Ruby
The Big Picture

Our topic sequence:

• Functional programming with Haskell (Done!)

• Imperative and object-oriented programming using dynamic typing with Ruby

• Logic programming with Prolog

• Whatever else in the realm of programming languages that we find interesting and have time for.
Introduction
whm wrote:
> I ran into John Cropper in the mailroom a few minutes ago. He said
> he was out at your place today and that you're doing well. I
> understand you've got a meeting coming up regarding math in your
> weaving book -- sounds like fun!

Hi, William

I'm doing well in the sense of surviving longer than expected. But
I'm still a sick person without much energy and with a lot of pain.
>
> My first lecture on Ruby is tomorrow. Ruby was cooked up by a
> Japanese fellow. Judging by the number of different ways to do the
> same thing, I wonder if Japanese has a word like "no".

Interesting. I know nothing about Ruby, but I've noticed it's
getting a lot of press, so there must be something to it.
What is Ruby?

"A dynamic, open source programming language with a focus on simplicity and productivity. It has an elegant syntax that is natural to read and easy to write." — ruby-lang.org

Ruby is commonly described as an "object-oriented scripting language".
(I don't like the term "scripting language"!)

I describe Ruby as a dynamically typed object-oriented language.

Ruby was invented by Yukihiro Matsumoto ("Matz"), a "Japanese amateur language designer", in his own words.

Ruby on Rails, a web application framework, has largely driven Ruby's popularity.
Here is a second-hand excerpt of a posting by Matz:
"Well, Ruby was born on February 24, 1993. I was talking with my colleague about the possibility of an object-oriented scripting language. I knew Perl (Perl4, not Perl5), but I didn't like it really, because it had smell of toy language (it still has). The object-oriented scripting language seemed very promising."

Another quote from Matz:
"I believe that the purpose of life is, at least in part, to be happy. Based on this belief, Ruby is designed to make programming not only easy but also fun. It allows you to concentrate on the creative side of programming, with less stress. If you don’t believe me, read this book [the "pickaxe" book] and try Ruby. I’m sure you’ll find out for yourself."
There is no written standard for Ruby. The language is effectively defined by MRI—Matz' Ruby Implementation.

The most recent stable version of MRI is 2.3.0.

The default version of Ruby on lectura is 1.8.7 but we'll use rvm (the Ruby Version Manager) to run version 2.2.4.

OS X, from Mavericks to El Capitan, has Ruby 2.0.0.

The last major upheaval in Ruby occurred between 1.8 and 1.9.

In general, there are few incompatibilities between 1.9.3 and the latest version.

The examples in these slides should work with with 1.9.3 through 2.3.0.
The Ruby Programming Language by David Flanagan and Matz
- Perhaps the best book on Safari that covers 1.9 (along with 1.8)
- I'll refer to it as "RPL".

Programming Ruby 1.9 & 2.0 (4th edition): The Pragmatic Programmers' Guide by Dave Thomas, with Chad Fowler and Andy Hunt
- Known as the "Pickaxe book"
- $28 for a DRM-free PDF at pragprog.com.
- I'll refer to it as "PA".
- First edition is here: http://ruby-doc.com/docs/ProgrammingRuby/

Safari has lots of pre-1.9 books, lots of books that teach just enough Ruby to get one into the water with Rails, and lots of "cookbooks".
ruby-lang.org
  • Ruby's home page

ruby-doc.org
  • Documentation

  • Here's a sample URL, for the String class in 2.2.4:
    http://ruby-doc.org/core-2.2.4/String.html

  • Suggestion: Create a Chrome "search engine" named rc ("Ruby class") with this expansion:
    http://www.ruby-doc.org/core-2.2.4/%s.html
    (See http://www.cs.arizona.edu/~whm/o1nav.pdf)
Ruby 2.0.0, as supplied by Apple with recent versions of OS X, should be fine for our purposes.

I installed Ruby 2.2.0 on my Mac using MacPorts. The "port" is `ruby22`.

Lot of people install Ruby versions using the Homebrew package manager, too.
Getting Ruby for Windows

Go to http://rubyinstaller.org/downloads/ and get "Ruby 2.2.4" (not x64)

When installing, I recommend these selections:
Add Ruby executables to your PATH
Associate .rb and .rbw files with this Ruby installation
Running Ruby
rvm—Ruby Version Manager

rvm is the Ruby Version Manager. It lets one easily select a particular version of Ruby to work with.

On lectura, we can select Ruby 2.2.4 and then check the version like this:

% rvm 2.2.4
% ruby --version
ruby 2.2.4p230 (2015-12-16 revision 53155) [x86_64-linux]

Depending on your bash configuration, rvm may produce a message like "Warning! PATH is not properly set up..." but if ruby --version shows 2.2.4, all is well.

Note: rvm does not work with ksh. If you're running ksh, let us know.
**IMPORTANT**: you must either

1. Do `rvm 2.2.4` each time you login on lectura.
   —OR—

2. Add the command `rvm 2.2.4` to one of your bash start-up files.

There are a variety of ways in which bash start-up files can be configured.

- With the default configuration for CS accounts, add the line
  
  `rvm 2.2.4 >& /dev/null`

  at the end of your `~/.profile`.

- If you're using the configuration suggested in my Fall 2015 352 slides, put that line at the end of your `~/.bashrc`.

- Let us know if you have trouble with this.
The `irb` command provides a REPL for Ruby.

`irb` can be run with no arguments but I usually start `irb` with a `bash` alias that specifies using a simple prompt and activates auto-completion:

```
alias irb="irb --prompt simple -r irb/completion"
```

When `irb` starts up, it first processes `~/ .irbrc`, if present.

`spring16/ruby/dotirbrc` is a recommended starter `~/ .irbrc` file.

```
% cp /cs/www/classes/cs372/spring16/ruby/dotirbrc ~/.irbrc
```

Control-D terminates `irb`. 
irb evaluates expressions as they are typed.

```
% irb
>> 1+2
=> 3

>> "testing" + "123"
=> "testing123"
```

Assuming you're using the ~/.irbrc suggested on the previous slide, you can use "it" to reference the last result:

```
>> it
=> "testing123"

>> it + it
=> "testing123testing123"
```
A couple more:

```ruby
>> `ssh lec uptime`
=> "18:00:58 up 10 days, 9:00, 99 users, load average: 0.50, 0.32, 0.32\n"
```

```ruby
>> it[-26,8]
=> "average:"
```

If an expression is definitely incomplete, irb displays an alternate prompt:

```ruby
>> 1.23 +
?> 2e3
=> 2001.23
```

Note: To save space on the slides I'll typically not show the result line (=> ...) when it's uninteresting.
Ruby basics
Every value is an object

In Ruby every value is an object.

Methods can be invoked using `receiver.method(parameters...)`

```ruby
>> "testing".count("t")      # How many "t"s are there?
 => 2

>> "testing".slice(1,3)
 => "est"

>> "testing".length()
 => 7
```

Repeat: In Ruby every value is an object.

What are some values in Java that are not objects?
Everything is an object, continued

Of course, "everything" includes numbers:
   >> 1.2.class()
   => Float

   >> (10-20).class()
   => Fixnum

   >> 17**25
   => 5770627412348402378939569991057

   >> it.succ()  # Remember: the custom .irbc is needed to use "it"
   => 5770627412348402378939569991058

   >> it.class()
   => Bignum
Everything is an object, continued

The TAB key can be used to show completions:

>> 100.<TAB><TAB>
Display all 107 possibilities? (y or n)
100.__id__               100.display
100.__send__             100.div
100.abs                  100.divmod
100.abs2                 100.downto
100.angle                100.dup
100.arg                  100.enum_for
100.between?             100.eql?
100.ceil                 100.equal?
100.chr                  100.even?
100.class                100.extend
100.clone                100.fdiv
100.coerce               100.floor
100.conj                 100.freeze
100.conjugate            100.frozen?
100.define_singleton_method 100.gcd
100.denominator          100.gcdlcm
Parentheses are optional, sometimes

Parentheses are often optional in method invocations:

```
>> 1.2.class
=> Float

>> "testing".count "aeiou"
=> 2
```

But, the following case fails. (Why?)

```
>> "testing".count "aeiou".class
TypeError: no implicit conversion of Class into String
from (irb):17:in `count'
```

Solution:

```
>> "testing".count("aeiou").class
=> Fixnum
```

I usually omit parentheses in simple method invocations.
A post-Haskell hazard!

Don't let the optional parentheses make you have a Haskell moment and leave out a comma between arguments:

```
>> "testing".slice 2 3
SyntaxError: (irb):20: syntax error, unexpected tINTEGER,
expecting end-of-input
```

Commas are required between arguments!

```
>> "testing".slice 2,3
=> "sti"
```
Operators are methods, too

Ruby operators are methods with symbolic names.

In general, 

```
expr1 op expr2
```

means 

```
expr1.op(expr2)
```

Example: 

```
>> 3 + 4
=> 7

>> 3.+(4)
=> 7

>> "abc".==(97.chr.+("bc"))
=> true
```
The **Kernel** module has methods for I/O and more. Methods in **Kernel** can be invoked with only the method name.

```
>> puts "hello"
hello
=> nil

>> printf "sum = %d, product = %d\n", 3+4, 3 * 4
sum = 7, product = 12
=> nil

>> puts gets.inspect
testing
"testing\n"
=> nil
```

See [http://ruby-doc.org/core-2.2.4/Kernel.html](http://ruby-doc.org/core-2.2.4/Kernel.html)
Extra Credit Assignment 2

For two assignment points of extra credit:

1. Run **irb** somewhere and try ten Ruby expressions with some degree of variety.

2. Capture the output and put it in a plain text file, eca2.txt. No need for your name, NetID, etc. in the file. No need to edit out errors.

3. On lectura, turn in eca2.txt with the following command:
   
   % turnin 372-eca2 eca2.txt

Due: At the start of the next lecture after we hit this slide.

 Needless to say, feel free to read ahead in the slides and show experimentation with the following material, too.

CSC 372 Spring 2016, Ruby Slide 26
Executing Ruby code in a file

The **ruby** command can be used to execute Ruby source code contained in a file.

By convention, Ruby files have the suffix `.rb`.

Here is "Hello" in Ruby:

```ruby
% cat hello.rb
puts "Hello, world!"

% ruby hello.rb
Hello, world!
```

Note that the code does not need to be enclosed in a method—"top level" expressions are evaluated when encountered.
Alternatively, code can be placed in a method that is invoked by an expression at the top level:

```ruby
% cat hello2.rb
def say_hello
  puts "Hello, world!"
end

say_hello
%
% ruby hello2.rb
Hello, world!
```

The definition of `say_hello` must precede the call.

We'll see later that Ruby is somewhat sensitive to newlines.
A line-numbering program

Here's a program that reads lines from standard input and writes each, with a line number, to standard output:

```
line_num = 1     # numlines.rb

while line = gets
    printf("%3d: %s", line_num, line)
    line_num += 1   # Ruby does not have ++ and --
end
```

Execution:

```
% ruby numlines.rb < hello2.rb
 1: def say_hello
 2:     puts "Hello, world!"
 3: end
 4:
 5: say_hello
```
Problem: Write a program that reads lines from standard input and writes them in reverse order to standard output. Use only the Ruby you've seen.

For reference, here's the line-numbering program:

```ruby
line_num = 1
while line = gets
  printf("%3d: %s", line_num, line)
  line_num += 1
end
```

Solution: (spring16/ruby/tac.rb)

```ruby
reversed = ""
while line = gets
  reversed = line + reversed
end
puts reversed
```
Some basic types
The value `nil`

`nil` is Ruby's "no value" value. The name `nil` references the only instance of the class.

```ruby
>> nil
=> nil

>> nil.class
=> NilClass

>> nil.object_id
=> 4
```

We'll see that Ruby uses `nil` in a variety of ways.

Speculate: Do uninitialized variables have the value `nil`?

```ruby
>> x
NameError: undefined local variable or method `x' for main
```

**TODO**

- `x = 1 if false`
- `p x # outputs nil`

It seems like the presence of an assignment for `x` causes a reference to `x` to produce `nil` if no assignment is ever done.
Strings and string literals

Instances of Ruby's `String` class represent character strings.

A variety of "escapes" are recognized in double-quoted string literals:

```ruby
>> puts "newline >\n< and tab >\t<"
newline >
< and tab >   <

>> "\n\t".length
=> 3

>> "Newlines: octal \012, hex \xa, control-j \cj"
=> "Newlines: octal \n, hex \n, control-j \n"
```

Section 3.2, page 49 in RPL has the full list of escapes.
String literals, continued

In single-quoted literals only \ and \ \ are recognized as escapes:

```
>> puts '\n\t'
\n\t
=> nil

>> '\n\t'.length  # Four chars: backslash, n, backslash, t
=> 4

>> puts '\\\\'
\\
=> nil

>> '\\\\'.length  # Two characters: apostrophe, backslash
=> 2
```
**String** has a lot of methods

The **public_methods** method shows the public methods that are available for an object. Here are some of the methods for **String**:

```ruby
>> "abc".public_methods.sort
    :>, :>=, :[], :[]=, :___id___, :___send___, :ascii_only?,
    :casecmp, :center, :chars, :chomp, :chomp!, :chop, :chop!, :chr,

>> "abc".public_methods.length
=> 169
```
Strings are mutable

Unlike Java, Haskell, and many other languages, strings in Ruby are mutable.

If two variables reference a string and the string is changed, the change is reflected by both variables:

```ruby
>> x = "testing"

>> y = x # x and y now reference the same instance of String

>> y << " this" # the << operator appends a string
=> "testing this"

>> x
=> "testing this"
```

Is it a good idea to have mutable strings?
Strings are mutable, continued

The `dup` method produces a copy of a string.

```ruby
>> x = "testing"
>> y = x.dup
=> "testing"

>> y << "...more"
=> "testing...more"

>> y
=> "testing...more"

>> x
=> "testing"
```

Some objects that hold strings `dup` the string when the string is added to the object.
Sidebar: applicative vs. imperative methods

Some methods have both an *applicative* and an *imperative* form.

**String**'s `upcase` method is applicative—it produces a new String but doesn't change its *receiver*, the instance of String on which it's called:

```
>> s = "testing"
=> "testing"

>> s.upcase
=> "TESTING"

>> s
=> "testing"
```
applicative vs. imperative methods, continued

In contrast, an imperative method potentially changes its receiver.

String's `upcase!` method is the imperative counterpart to `upcase`:

```ruby
>> s.upcase!
=> "TESTING"
```

```ruby
>> s
=> "TESTING"
```

A Ruby convention is that when methods have both an applicative and an imperative form, the imperative form ends with an exclamation mark.
String comparisons

Strings can be compared with a typical set of operators:

```ruby
>> s1 = "apple"

>> s2 = "testing"

>> s1 == s2
=> false

>> s1 != s2
=> true

>> s1 < s2
=> true

We'll talk about details of true and false later.
```
There is also a *comparison operator*: `<=>

It produces -1, 0, or 1 depending on whether the first operand is less than, equal to, or greater than the second operand.

>>> "apple" <=> "testing"
=> -1

>>> "testing" <=> "apple"
=> 1

>>> "x" <=> "x"
=> 0

This operator is sometimes read as "spaceship".
Substrings

Subscripting a string with a number produces a one-character string.

```ruby
>> s="abcd"

>> s[0]    # Positions are zero-based
=> "a"

>> s[1]    
=> "b"

>> s[-1]   # Negative positions are counted from the right
=> "d"

>> s[100]  # An out-of-bounds reference produces nil
=> nil
```

Historical note: With Ruby versions prior to 1.9, "abc"[0] is 97.

