Ruby

CSC 372, Spring 2018
The University of Arizona
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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

From: Ralph Griswold <ralph@CS.Arizona.EDU>
Date: Mon, 18 Sep 2006 16:14:46 -0700

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.

Ralph's obituary: http://www2.cs.arizona.edu/news/articles/200610-griswold.html

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 on Rails, a web application framework, has largely driven Ruby's popularity.

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

Matz says...

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."

Version stuff

ISO/IEC 30170:2012 is an international standard for Ruby but the language is effectively defined by MRI—Matz' Ruby Implementation.

The most recent stable version of MRI is 2.5.0.

On lectura we'll use `rvm` (the Ruby Version Manager) to run version 2.2.4.

macOS from Mavericks through Sierra has Ruby 2.0.0. High Sierra has Ruby 2.3.3.

The last major upheaval in Ruby occurred between 1.8 and 1.9. (2007)

In general, there are few incompatibilities between 1.9.3 (2011) and the latest version.

Notable: In 2.4, `Fixnum` and `Bignum` were unified to `Integer`.

Resources

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 call it "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 call it "PA".
- First edition is here: http://ruby-doc.com/docs/ProgrammingRuby/

O'Reilly Safari has:
- Many relatively new Ruby books
  One recommendation: The Ruby Way, 3rd edition by Hal Fulton
- Lots of books on Ruby on Rails
- Lots of pre-1.9 Ruby books

Resources, continued

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 the following URL template:
  http://www.ruby-doc.org/core-2.2.4/%s.html
  (See http://cs.arizona.edu/~whm/o1nav.pdf)

Getting and running Ruby

Getting Ruby for OS X

Ruby as supplied by Apple with recent versions of macOS, should be fine for our purposes.

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

Lots of people install Ruby versions using the Homebrew package manager.

Getting Ruby for Windows

Go to http://rubyinstaller.org/downloads and get
"Ruby 2.2.6" (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 on lectura

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.

Running Ruby on lectura, continued

<u>**IMPORTANT**</u>: 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 <u>configuration suggested</u> in my Fall 2015 352 slides, put

  ```
  rvm 2.2.4 >& /dev/null
  ```

  at the end of your **`~/.bashrc`**.

- <u>Let us know if you have trouble with this.</u>

irb—Interactive Ruby Shell

irb, *Interactive Ruby Shell*, provides a REPL for Ruby.

irb evaluates expressions as they are typed.

```
$ irb
>> "abc" + "12"
=> "abc12"
```

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

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

Note: To save space on the slides, the result line ***(=> ...)*** won't be shown when it's uninteresting.

Control-D terminates ***irb***.

Collaborative Learning Exercise

cs.arizona.edu/classes/cs372/spring18/cle-7.html

Note to self: `push-cle 7`

irb customization

I use a Bash alias for **irb** that requests 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.

spring18/ruby/dotirbrc is a recommended starter **~/.irbrc** file.

```
% cp /cs/www/classes/cs372/spring18/ruby/dotirbrc  ~/.irbrc
```

On Windows you might use a batch file named **irbs.bat** to start with those options. Example:

```
W:\372\ruby> type irbs.bat
irb --prompt simple -r irb/completion
```

Run it by typing **irbs** (not just **irb**).

irb customization, continued

I like "**it**" better than underscore for referencing the previous result.

With the **~/.irbrc** suggested on the previous slide, I can use "**it**" to reference the last result:

```
>> 3 + 4
=> 7

>> it * 3
=> 21

>> it.to_s
=> "21"
```

Observation: Ruby's flexibility lets me use a convention I like.

Ruby basics

Every value is an object

In Ruby, every value is an object.

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

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

>> "ostentatious".tr("aeiou","12345")


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

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 .irbrc is needed to use "it"
=> 5770627412348402378939569991058

>> it.class()
=> Bignum
```

Everything is an object, continued

The TAB key can be used to show completions in **irb**:

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

I almost always use parentheses when there's more than one argument:

```
>> "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"))
```

Kernel methods

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
```

What can say about value, type and side-effect for **puts** and **printf**?

See 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 interaction (both expressions and results) 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.

Sidebar: ~/notes/ruby.txt

A LHtLaL suggestion:

Start accumulating a file of brief notes on Ruby. Example:

```
$ cat ~/notes/ruby.txt
#running
rvm 2.2.4 to select version on lectura
irb is REPL, reads ~/.irbrc

#irb
_ is last value

#misc
Every value is an object
Can often omit parens on methods:
    3.class, "testing".count "t"
Operators are methods: 3+4 is really 3.+(4)

#i/o
gets, puts, printf (in Kernel module)
```

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:

```
% 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.

There is no evident compilation step or artifact produced. It just runs!

Executing Ruby code in a file, continued

Alternatively, code can be placed in a method that is invoked by an expression at the top level:

```
% 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

The program below 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
```

tac.rb

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:

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

Solution:

Some basic types

The value **nil**

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

```
>> nil
=> nil

>> nil.class
=> NilClass

>> nil.object_id
=> 4
```

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

Speculate: What happens if we use a variable that hasn't been assigned to?

Strings and string literals

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

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

```
>> 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 <u>single-quoted</u> string 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**:

```
>> "abc".public_methods.sort
=> [:!, :!=, :!~, :%, :*, :+, :<, :<<, :<=, :<=>, :==, :===, :=~,
 :>, :>=, :[], :[]=, :__id__, :__send__, :ascii_only?,
 :between?, :bytes, :bytesize, :byteslice, :capitalize,
:capitalize!, :casecmp, :center, :chars, :chomp, :chomp!, :chop,
:chop!, :chr, :class, :clear, :clone, :codepoints, :concat, :count,
:crypt, :define_singleton_method, :delete, :delete!, :display,
:downcase, :downcase!, :dump, :dup, :each_byte, :each_char,
:each_codepoint, :each_line, :empty?, ...

>> "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:

```
>> x = "testing"

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

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

>> y


>> x
```

Is it a good idea to have mutable strings?

Strings are mutable, continued

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

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

>> y << "...more"

>> y


>> x
```

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
```

Applicative vs. imperative methods, continued

In contrast, an *imperative* method potentially changes its receiver.

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

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

>> s
```

A Ruby convention:

When methods have both an applicative and an imperative form, the imperative form ends with an exclamation mark.

TODO: Sidebar on "Show me the code" with "click to toggle source" --see Piazza post

String comparisons

Strings can be compared with a typical set of operators:

```
>> s1 = "apple"

>> s2 = "testing"

>> s1 == s2
=> false

>> s1 != s2
=> true

>> s1 < s2
=> true
```

These operators work with most other types, too!

We'll talk about details of **true** and **false** later.

String comparisons, continued

There is also a *comparison operator*: `<=>`

Behavior:

```
>> "apple" <=> "testing"


>> "testing" <=> "apple"


>> "x" <=> "x"
```

Speculate: How is the operator `<=>` read aloud by some programmers?

What are the Java and C analogs for `<=>` when applied to strings?

Substrings

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

```
>> s="abcd"

>> s[0]            # Positions are zero-based


>> s[1]


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


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

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)***?

Substrings, continued

A subscripted string can be the target of an assignment. A string of any length can be assigned.

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

>> s[0] = 65.chr

>> s[1] = "tomi"

>> s


>> s[-3] = ""

>> s
```

Substrings, continued

A substring can be referenced with

s[*start*, *length*]

```
r e p l a c e
0 1 2 3 4 5 6
7 6 5 4 3 2 1  (negative)
```

```
>> s = "replace"

>> s[2,3]

>> s[3,100]

>> s[-4,3]

>> s[10,10]
```

Substrings with ranges

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

```
>> r = 2..-2
=> 2..-2

>> r.class
=> Range

>> s = "replaced"

>> s[r]


>> s[r] = ""

>> s
```

Substrings with ranges, continued

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

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

r	e	b	u	i	l	d	i	n	g	
0	1	2	3	4	5	6	7	8	9	
10	9	8	7	6	5	4	3	2	1	*(negative)*

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

>> s[2...-4]
=> "buil"          # three dots is "up to" @a

>> s[-8..-4]

>> s[-4..-8]
```

Changing substrings

A substring can be the target of an assignment:

```
>> s = "replace"

>> s[0,2] = ""

>> s

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

>> s["aria"] = "kton"

>> s
```

r	e	p	l	a	c	e	
0	1	2	3	4	5	6	
7	6	5	4	3	2	1	*(negative)*

p	l	a	c	e	
0	1	2	3	4	
5	4	3	2	1	*(negative)*

Interpolation in string literals

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

```
>> 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
```

It's idiomatic to use interpolation rather than concatenation to build a string from multiple values.

Numbers

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
```

LHtLaL:
Explore boundaries!

