Ruby

CSC 372, Fall 2022
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Introduction

"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."

Ruby by Observation

Let's see what we can learn about Ruby by trying some expressions using **irb** on lectura.

```
3+4
_.class
"x".<TAB><TAB>
("abc"*3_500).size.to_s
s = ('a'..'z').to_a.join
s[5,9]
s[5..9]
s[-3..]
"a test here".split.map {|s| s.size}
10[3]
s=`date; hostname`
s.gsub!("2","TWO"); print s
```

```
"call 555-1212" =~ /[0-9]+/
[$`, $&, $'] # just after above
"9-3".gsub(/\d/) {|d| d.to_i-1}
{1 => 2.0, :three => [!nil, 3] }
if 1 < 2 then 3 else 4 end
while line = gets; p line; end
print 3 unless 4 < 5
3.+(4)
Rational(1,3) * 300
1.i**2
```

irb—Interactive Ruby Shell

irb is the commonly used REPL for Ruby. Let's run it on lectura:

```
% irb
irb(main):001:0> 3 + 4
=> 7
```

irb's prompt changes if an expression is incomplete:

```
irb(main):002:0* "abc" +
irb(main):003:0*
irb(main):004:0*
irb(main):005:0> "xyz"
=> "abcxyz"
```

The slides won't show the result line (=> ...) when it is uninteresting.

Control-D terminates irb.

Use Control-C if you're stuck with an incomplete expression.

Version issues

The latest stable version of Ruby is 3.1.2.

Due to both compatibility concerns and my late switch to Ruby, the only available version of Ruby on lectura is 2.7, which is the last 2.X version.

Slides and assignments will be based on 2.7, released on 2019-12-25.

Ruby 3.0 improvements focus on performance, parallelism & concurrency, and static type analysis.

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 3.X

Resources

ruby-lang.org is Ruby's home page

ruby-doc.org/core-2.7.0 is the root of the 2.7.0 documentation

A few places of interest:

Ruby syntax:

ruby-doc.org/core-2.7.0/doc/syntax_rdoc.html

But, for example, there's no link from **Literals** in the table!

Instead, click **literals.rdoc** in the **Files** bar on the left!

Operator precedence:

ruby-doc.org/core-2.7.0/doc/syntax/precedence_rdoc.html

Class-level documentation, with **String** as an example:

https://ruby-doc.org/core-2.7.0/String.html

discord.com/invite/EnSevaRfct —"Official" Ruby Discord server

Resources, continued

Programming Ruby 1.9 & 2.0 (4^{th} edition): *The Pragmatic Programmers' Guide* by Dave Thomas, with Chad Fowler and Andy Hunt

– Known as the "Pickaxe book"
– $29.95 for a DRM-free PDF at pragprog.com.
– I'll call it "PA".
– Programming Ruby 3.2 (5th Edition) is in "beta"

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" .

learning.oreilly.com has:

- Many relatively new Ruby books
  One recommendation: The Ruby Way, 3^{rd} edition by Hal Fulton
- Lots of books on Ruby on Rails
- A number of of pre-1.9 Ruby books

Getting Ruby for Windows

Go to rubyinstaller.org/downloads and under "WITHOUT DEVKIT" get `Ruby 2.7.6-1 (x64)`.

When installing, I recommend the default selections:

- Add Ruby executables to your PATH
- Associate `.rb` and `.rbw` files with this Ruby installation
- Use UTF-8 as default external encoding

Then, on the "Completing the Ruby Setup Wizard Page", deselect **Run 'ridk install' to set up MSYS2...** before you click "Finish".

(You'll need to revisit this choice if you later want to install Ruby *gems* that have C extensions.)

Getting Ruby for macOS

The version of Ruby on recent versions of macOS should be fine for our purposes, assuming **ruby --version** shows 2.4 or better.

Alternatively, with Homebrew, you can do **brew install ruby@2.7**

Extra Credit Assignment 4

For two assignment points of extra credit:

1. Run **irb** and try ten Ruby expressions with some degree of variety. Explore the **String**, **Array**, **Integer**, **Float**, and **Rational** classes for methods to experiment with.

2. Capture the interaction (both expressions and results) and put it in a plain text file, eca4.txt. No need for your name, NetID, etc. in the file. No need to edit out errors.