Why doesn't Java provide s[n] instead of s.charAt(n)?
A subscripted string can be the target of an assignment. A string of any length can be assigned.

```ruby
>> s = "abc"
=> "abc"

>> s[0] = 65.chr
=> "A"

>> s[1] = "tomi"

>> s
=> "Atomic"

>> s[-3] = ""

>> s
=> "Atoic"
```
A substring can be referenced with 
s[start, length]

```ruby
>> s = "replace"
"replace"

>> s[2,3]
=> "pla"

>> s[3,100] # Note too-long behavior!
=> "lace"

>> s[-4,3]
=> "lac"

>> s[10,10]
=> nil
```
Substrings with ranges

Instances of Ruby's **Range** class represent a range of values. A **Range** can be used to reference a substring.

```ruby
gem> r = 2..-2
=> 2..-2

gem> r.class
=> Range

>> s = "replaced"

>> s[r]
=> "place"

>> s[r] = ""

>> s
=> "red"
```
Substrings with ranges, continued

It's more common to use literal ranges with strings:

```
>> s = "rebuilding"
>> s[2..-1]
=> "building"
```

```
>> s[2..-4]
=> "build"
```

```
>> s[2...-4] # three dots is "up to"
=> "bui"  

```

```
>> s[-8..-4]
=> "build"
```

```
>> s[-4..-8]
=> ""
```
A substring can be the target of an assignment:

```ruby
>> s = "replace"

>> s[0,2] = ""
=> ""

>> s
=> "place"

>> s[3..-1] = "naria"

>> s
=> "planaria"

>> s["aria"] = "kton" # If "aria" appears, replace it (error if not).
=> "kton"

>> s
=> "plankton"
```

Changing substrings
Interpolation in string literals

In a string literal enclosed with double quotes the sequence #{expr} causes interpolation of expr, an arbitrary Ruby expression.

```ruby
>> x = 10

>> y = "twenty"

>> s = "x = #{x}, y + y = #{y + y}"
=> "x = 10, y + y = twentytwenty"

>> puts "There are #{"".public_methods.length} string methods"
There are 169 string methods

>> "test #{"#{"abc".length\*4}"}"  # Arbitrary nesting works
=> "test 12"
```

It's idiomatic to use interpolation rather than concatenation to build a string from multiple values.
With 2.2.4 on lectura, integers in the range \( -2^{62} \) to \( 2^{62}-1 \) are represented by instances of **Fixnum**. If an operation produces a number outside of that range, the value is represented with a **Bignum**.

```
>> x = 2**62-1
=> 4611686018427387903

>> x.class
=> Fixnum

>> x += 1
=> 4611686018427387904

>> x.class
=> Bignum

>> x -= 1
=> 4611686018427387903

>> x.class
=> Fixnum
```

Is this automatic transitioning between **Fixnum** and **Bignum** a good idea? How do other languages handle this?
The **Float** class represents floating point numbers that can be represented by a double-precision floating point number on the host architecture.

```
>> x = 123.456
=> 123.456

>> x.class
=> Float

>> x ** 0.5
=> 11.111075555498667

>> x = x / 0.0
=> Infinity

>> (0.0/0.0).nan?
=> true
```
Arithmetic on two **Fixnum**s produces a **Fixnum**.

```ruby
>> 2/3
=> 0
```

```ruby
>> it.class
=> Fixnum
```

**Fixnum**s and **Float**s can be mixed. The result is a **Float**.

```ruby
>> 10 / 5.1
=> 1.9607843137254903
```

```ruby
>> 10 % 4.5
=> 1.0
```

```ruby
>> it.class
=> Float
```
Ruby has a `Complex` type.

```
>> x = Complex(2,3)
=> (2+3i)

>> x * 2 + 7
=> (11+6i)

>> Complex 'i'
=> (0+1i)

>> it ** 2
=> (-1+0i)
```
There's **Rational**, too.

```ruby
>> Rational(1,3)
=> (1/3)

>> it * 300
=> (100/1)

>> Rational 0.5
=> (1/2)

>> Rational 0.6
=> (5404319552844595/9007199254740992)

>> Rational 0.015625
=> (1/64)
```
Unlike some languages, Ruby does not automatically convert strings to numbers and numbers to strings as needed.

```ruby
>> 10 + "20"
TypeError: String can't be coerced into Fixnum
```

The methods `to_i`, `to_f`, and `to_s` are used to convert values to Fixnums, Floats and Strings, respectively.

```ruby
>> 10.to_s + "20"
=> "1020"

>> 10 + "20".to_f
=> 30.0

>> 10 + 20.9.to_i
=> 30
```
Arrays

A sequence of values is typically represented in Ruby by an instance of `Array`.

An array can be created by enclosing a comma-separated sequence of values in square brackets:

```ruby
>> a1 = [10, 20, 30]
=> [10, 20, 30]

>> a2 = ["ten", 20, 30.0, 2**40]
=> ["ten", 20, 30.0, 1099511627776]

>> a3 = [a1, a2, [[a1]]]
=> [[10, 20, 30], ["ten", 20, 30.0, 1099511627776], [[[10, 20, 30]]]]
```

What's a difference between Ruby arrays and Haskell lists?
Array elements and subarrays (sometimes called slices) are specified with a notation like that used for strings.

```ruby
>> a = [1, "two", 3.0, %w{a b c d}]
=> [1, "two", 3.0, ["a", "b", "c", "d"]]

>> a[0]
=> 1

>> a[1,2]        # a[start, length]
=> ["two", 3.0]

>> a[-1]
=> ["a", "b", "c", "d"]

>> a[-1][-2]
=> "c"
```
Elements and subarrays can be assigned to. Ruby accommodates a variety of cases; here are some:

```ruby
>> a = [10, 20, 30, 40, 50, 60]
>> a[1] = "twenty"; a
=> [10, "twenty", 30, 40, 50, 60]
>> a[2..4] = %w{a b c d e}; a
=> [10, "twenty", "a", "b", "c", "d", "e", 60]
>> a[1..-1] = []; a
=> [10]
>> a[0] = [1,2,3]; a
=> [[1, 2, 3]]
>> a[4] = [5,6]; a
=> [[1, 2, 3], nil, nil, nil, [5, 6]]
>> a[0,2] = %w{a bb ccc}; a
=> ["a", "bb", "ccc", nil, nil, [5, 6]]
```
Arrays, continued

A variety of operations are provided for arrays. Here's a sampling:

```ruby
>> a = []

>> a << 1; a
=> [1]

>> a << [2,3,4]; a
=> [1, [2, 3, 4]]

>> a.reverse!; a
=> [[2, 3, 4], 1]
```
A few more:

```ruby
>> a
=> [[2, 3, 4], 1]

>> a[0].shift
=> 2

>> a
=> [[3, 4], 1]

>> a.unshift "a","b","c"
=> ["a","b","c", [3, 4], 1]

>> a.shuffle.shuffle
=> ["a", [3, 4], "b", "c", 1]
```
Even more!

```ruby
>> a = [1,2,3,4]; b = [1,3,5]

>> a + b
=> [1, 2, 3, 4, 1, 3, 5]

>> a - b
=> [2, 4]

>> a & b
=> [1, 3]

>> a | b
=> [1, 2, 3, 4, 5]

>> ('a..'.'zzz').to_a.size
=> 18278
```
Comparing arrays

We can compare arrays with `==` and `!=`. Elements are compared in turn, possibly recursively.

```ruby
>> [1,2,3] == [1,2]
=> false

>> [1,2,[3,"bcd"]]] == [1,2] + [[3, "abcde"]]
=> false

>> [1,2,[3,"bcd"]]] == [1,2] + [[3, "abcde"[1..-2]]]
=> true
```
Comparing arrays

Comparison of arrays with \( <= \) is lexicographic.

\[
\begin{align*}
\text{>> } [1,2,3,4] & \stackrel{\_\_\_\_\_\_}{\text{ <=> }} [1,2,10] \\
& \Rightarrow -1
\end{align*}
\]

\[
\begin{align*}
\text{>> } [[10,20],[2,30],[5,"x"]].\text{sort} \\
& \Rightarrow [[2, 30], [5, "x"], [10, 20]]
\end{align*}
\]
Comparing arrays

Comparison with `<=>` produces `nil` if differing types are encountered.

```ruby
>> [1,2,3,4] <=> [1,2,3,"four"]
=> nil

```

Here's a simpler failing case. Should it be allowed?

```ruby
>> ["sixty",20,"two"].sort
ArgumentError: comparison of String with 20 failed
```
Comparing arrays, continued
At hand:
>> ["sixty",20,"two"].sort
ArgumentError: comparison of String with 20 failed
Contrast with Icon:
][ sort(["sixty",20,"two"])
r := [20,"sixty","two"] (list)
][ sort([3.0, 7, 2, "a", "A", ":", [2], [1], -1.0])
r := [2, 7, -1.0, 3.0, ":", "A", "a", [2], [1]] (list)
What does Icon do better? What does Icon do worse?
Here's Python 2:
>>> sorted([3.0, 7, 2, "a", "A", ":", [2], [1], -1.0])
[-1.0, 2, 3.0, 7, [1], [2], ':', 'A', 'a']
CSC#372#Spring#2016,#Ruby#Slide#64#


An array can hold a reference to itself:

```ruby
>> a = [1,2,3]
>> a.push a
=> [1, 2, 3, [...]]

>> a.size
=> 4

>> a[-1]
=> [1, 2, 3, [...]]

>> a[-1][-1][-1]
=> [1, 2, 3, [...]]
```

Arrays can be cyclic:

```ruby
>> a << 10
=> [1, 2, 3, [...], 10]

>> a[-2][-1]
=> 10
```
Type Checking
"The Java programming language is a statically typed language, which means that every variable and every expression has a type that is known at compile time."

-- The Java Language Specification, Java SE 7 Edition

Assume the following:

```
int i = ...; String s = ...; Object o = ...; static int f(int n);
```

What are the types of the following expressions?

- `i + 5`
- `i + s`
- `s + o`
- `o + o`
- `o.hashCode()`
- `f(i.hashCode())`
- `i = i + s`

Did we need to know any values or execute any code to determine those types?
Static typing, continued

Java does type checking based on the declared types of variables and the intrinsic types of literals.

Haskell supports type declarations but also provides type inferencing.

What are the inferred types for \(x\), \(y\), and \(z\) in the following expression?

\[(\text{isLetter } \$ \text{head } \$ [x] ++ y) \&\& z\]

> let \(f\) \(x\) \(y\) \(z\) = (\text{isLetter } \$ \text{head } \$ [x] ++ y) \&\& z

\(f :: \text{Char} -> \text{[Char]} -> \text{Bool} -> \text{Bool}\)

Did we need to know any values or execute any code to determine those types?

Haskell is a statically typed language—the type of every expression can be determined by analyzing the code.
Static typing, continued

With a statically typed language, the type for all expressions is determined when a body of code is compiled/loaded/etc. Any type inconsistencies that exist are discoverable at that time.

Without having to run any code a statically typed language lets us guarantee that various types of errors don't exist. Examples:

- Dividing a string by a float
- Taking the "head" of an integer
- Concatenating two numbers
- Putting an integer in a list of strings
Static typing, continued

How often did your Haskell code run correctly as soon as the type errors were fixed?

How does that compare with your experience with Java?
   With C?
   With Python?

"The best news is that Haskell's type system will tell you if your program is well-typed before you run it. This is a big advantage because most programming errors are manifested as typing errors."—Paul Hudak, Yale

Do you agree with Hudak?
Variables in Ruby have no type

In Java, variables are declared to have a type.

Variables in Ruby do not have a type. Instead, type is associated with values.

```
>> x = 10
>> x.class
=> Fixnum

>> x = "ten"
>> x.class
=> String

>> x = 2**100
>> x.class
=> Bignum
```
Dynamic typing

Ruby is a dynamically typed language. **There is no static analysis of the types involved in expressions.**

Consider this Ruby method:

```ruby
def f x, y, z
  return x[y + z] * x.foo
end
```

For some combinations of types it will produce a value. For others it will produce a `TypeError`.

With dynamic typing such methods are allowed to exist.
Dynamic typing, continued

With dynamic typing, no type checking is done when code is compiled. Instead, types of values are checked during execution, as each operation is performed.

Consider this Ruby code:
```ruby
while line = gets
    puts(f(line) + 3 + g(line)[-2])
end
```

What types must be checked each time through that loop?

Wrt. static typing, what are the implications of dynamic typing for...
  Compilation speed?
    Probably faster!
  Execution speed?
    Probably slower!
  Reliability?
    It depends...
A long-standing question in industry:
Can a good test suite find type errors in dynamically typed code as effectively as static type checking?

What's a "good" test suite?
Full code coverage? (every line executed by some test)
Full path coverage? (all combinations of paths exercised)
How about functions whose return type varies?

But wouldn't we want a good test suite no matter what language we're using?

"Why have to write tests for things a compiler can catch?"
—Brendan Jennings, SigFig
What ultimately matters?

What does the end-user of software care about?

Software that works

Facebook game vs. radiation therapy system

Fast enough

When does 10ms vs. 50ms matter?

Better sooner than later

A demo that's a day late for a trade show isn't worth much.

Affordable

How much more would you pay for a version of your favorite game that has half as many bugs?

I'd pay A LOT for a version of PowerPoint with more keyboard shortcuts!
Variety in type checking

Java is statically typed but casts introduce the possibility of a type error not being detected until execution.

C is statically typed but has casts that allow type errors during execution that are never detected.

Ruby, Python, and Icon have no static type checking whatsoever, but type errors during execution are always detected.

An example of a typing-related trade-off in execution time:
- C spends zero time during execution checking types.
- Java checks types during execution only in certain cases.
- Languages with dynamic typing check types on every operation, at least conceptually.

Is type inferencing applicable in a dynamically typed language?

UA CS TR 93-32a: Type Inference in the Icon Programming Language
"Why?" vs. "Why Not?"
"Why?" or "Why not?"

When designing a language some designers ask, "Why should feature X be included?"

Some designers ask the opposite: "Why should feature X not be included?"

Let's explore that question with Ruby.
A "here document" is a third way to literally specify a string.

```ruby
>> s = <<XYZZY
+-----+
| \  |
| */  |
| ' '  |
+-----+

XYZZY
=> "\n    +-----+

    | \ |

    | */ |

    | ' ' |

    +-----+

"
```

The string following `<<` specifies a delimiter that ends the literal. **The ending occurrence must be at the start of a line.**

"There's more than one way to do it!"—a Perl motto
Here's another way to specify string literals. See if you can discern some rules from these examples:

```ruby
>> %q{ just testin' this... }
=> " just testin' this... "

>> %Q| \n \t |
=> "\n \t"

>> %q(\u0041 is Unicode for A)
=> "\\u0041 is Unicode for A"

>> %q.test.
=> "test"
```

%q follows single-quote rules. %Q follows double quote rules. Symmetrical pairs like (), {}, and <> can be used.
How much is enough?

Partial summary of string literal syntax in Ruby:

```ruby
>> x = 5; s = "x is #{x}"
=> "x is 5"

>> '\\\n\t'.length
=> 6

>> hd = <<X
just
testing
X
=> "just\ntesting\n"

>> %q{ \n \t } + %Q|\n \t | + %Q(\u0021 \u{23})
=> " \n \t \n \t \n ! #"
```

How many ways does Haskell have to make a string literal?

How many ways should there be to make a string literal?

What's the minimum functionality needed?

Which would you remove?
"Why" or "Why not?" as applied to operator overloading

Here are some examples of operator overloading:

```ruby
>> [1,2,3] + [4,5,6] + [ ] + [7]
=> [1, 2, 3, 4, 5, 6, 7]

>> "abc" * 5
=> "abcabcabcabcabc"

>> [1, 3, 15, 1, 2, 1, 3, 7] - [3, 2, 1, 3]
=> [15, 7]

>> [10, 20, 30] * "...
=> "10...20...30"       # "intercalation"

>> "decimal: %d, octal: %o, hex: %x" % [20, 20, 20]
=> "decimal: 20, octal: 24, hex: 14"
```
"Why" or "Why not?", continued

What are some ways in which inclusion of a feature impacts a language?

• Increases the "mental footprint" of the language.
  – There are separate footprints for reading code and writing code.

• Maybe makes the language more expressive.

• Maybe makes the language useful for new applications.

• Probably increases size of implementation and documentation.

• Might impact performance.
Features come in all sizes!

Small: A new string literal escape sequence ("\U{65}" for "A")
Small: Supporting an operator on a new pair of types
Medium: Support for arbitrary precision integers

Large or small?
Support for object-oriented programming
Support for garbage collection
What would Ralph do?

At one of my first meetings with Ralph Griswold I put forth a number of ideas I had for new features for Icon.

He listened patiently. When I was done he said, "Go ahead. Add all of those you want to."

As I left his office he added, "But for every feature you add, first find one to remove."
The art of language design

There's a lot of science in programming language design but there's art, too.

Excerpt from interview with Perl Guru Damian Conway:
Q: "What languages other than Perl do you enjoy programming in?"
A: "I'm very partial to Icon. It's so beautifully put together, so elegantly proportioned, almost like a Renaissance painting."
http://www.pair.com/pair/current/insider/1201/damianconway.html (404 now!)

"Icon: A general purpose language known for its elegance and grace. Designed by Ralph Griswold to be successor to SNOBOL4."
—Digibarn "Mother Tongues" chart (see Intro slides)

Between SNOBOL4 and Icon there was there SL5 (SNOBOL Language 5).

I think of SL5 as an example of the "Second System Effect". It was never released.

Ralph once said, "I was laying in the hospital thinking about SL5. I felt there must be something simpler." That turned out to be Icon.

CSC 372 Spring 2016, Ruby Slide 86
Design example: invocation in Icon

Procedure call in Icon:
```
][ reverse("programming")
  r := "gnimmargorp" (string)

][ p := reverse
  r := function reverse (procedure)

][ p("foo")
  r := "oof" (string)
```

Doctoral student Steve Wampler added mutual goal directed evaluation (MGDE). A trivial example:
```
][ 3("one", 2, "III")
  r := "III" (string)

][ (?3)("one", 2, "III")
  r := "one" (string)
```
Invocation in Icon, continued

After a CSC 550A lecture where Ralph introduced MGDE, I asked, "How about 'string invocation', so that "+"(3,4) would be 7?"

What do you suppose Ralph said?
"How would we distinguish between unary and binary operators?"

Solution: Discriminate based on the operand count!

```
][ "-"(5,3)
    r := 2  (integer)
][ "-"(5)
    r := -5  (integer)
][ (?"+-")(3,4)
    r := -1  (integer)
```

Within a day or two I added string invocation to Icon.