Is this automatic transitioning between **Fixnum** and **Bignum** a good idea? How do other languages handle this?

Numbers, continued

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


>> (0.0/0.0).nan?
```

Numbers, continued

Arithmetic on two **Fixnum**s produces a **Fixnum**.

```
>> 2/3
=> 0

>> it.class
=> Fixnum
```

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

```
>> 10 / 5.1
=> 1.9607843137254903

>> 10 % 4.5
=> 1.0

>> it.class
=> Float
```

Numbers, continued

Ruby has a **Complex** type.

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

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

>> Complex 'i'


>> it ** 2
```

Numbers, continued

There's **Rational**, too.

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

>> it * 300



>> Rational 0.5



>> Rational 0.6



>> Rational 0.015625
```

Conversions

Unlike some languages, Ruby does not automatically convert strings to numbers and numbers to strings as needed.

```
>> 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 **Fixnum**s, **Float**s and **String**s, respectively.

```
>> 10.to_s + "20"


>> 10 + "20".to_f


>> 10 + 20.9.to_i
```

```
>> 33.to_<TAB><TAB>
33.to_c          33.to_int
33.to_enum       33.to_r
33.to_f          33.to_s
33.to_i
```

Arrays

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

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

```
>> 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?

Arrays, continued

Array elements and subarrays (sometimes called slices) are specified with a notation like that used for strings.

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

>> a[0]


>> a[1,2]          # a[start, length]


>> a[-1]


>> a[-1][-2]
```

Arrays, continued

Elements and subarrays can be assigned to. Ruby accommodates a variety of cases; here are some:

Semicolon separates expressions. We make a change and show new value.

```
>> a = [10, 20, 30, 40, 50, 60]

>> a[1] = "twenty"; a

>> a[2..4] = %w{a b c d e}; a

>> a[1..-1] = []; a
```

A few more:

```
>> a
=> [10]

>> a[0] = [1,2,3]; a


>> a[4] = [5,6]; a


>> a[0,2] = %w{a bb ccc}; a
```

What's important to retain from the examples above?

- Elements of arrays and subarrays can be assigned to.
- Lots of rules; some complex.

Arrays, continued

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

```
>> a = []

>> a << 1; a

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

>> a.reverse; a

>> a.reverse!; a
```

Arrays, continued

A few more:

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

>> a[0].shift


>> a


>> a.unshift "a","b","c"


>> a.shuffle.shuffle
```

Arrays, continued

Even more!

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

>> a + b

>> a - b

>> a & b

>> a | b

>> ('a'..'zzz').to_a.size
```

Comparing arrays

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

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

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

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

Comparing arrays

Comparison of arrays with <=> is lexicographic.

```
>> [1,2,3,4] <=> [1,2,10]
=> -1

>> [[10,20], [2,30], [5,"x"]].sort
=> [[2, 30], [5, "x"], [10, 20]]
```

Comparing arrays

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

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

Tie!

```
>> [[10,20],[5,30], [5,"x"]].sort
ArgumentError: comparison of Array with Array failed
```

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

```
>> ["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']
```

Arrays can be cyclic

An array can hold a reference to itself:

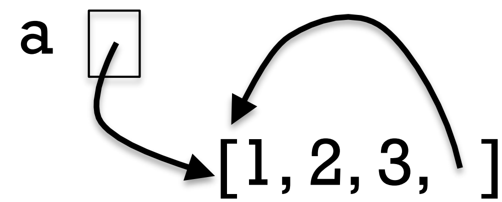
```
>> a = [1,2,3]

>> a.push a

>> a.size

>> a[-1]

>> a[-1][-1][-1]
```




```
>> a << 10

>> a[-2][-1]
```

Type Checking

Static typing

"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 9 Edition*

Example: assume the following...

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

What are the types of the following expressions?

```
i + 5
i + s
s + o
o + o
o.hashCode()
f(i.hashCode()) + 3F
i = i + s
```

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

Static typing, continued

If there's a type error in a Java program, **javac** doesn't produce a **.class** file—there's nothing to run.

```
% cat X.java
public class X {
    public static void main(String args[]) {
        System.out.println("Running!");
        System.our.println(3 + new int[5]);
        }}

% javac X.java
X.java:4: error: bad operand types for binary operator '+'
        System.out.println(3 + new int[5]);
                             ^
% java X
Error: Could not find or load main class X
```

- The file **X.class** wasn't created.
- Hazard: If we don't notice the **javac** error, we might run a copy of **X.class** created by a previous **javac X.java** invocation.

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 we knowthat it also provides type inferencing:

```
> :set +t
> f x y z = (isLetter $ head $ [x] ++ y) && z
f :: Char -> [Char] -> Bool -> Bool
```

Haskell, too, 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.

- All* type inconsistencies that exist are discovered at that time.

- Execution doesn't begin if errors exist.
    - Sometimes manifested by no "executable" file being produced.
    - With `ghci`, functions in a file with an error aren't loaded.

Static typing, continued

Important:

A statically typed language lets us guarantee that certain kinds of errors don't exist without having to run any code.

If a Java program compiles, we can be absolutely sure no errors of the following sort (and more) exist:

- Dividing a string by a float
- Concatenating a number with a list
- Subscripting a value that's not an array
- Misspelling the name of a method (true?)
- Invoking a method with the wrong number of arguments
- Forgetting a **`return`** at the end of a method that returns a value

Exception: Errors due to casts and boxing/unboxing can still exist!

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?

With others?

Paul Hudak of Yale wrote,

> "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."

Do you agree with Hudak?

Sidebar: Interpreted or compiled?

A common misunderstanding:

Python and Ruby are interpreted languages.
Java and C are compiled languages.

The fact:

Interpretation and compilation are attributes of an <u>implementation</u> of a language, not the language itself!

A simple, polarized viewpoint:

- Interpreters execute source code as-is.
- Compilers translate source code into machine code.

Reality:

- Language implementations use a variety of techniques that each fall along a broad spectrum from interpretation to compilation.
- A particular implementation of <u>any</u> language can be made to fall at either end of that spectrum, or anywhere in the middle.

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          # What's the class of the object held by x?
=> Fixnum

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

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

Methods in Ruby have no type

Array's **sample** method returns a random element of the receiver.

```
>> a = ["one", 2, [3], 4.0]

>> a.sample   => [3]

>> a.sample   => "one"
```

What's the type of **a.sample + a.sample**?

```
>> (a.sample + a.sample).class
=> String

>> (a.sample + a.sample).class
=> Float
```

The type of **a.sample**, **a.sample + a.sample, a.sample[0],** etc. is unknown until the expression is evaluated!

Dynamic typing

Ruby is a dynamically typed language.

Consider this Ruby method:

```
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`.

<u>With a dynamically typed language, types are not checked until an expression is evaluated.</u>

Another way to say it:

There is no static analysis of the types in Ruby expressions.

Dynamic typing, continued

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

Consider this Ruby code:

```
while line = gets
  puts(line[-x] + y)
end
```

What types must be checked each time through that loop?

- Is **gets** a method or a value?
- Can **x** be negated?
- Is **line** subscriptable with **-x**?
- Can **line[-x]** and **y** be added?
- Is **puts** a method?

Performance implications with dynamic typing

One performance cost with a dynamically typed language is execution-time type checking.

Evaluating the expression **`x + y`** might require decision-making like this:

```
if both x and y are integers
    add them
else if both x and y are floats
    add them
else if one is a float and the other an integer
    convert the integer to a float and add them
else if both x and y are strings
    concatenate them
...and more...
```

If that **`x + y`** is in a loop, <u>that decision making is done every time around</u>.

Note: The above "implementation" can be improved upon in many ways.

In contrast, consider this Java method:

```
int count(int wanted, int[] values)
{
    int result = 0;
    for (int value: values)
        if (value == wanted)
            result += 1;

    return result;
}
```

Generated *virtual machine* code:

```
 0: iconst_0       18: aload_3
 1: istore_2       19: iload   5
 2: aload_1        21: iaload
 3: astore_3       22: istore  6
 4: aload_3        24: iload   6
 5: arraylength    26: iload_0
 6: istore 4       27: if_icmpne 33
 8: iconst_0       30: iinc    2, 1
 9: istore 5       33: iinc    5, 1
11: iload  5       36: goto    11
13: iload  4       39: iload_2
15: if_icmpge 39   40: ireturn
```

See also https://en.wikipedia.org/wiki/Java_bytecode_instruction_listings

Static vs. dynamic typing

With respect to static typing, what are the implications of dynamic typing for...

Loading ("compilation") speed?

Execution speed?

The likelihood of code to be correct?

Can testing compensate?

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 user of software care about?

- Dynamic vs. static typing? Ruby vs. Java?
  - No!

- Software that works
  - Facebook game vs. radiation therapy system

- Fast enough
  - When does 10ms vs. 50ms matter?

- Better sooner than later
  - "First to volume" can be the key to success for a company.
  - A demo that's a day late for a trade show isn't worth much.

- Affordable
  - "People will pay to stop the pain." – Doug Higgins
  - I'd pay a LOT for a great system for writing slides.

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 <u>never</u> detected.

Ruby, Python, and Icon have no static type checking whatsoever, but type errors during execution are <u>always</u> 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.

"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 <u>not</u> be included?"

Let's explore that question with Ruby.

More string literals!

A "here document" is a third way to literally specify a string in Ruby:

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

And that's not all!

Here's another way to specify string literals. See if you can discern some rules from these examples:

```
>> %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"
```

How much is enough?

<u>Partial</u> summary of string literal syntax in 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 ! #"
```

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 of Ruby's would you remove?

