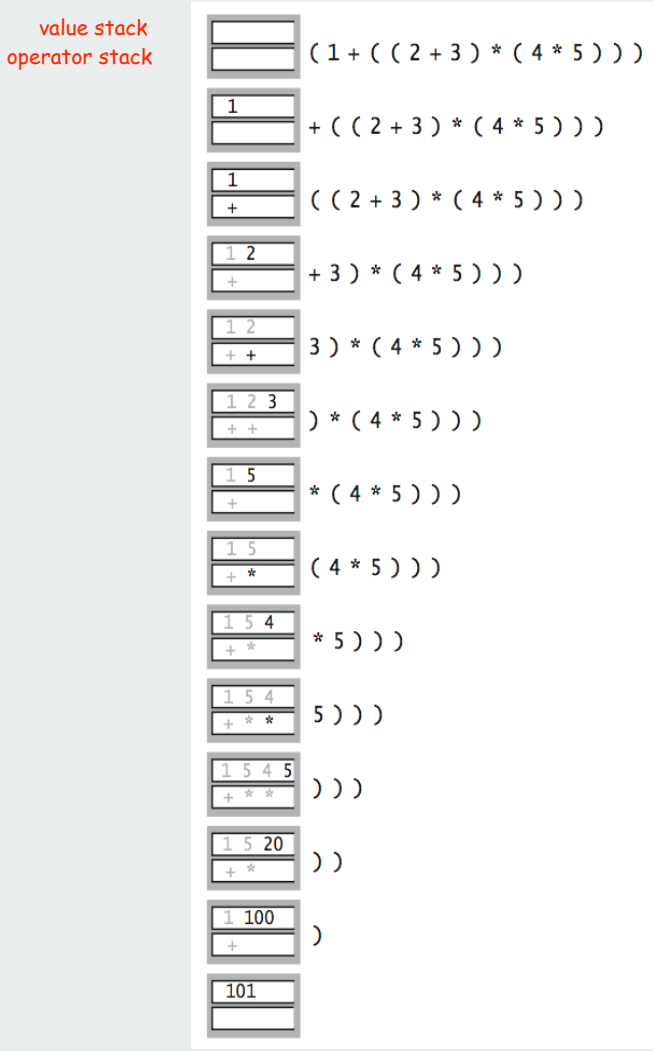
Goal. Evaluate infix expressions.



Two-stack algorithm. [E. W. Dijkstra]

- Value: push onto the value stack.
- Operator: push onto the operator stack.
- Left parens: ignore.
- Right parens: pop operator and two values; push the result of applying that operator to those values onto the operand stack.

Context. An interpreter!



Arithmetic Expression Evaluation

```
public class Evaluate {
   public static void main(String[] args) {
      Stack<String> ops  = new Stack<String>();
      Stack<Double> vals = new Stack<Double>();
      while (!StdIn.isEmpty()) {
         String s = StdIn.readString();
         if      (s.equals("("))               ;
         else if (s.equals("+"))    ops.push(s);
         else if (s.equals("*"))    ops.push(s);
         else if (s.equals(")")) {
            String op = ops.pop();
            if      (op.equals("+")) vals.push(vals.pop() + vals.pop());
            else if (op.equals("*")) vals.push(vals.pop() * vals.pop());
         }
         else vals.push(Double.parseDouble(s));
      }
      StdOut.println(vals.pop());
   }
}
```

```
% java Evaluate
( 1 + ( ( 2 + 3 ) * ( 4 * 5 ) ) )
101.0
```

Note: Old books have two-pass algorithm because generics were not available!

Stack-based programming languages

Observation 1.

Remarkably, the 2-stack algorithm computes the same value if the operator occurs after the two values.

```
( 1 ( ( 2 3 + ) ( 4 5 * ) * ) + )
```

Observation 2.

All of the parentheses are redundant!

```
1 2 3 + 4 5 * * +
```

Jan Lukasiewicz

Bottom line. Postfix or "reverse Polish" notation.

Applications. Postscript, Forth, calculators, Java virtual machine, ...

Queue applications

Familiar applications.

- iTunes playlist.
- Data buffers (iPod, TiVo).
- Asynchronous data transfer (file IO, pipes, sockets).
- Dispensing requests on a shared resource (printer, processor).

Simulations of the real world.

- Traffic analysis.
- Waiting times of customers at call center.
- Determining number of cashiers to have at a supermarket.

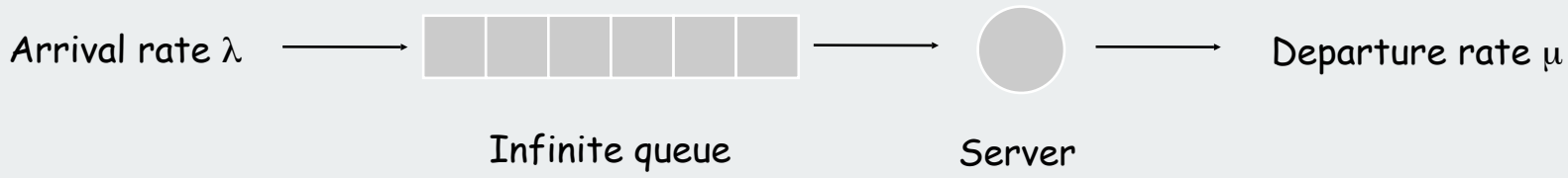
M/D/1 queuing model

M/D/1 queue.