Why did Ralph choose to allow this feature?
He felt it would increase the research potential of Icon.
An interesting language design example in Ruby is *parallel assignment*. Some simple examples:

```ruby
>> a, b = 10, [20, 30]

  >> a
  => 10

  >> b
  => [20, 30]

  >> c, d = b
  >> c
  => 20

  => 30
```
Could we do a swap with parallel assignment?

\[
\begin{align*}
\gg\ x,\ y &= 10, 20 \\
\gg\ x,\ y &= y, x \\
\gg\ x &= 20 \\
\gg\ y &= 10
\end{align*}
\]

This swaps, too:

\[
\begin{align*}
\gg\ x,\ y &= [y, x]
\end{align*}
\]

Contrast:

Icon has a swap operator: \( x :=: y \)
Parallel assignment, continued

Speculate: What does the following do?

```plaintext
>> a, b, c = [10, 20, 30, 40, 50]
```

```plaintext
>> [a, b, c]
=> [10, 20, 30]
```

Speculate again:

```plaintext
>> a, b, *c = [10, 20, 30, 40, 50]
```

```plaintext
>> [a, b, c]
=> [10, 20, [30, 40, 50]]
```

```plaintext
>> a, *b, *c = [10, 20, 30, 40, 50]
SyntaxError: (irb):57: syntax error, unexpected *
```

Section 4.5.5 in RPL has full details on parallel assignment. It is both more complicated and less general than pattern matching in Haskell. (!)
Control Structures
The **while** loop

Here's a loop to print the integers from 1 through 10, one per line.

```ruby
i = 1
while i <= 10 do  # "do" is optional
  puts i
  i += 1
end
```

When `i <= 10` produces **false**, control branches to the code following `end`, if any.

The body of the **while** is always terminated with **end**, even if there's only one expression in the body.
Java control structures such as if, while, and for are driven by the result of expressions that produce a value whose type is boolean.

C has a more flexible view: control structures consider a scalar value that is non-zero to be "true".

PHP considers zeroes, the empty string, the string "0", empty arrays, and more to be false.

Python and JavaScript, too, have sets of "truthy" and "falsy/falsey" values.

Here's the Ruby rule:

Any value that is not false or nil is considered to be "true".
Remember: Any value that is not false or nil is considered to be "true".

Let's analyze this loop, which reads lines from standard input using gets.

```ruby
while line = gets
  puts line
end
```

gets returns a string that is the next line of the input, or nil, on end of file.

The expression line = gets has two side effects but also produces a value.
  Side effects: (1) a line is read from standard input and (2) is assigned to line.
  Value: The string assigned to line.

If the first line of the file is "one", then the first time through the loop what's evaluated is while "one".

The value "one" is not false or nil, so the body of the loop is executed, causing "one" to be printed on standard output.

At end of file, gets returns nil. nil is assigned to line and produced as the value of the assignment, in turn terminating the loop.
From the previous slide:

\[
\text{while line} = \text{gets} \\
\quad \text{puts line} \\
\text{end}
\]

Partial understanding:
That loop reads and prints every line from standard input.

Full understanding:
What we worked through on the previous slide.

I think there's merit in full understanding.

Another example of full understanding:
Knowing the full set of truthy/falsy rules for a language.
String's chomp method removes a carriage return and/or newline from the end of a string, if present.

Here's a program that's intended to flatten all input lines to a single line:

```ruby
result = ""
while line = gets.chomp
  result += line
end
puts result
```

It doesn't work. What's wrong with it?

Here's the error:

```
% ruby while4.rb < lines.txt
while4.rb:2:in `<main>': undefined method `chomp' for nil:NilClass (NoMethodError)
```

while, continued
At hand:

```ruby
result = ""
while line = gets.chomp
  result += line
end
puts result
```

At end of file, `gets` returns `nil`, producing an error on `gets.chomp`.

Which of the two alternatives below is better? What's a third alternative?

```
result = ""
while line = gets
  line.chomp!
  result += line
end
puts result
```

```
result = ""
while line = gets
  result += line.chomp
end
puts result
```
Problem: Write a while loop that prints the characters in the string \textit{s}, one per line. Don't use the \texttt{length} or \texttt{size} methods of \texttt{String}.

Extra credit: Don't use any variables other than \textit{s}.

Solution: (\texttt{while5.rb})

\begin{verbatim}
i = 0
while c = s[i]
  puts c
  i += 1
end
\end{verbatim}

Solution with only \textit{s}: (\texttt{while5a.rb})

\begin{verbatim}
while s[0]
  puts s[0]
  s[0] = ""
end
\end{verbatim}
Unlike Java, Ruby does pay some attention to the presence of newlines in source code.

For example, a while loop cannot be trivially squashed onto a single line.

```ruby
while i <= 10 puts i i += 1 end  # Syntax error
```

If we add semicolons where newlines originally were, it works:

```ruby
while i <= 10; puts i; i += 1; end  # OK
```

There is some middle ground, too:

```ruby
while i <= 10 do puts i; i += 1 end  # OK. Note added "do"
```

Unlike Haskell and Python, indentation is never significant in Ruby.
Ruby considers a newline to terminate an expression, unless the expression is definitely incomplete.

For example, the following is ok because "i <=" is definitely incomplete.

```ruby
while i <=
  10 do puts i; i += 1 end
```

Is the following ok?

```ruby
while i <= 10 do puts i; i += 1 end
```

Nope...
```
syntax error, unexpected tLEQ
<= 10 do puts i; i += 1 end
^```
Can you think of any pitfalls that the incomplete expression rule could produce?

Example of a pitfall: Ruby considers

```ruby
x = a + b
    + c
```

to be two expressions: \( x = a + b \) and \( + c \).

Rule of thumb: If breaking an expression across lines, end lines with an operator:

```ruby
x = a + b +
    c
```

Alternative: Indicate continuation with a backslash at the end of the line.
Academic writing on programming languages commonly uses the term "statement" to denote a syntactic element that performs operation(s) but does not produce a value.

The term "expression" is consistently used to describe a construct that produces a value.

Ruby literature sometimes talks about the "while statement" even though `while` produces a value:

```ruby
>> i = 1
>> while i <= 3 do i += 1 end
=> nil
```

Dilemma: Do we call it the "while statement" or the "while expression"?

We'll see later that the `break` construct can cause a `while` loop to produce a value other than `nil`.
Logical operators

Ruby has operators for conjunction, disjunction, and "not" with the same symbols as Java and C, but with somewhat different semantics.

Conjunction is `&&`, just like Java, but note the values produced:

```ruby
>> true && false
=> false

>> 1 && 2
=> 2

>> true && "abc"
=> "abc"

>> nil && 1
=> nil
```

Remember:

Any value that is not `false` or `nil` is considered to be "true".

Challenge: Concisely describe the rule that Ruby uses to determine the value of a conjunction operation.
Disjunction is `||`, also like Java. As with conjunction, the values produced are interesting:

```ruby
>> 1 || nil
=> 1

>> false || 2
=> 2

>> "abc" || "xyz"
=> "abc"

>> s = "abc"
>> s[0] || s[3]
=> "a"

>> s[4] || false
=> false
```

Remember:
Any value that is not `false` or `nil` is considered to be "true".
Logical operators, continued

An exclamation mark inverts a logical value. The resulting value is always true or false.

```ruby
>> ! true
=> false

>> ! 1
=> false

>> ! nil
=> true

>> ! (1 || 2)
=> false

>> ! ("abc"[5] || [1,2,3][10])
=> true

>> ![nil]
=> false
```

Remember:

Any value that is not false or nil is considered to be "true".

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Logical operators, continued

There are also **and**, **or**, and **not** operators, but with very low precedence.

Why?
They eliminate the need for parentheses in some cases.

We can write this,
\[ x < 2 \land y > 3 \lor x \cdot y < 10 \lor z > 20 \]
instead of this:
\[ (x < 2 \land y > 3) \lor (x \cdot y < 10 \lor z > 20) \]

LHtLaL problem: Devise an example for ! vs. not.
Here is Ruby's if-then-else:

```ruby
>>> if 1 < 2 then "three" else [4] end
=> "three"

>>> if 10 < 2 then "three" else [4] end
=> [4]

>>> if 0 then "three" else [4] end * 3
=> "threethreethree"
```

Observations?

Speculate: Is the following valid? If so, what will it produce?
```ruby
if 1 > 2 then 3 end
```
If a language's `if-then-else` returns a value, it creates an issue about the meaning of an `if-then` with no `else`.

In Ruby, if there's no `else` clause and the control expression is `false`, `nil` is produced:
```ruby
>> if 1 > 2 then 3 end
=> nil
```

In the C family, `if-else` doesn't return a value.

Haskell and ML simply don't allow an `else`-less `if`.

In Icon, an expression like `if 2 > 3 then 4` is said to `fail`. No value is produced, and failure propagates to any enclosing expression, which in turn fails.

Ruby also provides `1 > 2 ? 3 : 4`, a ternary conditional operator, just like the C family. Is that a good thing or bad thing? (TMTOWTDI!)
The most common Ruby coding style puts the if, the else, the end, and the expressions of the clauses on separate lines:

```ruby
if lower <= x && x <= higher or inExRange(x, rangeList) then
  puts "x is in range"
  history.add x
else
  outliers.add x
end
```

Note the use of the low-precedence or instead of ||.

The trailing then above is optional.

then is not optional in this one-line expression:

```ruby
if 1 then 2 else 3 end
```
Ruby provides an `elsif` clause for "else-if" situations.

```ruby
if average >= 90 then
  grade = "A"
elsif average >= 80 then
  grade = "B"
elsif average >= 70 then
  grade = "C"
else
  grade = "F"
end
```

Note that there is no "end" to terminate the `then` clauses. `elsif` both closes the current `then` and starts a new clause.

It is not required to have a final `else`.

Is `elsif` syntactic sugar?
At hand:

```ruby
if average >= 90 then
  grade = "A"
elsif average >= 80 then
  grade = "B"
elsif average >= 70 then
  grade = "C"
else
  grade = "F"
end
```

Can we shorten it by thinking less imperatively and more about values?

See 5.1.4 in RPL for Ruby's `case` (a.k.a. "switch") expression.
**if and unless as modifiers**

if and **unless** can be used as *modifiers* to indicate conditional execution.

```ruby
>> total, count = 123.4, 5  # Note: parallel assignment

>> printf("average = %g\n", total / count) if count != 0
average = 24.68
=> nil
```

```ruby
>> total, count = 123.4, 0
>> printf("average = %g\n", total / count) unless count == 0
=> nil
```

The general forms are:

- `expr1 if expr2`
- `expr1 unless expr2`

What does `x.f if x` mean?
Ruby's `break` and `next` are similar to Java's `break` and `continue`.

Below is a loop that reads lines from standard input, terminating on end of file or when a line beginning with a period is read. Each line is printed unless the line begins with a pound sign.

```ruby
while line = gets
  if line[0] == "." then
    break
  end
  if line[0] == "#" then
    next
  end
  puts line
end
```

Problem: Rewrite the above loop to use `if` as a modifier.

```ruby
while line = gets
  break if line[0] == "." 
  next if line[0] == "#"
  puts line
end
```
break and next, continued

Remember that **while** is an expression that by default produces the value **nil** when the loop terminates.

If a while loop is exited with **break expr**, the value of **expr** is the value of the **while**.

Here's a contrived example to show the mechanics of it:

```ruby
% cat break2.rb
s = "x"
puts (while true do
    break s if s.size > 30
    s += s
end)
```

```ruby
% ruby break2.rb
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
```
Here are three examples of Ruby's **for** loop:

```ruby
for i in 1..100 do  # as with while, the do is optional
  sum += i
end

for i in [10,20,30]
  sum += i
end

for msymbol in "x".methods
  puts msymbol if msymbol.to_s.include? "!"
end
```

The "in" expression must be an object that has an **each** method.

In the first case, the "in" expression is a **Range**. In the latter two it is an **Array**.
The for loop supports parallel assignment:

```ruby
for s,n,sep in ["1",5,"-"], ["s",2,"o"], [" <-> ",10,""]]
  puts [s] * n * sep
end
```

Output:
```
1-1-1-1-1
sos
<->  <->  <->  <->  <->  <->  <->  <->  <->  <->
```

Consider the feature of supporting parallel assignment in the for.
- How would we write the above without it?
- What's the mental footprint of this feature?
- What's the big deal since there's already parallel assignment?
- Is this creeping featurism?
Methods and more
Here is a simple Ruby method:

```ruby
def add x, y
  return x + y
end
```

The keyword `def` indicates that this is a method definition.

Next is the method name.

The parameter list follows, optionally enclosed in parentheses. 

No types can be specified.

Zero or more expressions follow

`end` terminates the definition.
Method definition, continued

If the end of a method is reached without encountering a `return`, the value of the last expression becomes the return value.

Here is a more idiomatic definition for `add`:

```ruby
def add x, y
  x + y
end
```
As we saw in an early example, if no arguments are required, the parameter list can be omitted:

```ruby
def hello
  puts "Hello!"
end
```

What does `hello` return?

What does the last expression in `hello` return?
Testing methods with **irb**

One way to test methods in a file is to use **load**, a **Kernel** method.

% cat simple.rb
```ruby
def add x, y
  x + y
end

def hello
  puts "Hello!"
end
```

How does **load** in Ruby differ from :**load** in **ghci**?

**load "simple.rb"** is simply a Ruby expression that's evaluated by **irb**. Its side-effect is that the specified file is loaded.
Where's the class?!

I claim to be defining methods `add` and `hello` but there's no class in sight!

Methods can be added to a class at run-time in Ruby!

A freestanding method found in a file is associated with an object referred to as "main", an instance of `Object`.

At the top level, the name `self` references that object.

```ruby
>> [self.class, self.to_s] => [Object, "main"]

>> methods_b4 = self.private_methods
>> load "simple.rb"

>> self.private_methods - methods_b4
=> [:add, :hello]
```

We see that loading `simple.rb` added two methods to `main`. 
Where's the class, continued?

We'll later see how to define classes but our initial "mode" on the Ruby assignments will be writing programs in terms of top-level methods.

This is essentially procedural programming with an object-oriented library.
Default values for arguments

Ruby allows default values to be specified for a method's arguments:

```ruby
def wrap s, wrapper = "()"  # wrap3.rb
  wrapper[0] + s + wrapper[-1]  # Why -1?
end

>> wrap "abc", "<>"
=> "<abc>"

>> wrap "abc"
=> "(abc)"

>> wrap it, "|"
=> "| (abc) |
```

Lots of library methods use default arguments.

```ruby
>> "a-b c-d".split  #=> ["a-b", "c-d"]
>> "a-b c-d".split "-"  #=> ["a", "b c", "d"]
```
Ruby does not allow the methods of a class to be overloaded. Here's a Java-like approach that does not work:

```ruby
def wrap s
  wrap(s, "()")
end

def wrap s, wrapper
  wrapper[0] + s + wrapper[-1]
end
```

The imagined behavior is that if `wrap` is called with one argument it will call the two-argument `wrap` with "()" as a second argument. In fact, the second definition of `wrap` simply replaces the first. (Last `def` wins!)

```ruby
>> wrap "x"
ArgumentError: wrong number of arguments (1 for 2)
```

```ruby
>> wrap("testing", "[ ]") => "[testing]"
```
Sidebar: A study in contrast

Different languages approach overloading and default arguments in various ways. Here's a sampling:

- **Java**: Overloading; no default arguments
- **Ruby**: No overloading; default arguments
- **C++**: Overloading and default arguments
- **Icon**: No overloading; no default arguments; use an idiom

How does the mental footprint of the four approaches vary? What's the impact on the language's written specification?

Here is `wrap` in Icon:

```icon
procedure wrap(s, wrapper)
    /wrapper := "()" # if wrapper is &null, assign "()" to wrapper
    return wrapper[1] || s || wrapper[-1]
end
```

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Arbitrary number of arguments

Java's \texttt{String.format} and C's \texttt{printf} can accept any number of arguments.

This Ruby method accepts any number of arguments and prints them:

\begin{verbatim}
def showargs(*args)
  puts "#{args.size} arguments"
  for i in 0...args.size do  # Recall a...b is a to b-1
    puts "##{i}: #{args[i]}"
  end
end
\end{verbatim}

The rule: If a parameter is prefixed with an asterisk, an array is made of all following arguments.

\begin{verbatim}
>> showargs(1, "two", 3.0)
3 arguments:
#0: 1
#1: two
#2: 3.0
\end{verbatim}
Problem: Write a method `format` that interpolates argument values into a string where percent signs are found.

```ruby
>> format("x = %, y = %, z = %\n", 7, "ten", "zoo")
=> "x = 7, y = ten, z = zoo\n"

>> format "testing\n"
=> "testing\n"
```

Use `to_s` for conversion to `String`.

A common term for this sort of facility is "varargs"—variable number of arguments.

```ruby
def format(fmt, *args)
  result = ""
  for i in 0...fmt.size do
    if fmt[i] == "%" then
      result += args.shift.to_s
    else
      result += fmt[i]
    end
  end
  result
end
```
Here's an example of source file layout for a program with several methods:

```ruby
def main
  puts "in main"; f; g
end

def f; puts "in f" end
def g; puts "in g" end

main  # This runs the program
```

A rule: the definition for a method must be seen before it is executed.

The definitions for `f` and `g` can follow the definition of `main` because they aren't executed until `main` is executed.

Could the line "`main`" appear before the definition of `f`?

Try shuffling the three definitions and "`main`" to see what works and what doesn't.
Testing methods when there's a "main"

I'd like to load the following file and then test `showline`, but loading it in `irb` seems to hang. Why?