"Why" or "Why not?" as applied to operator overloading

Here are some examples of operator overloading:

```
>> [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] * "..."


>> "decimal: %d, octal: %o, hex: %x" % [20, 20, 20]
```

"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 mental 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!

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."

And then 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)

The art of language design, continued

- 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 simpler thing turned out to be Icon.
  - SL5 was an expansion
  - Icon was a contraction

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")


][ (?3)("one", 2, "III")
```

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?

<u>He felt it would increase the research potential of Icon.</u>

Design example: Parallel assignment

An interesting language design example in Ruby is *parallel assignment*:

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

>> a

>> b

>> c, d = b

>> a, b, c = "800-555-1211".split "-"

>> [a,b,c]
```

How could we do a swap with parallel assignment?

```
>> x, y = 10, 20
```

Another way?

Contrast:

Icon has a swap operator: `x :=: y`

Parallel assignment, continued

Speculate: Does the following work?

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

Speculate again:

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

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

Section 4.5.5 in RPL has full details on parallel assignment. It is both <u>more</u> complicated and <u>less</u> 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.

```
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.

while, continued

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".

while, continued

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**.

```
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 from standard input 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.

LHtLaL sidebar: Partial vs. full understanding

From the previous slide:

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

Partial understanding:

The 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.

More examples of full understanding:

- Knowing exactly how `*p++ = *q++` works in C.
- Knowing the rules for field initialization in Java.
- Knowing exactly when you need to quote shell special characters.
- Knowing the full set of truthy/falsy rules for a language.

while, continued

String's **chomp** method removes a carriage return and/or newline from the end of a string, <u>if present</u>.

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

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

Will it work?

while, continued

At hand:

```
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`

while, continued

Problem: Write a **while** loop that prints the characters in the string **s**, one per line. Don't use the **length** or **size** methods of **String**.

Extra credit: Don't use any variables other than **s**.

Solution: (**while5.rb**)

Solution with only **s**: (**while5a.rb**)

Source code layout

Unlike Java, Ruby does pay some attention to the presence of newlines in source code.

For example, a while loop <u>cannot</u> be trivially squashed onto a single line.

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

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

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

There is some middle ground, too:

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

Unlike Haskell and Python, <u>indentation is never significant in Ruby</u>.

Source code layout, continued

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.

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

Is the following ok?

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

Source code layout, continued

The incomplete expression rule does have have some pitfalls.

Example: Ruby considers

```
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:

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

Alternative: Indicate continuation with a backslash at the end of the line.

Expression or statement?

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:

```
>> 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:

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

>> 1 && 2


>> true && "abc"


>> nil && 1
```

> 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.

Logical operators, continued

Disjunction is `||`, also like Java. As with conjunction, the values produced are interesting:

```
>> 1 || nil


>> false || 2


>> "abc" || "xyz"


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


>> s[4] || 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 <u>always</u> **true** or **false**.

```
>> ! true

>> ! 1

>> ! nil

>> ! (1 || 2)

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

>> ![nil]
```

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

Logical operators, continued

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

Why?

We can write this,

```
x < 2 && y > 3 or x * y < 10 || z > 20
```

instead of this:

```
(x < 2 && y > 3) || (x * y < 10 || z > 20)
```

LHtLaL problem: Devise an example for ! vs. **`not`**.

if-then-else

Here is Ruby's **if-then-else**:

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


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


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

Observations?

Speculate: Is the following valid? If so, what will it produce?

```
if 1 > 2 then 3 end
```

if-then-else, continued

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 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.

Speculate: How does Ruby handle it?

```
>> if 1 > 2 then 3 end
```

Ruby also provides `1 > 2 ? 3 : 4`, a ternary conditional operator, just like the C family. Is that a good thing or bad thing?

if-then-else, continued

The most common Ruby coding style puts the **if**, the **else**, the **end**, and the expressions of the clauses on separate lines:

```
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 "**then**" at the end of the first line above is optional.

then is not optional in this one-line expression:

```
if 1 then 2 else 3 end
```

The **elsif** clause

Ruby provides an **elsif** clause for "else-if" situations.

```
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?

elsif, continued

At hand:

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

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

TODO: Slide with ruby/elsebug.rb. Note: Syntax highlighting shows it quickly! See s18 @152. Maybe make it a "Try it".

if and **unless** as *modifiers*

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

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

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

>> 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.

```
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.

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:

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

% ruby break2.rb
xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx
```

The **for** loop

Here are three examples of Ruby's **for** loop:

```
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 produce a value 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, continued

The **for** loop supports parallel assignment:

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

What's the output?

Consider the design choice 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

Method definition

Here is a simple Ruby method:

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

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

Following **def** 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`**:

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

Do you prefer the above or the below?

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

Which is more like Haskell?

Method definition, continued

As we saw in an early example, if no arguments are required, the parameter list can be omitted:

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

What does **hello** return?

Testing methods with **irb**

Ruby methods in a file can be tested by hand using **irb**.

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

% irb -r ./simple.rb          # .rb is not required
>> add 3,4
=> 7
```

If the environment variable **RUBYLIB** is set to "**.**", the "**./**" can be omitted:

```
% echo $RUBYLIB
.
% irb -r simple
...
```

Set it with "**export RUBYLIB=.**" in your **~/.bashrc**.

Testing methods with **irb**, continued

A source file can loaded with **Kernel.load**:

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

```
>> load "simple.rb"
=> true
>> add 3,4
=> 7
```

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.

How can we take advantage of **load** being a Ruby method?

Testing methods with **irb**, continued

Because **load** is a method, we can write <u>code that **load**s code</u>.

Here's a method to load **simple.rb**:

```
def r; load "simple.rb"; end          # could be in .irbrc
```

Usage:

```
% irb
>> r

>> add 3,4
=> 7
```

[...edit **simple.rb** *in another window and put a* **puts** *in* **add***...]*

```
>> r

>> add 3,4
add called...
=> 7
```

Where's the class?!

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

<u>Methods can be added to a class at run-time in Ruby!</u>

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.

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

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

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

We see that loading **simple.rb** added the method **add** 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:

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

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

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

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

TODO: show usage first, then code!

Lots of library methods use default arguments.

```
>> "a-b c-d".split          => ["a-b", "c-d"]
>> "a-b c-d".split "-"      => ["a", "b c", "d"]
```

Methods can't be overloaded!

Ruby does not allow the methods of a class to be overloaded. Here's a Java-like approach that does not work:

```
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!)

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

>> 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 <u>and</u> 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:

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

Arbitrary number of arguments

Java's **String.format** and C's **printf** can accept any number of arguments.

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

```
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
```

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

```
>> showargs(1, "two", 3.0)
3 arguments:
#0: 1
#1: two
#2: 3.0
```

TODO: show usage first, then code!

Arbitrary number of arguments, continued

Problem: Write a method **format** that interpolates argument values into a string where percent signs are found.

```
>> 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.

Whole programs

Source File Layout

Here's an example of source file layout for a program with several methods:

```
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
```

Execution:

```
% ruby main1.rb
in main
in f
in g
```

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 it: Shuffle around 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 **load**ing it in **irb** seems to hang. Why?

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

% irb
>> load "main3.rb"
```

...no output or >> prompt after the load...

Testing methods when there's a "main", cont.

Here's a technique that lets a program run normally with **ruby** but <u>not</u> run **main** when loaded with **irb**:

```
% 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 main3.rb** ...

Global variables

Variables prefixed with a **$** are global, and can be referenced in any method in any file, including top-level code.