- Customers are serviced at fixed rate of μ per minute.
- Customers arrive according to Poisson process at rate of λ per minute.

inter-arrival time has exponential distribution

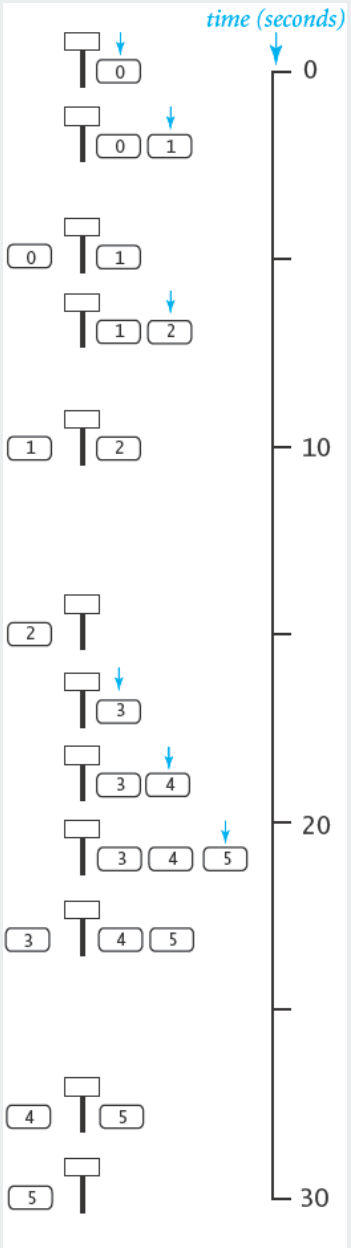
$$\Pr[X \le x] = 1 - e^{-\lambda x}$$



Q. What is average wait time W of a customer?

Q. What is average number of customers L in system?

M/D/1 queuing model: example



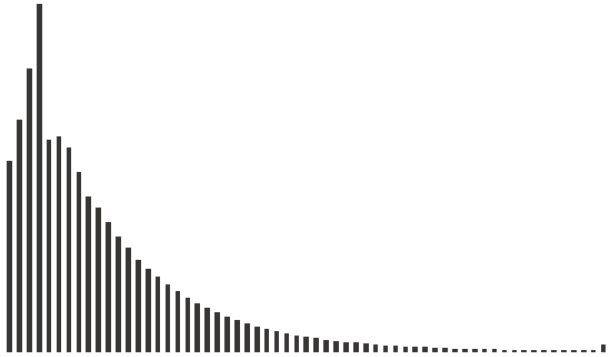
	arrival	departure	wait
0	0	5	5
1	2	10	8
2	7	15	8
3	17	23	6
4	19	28	9
5	21	30	9

M/D/1 queuing model: experiments and analysis

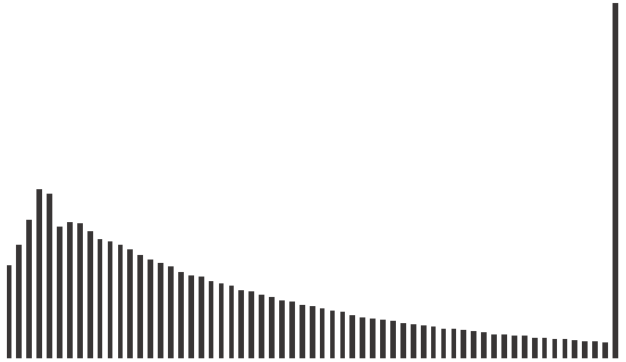
Observation.

As service rate μ approaches arrival rate λ, service goes to h***.

```
% java MD1Queue .167 .25
```



```
% java MD1Queue .167 .22
```



Queueing theory (see ORFE 309).

$$W = \frac{\lambda}{2\mu(\mu-\lambda)} + \frac{1}{\mu}, \quad L = \lambda W$$

Little's Law

wait time W and queue length L approach infinity as service rate approaches arrival rate

M/D/1 queuing model: event-based simulation

```
public class MD1Queue
{
   public static void main(String[] args)
   {
      double lambda = Double.parseDouble(args[0]);   // arrival rate
      double mu     = Double.parseDouble(args[1]);   // service rate
      Histogram hist = new Histogram(60);
      Queue<Double> q = new Queue<Double>();
      double nextArrival = StdRandom.exp(lambda);
      double nextService = 1/mu;
      while (true)
      {
         while (nextArrival < nextService)
         {
            q.enqueue(nextArrival);
            nextArrival += StdRandom.exp(lambda);
         }
         double wait = nextService - q.dequeue();
         hist.addDataPoint(Math.min(60,  (int) (wait)));
         if (!q.isEmpty())
            nextService = nextArrival + 1/mu;
         else
            nextService = nextService + 1/mu;
      }
   }
}
```