```ruby
% cat main3.rb
def showline s
  puts "Line: #{s.inspect} (#{s.size} chars)"
end
def main
  while line = gets; showline line; end
end
main
```

```ruby
% irb
>> load "main3.rb"
...no output or >> prompt after the load...
```

Actually, it's waiting for input! After the `defs` for `showline` and `main`, `main` is called. `main` does a `gets`, and that `gets` is waiting for input.
Here's a technique that lets the program run normally with `ruby` but not run `main` when loaded with `irb`:

```ruby
% cat main3a.rb
def showline s
  puts "Line: #{s.inspect} (#{s.size} chars)"
end
def main
  while line = gets; showline line; end
end
main unless $0 == "irb"
```

% `irb` >> load "main3a.rb"
>> showline "testing"
Line: "testing" (7 chars)
>> main
(waits for input)

Call `main` unless the name of the program being run is "irb".

Now I can test methods by hand in `irb` but still do `ruby main3a.rb` ...
Scoping rules for variables

Ordinary variables are local to the method in which they're created.

Example: (global0.rb)

def f
  puts "f: x = #{x}"    # undefined local variable or method `x'
end

def g
  x = 100     # This x is visible only in g
end

x = 10   # This x is visible only at the top-level in this file.
g
puts "top-level: x = #{x}"
Variables prefixed with a $ are global, and can be referenced in any method in any file, including top-level code.

```ruby
def f
  puts "f: \$x = \#\{$x\}" 
end

def g
  \$x = 100
end

\$x = 10
f
g

puts "top-level: \$x = \#\{$x\}"
```

The code at left...
1. Sets \$x at the top-level.
2. Prints \$x in f.
3. Changes \$x in g.
4. Prints the final value of \$x at the top-level.

Output:

```
f: \$x = 10
top-level: \$x = 100
```
A rule in Ruby is that if an identifier begins with a capital letter, it represents a constant.

The first assignment to a constant is considered initialization.

```ruby
>> MAX_ITEMS = 100
```

Assigning to an already initialized constant is permitted but a warning is generated.

```ruby
>> MAX_ITEMS = 200
(irb):4: warning: already initialized constant MAX_ITEMS
=> 200
```

Modifying an object referenced by a constant does not produce a warning:

```ruby
>> L = [10,20]
=> [10, 20]

>> L.push 30
=> [10, 20, 30]
```
Constants, continued

Pitfall: If a method is given a name that begins with a capital letter, it compiles ok but it can't be run!

```ruby
>> def Hello; puts "hello!" end

>> Hello
NameError: uninitialized constant Hello
```
There are a number of predefined constants. Here are a few:

**RUBY_VERSION**

The version of Ruby that's running.

**ARGV**

An array holding the command line arguments, like the argument to `main` in a Java program.

**ENV**

An object holding the "environment variables" (shown with `env` on UNIX machines and `set` on Windows machines.)

**STDIN, STDOUT**

Instances of the `IO` class representing standard input and standard output (the keyboard and screen, by default).
Duck Typing
Duck typing

Definition from Wikipedia (c.2015):

*Duck typing* is a style of typing in which an object's methods and properties determine the valid semantics, rather than its inheritance from a particular class or implementation of an explicit interface.

Recall these examples of the `for` loop:

```ruby
for i in 1..100 do ...end
```

```ruby
for i in [10,20,30] do ... end
```

*for* only requires that the "in" value be an object that has an *each* method. (It doesn't need to be a subclass of *Enumerable*, for example.)

This is an example of *duck typing*, so named based on the "duck test":

*If it looks like a duck, swims like a duck, and quacks like a duck, then it probably is a duck.*

For the case at hand, the value produced by the "in" expression qualifies as a "duck" if it has an *each* method.
Duck typing, continued

For reference:

_Duck typing_ is a style of typing in which an object's methods and properties determine the valid semantics, rather than its inheritance from a particular class or implementation of an explicit interface.

—Wikipedia (c.2015)

Duck typing is both a technique and a mindset.

Ruby both facilitates and uses duck typing.

We don't say Ruby is duck typed. We say that Ruby allows duck typing.
Duck typing, continued

The key characteristic of duck typing is that we only care about whether an object supports the operation(s) we require.

With Ruby's `for` loop, it is only required that the `in` value have an `each` method.

Consider this method:

```ruby
def double x
  x * 2
end
```

**Remember:** `x * 2` actually means `x.*(2)` — invoke the method `*` on the object `x` and pass it the value `2` as a parameter.

What operation(s) does `double` require that `x` support?
Duck typing, continued

```
>> double 10
=> 20

>> double "abc"
=> "abcabc"

>> double [1,2,3]
=> [1, 2, 3, 1, 2, 3]

>> double Rational(3)
=> (6/1)

>> double 1..10
NoMethodError: undefined method `*' for 1..10:Range
```

Is it good or bad that `double` operates on so many different types?

Is `double` polymorphic? What's the type of `double`?

Should we limit `double` to certain types, like numbers, strings and lists?
Recall: The key characteristic of duck typing is that we only care about whether an object supports the operation(s) we require.

Should we have `double` check for known types?
```ruby
def double x
  if [Fixnum, Float, String, Array].include? x.class
    x * 2
  else raise "Can't double a #{x.class}!" end
end
```

```ruby
>> double "abc"
=> "abcabc"
>> double 1..2
RuntimeError: Can't double a Range!
>> double Rational(3)
RuntimeError: Can't double a Rational!
```
Here's `wrap` from slide 125. What does it require of `s` and `wrapper`?

```ruby
def wrap s, wrapper = "()"
    wrapper[0] + s + wrapper[-1]
end
```

```ruby
>> wrap "test", "<>"
=> "<test>"
```

Will the following work?

```ruby
>> wrap "test", ["<<<",">>>"]
=> "<<<test>>>"

>> wrap [1,2,3], ["..."]
=> ["...", 1, 2, 3, "]

>> wrap 10, 3
=> 11
```
Recall: The key characteristic of duck typing is that we only care about whether an object supports the operation(s) we require.

Does the following Java method exemplify duck typing?

```java
static double sumOfAreas(Shape shapes[]) {
    double area = 0.0;
    for (Shape s: shapes)
        area += s.getArea();
    return area;
}
```

No! `sumOfAreas` requires an array of `Shape` instances.

Could we change `Shape` to `Object` above? Would that be duck typing?

Does duck typing require a language to be dynamically typed?
Iterators and blocks
Iterators and blocks

Some methods are *iterators*. One of the many iterators in the **Array** class is **each**.

**each** iterates over the elements of the array. Example:

```ruby
>> x = [10,20,30]
>> x.each { puts "element" }

element
element
element
=> [10, 20, 30]  # (each returns its receiver but it's often not used)
```

The construct `{ puts "element" }` is a **block**.

**Array#each** invokes the block once for each element of the array.

Because there are three values in `x`, the block is invoked three times, printing "element" each time.
Recall: An iterator is a method that can invoke a block.

Iterators can pass one or more values to a block as arguments.

A block can access arguments by naming them with a parameter list, a comma-separated sequence of identifiers enclosed in vertical bars.

```ruby
>> [10, "twenty", [30,40]].each { |e| puts "element: #{e}" }
element: 10
element: twenty
element: [30, 40]
=> [10, "twenty", [30, 40]]
```

The behavior of the iterator `Array#each` is to invoke the block with each array element in turn.
Iterators and blocks, continued

For reference:

```ruby
[10, "twenty", [30,40]].each { |e| puts "element: #{e}" }
```

Problem: Using a block, compute the sum of the numbers in an array containing values of any type. (Use `e.is_a? Numeric` to decide whether `e` is a number of some sort.)

```ruby
>> sum = 0
>> [10, "twenty", 30].each { ??? }
```

```ruby
>> sum #=> 40
```

Note: `sum = ...` inside the block changes it outside the block. (Rules coming soon!)

```ruby
>> sum = 0
>> (1..100).to_a.each { |e| sum += e if e.is_a? Numeric }
```

```ruby
>> sum #=> 5050
```
Sidebar: Iterate with `each` or use a `for` loop?

Recall that the `for` loop requires the value of the "in" expression to have an `each` method.

That leads to a choice between a `for` loop,

```ruby
for name in "x".methods do
  puts name if name.to_s.include? "!"
end
```

and iteration with `each`,

```ruby
"x".methods.each { |name| puts name if name.to_s.include? "!" }
```

Which is better?
Iterators and blocks, continued

**Array#each** is typically used to create side effects of interest, like printing values or changing variables.

In contrast, with some iterators it is the value returned by an iterator that is of principle interest.

See if you can describe what the following iterators are doing.

```ruby
>> [10, "twenty", 30].collect { |v| v * 2 }
=> [20, "twentytwenty", 60]
```

```ruby
>> [[1,2], "a", [3], "four"].select { |v| v.size == 1 }
=> ["a", [3]]
```

What do those remind you of?
The block for `Array#sort` takes two arguments.

```ruby
>> [30, 20, 10, 40].sort { |a,b| a <=> b }
=> [10, 20, 30, 40]
```

Speculate: what are the arguments being passed to `sort`'s block? How could we find out?

```ruby
>> [30, 20, 10, 40].sort { |a,b| puts "call: #{a} #{b}"; a <=> b }
call: 30 10
call: 10 40
call: 30 40
call: 20 30
call: 10 20
=> [10, 20, 30, 40]
```

How could we reverse the order of the `sort`?

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Problem: sort the words in a sentence by descending length.

```ruby
>> "a longer try first".split.sort { |a,b| b.size <=> a.size }
=> ["longer", "first", "try", "a"]
```

What do the following examples remind you of?

```ruby
>> [10, 20, 30].inject(0) { |sum, i| sum + i }
=> 60

>> [10,20,30].inject([]) {
    |memo, element| memo << element << "---"
} => [10, "---", 20, "---", 30, "---"]
```
We can query the "ancestors" of a class like this:

`>> Array.ancestors`  
`=> [Array, Enumerable, Object, Kernel, BasicObject]`

For now we'll simply say that an object can call methods in its ancestors.

*Enumerable* has a number of iterators. Here are some:

`>> [2,4,5].any? { |n| n.odd? }`  
`=> true`

`>> [2,4,5].all? { |n| n.odd? }`  
`=> false`

`>> [1,10,17,25].find { |n| n % 5 == 0 }`  
`=> 10`
At hand:

A object can call methods in its ancestors. An ancestor of Array is Enumerable.

Another Enumerable method is max:

```
>> \["apple", "banana", "grape"\].max {
  | a,b | v = "aeiou"
  a.count(v) <=> b.count(v)
} => "banana"
```

The methods in Enumerable use duck typing. They require only an each method except for min, max, and sort, which also require <=>.

See http://ruby-doc.org/core-2.2.4/Enumerable.html
Recall: An iterator is a method that can invoke a block.

Many classes have one or more iterators. One way to find them is to search their ruby-doc.org page for "block".

```ruby
$ 3.times { |n| puts n }
```

Iterators abound!

```ruby
>> 3.times { |n| puts n }
0
1
2
=> 3
```

If no block is given, an Enumerator is returned instead.

What will `3.times { |n| puts n }` do?
A few more iterators

Three more examples:

```ruby
>> "abc".each { |c| puts c }
NoMethodError: undefined method `each' for "abc":String

>> "abc".each_char { |c| puts c }
a
b
c
=> "abc"

>> i = 0
>> "Mississippi".gsub("i") { (i += 1).to_s }
=> "M1ss2ss3pp4"
```
An alternative to enclosing a block in braces is to use `do/end`:

```ruby
a.each do
  |element|
  print "element: #{element}\n"
end
```

Common style is to use brackets for one-line blocks, like previous examples, and `do...end` for multi-line blocks.

The opening brace or `do` for a block must be on the same line as the iterator invocation. Here's an error:

```ruby
a.each
do  # syntax error, unexpected keyword_do_block,
   # expecting $end
  |element|
  print "element: #{element}\n"
end
```

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sumnums.rb reads lines from standard input, assumes the lines consist of integers separated by spaces, and prints their total, count, and average.

total = n = 0
readlines().each do
  line
    line.split(" ").each do
      word
        total += word.to_i
        n += 1
    end
end
printf("total = %d, n = %d, average = %g\n", total, n, total / n.to_f) if n != 0

Kernel#readlines reads/returns all of standard input as an array of lines.

The printf format specifier %g indicates to format a floating point number and select the better of fixed point or exponential form based on the value.
Scoping issues with blocks

Blocks raise issues with the scope of variables.

If a variable exists outside of a block, references to that variable in a block refer to that existing variable. Example:

```ruby
>> sum = 0  # Note: sum will accumulate across two iterator calls

>> [10,20,30].each{|x| sum += x}

>> sum
=> 60

>> [10,20,30].each{|x| sum += x}

>> sum
=> 120
```
Scoping issues with blocks, continued

If a variable is created in a block, the scope of the variable is limited to the block.

In the example below we confirm that \texttt{x} exists only in the block, and that the block's parameter, \texttt{e}, is local to the block.

\begin{verbatim}
>> e = "eee"
>> x
NameError: undefined local variable or method `x' ...

>> [10,20,30].each {|e| x = e * 2; puts x}
20
...
>> x
NameError: undefined local variable or method `x' ...
>> e
=> "eee"  # e's value was not changed by the block
\end{verbatim}
Scoping issues with blocks, continued

Pitfall: If we write a block that references a currently unused variable but later add a use for that variable outside the block, we might get a surprise.

Version 1:
```ruby
a.each do |x|
  result = ... # first use of result in this method
  ...
end
```

Version 2:
```ruby
result = ... # new first use of result in this method
...
result = ... # references/clobbers result in outer scope
end
...
...use result... # uses value of result set in block. Surprise!
```

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Scoping issues with blocks, continued

We can make variable(s) local to a block by adding them at the end of the block's parameter list, preceded by a semicolon.

```ruby
result = ...
...
a.each do
  |x; result, tmp|
  result = ... # result is local to block
...
end
...
...use result...  # uses result created outside of block
```
Writing iterators
Recall: An iterator is a method that can invoke a block.

The `yield` expression invokes the block associated with the current method invocation. Arguments of `yield` become parameters of the block.

Here is a simple iterator that yields two values, a 3 and a 7:

```
def simple
  puts "simple: Starting..."
  yield 3
  puts "simple: Continuing"
  yield 7
  puts "simple: Done"
  "simple result"
end
```

Usage:

```
>> simple { |x| puts "x = #{x}" }
simple: Starting...
  x = 3
simple: Continuing...
  x = 7
simple: Done...
=> "simple result"
```

The `puts` in `simple` are used to show when `simple` is active. Note the interleaving of execution between the iterator and the block.
At hand:
```ruby
def simple
  puts "simple: Starting..."
  yield 3
  puts "simple: Continuing..."
  yield 7
  puts "simple: Done..."
  "simple result"
end
```

There's no formal parameter that corresponds to a block. The block, if any, is implicitly referenced by `yield`.

The parameter of `yield` becomes the named parameter for the block.

Calling `simple` without a block produces an error on the first `yield`:
```ruby
>> simple
simple: Starting...
LocalJumpError: no block given (yield)
```

A simple iterator, continued

Usage:
```ruby
>> simple { |x| puts \tx = #{x}\ }  
simple: Starting...  
  x = 3  
simple: Continuing...  
  x = 7  
simple: Done...  
=> "simple result"
```
Write `from_to`

Problem: Write an iterator `from_to(f, t, by)` that yields the integers from `f` through `t` in steps of `by`, which defaults to 1. Assume `f <= t`.

```ruby
>> from_to(1,3) { |i| puts i }
1
2
3
=> 3
```

```ruby
>> from_to(0,99,25) { |i| puts i }
0
25
50
75
=> 4
```

Parameters are passed to the iterator (the method) just like any other method.
Solution:

```ruby
def from_to(from, to, by = 1)
  n = from
  results = 0
  while n <= to do
    yield n
    n += by
    results += 1
  end
  results
end
```

Another test:

```ruby
>> from_to(-5,5,1) { |i| print i, " " }
-5 -4 -3 -2 -1 0 1 2 3 4 5 => 11
```
yield, continued

To pass multiple arguments for a block, specify multiple arguments for yield.

Imagine an iterator that produces overlapping pairs from an array:

```ruby
>> elem_pairs([3,1,5,9]) { |x,y| print "x = #{x}, y = #{y}\n" }
ex = 3, y = 1
ex = 1, y = 5
ex = 5, y = 9
```

Implementation:
```ruby
def elem_pairs(a)
  for i in 0...(a.length-1)
    yield a[i], a[i+1]  # yield(a[i], a[i+1]) is ok, too
  end
end
```

Speculate: What will be the result with `yield [a[i], a[i+1]]`? (Extra [...])
A round-trip with `yield`

When `yield` passes a value to a block the result of the block becomes the value of the `yield` expression.

Here is a trivial iterator to show the mechanics:
```ruby
def round_trip x
  r = yield x
  "yielded #{x} and got back #{r}"
end
```

Usage:
```ruby
>> round_trip(3) { |x| x * 5 }  # parens around 3 are required!
=> "yielded 3 and got back 15"

>> round_trip("testing") { |x| x.size }
=> "yielded testing and got back 7"
```
A round-trip with `yield`, continued

At hand:
```ruby
def round_trip x
  r = yield x
  "yielded #{x} and got back #{r}"
end
```

```ruby
>> round_trip(3) { |x| x * 5 }
=> "yielded 3 and got back 15"
```

1. Iterator yields 3 to block. `x` becomes 3.

2. Block returns 15, which becomes value of `yield 3`.

3. Value of `yield 3` is assigned to `r`.
Consider this iterator:

```ruby
>> select([[1,2], "a", [3], "four"]) { |v| v.size == 1 }
=> ["a", [3]]
```

```ruby
>> select("testing this here".split) { |w| w.include? "e" }
=> ["testing", "here"]
```

What does it appear to be doing?
Producing the elements in its argument, an array, for which the block produces true.

Problem: Write it!
At hand:

```ruby
>> select([[1,2], "a", [3], "four"]) { |v| v.size == 1 }
=> ["a", [3]]
```

Solution:

```ruby
def select(array)
  result = []
  for element in array
    if yield element then
      result << element
    end
  end
  result
end
```

What does the iterator/block interaction look like?

<table>
<thead>
<tr>
<th>Iterator</th>
<th>Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>if yield [1,2] then # [1,2].size == 1</td>
<td></td>
</tr>
<tr>
<td>result &lt;&lt; [1,2]</td>
<td></td>
</tr>
<tr>
<td>if yield &quot;a&quot; then # &quot;a&quot;.size == 1</td>
<td></td>
</tr>
<tr>
<td>result &lt;&lt; &quot;a&quot;</td>
<td></td>
</tr>
<tr>
<td>if yield [3] then # [3].size == 1</td>
<td></td>
</tr>
<tr>
<td>result &lt;&lt; [3]</td>
<td></td>
</tr>
<tr>
<td>if yield &quot;four&quot; then # &quot;four&quot;.size == 1</td>
<td></td>
</tr>
<tr>
<td>result &lt;&lt; &quot;four&quot;</td>
<td></td>
</tr>
</tbody>
</table>

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Is `select` limited to arrays?