```
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
```

Predefined global variables

Ruby has a number of *predefined global variables*:

```
>> puts global_variables.sort * ", "
$!, $", $$, $&, $', $*, $+, $,, $-0, $-F, $-I, $-K, $-W, $-a, $-d, $-i, $-l, $-
p, $-v, $-w, $., $/, $0, $1, ..., $9, $:, $;, $<, $=, $>, $?, $@, $DEBUG,
$FILENAME, $KCODE, $LOADED_FEATURES, $LOAD_PATH,
$PROGRAM_NAME, $SAFE, $VERBOSE, $\, $_, $`, $binding,
$stderr, $stdin, $stdout, $~
```

A few:

- `$0` Program name (`>> $0 => "irb2.2"`)
- `$,` Used by `print` and `Array.join`. (`>> $, = "-"; [1,2].join=> "1-2"`)
- `$:` Directories where `load` and `require` look for files. (Try it!)
- `$_` Last string read by `Kernel.gets` and `Kernel.readline`. (Try it!)

More: The *Global Variables* section of *The Top-Level Environment* in RPL, chapter 10.

Sidebar: "sigil"

Wikipedia says,

> "In computer programming, a *sigil* is a symbol attached to a variable name, showing the variable's datatype or scope, usually a prefix, as in **$foo**, where **$** is the sigil.
>
> "Sigil, from the Latin sigillum, meaning a 'little sign', means a sign or image supposedly having magical power."
>
> "In 1999 Philip Gwyn adopted the term 'to mean the funny character at the front of a Perl variable'."

Are **reverse!** and **nan?** examples of sigils?

Lots more: https://en.wikipedia.org/wiki/Sigil_(computer_programming)

Local variables are local

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

```
% cat scope1.rb
x = 10

puts "top-level: x = #{x}"

def f
   puts "in f: x = #{x}"
end

f

% ruby scope1.rb
top-level: x = 10
scope1.rb:6:in 'f': undefined local variable or method 'x'
```

Constants

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.

```
>> MAX_ITEMS = 100
```

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

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

Modifying an object referenced by a constant does <u>not</u> produce a warning:

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

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

Constants

Like globals, constants can be accessed in all methods.

```
% cat constant1.rb
MAX_LEVELS = 1000

def f
   puts "f: max levels = #{MAX_LEVELS}"
end

f

puts "top-level: max levels = #{MAX_LEVELS}"

% ruby constant1.rb
f: max levels = 1000
top-level: max levels = 1000
```

Find out: Can a constant be created in a method?

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!

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

>> Hello
NameError: uninitialized constant Hello
```

Constants, continued

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:

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

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

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

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

Consider this method:

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

<u>Remember</u>: 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
```

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

- Is it good or bad that **double** operates on so many different types?
- Is **double** polymorphic?
- What's the type of **double**?

Duck typing, continued

Should we have **double** check for known types?

```
def double x
   if [Fixnum, Float, String, Array].include? x.class
      x * 2
   else raise "Can't double a #{x.class}!" end
end
```

```
>> double "abc"  => "abcabc"
>> double 1..2     RuntimeError: Can't double a Range!
```

Previously...

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

What benefit does the new error provide?

Duck typing, continued

Being considered—have **double** check for specific types:

```
def double x
   if [Fixnum, Float, String, Array].include? x.class
      x * 2
   else raise "Can't double a #{x.class}!" end
end
```

What does the following suggest?

```
>> double Rational(3)
RuntimeError: Can't double a Rational!
```

-
-

Bottom line: Checking for types is the antithesis of duck typing.

See also: the Open/closed principle

Duck typing, continued

Here's ***wrap*** from slide 138. What does it require of ***s*** and ***wrapper***?

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

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

Will the following work?

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

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

```
>> wrap 10,3
```

Duck typing, continued

Recall: <u>The key characteristic of duck typing is that we only care about whether an object supports the operation(s) we require</u>.

Does the following Java method exemplify duck typing?

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

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:

```
>> x = [10,20,30]

>> x.each { puts "element" }
element
element
element
=> [10, 20, 30]
```
(**each** *returns its receiver but it's often not used)*

> An *iterator* is a method that can invoke a *block*.

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.

Iterators and blocks, continued

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.

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

The behavior of the iterator **Array.each** is to invoke the block with each array element in turn.

Iterators and blocks, continued

For reference:

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

Problem: Fill in the block below to compute the sum of the numbers in an array containing values of any type.

```
>> sum = 0
>> [10, "twenty", 30.0].each { ______________________________ }

>> sum     => 40.0
```

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

Use **e.is_a?(Numeric)** to decide whether **e** is a number of some sort.

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,

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

and iteration with **each**,

```
"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.

```
>> [10, "twenty", 30].collect { |v| v * 2 }
```

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

What do those remind you of?

Iterators and blocks, continued

The block for **Array.sort** takes two arguments.

```
>> [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?

Iterators and blocks, continued

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

```
>> "a longer try first".split.sort {                    }
=> ["longer", "first", "try", "a"]
```

What do the following examples remind you of?

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

>> [10,20,30].inject([]) {
        |memo, element| memo << element << "---" }
=> [10, "---", 20, "---", 30, "---"]
```

Iterators in Enumerable

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 of 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
```

Iterators in **Enumerable**

At hand:

A object can call methods of 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**

Iterators abound!

Recall: <u>An iterator is a method that can invoke a block.</u>

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

times {|i| block } → self

times → an_enumerator

Iterates the given block `int` times, passing in values from zero to `int - 1`.

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

What will **3.times { |n| puts n }** do?

```
>> 3.times { |n| puts n }
```

A few more iterators

Three more examples:

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

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

>> i = 0
>> "Mississippi".gsub("i") { (i += 1).to_s }
```

The "do" syntax for blocks

An alternative to enclosing a block in braces is to use **do**/**end**:

```
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.

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

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

Problem: **sumnums.rb**

sumnums.rb computes some simple statistics for lines of zero or more integers read from standard input:

```
$ cat nums.dat
5 10 0 50
 200
1 2 3 4 5 6 7 8 9 10

$ ruby sumnums.rb < nums.dat
total = 320, n = 15, average = 21.3333
```

Write it! Notes:

- Use nested iterators/blocks. (Don't use **for**s!)
- **Kernel.readlines** returns an array of all lines of standard input:
  `readlines => ["5 10 0 50\n", "  200\n", "1 2 3 4 5 6 7 8...\n"]`
- `" 10  20   30".split      => ["10", "20", "30"]`
- `"10".to_i                 => 10`

sumnums.rb solution

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:

```
>> 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 **x** exists only in the block, and that the block's parameter, e, is local to the block.

```
>> 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
```

LHtLaL

Scoping issues with blocks, continued

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

Version 1:

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

Version 2:

```
result = ...       # new first use of result in this method
...
a.each do |x|
    ...
    result = ... # references/clobbers result in outer scope
end
...
...use result...   # uses value of result set in block.  Surprise!
```

Scoping issues with blocks, continued

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

```
result = ...
...
a.each do
   |x; result, tmp|
    result = ... # result is local to block
    ...
end

...
...use result...   # uses result created outside of block
```

Various types of iteration side-by-side

```
>> [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.

Writing iterators

(entwined with)

Collaborative Learning Exercise 8

cs.arizona.edu/classes/cs372/spring18/cle-8.html

Note to self: `push-cle 8`

A simple iterator

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.

Do the CLE!

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

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

Usage:

```
>> simple  {|x|puts "\tx = #{x}" }
```

The **puts** in **simple** are used to show when **simple** is active. Note the interleaving of execution between the iterator and the block.

A simple iterator, continued

At hand:

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

Usage:

<u>There's no formal parameter that corresponds to a block.</u> 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**:

```
>> simple
simple: Starting...
LocalJumpError: no block given (yield)
```

Iterators with parameters

Problem:

Write an iterator **`around(x, delta)`** that yields (i.e., invokes its block with) three values in turn: **`x-delta`**, **`x`**, and **`x+delta`**. It returns the range spanned by the three values.

Examples:

```
>> around(5,1) { |x| puts x }
4
5
6
=> 2

>> vals = []; around(Complex(0,1),0.5) {|v| vals << v}
=> 1.0

>> vals
=> [(-0.5+1i), (0.0+1i), (0.5+1i)]
```

Iterators with parameters, continued

At hand:

```
>> around(11,2) { |v| print "#{v} " }
9 11 13 => 4
```

Solution:

```
def around(x, delta)
   [-1, 0, 1].each do
      |m|
      yield x + m*delta
   end
   delta * 2
end
```

Note that parameters are passed to an iterator just like any other method.

CLE problem: **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**. **from_to** returns the number of integers yielded.

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

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

Do the CLE!

from_to, continued

Solution:

```
def from_to(from, to, by = 1)
```

Desired:

```
>> from_to(1,10,2) { |i| puts i }
1
3
5
7
9
=> 5

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

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

Imagine an iterator that produces overlapping pairs from an array:

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

Implementation:

```
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
```

A round-trip with **yield**

<u>When **yield** passes a value to a block the result of the block becomes the value of the **yield** expression.</u>

Here is a trivial iterator to show the mechanics:

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

Usage:

```
>> 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:

```
def round_trip(x)
   r = yield x
   "yielded #{x} and got back #{r}"
end

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

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

`r = yield 3`   `{|x| x * 5 }`

Do the CLE!

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

3. Value of **yield 3** is assigned to `r`.

4. **round_trip** returns "**yielded 3 and ...**"

Round trips with **yield**

Consider this iterator:

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

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

What does it appear to be doing?

CLE Problem: Write it!

Round trips with **yield**, continued

At hand:

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

Solution:

What does the iterator/block interaction look like?

<u>Iterator</u> <u>Block</u>

if yield [1,2] then # [1,2].size == 1

Do nothing with [1,2]

if yield "a" then # "a".size == 1

Add "a" to result

if yield [3] then # [3] .size == 1

Add [3] to result

if yield "four" then #"four".size == 1

Do nothing with "four"

Round trips with **yield**, continued

Is **select** limited to arrays?

```
>> select(1..10) {|n| n.odd? && n > 5 }
```

Why do we see that behavior?

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

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

  result
end
```

Round trips with **yield**, continued

What's the difference between our **select**,

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

And Ruby's **Array.select**?

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

-
-

Sidebar: Ruby vs. Haskell

```
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"]
```

```
>> select(["just","a", "test"]) { |x| x.size == 4 }
=> ["just", "test"]
```

Which is better?

The **Hash** class

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 <u>any</u> 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:

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

Subscripting with a key fetches the associated value.

```
>> numbers["two"]
```

What will happen with a non-existent key?

```
>> numbers["three"]
```

At hand:

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

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

```
>> numbers.keys



>> numbers.invert



>> numbers.flatten



>> numbers.to_a
```

Hash, continued

At hand:

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

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

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

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

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

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

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

Hash, continued

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"], {...}=>{...}}
```

Hash, continued

Here's a sequence that shows some of the flexibility of hashes.

```
>> 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]}
```

Keys for a given **Hash** may be a mix of types. Ditto for values. (Unlike a Java **HashMap**.)

TODO: Talk about h[h] = hand compare_by_identity

Iterators and hashes

Here is a **Hash** literal:

```
>> h = {"a" => [10], 2 => [3,5,3], true => [2,5]}
```

Let's iterate over the key/value pairs in **h**:

```
>> h.each {|k,v| puts "k=#{k}, v=#{v}"}
k=a, v=[10]
k=2, v=[3, 5, 3]
k=true, v=[2, 5]
=> {"a"=>[10], 2=>[3, 5, 3], true=>[2, 5]}
```

Here's **select** on a **Hash**:

```
>> s = h.select {|k,v| v.size.odd? }
=> {"a"=>[10], 2=>[3, 5, 3]}
```

There's also **keep_if**. Speculate: How does it differ from **select**?

```
>> h.keep_if {|k,v| v.size.odd? }
=> {"a"=>[10], 2=>[3, 5, 3]}
```

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**:

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

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

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

>> h["x"]


>> h["y"]
```

tally.rb

Problem: write **tally.rb**, to tally occurrences of blank-separated "words" on standard input.

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

How can we approach it? (Don't peek!)

tally.rb

Solution:

```
# 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
```

We want:

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

Contrast with **while**/**for** vs. iterators:

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

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

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

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

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

Problem: Produce nicely labeled output, like this:

```
Word      Count
be            2
not           1
or            1
to            2
```

tally.rb, continued

At hand:

```
>> counts.sort
[["be", 2], ["not", 1], ["or", 1], ["to", 2]]
```

```
Word    Count
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.

More on **Hash** sorting

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)

```
>> 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?

```
counts.sort do




end
=> [["be", 2], ["to", 2], ["not", 1], ["or", 1]]
```

xref.rb

Let's turn **tally.rb** into a cross-reference program:

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

% ruby xref.rb < xref.1
Word        Lines
be          1, 2, 3
is          2
not         2
or          1
question    3
the         3
to          1, 2, 3
```

```
% cat tally.rb
counts = Hash.new(0)

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

How can we approach it? (Don't peek!)

xref.rb, continued

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:

```
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
```

xref.rb, continued

If we add "p refs" after that loop, here's what we see:

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

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

We want:

```
% ruby xref.rb < xref.1
Word        Lines
be          1, 2, 3
is          2
not         2
...
```

xref.rb, continued

At hand:

```
{"to"=>[0, 1, 2], "be"=>[0, 1, 2], "or"=>[0], "not"=>[1], ...
```

We want:

```
Word        Lines
be          1, 2, 3
...
```

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

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

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

Another **Hash** behavior

Observe:

```
>> 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?

Symbols

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

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

>> s1.class
=> Symbol
```

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

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

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

```
>> "testing".object_id     => 3673780
>> "testing".object_id     => 4598080
```

Symbols, continued

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

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

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

Recall that **.methods** returns an array of symbols:

```
>> "".methods.sort
=> [:!, :!=, :%, :*, :+, :<, :<<, :<=, :<=>, :==, :===, :=~, :>, :>=,
:__id__, :__send__, :ascii_only?, :b, :between?, :bytes,
:bytesize, :byteslice, :capitalize, :capitalize!, :casecmp, :center,
:chars, :chomp, :chomp!, :chop, :chop!, :chr, :class, :clear, ...
```

Symbols and hashes

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

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

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

>> moves[:up]                 => [0, 1]

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

>> moves["down"]
=> nil
```

Some syntactic sugar with hashes and symbols: (Why not?!)

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

Regular Expressions

A little theory

In computer science theory, a *language* is a set of strings. The set may be infinite.

The <u>Chomsky</u> 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.

An example of a context-sensitive language is all strings of the form $\mathtt{a}^{\mathtt{n}}\mathtt{b}^{\mathtt{n}}\mathtt{c}^{\mathtt{n}}$.

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 infinite 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.

- <u>A regular language can also be described by a regular expression</u>.

A little theory, continued

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 `ab` repeated one or more times and followed by zero or more `c`'s.

Examples: `ab`, `ababc`, and `abababababcccccc`.

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

Good news and bad news

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 <u>type</u>.

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 <u>summary</u> 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.

Good news and bad news, continued

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,}|\[(((?(?<!\[)\.)(25[0-
5]|2[0-4]\d|[01]?\d? \d)){4}|[a-zA-Z\d\-]*[a-zA-
Z\d]:((?=[\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 */regexp/* syntax, for regular expression literals.

```
>> 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/` describes a language of five character strings of this form:

a<*anychar*>b<*anychar*>c

Some words containing strings in that language:

"albacore", "barbecue", "drawback", and "iambic".

The match operator

The Ruby 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.

```
>> "albacore" =~ /a.b.c/      => 0

>> "drawback" =~ /a.b.c/      => 2

>> "abc" =~ /a.b.c/           => nil

>> "abcdef" =~ /..f/


>> "abcdef" =~ /.f./


>> "abc" =~ /..../
```

Sidebar: rgrep.rb

Problem: Write in Ruby a trivial version of the UNIX **grep** command.

Usage:

```
$ ruby rgrep.rb g.h.i < /usr/share/dict/words


$ ruby rgrep.rb l.m.n < /usr/share/dict/words | wc -l


$ ruby rgrep.rb  ………………….. < /usr/share/dict/words
```

Hint: #{...} interpolation works in /.../ (regular expression) literals:

```
>> s = "ab"
>> /#{s}-#{s.reverse}/ =~ "cab-bat"
=> 1
```

rgrep.rb, continued

Desired:

```
$ ruby rgrep.rb g.h.i < /usr/share/dict/words
lengthwise
```

Solution:

The match operator, continued

After a successful match using **=~** 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:

```
>> "limit=300" =~ /=/      => 5
>> $`                      => "limit"  (left of the match)
>> $&                      => "="      (the match itself)
>> $'                      => "300"    (right of the match)
```

The match operator, continued

Here's a handy utility routine from the Pickaxe book:

```
def show_match(s, re)
    if s =~ re then
        "#{$`}<<#{$&}>>#{$'}"
    else
        "no match"
    end
end
```

Usage:

```
>> show_match("limit is 300", /is/)


>> %w{albacore drawback iambic}.
        each { |w| puts show_match(w, /a.b.c/) }
```

<u>Great idea</u>: Put it in your **.irbrc**! Call it "**sm**", to save some typing!

LHtLaL: write learning tools!

When learning a language look for opportunities to use the language to learn about the language.

With **show_match** we're using Ruby to learn about Ruby regular expressions.

When teaching Icon I wrote a procedure named **snapshot()** to explore Icon's *string scanning* facility. A simple example:

```
][ "testing" ? while move(3) do snapshot()
&subject =  t e s t i n g
&pos =  4         |

&subject =  t e s t i n g
&pos =  7               |

Failure
```

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

```
>> show_match("testing", /[aeiou]/)
=> "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.

```
>> show_match("Testing 1, 2, 3...", /[0-9]/)
```

```
>> show_match("Take five!", /[0-9]/)
```

Character classes

[^*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]/)
```

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?

Character classes, continued

Describe what's matched by this regular expression:

```
/.[a-z][0-9][a-z]./
```

In the following, which portion of the string is matched, if any?