```
>> select(1..10) { |n| n.odd? && n > 5 }
=> [7, 9]
```

Why does that work?
Because `for var in x` works for any `x` that has an `each` method. (Duck typing!)

What's a better name than `array` for `select`'s parameter?

Problem: Rewrite `select` to use the iterator `each` instead of a for loop. Also use an `if` modifier with the `yield`.

```ruby
def select array
  result = [ ]
  for element in array
    if yield element then
      result << element
    end
  end
  result
end
```
Round trips with `yield`, continued

Solution:
```ruby
def select eachable
    result = []
    eachable.each do |element|
        result << element if yield element
    end
    result
end
```

```ruby
def select array
    result = []
    for element in array
        if yield element then
            result << element
        end
    end
    result
end
```

What's the difference between our `select`,
```ruby
select([[1,2], "a", [3], "four"]) { |v| v.size == 1 }
```

And Ruby's `Array#select`?
```ruby
[[1,2], "a", [3], "four"].select { |v| v.size == 1 }
```

Ruby's `Array#select` is a method of `Array`. Our `select` is added to the object "main". (See slide 123.)
def select array
    result = []
    for element in array
        if yield element then
            result << element
        end
    end
    result
end

>> select(_ 
[
] = []
select f (x:xs)
    | f x = x : select f xs
    | otherwise = select f xs

> select (\x -> length x == 4) ["just","a","test"]
["just","test"]

Which is better?
Various types of iteration side-by-side

```ruby
>> [10, "twenty", [30,40]].each { |e| puts "element: #{e}" }
>> sum = 0; [1,2,3].each { |x| sum += x }
    Invokes block with each element in turn for side-effect(s). Result of each uninteresting.

>> [10,20,30].map { |x| x * 2 } => [20, 40, 60]
    Invokes block with each element in turn and returns array of block results.

>> [2,4,5].all? { |n| n.odd? } => false
    Invokes block with each element in turn; each block result contributes to final result of true or false, possibly short-circuiting.

>> [[1,2], "a", [3], "four"].select { |v| v.size == 1 } => ["a", [3]]
    Invokes block to determine membership in final result.

>> "try this first".split.sort { |a,b| b.size <=> a.size } => [...]  
    Invokes block an arbitrary number of times; each block result guides further computation towards final result.
```
The **Hash** class
Ruby's **Hash** class is similar to the **Map** family in Java and dictionaries in Python. It's like an array that can be subscripted with values of any type.

The expression `{ }` (empty curly braces) creates a **Hash**:

```
>> numbers = {} => {} 

>> numbers.class => Hash
```

Subscripting with a *key* and assigning a value stores that key/value pair.

```
>> numbers["one"] = 1 

>> numbers["two"] = 2 

>> numbers 

=> {"one"=>1, "two"=>2} 

>> numbers.size 

=> 2 
```
At hand:

```ruby
>> numbers
=> {"one"=>1, "two"=>2}
```

Subscripting with a key fetches the associated value. If the key is not found, `nil` is produced.

```ruby
>> numbers["two"]
=> 2
```

```ruby
>> numbers["three"]
=> nil
```
At hand:

>> numbers  => {"one"=>1, "two"=>2}

The Hash class has many methods. Here's a sampling:

>> numbers.keys
=> ["one", "two"]

>> numbers.values
=> [1, 2]

>> numbers.invert
=> {1=>"one", 2=>"two"}

>> numbers.to_a
=> [["one", 1], ["two", 2]]

Some of the many Hash iterators: delete_if, each_pair, select
At hand:

```ruby
>> numbers
=> {"one"=>1, "two"=>2}
```

The value associated with a key can be changed via assignment.

```ruby
>> numbers["two"] = "1 + 1"
```

A key/value pair can be removed with `Hash#delete`.

```ruby
>> numbers.delete("one")
=> 1  # Returns associated value
```

```ruby
>> numbers
=> {"two"=>"1 + 1"}
```

```ruby
>> numbers["one"]
=> nil
```
The rules for keys and values:

- Key values must have a `hash` method that produces a `Fixnum`. (Duck typing!)
- Any value can be the value in a key/value pair.

```
>> h = {}; a = [1,2,3]
>> h[a] = "-"
>> h[String] = ["a","b","c"]
>> h["x".class] * h[(1..3).to_a]
=> "a-b-c"

>> h[h] = h
>> h
=> {[1, 2, 3]=>"-", String=>["a", "b", "c"], {...}=>{...}}
```

Note that keys for a given `Hash` may be a mix of types. Ditto for values. (Unlike a Java `HashMap`.)
Inconsistencies can arise when using mutable values as keys.

```ruby
>> h = {}; a = []
>> h[a] = "x"

>> h
=> {[]=>"x"}

>> a << 1
>> h
=> {[1]=>"x"}

>> h[a]
=> nil
```

Ruby treats string-valued keys as a special case and makes a copy of them.
Here's a sequence that shows some of the flexibility of hashes.

```ruby
>> h = {}

>> h[1000] = [1,2]

>> h[true] = {}

>> h[[1,2,3]] = [4]

>> h
=> {1000=>[1, 2], true=>{}, [1, 2, 3]=>[4]}

>> h[h[1000] + [3]] << 40

>> h[!h[10]]["x"] = "ten"

>> h
=> {1000=>[1, 2], true=>{"x"=>"ten"}, [1, 2, 3]=>[4, 40]}
```
Default values

An earlier simplification: If a key is not found, `nil` is returned.
Full detail: If a key is not found, the *default value* of the hash is returned.

The default value of a hash defaults to `nil` but an arbitrary default value can be specified when creating a hash with `new`:

```ruby
>> h = Hash.new("Go Fish!") # Example from ruby-doc.org

>> h.default
=> "Go Fish!"

>> h["x"] = [1,2]

>> h["x"]
=> [1, 2]

>> h["y"]
=> "Go Fish!"
```
Problem: write `tally.rb`, to tally occurrences of blank-separated "words" on standard input.

```ruby
% ruby tally.rb
to be or
not to be
^D
{"to"=>2, "be"=>2, "or"=>1, "not"=>1}
```

How can we approach it?
Solution:

```ruby
# Use default of zero so += 1 works
counts = Hash.new(0)

readlines.each do |line|
  line.split(" ").each do |word|
    counts[word] += 1
  end
end

# Like puts counts.inspect
p counts
```

tally.rb

```ruby
% ruby tally.rb
to be or
not to be
^D
{"to"=>2, "be"=>2,
"or"=>1, "not"=>1}
```

Contrast with `while/for` vs. iterators:

```ruby
counts = Hash.new(0)
while line = gets do
  for word in line.split(" ") do
    counts[word] += 1
  end
end

# Like puts counts.inspect
p counts
```

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The output of `tally.rb` is not customer-ready!

```ruby
{"to"=>2, "be"=>2, "or"=>1, "not"=>1}
```

Hash#sort produces an array of key/value arrays ordered by the keys, in ascending order:

```ruby
counts.sort
=> [['be', 2], ['not', 1], ['or', 1], ['to', 2]]
```

Problem: Produce nicely labeled output, like this:

<table>
<thead>
<tr>
<th>Word</th>
<th>Count</th>
</tr>
</thead>
<tbody>
<tr>
<td>be</td>
<td>2</td>
</tr>
<tr>
<td>not</td>
<td>1</td>
</tr>
<tr>
<td>or</td>
<td>1</td>
</tr>
<tr>
<td>to</td>
<td>2</td>
</tr>
</tbody>
</table>
At hand:
  >>> counts.sort
  ["be", 2], ["not", 1], ["or", 1], ["to", 2]]

Solution:
  ([["Word","Count"] + counts.sort).each do
   |k,v| printf("%-7s %5s\n", k, v)
  end

Notes:
  • The minus in the format %-7s left-justifies, in a field of width seven.
  • As a shortcut for easy alignment, the column headers are put at the start of the array, as a fake key/value pair.
  • We use %5s instead of %5d to format the counts and accommodate "Count", too. (This works because %s causes to_s to be invoked on the value being formatted.)
  • A next step might be to size columns based on content.
Hash\#sort's default behavior of ordering by keys can be overridden by supplying a block. The block is repeatedly invoked with two key/value pairs, like ["be", 2] and ["or", 1].

Here's a block that sorts by descending count: (the second element of the two-element arrays)

```ruby
>> counts.sort { |a,b| b[1] <=> a[1] }
=> [["to", 2], ["be", 2], ["or", 1], ["not", 1]]
```

How we could resolve ties on counts by alphabetic ordering of the words?

```ruby
counts.sort do
  |a,b|
  r = b[1] <=> a[1]
  if r != 0 then r else a[0] <=> b[0] end
end
=> [["be", 2], ["to", 2], ["not", 1], ["or", 1]]
```
Let's turn `tally.rb` into a cross-reference program:

```ruby
% cat xref.1
to be or
not to be is not
to be the question
%
ruby xref.rb < xref.1
```

<table>
<thead>
<tr>
<th>Word</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>be</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>is</td>
<td>2</td>
</tr>
<tr>
<td>not</td>
<td>2</td>
</tr>
<tr>
<td>or</td>
<td>1</td>
</tr>
<tr>
<td>question</td>
<td>3</td>
</tr>
<tr>
<td>the</td>
<td>3</td>
</tr>
<tr>
<td>to</td>
<td>1, 2, 3</td>
</tr>
</tbody>
</table>

How can we approach it?

```ruby
counts = Hash.new(0)
readlines.each do
  |line|
  line.split(' ').each do
    |word|
    counts[word] += 1
  end
end
end
```
Changes:

- Use `each_with_index` to get line numbers (0-based).
- Turn `counts` into `refs`, a Hash whose values are arrays.
- For each `word` on a line...
  - If `word` hasn't been seen, add a key/value pair with `word` and an empty array.
  - Add the current line number to `refs[word]`

Revised:

```ruby
refs = {}
readlines.each_with_index do |line, num|
  line.split(" ").each do |word|
    refs[word] = [] unless refs.member? word
    refs[word] << num unless refs[word].member? num
  end
end
```

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If we add "\texttt{p refs}" after that loop, here’s what we see:

\begin{verbatim}
% cat xref.1
to be or
not to be is not
to be the question
\end{verbatim}

\begin{verbatim}
% ruby xref.rb < xref.1
{"to"=>[0, 1, 2], "be"=>[0, 1, 2], "or"=>[0], "not"=>[1],
"is"=>[1], "the"=>[2], "question"=>[2]}
\end{verbatim}

We want:

\begin{verbatim}
% ruby xref.rb < xref.1
Word    Lines
be      1, 2, 3
is      2
not     2
\end{verbatim}
At hand:
    "to"=>[0, 1, 2], "be"=>[0, 1, 2], "or"=>[0], "not"=>[1], ...

We want:

<table>
<thead>
<tr>
<th>Word</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>be</td>
<td>1, 2, 3</td>
</tr>
</tbody>
</table>

...

Let's get fancy and size the "Word" column based on the largest word:

```ruby
max_len = refs.map{|k,v| k.size}.max
fmt = "%-#{max_len}s  %s
"

print fmt % ["Word", "Lines"]
refs.sort.each do |k,v|
  printf(fmt, k, v.map{|n| n+1} * ", ")
end
```

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Another Hash behavior

Observe:

```ruby
>> h = Hash.new { |h,k| h[k] = [] }

>> h"to"
=> []

>> h
=> {"to"=>[]}
```

If Hash.new is called with a block, that block is invoked when a non-existent key is accessed.

The block is passed the Hash and the key.

What does the block above do when a key doesn't exist?
It adds a key/value pair that associates the key with a new, empty array.
Symbols

An identifier preceded by a colon creates a `Symbol`.

```ruby
>> s1 = :testing
=> :testing

>> s1.class
=> Symbol
```

A symbol is much like a string but a given identifier always produces the same `Symbol` object.

```ruby
>> s1.object_id
=> 1103708
>> :testing.object_id
=> 1103708
```

In contrast, two identical string literals produce two different `String` objects:

```ruby
>> "testing".object_id
=> 3673780
>> "testing".object_id
=> 4598080
```
Symbols, continued

A symbol can also be made from a string with to_sym:

```ruby
>> "testing".to_sym
=> :testing
```

```ruby
>> "==".to_sym
=> :==
```

Recall that .methods returns an array of symbols:

```ruby
>> ".methods.sort
:__id__, __send__, ascii_only?, :b, :between?, :bytes,
:bytesize, :byteslice, :capitalize, :capitalize!, :casecmp, :center,
Symbols and hashes

Because symbols can be quickly compared, they're commonly used as hash keys.

```ruby
# Define a hash with symbols as keys
moves = {}
moves[:up] = [0, 1]
moves[:down] = [0, -1]

# Access the values using symbols
>> moves
=> {:up=>[0, 1], :down=>[0, -1]}

> moves["up".to_sym]
=> [0, 1]

>> moves["down"]
=> nil
```
Symbols and hashes, continued

Instead of a series of assignments we can use an initialization syntax:

```ruby
>> moves = { :up => [0,1], :down => [0,-1] }
=> {:up=>[0, 1], :down=>[0, -1]}
```

There's even more syntactic sugar available:

```ruby
>> moves = { up:[0,1], down:[0,-1] }
=> {:up=>[0, 1], :down=>[0, -1]}
```
Regular Expressions
In computer science theory, a *language* is a set of strings. The set may be infinite.

The Chomsky hierarchy of languages looks like this:

- Unrestricted languages ("Type 0")
- Context-sensitive languages ("Type 1")
- Context-free languages ("Type 2")
- Regular languages ("Type 3")

Roughly speaking, natural languages are unrestricted languages that can only be specified by unrestricted grammars.

Programming languages are usually context-free languages—they can be specified with context-free grammars, which have restrictive rules.

- Every Java program is a string in the context-free language that is specified by the Java grammar.

A regular language is a very limited kind of context-free language that can be described by a regular grammar.

- A regular language can also be described by a regular expression.
A regular expression is simply a string that may contain *metacharacters*—characters with special meaning.

Here is a simple regular expression:

\[a^+\]

It specifies the regular language that consists of the strings \{a, aa, aaa, ...\}.

Here is another regular expression:

\[(ab)^+c^*\]

It describes the set of strings that start with \texttt{ab} repeated one or more times and followed by zero or more \texttt{c}'s.

Some strings in the language are \texttt{ab}, \texttt{ababc}, and \texttt{ababababcccccccc}.

The regular expression \((\text{north}|\text{south})(\text{east}|\text{west})\) describes a language with four strings: \{northeast, northwest, southeast, southwest\}. 

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Regular expressions have a sound theoretical basis and are also very practical.

UNIX tools such as the `ed` editor and the `grep` family introduced regular expressions to a wide audience.

Most current editors and IDEs support regular expressions in searches.

Many languages provide a library for working with regular expressions.
  - Java provides the `java.util.regex` package.
  - The command `man regex` shows the interface for POSIX regular expression routines, usable in C.

Some languages, Ruby included, have a regular expression type.
Good news and bad news, continued

Regular expressions as covered in a theory class are relatively simple.

Regular expressions as available in many languages and libraries have been extended far beyond their theoretical basis.

In languages like Ruby, regular expressions are truly a language within a language.

An edition of the "Pickaxe" book devoted four pages to its summary of regular expressions.

- Four more pages sufficed to cover integers, floating point numbers, strings, ranges, arrays, and hashes.

Entire books have been written on the subject of regular expressions.

A number of tools have been developed to help programmers create and maintain complex regular expressions.
Here is a regular expression written by Mark Cranness and posted at RegExLib.com:

```
^((?>[a-zA-Z\d!#$%&'\*+\/-=\?\-_\{|\}\~]+\x20*)|"((?=(?!\[\x01-\x7f])[^"\\]|\\)[\x01-\x7f])*"\x20*)*(? <angle><))?((?!\.)(?>\.\?[^a-zA-Z\d!#$%&'\*+\/-=\?\-_\{|\}\~]+)+|"((?=(?!\[\x01-\x7f])[^"\\]|\\)[\x01-\x7f])*")@(((?!-)[a-zA-Z\d\-]+(?<!-\.)+[a-zA-Z]{2,}|\[(?!(?!\[)\.[0-5]|2[0-4]\d|[01]?\d? \d)\]{4}|[a-zA-Z\d\-]*[a-zA-Z\d]:((?=[\x01-\x7f])[^^\]\[\]\[\x01-\x7f]\]]\[\x01-\x7f]+))(?=\|$+(angle>)$)
```

It describes RFC 2822 email addresses.

My opinion: regular expressions are good for simple tasks but grammar-based parsers should be favored as complexity rises, especially when an underlying specification includes a grammar.

We'll cover a subset of Ruby's regular expression capabilities.
A simple regular expression in Ruby

One way to create a regular expression (RE) in Ruby is to use the \( /\text{regexp}/ \) syntax, for regular expression literals.

```ruby
>> re = /a.b.c/  #=> /a.b.c/

>> re.class  #=> Regexp
```

In a RE, a dot is a metacharacter (a character with special meaning) that will match any (one) character.

Letters, numbers, and some special characters simply match themselves.

The RE \(/a.b.c/\) matches strings that contain the five-character sequence \(a<\text{anychar}>b<\text{anychar}>c\)

Examples: "albacore", "barbecue", "drawback", and "iambic".
The match operator

The binary operator =~ is called "match".

One operand must be a string and the other must be a regular expression. If the string contains a match for the RE, the position of the match is returned. `nil` is returned if there is no match.

```ruby
>> "albacore" =~ /a.b.c/    #=> 0
>> "drawback" =~ /a.b.c/    #=> 2
>> "abc" =~ /a.b.c/        #=> nil

>> "abcdef" =~ /..f/        #=> 3

>> "abcdef" =~ /.f./        #=> nil

>> "abc" =~ /..../          #=> nil
```
Regular expressions are "in deep" in Ruby

Language-wise, what's an implication of the following?

```
>> /x/.class  => Regexp
```

Ruby has syntactic support for regular expressions. We can say that regular expressions are *first-class values* in Ruby.

In general there are two levels of support for a type:
- **Syntactic support**
  - Most languages have syntactic support for strings with "...".
  - Scala and ActionScript have syntactic support for XML.
  - In Icon, 'aeiou' is a *character set*, not a string.

- **Library support**
  - Java and Python have classes for working with REs.
  - C and Icon have function libraries for working with REs.

What are the tradeoffs between the two levels?

Example from Icon: `cset("aeiou")` vs. 'aeiou'
The UNIX `grep` command reads standard input or files named as arguments and prints lines that contain a specified regular expression:

```
$ grep g.h.i < /usr/share/dict/words
lengthwise
```

```
$ grep l.m.n < /usr/share/dict/words | wc -l
  252   252  2825
```

```
$ grep ....................... < /usr/share/dict/words
electroencephalograph's
```

Problem: Write a simple `grep` in Ruby that will handle the cases above.

Hint: `#{...}` interpolation works in `/....` (regular expression) literals.
UNIX grep:

$ grep g.h.i < /usr/share/dict/words

Solution:

while line = STDIN.gets  # STDIN so "g.h.i" isn't opened for input
  puts line if line =~ /#{ARGV[0]}/
end

Usage:

$ ruby rgrep.rb g.h.i < /usr/share/dict/words
lengthwise

$ ruby rgrep.rb ....................... < /usr/share/dict/words
electroencephalograph's
The match operator, continued

After a successful match we can use some cryptically named predefined global variables to access parts of the string:

- $` Is the portion of the string that precedes the match. (That's a backquote—ASCII code 96.)

- $& Is the portion of the string that was matched by the regular expression.

- $' Is the portion of the string following the match.

Example:

```ruby
>> "limit=300" =~ /=/ => 5
>> $` => "limit" (left of the match)
>> $& => "=" (the match itself)
>> $' => "300" (right of the match)
```
Here's a handy utility routine from the Pickaxe book:

```ruby
def show_match(s, re)
    if s =~ re then
        "#{'$'}<<#{'$&'}}#{'$'}"
    else
        "no match"
    end
end
end
```

Usage:

```ruby
>> show_match("limit is 300","/is/"
=> "limit <<is>> 300"
```

```ruby
>> %w{albacore drawback iambic}.
    each { |w| puts show_match(w, /a.b.c/ ) }
<<albac>ore
dr<<awbac>rk
i<<ambic>
```

**Great idea:** Put it in your `.irbrc`! Call it "sm", to save some typing!
Character classes

[characters] is a character class—a RE that matches any one of the characters enclosed by the square brackets.

/\[aeiou]/\ matches a single lower-case vowel

=> "t<<e>>sting"

A dash between two characters in a class specification creates a range based on the collating sequence.  \[0-9\] matches a single digit.

=> "Testing <<1>>, 2, 3..."

=> "no match"
[^characters] is a RE that matches any single character not in the class. (It matches the complement of the class.)

/[^0-9]/ matches a single character that is not a digit.
    >> show_match("1,000", /[^0-9]/)
    => "1<<,>>000"

For any RE we can ask,

    What is the shortest string the RE can match? What is the longest?

What is the shortest string that [A-Za-z345] can match? The longest?
    One for both! [anything] always has a one-character match!
Describe what's matched by this regular expression:

/.[a-z][0-9][a-z]./

A five character string whose middle three characters are, in order, a lowercase letter, a digit, and a lowercase letter.

In the following, which portion of the string is matched, if any?

```ruby
>> show_match("A1b33s4ax1", /.[a-z][0-9][a-z]./)
=> "A1b3<<3s4ax>>1"
```
String#gsub does global substitution with both plain old strings and regular expressions

```ruby
>> "520-621-6613".gsub("-", "<DASH>")
=> "520<DASH>621<DASH>6613"

>> "520-621-6613".gsub(/[02468]/, "(e#)"")
=> "5(e#)(e#)-(e#)(e#)1-(e#)(e#)13"
```

There's an imperative form of gsub, too.
Some frequently used character classes can be specified with \C
\d   Stands for [0-9]
\w   Stands for [A-Za-z0-9_]  
\s   Whitespace—blank, tab, carriage return, newline, formfeed

The abbreviations \D, \W, and \S produce a complemented class.

Examples:
>> show_match("Call me at 555-1212", /d/d/d/d/d/d/d/)
=> "Call me at <<555-1212>>"

>> "fun double(n) = n * 2".gsub(/w/,."
=> ".......(.) = .*"

>> "BIOW 208, 14:00-15:15 TR".gsub(/D/, ""
=> "20814001515"

>> "buzz93@tv-2000.com".gsub(/[^w-]/,"*
=> "******@********.***"
Backslashes suppress special meaning

Preceding an RE metacharacter with a backslash suppresses its meaning.

```ruby
>> show_match("123.456", /\.../)
=> "12<<3.4>>56"

>> "5-3^2*2.0".gsub(/[^\^-6]/, "_")
=> "5_3_2*2_0"

>> show_match("x = y[1] + z", /\[d\]/)
=> "x = y<<[1]>> + z"
```

An old technique with regular expressions is to take advantage of the fact that metacharacters often aren’t special when used out of context:

```ruby
>> "5-3^2*2.0".gsub(/[-6^]/, "_")
=> "5_3_2*2_0"
```
Alternatives can be specified with a vertical bar:

```ruby
>> show_match("a green box", /red|green|blue/)
=> "a <<green>> box"

>> %w{you ate a pie}.select { |s| s =~ /ea|ou|ie/ }
=> ["you", "pie"]
```
Parentheses can be used for grouping. Consider this regular expression:

`/(two|three) (apple|biscuit)s/`

It corresponds to a regular language that is a set of four strings:

{two apples, three apples, two biscuits, three biscuits}

Usage:

```ruby
>> "I ate two apples." =~ /(two|three) (apple|biscuit)s/
=> 6

>> "She ate three mice." =~ /(two|three) (apple|biscuit)s/
=> nil
```

Another:

```ruby
>> %w{you ate a mouse}.select { |s| s =~ /.(ea|ou|ie)./ }  
=> ["mouse"]
```
Simple app: looking for letter patterns

Imagine a program to look through a word list for a pattern of consonants and vowels specified on the command line, showing matches in bars.

```
% ruby convow.rb cvcvcvcvcvcvcvcvc < web2
c|hemicominerallogic|al
|hepatoperitonitis|
o|verimaginativenes|s
```

A capital letter means to match exactly that letter, in lowercase. e matches either consonant or vowel.

```
% ruby convow.rb vvvDvvv < web2
Chromat|ioideae|
Rhodobacter|ioideae|
```

```
% ruby convow.rb vvvCvvv < web2  | wc -l
24
```

```
% ruby convow.rb vvvvevvv < web2  | wc -l
43
```
Here's a solution. We loop through the command line argument and build up a regular expression of character classes and literal characters, and then look for lines with a match.

```ruby
re = ""
ARGV[0].each_char do |char|
  re += case char
         when "v" then "[aeiou]"
         when "c" then "[^aeiou]"
         when "e" then "[a-z]"
         else char.downcase
       end
end
puts re
re = /#{re}/ # Transform re from String to Regexp
STDIN.each do |line|
  puts ['$`, $&, $']*"|" if line.chomp =~ re
end
```

$ ruby convow.rb cvc
[^aeiou][aeiou][^aeiou]

$ ruby convow.rb cEEcc
[^aeiou]ee[^aeiou][^aeiou]

CSC 372 Spring 2016, Ruby Slide 223
There are regular expression operators

A rule we've been using but haven't formally stated is this:

If \( R_1 \) and \( R_2 \) are regular expressions then \( R_1R_2 \) is a regular expression.
In other words, juxtaposition is the concatenation operation for REs.

There are also postfix operators on regular expressions.

If \( R \) is a regular expression, then...

\[ R^* \] matches zero or more occurrences of \( R \)
\[ R^+ \] matches one or more occurrences of \( R \)
\[ R^? \] matches zero or one occurrences of \( R \)

All have higher precedence than juxtaposition.

*, +, and ? are commonly called quantifiers but PA doesn't use that term.
The *, +, and ? quantifiers

At hand:
- $R^*$ matches zero or more occurrences of $R$
- $R^+$ matches one or more occurrences of $R$
- $R?$ matches zero or one occurrences of $R$

What does the RE $ab^*c+d$ describe?
- An 'a' that is followed by zero or more 'b's that are followed by one or more 'c's and then a 'd'.

```ruby
>> show_match("acd", /ab*c+d/)
=> "<<acd>>"

>> show_match("abcccc", /ab*c+d/)
=> "no match"

>> show_match("abcabccccddd", /ab*c+d/)
=> "abc<<abcccccd>>dd"
```
The *, +, and ? quantifiers, continued

At hand:
- \( R^* \) matches zero or more occurrences of \( R \)
- \( R^+ \) matches one or more occurrences of \( R \)
- \( R? \) matches zero or one occurrences of \( R \)

What does the RE \(-?\d+\) describe?
Integers with any number of digits

```ruby
>> show_match("y is -27 initially", /-?\d+/)
=> "y is <<-27>> initially"

>> show_match("maybe --123.4e-10 works", /-?\d+/)
=> "maybe <<-123>>.4e-10 works"

>> show_match("maybe --123.4e-10 works", /-?\d*/ # *, not +
=> "<><><><>maybe --123.4e-10 works"
```
The *, +, and ? quantifiers, continued

What does a(12|21|3)*b describe?
Matches strings like ab, a3b, a312b, and a3123213123333b.

Write an RE to match numbers with commas, like these:

58 4,297 1,000,000 446,744 73,709,551,616

/\d(?\d(?\d))(,\d\d\d)*/ -- Alan Smith
\d\d\d|\d\d|\d)(,\d\d\d)* # Why is \d\d\d first?

Write an RE to match floating point literals, like these:

1.2 .3333e10 -4.567e-30 .0001

>> %w{1.2 .3333e10 -4.567e-30 .0001}.
each { |s| puts show_match(s, /-?\d*\.\d+(e-?\d+)?/) }
<<1.2>>
<<.3333e10>>
<<-4.567e-30>>
<<.0001>>

Note the \. to match only a period.
*, +, and ? are greedy!

The operators *, +, and ? are "greedy"—each tries to match the longest string possible, and cuts back only to make the full expression succeed.

Example:

Given a.*b and the input 'abbb', the first attempt is:

- a matches a
- .* matches bbb
- b fails—no characters left!

The matching algorithm then backtracks and does this:

- a matches a
- .* matches bb
- b matches b
More examples of greedy behavior:

```ruby
>> show_match("xabbbbc", /a.*b/)
=> "x<<abbbbc>>c"

>> show_match("xabbbbc", /ab?b?/) => "x<<abb>>bbc"

>> show_match("xabbbbcxyzc", /ab?b?.*c/)
=> "x<<abbbbcxyzc>>"
```

Why are *, +, and ? greedy?
Lazy/reluctant quantifiers

In the following we'd like to match just 'abc' but the greedy asterisk goes too far:

```ruby
show_match("x + 'abc' + 'def' + y", /'.*'/) => "x + <<'abc' + 'def'>> + y"
```

We can make * lazy by putting ? after it, causing it to match only as much as needed to make the full expression match. Example:

```ruby
>> show_match("x + 'abc' + 'def' + y", /'.*?'/) => "x + <<'abc'>> + 'def' + y"
```

?? and +? are supported, too. The three are also called reluctant quantifiers.

Once upon a time, before *? was supported, one would do this:

```ruby
>> show_match("x + 'abc' + 'def' + y", /[^[']+/) => "x + <<'abc'>> + 'def' + y"
```
Specific numbers of repetitions

We can use curly braces to require a specific number of repetitions:

```ruby
>> show_match("Call me at 555-1212!", /\d{3}-\d{4}/)
=> "Call me at <<555-1212>>!"
```

There are also forms with `{min,max}` and `{min,}

```ruby
>> show_match("3/17/2013", /\d{1,2}/\d{1,2}/(\d{4}|\d{2})/)
=> "<<3/17/2013>>"
```

Note that the RE above has escaped slashes to match the literal slashes.
split and scan with regular expressions

We can split a string using a regular expression:
```ruby
>> "one, two,three / four".split(/\s,\s+/) # w.s., commas, slashes
=> ["", "one", "two", "three", "four"]
```

Note that leading delimiters produce an empty string in the result.

If we can describe the strings of interest instead of what separates them, scan is a better choice:
```ruby
>> "one, two,three / four".scan(/\w+/)
=> ["one", "two", "three", "four"]
```
```ruby
>> "10.0/-1.3...5.700+[1.0,2.3]".scan(/-?\d+\./\d+/)
=> ["10.0", "-1.3", "5.700", "1.0", "2.3"]
```

Here's a way to keep all the pieces:
```ruby
>> "one, two,three / four".scan(/\w+|\W+/)
=> [" ", "one", ",", "two", ",", "three", "/", "four"]
```
Reminder: \texttt{s =~ /x/} succeeds if "x" appears anywhere in \texttt{s}.

The metacharacter ^ is an \textit{anchor} when used at the start of a RE. (At the start of a character class it means to complement.)

^ doesn't match any characters but it constrains the following regular expression to appear at the beginning of the string being matched against.

\begin{verbatim}
>> show_match("this is x", /^x/)
=> "no match"

>> show_match("this is x", /^this/)
=> "<<this>> is x"
\end{verbatim}

What will \(^x|y/ \text{ match?} \text{ Hint: it's not the same as } /^\text{x|y}/\\)

What does \(^.[^0-9]/ \text{ match?}\\)

\textbf{TODO}: Talk about newlines, and \textbackslash A, \textbackslash Z, and \textbackslash z
Another anchor is $. It constrains the preceding regular expression to appear at the end of the string.

```ruby
>> show_match("ending", /end$/)
=> "no match"

>> show_match("the end", /end$/)
=> "the <<end>>"
```

What does /\d+$/ match?
Can it be shortened?
We can combine the ^ and $ anchors to fully specify a string.

Problem: Write a RE to match lines with only a curly brace and (maybe) whitespace.

```ruby
>> show_match(" } ", /^\s*[^{}]\s*$/) => "<< } >>"
```

Using grep, print lines in Ruby source files that are exactly three characters long.

```sh
% grep ^...$ *.rb
```

The sets of metacharacters recognized by grep, egrep, and egrep -P differ. fgrep treats all characters as literals. The set in egrep -P is closest to Ruby, but there's also rgrep.rb from slide 210.
What does \w+\d+/ specify?

*One or more "word" characters followed by one or more digits.*

How do the following matches differ from each other?

```ruby
line =~ /\w+\d+/  
line =~ /\w+\d+/  
line =~ /\w+\d+$/  
line =~ /\w+\d+$/  
line =~ /^\w+\d+$/  
line =~ /^.*\w+\d+$/  
line =~ /^.*\w+\d+$/  
```
Imagine a program that's reading dozens of large data files whose lines start with first names, like "Mary". We're getting drowned by the data.

```ruby
for fname in files
  f = open(fname)
  while line = f.gets
    ...lots of processing to build a data structure, bdata...
  end
  p bdata     # outputs way too much to easily analyze!!
end
```

We *could* edit data files down to a few names but here's an RE-based solution.

```ruby
for fname in files
  f = open(fname)
  while line = f.gets
    next unless line =~ /^\(John|Dana|Mary\),/  # Note trailing comma!
    ...processing...     # toomuch.rb
  end
end
```
Recall that `convow.rb` on slide 223 simply does `char.downcase` on any characters it doesn't recognize. `downcase` doesn't change ^ or $.