```
>> show_match("Alb33s4axl", /.[a-z][0-9][a-z]./)
```

Character classes, continued

String.gsub does global substitution with both plain old strings and regular expressions

```
>> "520-621-6613".gsub("-", "<DASH>")
=> "520<DASH>621<DASH>6613"

>> "B3WF5-NPH41-MVXRP-67C9J-J8A9M".
   gsub(/[A-Z][0-9]/, "<LD>")
```

Character classes, continued

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/,".")
=> "... ......(.) = . * ."

>> "ILC 119, 15:30-16:45 MW".gsub(/\D/, "")
=> "11915301645"

>> "buzz93@tv-2000.com".gsub(/[\w-]/,"*")
=> "******@*******.***"
```

Backslashes suppress special meaning

Preceding an RE metacharacter with a backslash suppresses its meaning.

```
>> show_match("123.456", /.\../)
```

```
>> "5-3^2*2.0".gsub(/[\^.\-6]/, "_")
```

```
>> show_match("x1 = y2[3] + z4", /\[\d\]/)
=> "x1 = y2<<[3]>> + z4"
```

An old technique with regular expressions is to take advantage of the fact that some metacharacters only have meaning when used in certain positions:

```
>> "5-3^2*2.0".gsub(/[-6^.]/, "_")
=> "5_3_2*2_0"
```

Alternatives

Alternatives can be specified with a vertical bar:

```
>> show_match("a green box", /red|green|blue/)


>> %w{you ate a pie}.select { |s| s =~ /ea|ou|ie/ }
```

Alternatives and grouping

Parentheses can be used for grouping. Speculate: What regular language corresponds to the following regular expression?

```
/(two|three) (apple|biscuit)s/
```

Usage:

```
>> "I ate two apples." =~ /(two|three) (apple|biscuit)s/

>> "She ate three mice." =~ /(two|three) (apple|biscuit)s/
```

Another:

```
>> %w{you ate a mouse}.select { |s| s =~ /.(ea|ou|ie)./ }
```

Simple app: looking for letter patterns

Problem: Read a list of words and print words that contain a specified pattern of consonants and vowels.

```
% ruby convow.rb cvcvcvcvcvcvcvcvc < web2
c|hemicomineralogic|al
|hepatoperitonitis|
o|verimaginativenes|s
```

web2 is in spring18

- A capital letter means to match exactly that letter, in lowercase.
- An 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 vvvevvv < web2  | wc -l
43
```

convow.rb

Solution: Loop through the command line argument's characters and build up a regular expression of character classes and literal characters. Then look for lines with a match.

```
re = ""
ARGV[0].each_char do |char|
   re += case char                    # An example of Ruby's case
         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]
```

There are regular expression operators

A rule we've been using but haven't formally stated is this:

If $\mathtt{R_1}$ and $\mathtt{R_2}$ are regular expressions then $\mathtt{R_1R_2}$ 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?

```
>> show_match("acd", /ab*c+d/)
```

```
>> show_match("abcccc", /ab*c+d/)
```

```
>> show_match("abcabccccddd", /ab*c+d/)
```

The *, +, and ? quantifiers, continued

At hand:

R* matches <u>zero or more</u> occurrences of R
R+ matches <u>one or more</u> occurrences of R
R? matches <u>zero or one</u> occurrences of R

What does the RE -?\d+ describe?

```
>> show_match("y is -27 initially", /-?\d+/)
```

```
>> show_match("maybe --123.4e-10 works", /-?\d+/)
```

```
>> show_match("maybe --123.4e-10 works", /-?\d*/)  # *, not +
```

The `*`, `+`, and `?` quantifiers, continued

What does `a(12|21|3)*b` describe?

Write an RE to match numbers with commas, like these:

`58   4,297   1,000,000   446,744   73,709,551,616`

The *, +, and ? quantifiers, continued

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, /                    /) }
<<1.2>>
<<.3333e10>>
<<-4.567e-30>>
<<.0001>>
```

*, +, 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`

*, +, and ? are greedy, continued

More examples of greedy behavior:

```
>> show_match("xabbbbc", /a.*b/)
=> "x<<abbbb>>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:

```
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:

```
>> show_match("x + 'abc' + 'def' + y", /'.*?'/)
=> "x + <<'abc'>> + 'def' + y"
```

?? and **+?** are supported, too. The three are also called *reluctant quantifiers*.

Sidebar: primitives vs. idioms

From the previous slide:

```
>> show_match("x + 'abc' + 'def' + y", /'.*?'/)
=> "x + <<'abc'>> + 'def' + y"
```

Years ago, before reluctant quantifiers were introduced, a complemented character class was used to stop at the next occurrence of a character:

```
>> show_match("x + 'abc' + 'def' + y", /'[^']+'/)
=> "x + <<'abc'>> + 'def' + y"
```

A common language design trade-off is what primitives to provide vs. how many idioms/techniques users must master.

Sidebar, continued

Here is a complete summary of Icon's *string scanning* facility: (81 words)

Functions that produce positions to be used with `tab(n)`:

`many(cs)`	produces position after run of characters in `cs`
`upto(cs)`	generates positions of characters in `cs`
`find(s)`	generates positions of `s`
`match(s)`	produces position after `s`, if `s` is next
`any(cs)`	produces position after a character in `cs`
`bal(s, cs1, cs2, cs3)`	similar to `upto(cs)`, but used with "balanced" strings.

Other functions:

`pos(n)`	tests if `&pos` is equivalent to `n`
`move(n)`	advances `&pos` by n

`expr1 ? expr2` scans `expr1` with `expr2`

http://www.rexegg.com/regex-quickstart.html:1,352 words

https://docs.microsoft.com/en-us/dotnet/standard/base-types/regular-expression-language-quick-reference: 2,091 words

But, there are many idioms and techniques that need to be mastered to use Icon's string scanning mechanism effectively.

Specific numbers of repetitions

We can use curly braces to require a specific number of repetitions:

```
>> show_match("Call me at 555-1212!", /\d{3}-\d{4}/)
=> "Call me at <<555-1212>>!"
```

An inclusive range can be specified with R{min,max}:

```
>> mdy = /\d{1,2}-\d{1,2}-(\d{4}|\d{2})/

>> show_match("3-17-2018", mdy)
=> "<<3-17-2018>>"

>> show_match("12-1-99", mdy)
=> "<<12-1-99>>"

>> show_match("7-555-99", mdy)
=> "no match"
```

Speculate: What do R{,n} and R{n,} specify?

split and **scan** with regular expressions

We can split a string using a regular expression:

```
>> " one, two,three / four".split(/[\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:

```
>> " one, two,three / four".scan(/\w+/)
=> ["one", "two", "three", "four"]

>> "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:

```
>> " one, two,three / four".scan(/\w+|\W+/)
=> [" ", "one", ", ", "two", ",", "three", " / ", "four"]
```

Anchors

Reminder: `s =~ /x/` succeeds if "`x`" appears <u>anywhere</u> in `s`.

The metacharacter `^` is an *anchor* when used <u>at the start</u> 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.

```
>> show_match("this is x", /^x/)        => "no match"

>> show_match("this is x", /^this/)     => "<<this>> is x"
```

What will `/^x|y/` match? Hint: it's not the same as `/^(x|y)/`

What does `/^.[^0-9]/` match?

Anchors, continued

Another anchor is `$`. It constrains the preceding regular expression to appear at the end of the string.

```
>> show_match("ending", /end$/)
```

```
>> show_match("the end", /end$/)
```

What does `/\d+$/` match?

Can `/\d+$/` be shortened?

Anchors, continued

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. (Recall that **\s** matches a single character of whitespace.)

```
>> show_match(" }  ",                    )        (Oops! Don't peek!)
=> "<< }  >>"
```

Using **grep**, print lines in Ruby source files that are exactly three characters long. (Oops! Don't peek!)