The command

```ruby
% ruby convow.rb ^cvc$
```

builds this RE

```
/^[^aeiou][aeiou][^aeiou]$/
```

Let's explore with it:

```ruby
% ruby convow.rb ^cvc$ < web2 | wc -l
858
% ruby convow.rb ^vcccccv$ < web2 | wc -l
15
% ruby convow.rb ^vccccccccv$ < web2
| oxyphyte |
```
Named groups

The following regular expression uses three named groups to capture the elements of a binary arithmetic expression

```ruby
>> re = /(?<lhs>\d+)(?<op>[+\-*\/])(?<rhs>\d+)/
```

After a successful match, the predefined global `$~`, an instance of `MatchData`, shows us the groups:

```ruby
>> re =~ "What is 100+23?"
=> 8

>> $~
=> #<MatchData "100+23" lhs:"100" op:"+" rhs:"23">

>> $~["lhs"]
=> "100"
```

Named groups are sometimes called named backreferences or named captures.
Named groups, continued

At hand:
/(<lhs>\d+)(?<op>[\+\-\*\/])(?<rhs>\d+)/

Important: Named groups must always be enclosed in parentheses.

Consider the difference in these two REs:
/x(<n>\d+)/
   Matches strings like "x10" and "testx7ing"

/x?<n>\d+/  
   Matches strings like "<n>10", "ax<n>10", "testx<n>10ing"

Design lesson:
   "(?) in a RE originally had no meaning, so it provided an opportunity for extension without breaking any existing REs.

Post-lecture addition: See "NAMED CAPTURES AND LOCAL VARIABLES" in RPL.
Application: Time totaling

Consider an application that reads elapsed times on standard input and prints their total:

```ruby
% ruby ttl.rb
3h
15m
4:30
^D
7:45
```

Multiple times can be specified per line, separated by spaces and commas.

```ruby
% ruby ttl.rb
10m, 3:30
20m 2:15 1:01 3h
^D
10:16
```

How can we approach it?
def main
  mins = 0
  while line = gets do
    line.scan(/[^\s,]+/).each { |time| mins += parse_time(time) }
  end
  printf("%d:%02d\n", mins / 60, mins % 60)
end

def parse_time(s)
  if s =~ /^([^<hours><\d+>)(?<mins>[0-5]\d)$/
    $~["hours"].to_i * 60 + $~["mins"].to_i
  elsif s =~ /^([^<n><\d+>)(?<which>[hm])$/
    n = $~["n"].to_i
    if $~["which"] == "h" then n * 60
      else n end
  else
    0 # return 0 for things that don't look like times
  end
end
main
Example: consuming a string

Problem: Write a method `pt(s)` that takes a string like "[(10,'a'),(3,'x'),(7,'o')]" and returns an array with the sum of the numbers and a concatenation of the letters. If `s` is malformed, `nil` is returned.

Examples:

```ruby
>> pt "[(10,'a'),(3,'x'),(7,'o')]"
=> [20, "axo"]

>> pt "[(100,'c')]"
=> [100, "c"]

>> pt "[(10,'x'),(5,7,'y')]"
=> nil

>> pt "[(10,'x'),(5,'y'),]"
=> nil
```
Example, continued

Desired:

```ruby
>> pt "[(10,'a'),(3,'x'),(7,'o')]"
=> [20, "axo"]
```

Approach:

1. Remove outer brackets: "(10,'a'),(3,'x'),(7,'o')"
2. Append a comma: "(10,'a'),(3,'x'),(7,'o'),". (Why?!) 
3. Recognize \((\text{NUM,LET})\), and replace with ""
4. Repeat 3. until failure
5. If nothing left but an empty string, success!

Important: By appending that comma we produce a simple repetition, 

\((\text{tuple },)+\)

rather than

\(\text{tuple } (, \text{tuple})*\)
Solution:
```ruby
def pt(s) # process_tuples.rb
    if s =~ /^\[(?<tuples>.*)\]/ then
        tuples = $~['tuples'] + ','
        sum, lets = 0, ''
        tuples.gsub!(/\((?<num>\d+),(?<let>[a-z])\)/, ') do
            sum += $~['num'].to_i
            lets << $~['let']
        end
    end
    if tuples.empty? then
        [sum, lets]
    end
end
```

**Approach:**
1. Remove outer brackets
2. Append a comma
3. Recognize (NUM,LET), and replace with ""
4. Repeat 3. until failure
5. If nothing left but an empty string, success!

Todo: Named groups can set local variables

Example, continued
Avoiding repetitious REs

calc.rb on assignment 6 accepts input lines such as these:

```
x=7
yval=x+10*x
x+yval+z
```

Here's a very repetitious RE that recognizes calc.rb input lines:
```
valid_line = /^([a-zA-Z][a-zA-Z\d]*=)?([a-zA-Z][a-zA-Z\d]*|\d+)([-+*\/*\[\d\]([a-zA-Z][a-zA-Z\d]*|\d+))*/
```

Let's use some intermediate variables to build that same RE.
```
var = /[a-zA-Z][a-zA-Z\d]*/i # trailing "i": case insensitive

expr = /(#{var}|\d+)/

op = /[-+*\/*\[\d\]*/

valid_line = /^(#{var}=)?#{expr}(#{op}#{expr})*/
```
Lots more with regular expressions

Our look at regular expressions ends here but there's lots more, like...

- Back references—/(.)(.).\2\1/ matches 5-character palindromes
- Nested regular expressions
- Nested and conditional groups
- Conditional subpatterns
- Zero-width positive lookahead

Groups can be accessed in code with $1, $2, ...

Proverb:

A programmer decided to use regular expressions to solve a problem. Then the programmer had two problems.

Regular expressions are great, up to a point.

SNOBOL4 patterns, Icon's string scanning facility, and Prolog grammars can all recognize unrestricted languages and are far less complex than the regular expression facility in most languages.
Defining classes
Imagine a class named **Counter** that models a tally counter.

Here's how we might create and interact with an instance of Counter:

```ruby
    c1 = Counter.new
    c1.click
    c1.click

    puts c1  # Output: Counter's count is 2
    c1.reset

    c2 = Counter.new "c2"
    c2.click

    puts c2  # Output: c2's count is 1
    c2.click
    puts "c2 = #{c2.count}"  # Output: c2 = 2
```
Here is a partial implementation of Counter:

```ruby
class Counter
  def initialize(label = "Counter")
    ...
  end
  ...
end  # Counter.rb
```

Class definitions are bracketed with `class` and `end`. Class names must start with a capital letter. Unlike Java there are no filename requirements.

The `initialize` method is the constructor, called when `new` is invoked.

```ruby
c1 = Counter.new

c2 = Counter.new "c2"
```

If no argument is supplied to `new`, the default value of "Counter" is used.
Here is the body of `initialize`:

```ruby
class Counter
  def initialize(label = "Counter")
    @count = 0
    @label = label
  end
end
```

Instance variables are identified by prefixing them with `@`.

An instance variable comes into existence when it is assigned to. The code above creates `@count` and `@label`. (There are no instance variable declarations.)

Just like Java, each object has its own copy of instance variables.
Let's add `click` and `reset` methods, which are straightforward:

```ruby
class Counter
  def initialize(label = "Counter")
    @count = 0
    @label = label
  end

  def click
    @count += 1
  end

  def reset
    @count = 0
  end
end
```

Counter, continued
In Ruby the instance variables of an object cannot by accessed by any other object.

The only way way to make the value of \texttt{@count} available to other objects is via methods.

Here's a simple "getter" for the counter's count.

\begin{verbatim}
def count
    @count
end
\end{verbatim}

Let's override \texttt{Object#to\_s} with a \texttt{to\_s} that produces a detailed description:

\begin{verbatim}
def to\_s
    return "#{\texttt{@label}}'s count is #{\texttt{@count}}"
end
\end{verbatim}

In Ruby, there is simply no such thing as a public instance variable. All access must be through methods.
Full source for **Counter** thus far:

```ruby
class Counter
  def initialize(label = "Counter")
    @count = 0; @label = label
  end

  def click
    @count += 1
  end

  def reset
    @count = 0
  end

  def count
    # Note the convention: count, not get_count
    @count
  end

  def to_s
    return "#{@label}'s count is #{@count}"
  end
end
```

```
# Counter.rb
```

Common error: omitting the `@` on a reference to an instance variable.
An interesting thing about instance variables

Consider this class: (instvar.rb)

```ruby
class X
  def initialize(n)
    case n
    when 1 then @x = 1
    when 2 then @y = 1
    when 3 then @x = @y = 1
    end; end; end

What's interesting about the following?

```ruby
> X.new 1
=> #<X:0x00000101176838 @x=1>

> X.new 2
=> #<X:0x00000101174970 @y=1>

> X.new 3
=> #<X:0x0000010117aaa0 @x=1, @y=1>
```

Instances of a class can have differing sets of instance variables!
If `class X ... end` has been seen and another `class X ... end` is encountered, the second definition adds and/or replaces methods.

Let's confirm `Counter` has no `label` method.

```ruby
>> c = Counter.new "ctr 1"
```

```ruby
>> c.label
NoMethodError: undefined method `label' ...
```

Now we add a `label` method: (we're typing lines into `irb` but could load)

```ruby
>> class Counter
>>   def label; @label; end
>> end
```

```ruby
>> c.label
=> "ctr 1"
```

What's an implication of this capability?

*We can add methods to classes written by others!*
In Icon, the unary ? operator can be used to generate a random number or select a random value from an aggregate.

Icon Evaluator, Version 1.1
][ ?10
  r1 := 3 (integer)
][ ?"abcd"
  r2 := "b" (string)

I miss that. Let's add something similar to Ruby!

If we call Kernel#rand with a Fixnum n it will return a random Fixnum r such that 0 <= r < n.

There's no unary ? to overload in Ruby so let's just add a rand method to Fixnum and String.
Here is `random.rb`:

```ruby
class Fixnum
  def rand
    Kernel.rand(self) + 1
  end
end

class String
  def rand
    self[size.rand-1]  # Uses Fixnum.rand
    end
end
```

```
>> load "random.rb"
>> 12.times { print 6.rand, " " }
2 1 2 4 2 1 4 3 4 4 6 3
>> 8.times { print "HT".rand, " " }
H H T H T T H H
```

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An interesting thing about class definitions

Observe the following. What does it suggest to you?

```ruby
>> class X
>> end
=> nil

>> p (class Y; end)
nil
=> nil

>> class Z; puts "here"; end
here
=> nil
```

Class definitions are executable code!
Class definitions are executable code

At hand: A class definition is executable code. The following class definition uses a case statement to selectively execute defs for methods.

```ruby
class X
    print "What methods would you like? 
    gets.split.each do |m|
    case m
        when "f" then def f; "from f" end
        when "g" then def g; "from g" end
        when "h" then def h; "from h" end
    end
end
end
```

Use:

```ruby
>> load "dynmethods1.rb"
What methods would you like? f g
>> x = X.new => #<X:0x007fc45c0b0f40>
>> x.f => "from f"
>> x.g => "from g"
>> x.h
NoMethodError: undefined method `h' for #<X:...>
```

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Kernel#eval parses a string containing Ruby source code and executes it.

```ruby
>> s = "abc"

>> n = 3

>> eval "x = s * n" => "abcabcabc"

>> x => "abcabcabc"

>> eval "x[2..-2].length" => 6

>> eval gets
s.reverse
=> "cba"
```

Note that eval uses variables from the current scope and that an assignment to x is reflected in the current scope. (Note: There are details about scoping!)

Bottom line: A Ruby program can generate code for itself.
mk_methods.rb prompts for a method name, parameters, and method body. It then creates that method and adds it to class X.

```ruby
>> load "mk_methods.rb"
What method would you like? add
Parameters? a, b
What shall it do? a + b
Method add(a, b) added to class X

What method would you like? last
Parameters? x
What shall it do? x[-1]
Method last(x) added to class X

What method would you like? ^D => true
  >> x = X.new    #=> #<X:0x0000010185d930>
  >> x.add(3,4)  #=> 7
  >> x.last "abcd"  #=> "d"
```
Here is `mk_methods.rb`. Note that the body of the class is a while loop.

```ruby
class X
    while (print "What method would you like? "; name = gets)
        name.chomp!

        print "Parameters? 
        params = gets.chomp

        print "What shall it do? 
        body = gets.chomp

        code = "def \#{name} (#{params}); \#{body}; end"

        eval(code)
        print("Method \#{name}(#{params}) added to class \#{self}"

    end
    end

Is this a useful capability or simply fun to play with?
```

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Does `eval` pose any risks?

```ruby
while (print("? "); line = gets)
  eval(line)
end # eval1.rb
```

Interaction: (input is underlined)
```
% ruby eval1.rb
? puts 3*5
15
? puts "abcdef".size
6
? system("date")
Mon Mar 23 19:09:35 MST 2015
? system("rm -rf ...")
...
? system("chmod 777 ...")
...
At hand:

```ruby
% ruby eval1.rb
? system("rm -rf ...")
...
? system("chmod 777 ...")
...
```

But, we can do those things without using Ruby!

**eval** gets risky when we can't trust the source of the data. Examples:

- A collaborator on a project sends us a data file.
- A Ruby on Rails web app calls **eval** with user-supplied data. (!)

It's very easy to fall victim to a variety of *code-injection attacks* when using **eval**.

The **define_method** (et. al) machinery is often preferred over **eval** but risks still abound!

Related topic: Ruby supports the notion of *tainted* data.
Like Java, Ruby provides a way to associate data and methods with a class itself rather than each instance of a class.

Java uses the **static** keyword to denote a class variable.

In Ruby a variable prefixed with two at-signs is a class variable.

Here is **Counter** augmented with a class variable that keeps track of how many counters have been created.

```ruby
class Counter
  @@created = 0 # Must precede any use of @@created
  def initialize(label = "Counter")
    @count, @label = 0, label
    @@created += 1
  end
end
```

Note: Unaffected methods are not shown.
To define a class method, simply prefix the method name with the name of the class:

```ruby
class Counter
    @@created = 0
    ...
    def Counter.created
        return @@created
    end
end
```

Usage:

```ruby
>> Counter.created          #=> 0
>> c = Counter.new
>> Counter.created          #=> 1
>> 5.times { Counter.new }
>> Counter.created          #=> 6
```
By default, methods are public. If `private` appears on a line by itself, subsequent methods in the class are private. Ditto for `public`.

```ruby
class X
  def f; puts "in f"; g end  # Note: calls g
  private
  def g; puts "in g" end
end
```

Usage:
```
>> x = X.new
>> x.f
in f
in g
>> x.g
NoMethodError: private method `g' ...
```

Speculate: What are `private` and `public`? Keywords?
Methods in `Module`! (`Module` is an ancestor of `Class`.)
If `Counter` were in Java, we might provide methods like `void setCount(int n)` and `int getCount()`.

Our `Counter` already has a `count` method as a "getter".

For a "setter" we implement `count=`, with a trailing equals sign.

```ruby
def count= n
  puts "count=(#{n}) called"  # Just for observation (LHtLAL)
  @count = n unless n < 0
end
```

Usage:

```ruby
>> c = Counter.new
>> c.count = 10
  count=(10) called
=> 10
>> c                                   => Counter's count is 10
```

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Here's a class to represent points on a Cartesian plane:

```ruby
class Point
  def initialize(x, y)
    @x = x
    @y = y
  end
  def x; @x end
  def y; @y end
end
```

Usage:

```ruby
>> p1 = Point.new(3,4) #=> #<Point:0x00193320 @x=3, @y=4>
>> [p1.x, p1.y] #=> [3, 4]
```

It can be tedious and error prone to write a number of simple getter methods like `Point#x` and `Point#y`. 
The method `attr_reader` creates getter methods.

Here's an equivalent definition of `Point`:
```ruby
class Point
  def initialize(x, y)
    @x = x
    @y = y
  end
  attr_reader :x, :y
end
```

Usage:
```ruby
>> p = Point.new(3,4)
>> p.x => 3
>> p.x = 10
NoMethodError: undefined method `x=' for #<Point: ...>
```

Why does `p.x = 10` fail?
If you want both getters and setters, use `attr_accessor`.

```ruby
class Point
  def initialize(x, y)
    @x = x
    @y = y
  end

  attr_accessor :x, :y
end
```

Usage:

```ruby
>> p = Point.new(3, 4)
>> p.x
=> 3
>> p.y = 10
```

It's important to appreciate that `attr_reader` and `attr_accessor` are methods that create methods. (What if Ruby didn't provide them?)
Operator overloading
In most languages at least a few operators are "overloaded"—an operator stands for more than one operation.

C: + is used to express addition of integers, floating point numbers, and pointer/integer pairs.

Java: + is used to express addition and string concatenation.

Icon: \(*x\) produces the number of...
   characters in a string
   values in a list
   key/value pairs in a table
   results a "co-expression" has produced

Icon: + means only addition; \(s_1 \mid \mid s_2\) is string concatenation

What are examples of overloading in Ruby? In Haskell?
We've seen that Ruby operators can be expressed as method calls:

\[ 3 + 4 \text{ is } 3.+@4() \]

Here's what subscripting means:

\[ "abc"[2] \text{ is } "abc".[](2) \]
\[ "testing"[2,3] \text{ is } "testing".[](2,3) \]

Unary operators are indicated by adding @ after the operator:

\[ -5 \text{ is } 5.-@() \]
\[ !"abc" \text{ is } "abc".!.@() \]

Challenge: See if you can find a binary operation that can't be expressed as a method call.
Let's use a dimensions-only rectangle class to study overloading in Ruby:

```ruby
class Rectangle
  def initialize(w, h)
    @width, @height = w, h
  end
  attr_reader :width, :height
  def area
    width * height
  end
  def inspect
    "#{width} x #{height} Rectangle"
  end
end
```

Usage:

```ruby
>> r = Rectangle.new(3,4) #=> 3 x 4 Rectangle
>> r.area               #=> 12
>> r.width              #=> 3
```
Let's imagine that we can compute the "sum" of two rectangles:

```
>> a = Rectangle.new(3,4)  => 3 x 4 Rectangle
>> b = Rectangle.new(5,6)  => 5 x 6 Rectangle
>> a + b                   => 8 x 10 Rectangle
>> c = a + b + b           => 13 x 16 Rectangle
>> (a + b + c).area        => 546
```

As shown above, what does `Rectangle + Rectangle` mean?
Operator overloading, continued

Our vision:

```ruby
>> a = Rectangle.new(3,4); b = Rectangle.new(5,6)
>> a + b => 8 x 10 Rectangle
```

Here's how to make it so:

```ruby
class Rectangle
  def + rhs
    Rectangle.new(self.width + rhs.width, self.height + rhs.height)
  end
end
```

Remember that `a + b` is equivalent to `a.+(b)`. We are invoking the method "+" on `a` and passing it `b` as a parameter.

The parameter name, `rhs`, stands for "right-hand side".

Do we need `self` in `self.width` or would just `width` work? How about `@width`?

Even if somebody else had provided `Rectangle`, we could still overload `+` on it—the lines above are additive, assuming `Rectangle.freeze` hasn't been done.
Operator overloading, continued

For reference:
```ruby
def + rhs
    Rectangle.new(self.width + rhs.width, self.height + rhs.height)
end
```

Here is a **faulty implementation** of our idea of rectangle addition:
```ruby
def + rhs
    @width += rhs.width; @height += rhs.height
end
```

What's wrong with it?
```ruby
>> a = Rectangle.new(3,4)
>> b = Rectangle.new(5,6)

>> c = a + b => 10

>> a => 8 x 10 Rectangle
```

The problem:

> *We're changing the attributes of the left operand instead of creating and returning a new instance of Rectangle.*
Operator overloading, continued

Just like with regular methods, we have complete freedom to define what's meant by an overloaded operator.

Here is a method for **Rectangle** that defines unary minus to be **imperative** "rotation" (a clear violation of the Principle of Least Astonishment!)

```ruby
def -@    # Note: @ suffix to indicate unary form of -
    @width, @height = @height, @width
    self
end

>> a = Rectangle.new(2,5) => 2 x 5 Rectangle
>> -a                => 5 x 2 Rectangle
>> a + -a            => 4 x 10 Rectangle
>> a                => 2 x 5 Rectangle
```

Goofy, yes?
Operator overloading, continued

At hand:
```ruby
def -@
    @width, @height = @height, @width
    self
end
```

What's a more sensible implementation of unary `-`?
```ruby
def -@
    Rectangle.new(height, width)
end
```

```ruby
>> a = Rectangle.new(5,2)  #=> 5 x 2 Rectangle
>> -a                      #=> 2 x 5 Rectangle
>> a                       #=> 5 x 2 Rectangle
>> a += -a; a               #=> 7 x 7 Rectangle
```
Consider "scaling" a rectangle by some factor. Example:

```ruby
>> a = Rectangle.new(3,4)  #=> 3 x 4 Rectangle
>> b = a * 5               #=> 15 x 20 Rectangle
>> c = b * 0.77            #=> 11.55 x 15.4 Rectangle
```

Implementation:
```ruby
def * rhs
    Rectangle.new(self.width * rhs, self.height * rhs)
end
```

A problem:
```ruby
>> a       #=> 3 x 4 Rectangle
>> 3 * a   #=> TypeError: Rectangle can't be coerced into Fixnum
```

What's wrong?
```ruby
We've implemented only Rectangle * Fixnum
```
Imagine a case where it's useful to reference width and height uniformly, via subscripts:

```
>> a = Rectangle.new(3,4) => 3 x 4 Rectangle
>> a[0]               => 3
>> a[1]               => 4
>> a[2]               RuntimeError: out of bounds
```

Note that `a[n]` is `a.[ ](n)`

Implementation:
```
def [] n
  case n
  when 0 then width
  when 1 then height
  else raise "out of bounds"
  end
end
```
Is Ruby extensible?

A language is considered to be extensible if we can create new types that can be used as easily as built-in types.

Does our simple Rectangle class and its overloaded operators demonstrate that Ruby is extensible?

What would \( a = b + c \times 2 \) with Rectangles look like in Java?

Maybe: `Rectangle a = b.plus(c.times(2));`

How about in C?

Would `Rectangle a = rectPlus(b, rectTimes(c, 2));` be workable?

Haskell goes further with extensibility, allowing new operators to be defined.
Ruby is mutable

Ruby is not only extensible; it is also mutable—we can change the meaning of expressions.

If we wanted to be sure that a program never used integer addition, we could start with this:

```ruby
class Fixnum
  def + x
    raise "boom!"
  end
end
```

What else would we need to do?

Contrast: C++ is extensible, but not mutable. For example, in C++ you can define the meaning of `Rectangle * int` but you can't change the meaning of integer addition, as we do above.
Inheritance
A Shape hierarchy in Ruby

Here's the classic Shape/Rectangle/Circle inheritance example in Ruby:

```ruby
class Shape
  def initialize(label)
    @label = label
  end

  attr_reader :label
end

class Rectangle < Shape
  def initialize(label, width, height)
    super(label)
    @width, @height = width, height
  end

  def area
    width * height
  end

  def inspect
    "Rectangle #{label} (#{width} x #{height})"
  end

  attr_reader :width, :height
end

Rectangle < Shape specifies inheritance.

Note that Rectangle methods use the generated width and height methods rather than @width and @height.
```
class Circle < Shape
  def initialize(label, radius)
    super(label)
    @radius = radius
  end

  attr_reader :radius

  def area
    Math::PI * radius * radius
  end

  def perimeter
    Math::PI * radius * 2
  end

  def inspect
    "Circle #{label} (r = #{radius})"
  end
end

Math::PI references the constant PI in the Math class.
Similarities to inheritance in Java

Inheritance in Ruby has a lot of behavioral overlap with Java:

- Subclasses inherit superclass methods.
- Methods in a subclass can call superclass methods.
- Methods in a subclass override superclass methods of the same name.
- Calls to a method \( f \) resolve to \( f \) in the most-subclassed (most-derived) class.

There are differences, too:

- Subclass methods can always access superclass fields.
- Superclass constructors aren't automatically invoked when creating an instance of a subclass.
There's no `abstract`

The `abstract` reserved word is used in Java to indicate that a class, method, or interface is abstract.

Ruby does not have any language mechanism to mark a class or method as abstract.

Some programmers put "abstract" in class names, like `AbstractWindow`.

A method-level practice is to have abstract methods raise an error if called:

```ruby
class Shape
  def area
    raise "Shape#area is abstract"
  end
end
```

There is also an `abstract_method"gem"` (a package of code and more):

```ruby
class Shape
  abstract_method :area
  ...
```
Inheritance is important in Java

A common use of inheritance in Java is to let us write code in terms of a superclass type and then use that code to operate on subclass instances.

With a Shape hierarchy in Java we might write a routine sumOfAreas:

```java
static double sumOfAreas(Shape shapes[]) {
    double area = 0.0;
    for (Shape s: shapes)
        area += s.getArea();
    return area;
}
```

We can make Shape.getArea() abstract to force concrete subclasses to implement getArea().

sumOfAreas is written in terms of Shape but works with instances of any subclass of Shape.
Here is `sumOfAreas` in Ruby:

```ruby
def sumOfAreas(shapes)
    area = 0.0
    for shape in shapes do
        area += shape.area
    end
    area
end
```

Does it rely on inheritance in any way?

Even simpler:

```ruby
sum = shapes.inject (0.0) { |memo, shape| memo + shape.area }
```

Dynamic typing in Ruby makes it unnecessary to require common superclasses or interfaces to write polymorphic methods that operate on a variety of underlying types.

If you look closely, you'll find that some common design patterns are simply patterns of working with inheritance hierarchies in statically typed languages.
Imagine an abstract class \texttt{VString} with two concrete subclasses: \texttt{ReplString} and \texttt{MirrorString}.

A \texttt{ReplString} is created with a string and a replication count. It supports \texttt{size}, substrings with \texttt{[pos]} and \texttt{[start, len]}, and \texttt{to_s} operations.

\begin{verbatim}
>> r1 = ReplString.new("abc", 2) => ReplString(6)

>> r1.size => 6

>> r1[0] => "a"

>> r1[10] => nil

>> r1[2,3] => "cab"

>> r1.to_s => "abcabc"
\end{verbatim}
A **MirrorString** represents a string concatenated with a reversed copy of itself.

```ruby
>> m1 = MirrorString.new("abcdef")
=> MirrorString(12)

>> m1.to_s
=> "abcdeffedcba"

>> m1.size
=> 12

>> m1[3,6]
=> "deffed"
```

What's a trivial way to implement the **VString/ReplString/MirrorString** hierarchy?
A trivial VString implementation

class VString
    def initialize(s)
        @s = s
    end

    def [](start, len = 1)
        @s[start, len]
    end

    def size
        @s.size
    end

    def to_s
        @s.dup
    end
end

class ReplString < VString
    def initialize(s, n)
        super(s * n)
    end

    def inspect
        "ReplString(#{size})"
    end
end

class MirrorString < VString
    def initialize(s)
        super(s + s.reverse)
    end

    def inspect
        "MirrorString(#{size})"
    end
end
New requirements:
   A VString can be created using either a VString or a String.
   A ReplString can have a very large replication count.

Will VStrings in constructors work with the implementation as-is?
   >> m2 = MirrorString.new(ReplString.new("abc",3))
   NoMethodError: undefined method `reverse' for ReplString

   >> r2 = ReplString.new(MirrorString.new("abc"),5)
   NoMethodError: undefined method `*' for MirrorString

What's the problem?
   The ReplString and MirrorString constructors use * n and .reverse

What will ReplString("abc", 2_000_000_000_000) do?
Here's some behavior that we'd like to see:

```ruby
>> s1 = ReplString.new("abc", 2_000_000_000_000)
  => ReplString("abc",2000000000000)

>> s1[0]  => "a"
>> s1[-1] => "c"
>> s1[1_000_000_000] => "b"

>> s2 = MirrorString.new(s1)
  => MirrorString(ReplString("abc",2000000000000))

>> s2.size  => 12000000000000
>> s2[-1]  => "a"
>> s2[s2.size/2 - 3, 6] => "abccba"
```

VString, continued
Let's review requirements:

- Both `ReplString` and `MirrorString` are subclasses of `VString`.
- A `VString` can be created using either a `String` or a `VString`.
- The `ReplString` replication count can be a `Bignum`.
- If `vs` is a `VString`, `vs[pos]` and `vs[pos,len]` produce `Strings`.
- `VString#size` works, possibly producing a `Bignum`.
- `VString#to_s "works" but is problematic with long strings.

How can we make this work?
Let's play computer!

```ruby
>> s = MirrorString.new(ReplString.new("abc", 1_000_000))
=> MirrorString(ReplString("abc", 1000000))

>> s.size
=> 6000000

>> s[-1]
=> "a"

>> s[3_000_000]
=> "c"

>> s[3_000_000,6]
=> "cbacba"
```

**VString** stands for "virtual string"—the hierarchy provides the illusion of very long strings but uses very little memory.

What data did you need to perform those computations?
Modules and "mixins"
A Ruby *module* can be used to group related methods for organizational purposes.

Imagine some methods to comfort a homesick Haskell programmer at Camp Ruby:

```ruby
module Haskell
  def Haskell.head(a)  # Class method--prefixed with class name
    a[0]
  end

  def Haskell.tail(a)
    a[1..-1]
  end
  ...
end

>> a = [10, "twenty", 30, 40.0]
>> Haskell.head(a)
=> 10
>> Haskell.tail(a)
=> ["twenty", 30, 40.0]
```
In addition to providing a way to group related methods, a module can be "included" in a class. When a module is used in this way it is called a "mixin" because it mixes additional functionality into a class.

Here is a revised version of the Haskell module. The class methods are now written as instance methods; they use self and have no parameter:

```ruby
module Haskell
  def head
    self[0]
  end

  def tail
    self[1..-1]
  end
end
```

Previous version:

```ruby
module Haskell
  def Haskell.head(a)
    a[0]
  end

  def Haskell.tail(a)
    a[1..-1]
  end
end
```
Mixins, continued

We can mix our Haskell methods into the `Array` class like this:

```ruby
% cat mixin1.rb
require './Haskell'     # loads ./Haskell.rb if not already loaded
class Array
    include Haskell
end
```

We can load `mixin1.rb` and then use `.head` and `.tail` on arrays:

```ruby
>> load "mixin1.rb"
>> ints = (1..10).to_a => [1, 2, 3, 4, 5, 6, 7, 8, 9, 10]

>> ints.head
=> 1

>> ints.tail
=> [2, 3, 4, 5, 6, 7, 8, 9, 10]

>> ints.tail.tail.head
=> 3
```

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We can add those same capabilities to **String**, too:

```
class String
  include Haskell
end
```

**Usage:**

```
>> s = "testing"
```

```
>> s.head => "t"
>> s.tail => "esting"
>> s.tail.tail.head => "s"
```

In addition to the `include` mechanism, what other aspect of Ruby facilitates mixins?
The Ruby core classes and standard library make extensive use of mixins.

The class method `ancestors` can be used to see the superclasses and modules that contribute methods to a class:

```ruby
>> Array.ancestors
=> [Array, Enumerable, Object, Kernel, BasicObject]

>> Fixnum.ancestors
=> [Fixnum, Integer, Numeric, Comparable, Object, Kernel, BasicObject]

>> load "mixin1.rb"

>> Array.ancestors
=> [Array, Haskell, Enumerable, Object, Kernel, BasicObject]
```
The method included_modules shows the modules that a class includes.

>> Array.included_modules => [Haskell, Enumerable, Kernel]

>> Fixnum.included_modules => [Comparable, Kernel]

instance_methods can be used to see what methods are in a module:


>> Comparable.instance_methods.sort => [:<, :<=, :==, :>, :>=, :between?]

>> Haskell.instance_methods => [:head, :tail]
When talking about iterators we encountered **Enumerable**. It's a module:

```ruby
>> Enumerable.class
=> Module
```

```ruby
```

The methods in **Enumerable** use duck typing, requiring only an **each** method. **min**, **max**, and **sort**, also require `<=>` for values operated on.

If class implements **each** and includes **Enumerable** then all those methods become available to instances of the class.
Here's a class whose instances simply hold three values:
```ruby
class Trio
  include Enumerable
  def initialize(a,b,c); @values = [a,b,c]; end

  def each
    @values.each { |v| yield v }
  end
end
```
Because Trio implements each and includes Enumerable, lots of stuff works:
```ruby
>> t = Trio.new(10, "twenty", 30)
>> t.member?(30) => true
>> t.map{|e| e * 2} => [20, "twentytwenty", 60]
>> t.partition{|e| e.is_a? Numeric } => [[10, 30], ["twenty"]]
```
What would the Java equivalent be for the above?
Another common mixin is `Comparable`:

```ruby
>> Comparable.instance_methods
=> [:==, :>, &:>=, :<, :<=, :between?]
```

`Comparable`'s methods are implemented in terms of `<=>.

Let's compare rectangles on the basis of areas:

```ruby
class Rectangle
  include Comparable
  def <=> rhs
    (self.area - rhs.area) <=> 0
  end
end
```
Comparable, continued

Usage:

```ruby
>> r1 = Rectangle.new(3,4)    #=> 3 x 4 Rectangle
>> r2 = Rectangle.new(5,2)    #=> 5 x 2 Rectangle
>> r3 = Rectangle.new(2,2)    #=> 2 x 2 Rectangle

>> r1 < r2                    #=> false
>> r1 > r2                    #=> true
>> r1 == Rectangle.new(6,2)   #=> true
>> r2.between?(r3,r1)         #=> true
```

Is `Comparable` making the following work?

```ruby
>> [r1,r2,r3].sort
 #=> [2 x 2 Rectangle, 5 x 2 Rectangle, 3 x 4 Rectangle]

>> [r1,r2,r3].min
 #=> 2 x 2 Rectangle
```
In conclusion...
What do you like (or not?) about Ruby?

- Everything is an object?
- Substring/subarray access with \( x[... \] \) notation?
- Negative indexing to access from right end of strings and arrays?
- if modifiers? (\texttt{puts x if x > y})
- Iterators and blocks?
- Ruby's support for regular expressions?
- Monkey patching? Adding methods to existing classes?
- Programmer-defined operator overloading?
- Dynamic typing?

Is programming more fun with Ruby?

If you know Python, do you prefer Python or Ruby?
September 3, 2006:
    n=1
    d = Date.new(2006, 8, 22)
    incs = [2,5]
    pos = 0
    while d < Date.new(2006, 12, 6)
        if d != Date.new(2006, 11, 23)
            printf("%s %s, #%2d\n",
                if d.cwday() == 2: "T"; else "H";end,
                d.strftime("%m/%d/%y"), n)
                n += 1
        end
        d += incs[pos % 2]
        pos += 1
    end

Output:
    T 08/22/06, # 1
    H 08/24/06, # 2
    T 08/29/06, # 3
    ...

My first practical Ruby program
More with Ruby...

If we had more time, we'd...

• Learn about `lambda`s, blocks as explicit parameters, and `call`.

• Play with `ObjectSpace`. (Try `ObjectSpace.count_objects`)

• Do some metaprogramming with `hooks` like `method_missing`, `included`, and `inherited`.

• Experiment with internal Domain Specific Languages (DSL).

• Look at how Ruby on Rails puts Ruby features to good use.

• Write a Swing app with JRuby, a Ruby implementation for the JVM.

• Take a peek at BDD (Behavior-Driven Development) with Cucumber and RSpec.