Anchors, continued

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?

```
line =~ /\w+\d+/

line =~ /^\w+\d+/

line =~ /\w+\d+$/

line =~ /^\w+\d+$/

line =~ /^.\w+\d+.$/

line =~ /^.*\w+\d+$/
```

Sidebar: Dealing with too much input

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.

```
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!!
```

We *could* edit some data files down to a few names. Could we achieve the same effect more easily using regular expressions?

Sidebar: **convow.rb** with anchors

Recall that **convow.rb** earlier simply does **char.downcase** on any characters it doesn't recognize. **downcase** doesn't change **^** or **$**.

The command

```
% ruby convow.rb ^cvc$
```

builds this this RE, which matches only three-letter **cvc** words:

```
/^[^aeiou][aeiou][^aeiou]$/
```

Let's explore with it:

```
% ruby convow.rb ^cvc$ < web2 | wc -l
858
% ruby convow.rb ^vccccv$ < web2 | wc -l
15
% ruby convow.rb ^vcccccv$ < web2
|oxyphyte|
```

Named groups

The following regular expression uses three *named groups* to capture the elements of a binary arithmetic expression

```
>> re = /(?<lhs>\d+)(?<op>[+\-*\/])(?<rhs>\d+)/
```

After a successful match, the predefined global **$~**, an instance of **MatchData**, shows us the groups:

```
>> 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.

For a pitfall/feature, 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 ttl.rb
3h
15m
4:30
^D
7:45
```

Multiple times can be specified per line, separated by spaces and commas.

```
% ruby ttl.rb
10m, 3:30
20m 2:15 1:01 3h
^D
10:16
```

How can we approach it? (Don't peek!)

Time totaling, continued

```
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:

```
>> 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:

```
>> 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 `(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,

(*tuple* ,)+

rather than

tuple (, *tuple*)*

Example, continued

Solution:

```
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"]
            ""  # block result--replaces matched string in tuples
        end
        if tuples.empty? then
            [sum,lets]
        end
    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!

Avoiding repetitious REs

Imagine a simple calculator that accepts input lines such as these:

```
x=7
yval=x+10*x
x+yval+z
```

Here's a very repetitious RE that recognizes those lines above:

```
valid_line = /^([a-zA-Z][a-zA-Z\d]*=)?([a-zA-Z][a-zA-
Z\d]*|\d+)([-+*\/]([a-zA-Z][a-zA-Z\d]*|\d+))*$/
```

Let's use some intermediate variables to build that same RE.

```
var = /[a-z][a-z\d]*/i       # trailing "i": case insensitive

expr = /(#{var}|\d+)/

op = /[-+*\/]/

valid_line = /^(#{var}=)?#{expr}(#{op}#{expr})*$/
```

Good news and bad news

Good news:

Lots of programs support regular expressions:

- The **grep** family (**g**lobal**/r**egular **e**xpression**/p**rint, derived from the **ed** editor.)
- Most editors and IDEs
- MySQL has **REGEXP** and **RLIKE** operators
- Lots more...

Most programming languages have some sort of support for regular expressions.

Bad news:

- "Core" RE primitives are very consistently supported but the farther you get from that core, the less consistent support becomes.

- There's deliberate variation, too. Example: **grep**, **egrep**, and **egrep -P** regular expressions differ.

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
- Matching strings with newlines (`\A`, `\Z`, `\z`)

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.

Discernment:
Levels of support for types

Examples

Language-wise, what's an implication of the following examples?

Haskell:

```
> :t "abc"                => "abc" :: [Char]
```

Python:

```
>>> type({})             =>  <class 'dict'>
```

Ruby:

```
>> /.s./ =~ "test"       => 1
```

Java:

```
jshell> new char [] {'a', 'b', 'c'}  => char[3] { 'a', 'b', 'c' }
```

Icon:

```
][ 'tim korb'            =>  ' bikmort'  (cset)
```

Levels of support

A language's support for a type can be viewed as at one of three levels:

Syntactic support

- Most languages have syntactic support for strings with "...".
- Scala and ActionScript have syntactic support for XML.
- Python has `x in y` and `x not in y` tests for membership.

Language support:

- Icon has a `table` type but no literal syntax, only `table(`*`default`*`)`.

Library support

- Java and Python have classes for working with REs.
  - Python does have raw strings—`r"..."`
- C and Icon have function libraries for working with REs.

What are the tradeoffs between the levels?

Defining classes

A tally counter

Imagine a class named **Counter** that models a tally counter.

Here's how we might create and interact with an instance of Counter:


```
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
```

Counter, continued

Here is a partial implementation of **Counter**:

```
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.

```
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**:

```
class Counter
   def initialize(label = "Counter")
      @count = 0
      @label = label
   end
   ...
end
```

Instance variables are identified by prefixing them with **@**. (A *sigil*!)

<u>An instance variable comes into existence when it is assigned to</u>. The code above creates **@count** and **@label**.

Note: There are no instance variable declarations!

Just like Java, each object has its own copy of instance variables.

Counter, continued

Problem: Fill in **click** and **reset** methods.

```
class Counter
    def initialize(label = "Counter")
        @count = 0
        @label = label
    end

    def click

    end

    def reset

    end
end
```

Counter, continued

In Ruby:

- An object's instance variables cannot by accessed by any other object.
- Only methods can access instance variables.

Problem: Implement **count** (gets the count) and **to_s** for **Counter**:

```
>> c1 = Counter.new "c1"
>> c1.count    => 0
>> c1.click
>> c1.to_s     => "c1's count is 1"
```

Solutions:

Counter, continued

Full source for **Counter** thus far:

```
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
      "#{@label}'s count is #{@count}"
   end
end # Counter.rb
```

Common error: omitting an instance variable's @ sigil.

An interesting thing about instance variables

Consider this class: (**instvar.rb**)

```
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?

```
>> X.new 1     => #<X:0x00000101176838 @x=1>
>> X.new 2     => #<X:0x00000101174970 @y=1>
>> X.new 3
```

Addition of methods

If **class X ... end** has been seen and another **class X ... end** is encountered, <u>the second definition adds and/or replaces methods.</u>

Let's confirm **Counter** has no **label** method.

```
>> c = Counter.new "ctr 1"

>> c.label
NoMethodError: undefined method `label' ...
```

Now we <u>add</u> a **label** method: (we're typing lines into **irb** but could **load**)

```
>> class Counter
>>   def label; @label; end
>> end

>> c.label       => "ctr 1"
```

What's an implication of this capability?

Addition of methods, continued

Icon's 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!

There's no unary **?** to overload in Ruby. Instead we'll add a **rand** method to **Fixnum** and **String**.

If we call **Kernel.rand** with a **Fixnum n** it returns a random **Fixnum r** such that **0 <= r < n**.

Addition of methods, continued

Here is **random.rb**:

```
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, " " }


>> 8.times { print "HT".rand, " " }
```

An interesting thing about class definitions

Observe the following. What does it suggest to you?

```
>> class X
>> end
=> nil

>> p (class Y; end)
nil
=> nil

>> class Z; puts "here"; end
here
=> nil
```

Class definitions are executable code

At hand: A class definition is executable code. The following class definition uses a **case** statement to selectively execute **def**s for methods.

```
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:

```
>> 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:...>
```

Sidebar: Fun with **eval**

Kernel.eval parses a string containing Ruby source code and executes it.

```
>> s = "abc"; n = 3

>> eval "x = s * n"


>> x


>> eval "x[2..-2].length"   => 6

>> eval gets
s.reverse
```

Two of several details about **eval** and scoping:

- **eval** uses variables from the current scope.
- An assignment to **x** is reflected in the current scope.

Sidebar, continued

mk_methods.rb prompts for a method name, parameters, and method body. It then creates that method and adds it to class **X**.

```
>> 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.

```
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}\n\n");
  end
end
```

Is this a useful capability or simply fun to play with?

Sidebar: Risks with eval

Does **eval** pose any risks?

```
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")
Sun Mar 25 23:42:58 MST 2018
? system("rm –rf ...")
...
? system("chmod 777 ...")
...
```

Sidebar, continued

At hand:

```
% ruby eval1.rb
? system("rm –rf ...")
...
? system("chmod 777 ...")
...
```

```
while (print("? "); line = gets)
    eval(line)
end # eval1.rb
```

But, we can do those things without using Ruby!

eval gets risky when we can't trust the source of the data. Examples:

- A calculator web app calls **eval** with the user's input. (Bonehead!)
- A friend with a compromised system sends us a data file. (Subtle!)

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.

Class variables and methods

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.

```
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.

Class variables and methods, continued

To define a class method, simply prefix the method name with the name of the class:

```
class Counter
   @@created = 0
   ...
   def Counter.created
      @@created
   end
end
```

Usage:

```
>> Counter.created            => 0
>> c = Counter.new
>> Counter.created            => 1
>> 5.times { Counter.new }
>> Counter.created            => 6
```

A little bit on access control

By default, methods are public. If **private** appears on a line by itself, subsequent methods in the class are private. Ditto for **public**.

```
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?

Getters and setters

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.

```
def count= n
    puts "count=(#{n}) called"   # Just for observation (LHtLAL)
    @count = n unless n < 0
end
```

Usage:

```
>> c = Counter.new
>> c.count = 10
count=(10) called
=> 10
>> c                          => Counter's count is 10
```

Getters and setters, continued

Here's a class to represent points on a Cartesian plane:

```
class Point
    def initialize(x, y)
        @x = x
        @y = y
    end
    def x; @x end
    def y; @y end
end
```

Usage:

```
>> p1 = Point.new(3,4)    => #<Point:0x..193320 @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**.

Getters and setters, continued

The method **attr_reader** creates getter methods.

Here's an equivalent definition of **Point**:

```
class Point
   def initialize(x, y)
      @x = x
      @y = y
   end
   attr_reader :x, :y
end
```

Usage:

```
>> p = Point.new(3,4)
>> p.x                    => 3
>> p.x = 10
NoMethodError: undefined method `x=' for #<Point: ...>
```

Why does **p.x = 10** fail?

Getters and setters, continued

If you want both getters and setters, use **attr_accessor**.

```
class Point
   def initialize(x, y)
      @x = x
      @y = y
   end
   attr_accessor :x, :y
end
```

Usage:

```
>> p = Point.new(3,4)
>> p.x
=> 3
>> p.y = 10
```

It's important to appreciate that **attr_reader** and **attr_accessor** are <u>methods that create methods</u>. (What if Ruby didn't provide them?)

Operator overloading

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 numeric 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; `s1 || s2` is string concatenation

What are examples of overloading in Ruby? In Haskell?

Operators as methods

We've seen that Ruby operators can be expressed as method calls:

```
3 + 4             is    3.+(4)
```

Here's what subscripting means:

```
"abc"[2]          is    "abc".[](2)
"testing"[2,3]    is    "testing".[](2,3)
```

Unary operators are indicated by adding `@` after the operator:

```
-5       is   5.-@()

!"abc"   is   "abc".!@()
```

Challenge:

Find a binary operation that can't be expressed as a method call.

Operator overloading, continued

We'll use a dimensions-only rectangle class to study overloading in Ruby:

```
class Rectangle
   def initialize(w,h)
      @width, @height = w, h
   end
   attr_reader :width, :height
   def area; width * height; end
   def inspect                                  # irb uses inspect
      "#{width} x #{height} Rectangle"
   end
end
```

Usage:

```
>> r = Rectangle.new(3,4)    => 3 x 4 Rectangle
>> r.area                    => 12
>> r.width                   => 3
```

Operator overloading, continued

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


>> c = a + b + b


>> (a + b + c).area
```

Operator overloading, continued

Our vision:

```
>> a = Rectangle.new(3,4); b = Rectangle.new(5,6)
>> a + b       => 8 x 10 Rectangle
```

Here's how to make it so:

```
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:

```
def + rhs
  Rectangle.new(self.width + rhs.width, self.height + rhs.height)
end
```

Here is a **faulty implementation** of our idea of rectangle addition:

```
def + rhs
  @width += rhs.width; @height += rhs.height
end
```

What's wrong with it?

```
>> a = Rectangle.new(3,4)
>> b = Rectangle.new(5,6)

>> c = a + b

>> a
```

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!)

```
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?

Operator overloading, continued

At hand:

```
def -@
    @width, @height = @height, @width
    self
end
```

How could we get more sensible behavior, like the following?

```
>> 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
```

Solution:

Operator overloading, continued

Problem: Implement "scaling" a rectangle by some factor. Example:

```
>> 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
```

Solution:

What does the following do?

```
>> 3 * Rectangle.new(3,4)
```

Operator overloading, continued

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 * 2` with **Rectangle**s 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:

```
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:

```
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-extended) 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:

```
class Shape
   def area
      raise "Shape#area is abstract"
   end
end
```

There is also an **abstract_method** "gem" (a package of code and more):

```
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**:

```
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**.

Inheritance is less important in Ruby

Here is **sumOfAreas** in 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:

```
sum = shapes.inject (0.0) {|acc, shape| acc + 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.

Example: **VString**

Imagine an abstract class **VString** with two concrete subclasses: **ReplString** and **MirrorString**.

A **ReplString** is created with a string and a replication count. It supports **size**, substrings with **[pos]** and **[start, len]**, and **to_s**.

```
>> r1 = ReplString.new("abc", 2)     => ReplString(6)

>> r1.size       => 6

>> r1[0]         => "a"

>> r1[10]        => nil

>> r1[2,3]       => "cab"

>> r1.to_s       => "abcabc"
```

A **MirrorString** represents a string concatenated with a reversed copy of itself.

```
>> 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
```

VString, continued

New requirements:

A **VString** can be created using either a **VString** or a **String**.

A **ReplString** can have a very large replication count.

Will **VString**s in constructors work with the implemetation 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?

VString, continued

Here's some behavior that we'd like to see:

```
>> 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 **String**s.
- **VString#size** works, possibly producing a **Bignum**.
- **VString#to_s** "works" but is problematic with long strings.

How can we make this work?

VString, continued

Let's play computer!

```
>> s = MirrorString.new(ReplString.new("abc",1_000_000))
=> MirrorString(ReplString("abc",1000000))

>> s.size

>> s[-1]

>> s[3_000_000]

>> s[3_000_000,6]
```

VString stands for "virtual string"—the hierarchy provides the illusion of very long strings but uses very little memory.

To be continued, on assignment 7!

What data did you need to perform those computations?

Modules and "mixins"

Modules

A Ruby *module* can be used to group related methods for organizational purposes.

Some methods for a homesick Haskell programmer at Camp Ruby:

```
module Haskell
   def Haskell.head(a)   # Class method--prefixed with class name
      a[0]
   end

   def Haskell.tail(a)
      a[1..-1]
   end
   ...more...
end

>> a = [10, "twenty", 30, 40.0]

>> Haskell.head(a)


>> Haskell.tail(a)
```

Modules as "mixins"

A module can be "included" in a class.

- Such a module 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:

```
module Haskell
   def head
      self[0]
   end

   def tail
      self[1..-1]
   end
end
```

Previous version:

```
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:

```
% 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:

```
>> 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
```

Mixins, continued

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?

Modules and superclasses

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:

```
>> Fixnum.ancestors
=> [Fixnum, Integer, Numeric, Comparable, Object, Kernel,
BasicObject]


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

>> load "mixin1.rb"

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

Modules and superclasses, continued

The method **included_modules** shows the modules that a class **include**s.

```
>> Array.included_modules     => [Haskell, Enumerable, Kernel]

>> Fixnum.included_modules  => [Comparable, Kernel]
```

instance_methods can be used to see what methods are in a module:

```
>> Enumerable.instance_methods.sort => [:all?, :any?,
:chunk, :collect, :collect_concat, :count, :cycle, :detect, :drop,
:drop_while, :each_cons, :each_entry, ...more...

>> Comparable.instance_methods.sort
=> [:<, :<=, :==, :>, :>=, :between?]

>> Haskell.instance_methods
=> [:head, :tail]
```

The **Enumerable** module

When talking about iterators we encountered **Enumerable**. It's a module:

```
>> Enumerable.class
=> Module

>> Enumerable.instance_methods.sort => [:all?, :any?,
:chunk, :collect, :collect_concat, :count, :cycle, :detect, :drop,
:drop_while, :each_cons, :each_entry, :each_slice,
:each_with_index, :each_with_object, :entries, :find, :find_all,
:find_index, :first, :flat_map, :grep, :group_by, :include?,
:inject, :map, :max, :max_by, :member?, :min, :min_by,
:minmax, :minmax_by, :none?, :one?, :partition, :reduce,...
```

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.

The **Enumerable** module, continued

Here's a class whose instances simply hold three values:

```
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:

```
>> 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?

The **Comparable** module

Another common mixin is **Comparable**:

```
>> Comparable.instance_methods
=> [:==, :>, :>=, :<, :<=, :between?]
```

Comparable's methods are implemented in terms of **<=>**.

Let's compare rectangles on the basis of area:

```
class Rectangle
  include Comparable
  def <=> rhs
    (self.area - rhs.area) <=> 0
  end
end
```

Comparable, continued

Usage:

```
>> 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?

```
>> [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? (**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?

My first practical Ruby program

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
...
```

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.