3. On lectura, turn in eca4.txt with the following command:

```
% turnin 372-eca4 eca4.txt
```

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

Ruby basics

Every value is an object

In Ruby, <u>every value is an object</u>.

Methods can be invoked using ***<u>receiver</u>*.*method*(*parameters...*)**

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


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


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

Repeat: In Ruby, every value is an object.

What are some values in Java that are not objects? How about Python?

Everything is an object, continued

Of course, "everything" includes numbers:

```
>> 1.2.class()
=> Float

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

>> 17**37
=> 3362095853201812742282475234995233875224247377

>> _.pred()


>> _.class()
=> Integer
```

Everything is an object, continued

The TAB key shows completions in ***irb***:

```
>> 7.<TAB><TAB>
 7.bit_length          7.to_s
 7.digits              7.to_i
 7.lcm                 7.to_f
 7.gcd                 7.to_r
 7.rationalize         7.div
 7.next                7.divmod
 7.gcdlcm              7.fdiv
 7.denominator         7.coerce
 7.numerator           7.modulo
 7.upto                7.remainder
 7.chr                 7.abs
 7.inspect             7.magnitude
 7.size                7.integer?
 7.succ                7.floor
 7.ord                 7.ceil
 7.to_int              (119 in all...)
```

Parentheses are optional, sometimes

Parentheses are <u>often</u> 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)
```

Solution:

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

I usually omit parentheses in simple method invocations.

A post-Haskell hazard!

You might have a Haskell moment and leave out a comma between arguments:

```
>> "testing".slice 2 3
SyntaxError ((irb):14: syntax error, unexpected integer literal,
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"
```

Note: String#slice makes for a good example but we'll soon see an operator-based slice.

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"))      # Try it w/o parens, too!
```

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 (typed by user)
"testing\n"
=> nil
```

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

See ruby-doc.org/core-2.7.0/Kernel.html

Sidebar: ~/notes/ruby.txt

A LHtLaL suggestion:

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

```
$ cat ~/notes/ruby.txt
#FAQ
https://ruby-doc.org/core-2.7.0/String.html

#irb (REPL)
reads ~/.irbrc
_ is last value, like `it` in Haskell

#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          # fall22/ruby/hello2.rb
def say_hello
   puts "Hello, world!"
end

say_hello

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

The definition of **say_hello** <u>must precede the call</u>.

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:

Usage:

```
% cal | ruby tac.rb

27 28 29 30
20 21 22 23 24 25 26
13 14 15 16 17 18 19
 6  7  8  9 10 11 12
       1  2  3  4  5
Su Mo Tu We Th Fr Sa
   November 2022
```

ADD SLIDE on pitfall with gets vs. STDIN.gets; show ENOENT error!

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.

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 >     <

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

All escapes:

docs.ruby-lang.org/en/2.7.0/syntax/literals_rdoc.html#label-Strings

Unicode:

```
>> "\u{1F355} \u{2b} \u{1F41F} = \u{1f610}"
=> "🍕 + 🐟 = 😐"
```

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


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

>> '\'\\'.length
```

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**:

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

>> "".public_methods.length
=> 183
```

Strings are mutable

Unlike Python, 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"
>> x2 = x.dup
=> "testing"

>> x2 << "...more"

>> x2


>> x
```

Some objects that hold strings **dup** strings they are given.

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.

Strings can be compared with a typical set of operators:

```
>> "apples" == "oranges"
=> false

>> "apples" != "oranges"
=> true

>> "apples" < "Oranges"
```

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

These (common) operators work with most other types, too!

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]*** **#** Negative positions are counted from the right

>> ***s[100]***

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 = "tack"

>> s[0] = 65.chr

>> s[1] = "tomi"

>> s


>> s[-1] = ""

>> s
```

Substrings, continued

A substring can be referenced with

s[*start*, *length*]

```
>> s = "replace"

>> s[2,3]

>> s[3,100]

>> s[-4,3]

>> s[10,10]
```

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

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 range literals with strings:

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

```
 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]


>> s[-8..-4]


>> s[-4..-8]


>> s[2..]
```

Changing substrings

A substring can be the target of an assignment:

```
>> s = "replace"

>> s[0,2] = ""

>> 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)*

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

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

>> s
```

Expression interpolation in string literals

In a string literal enclosed with double quotes the sequence #{*expr*} causes interpolation of the value 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 183 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

Ruby's **Integer** class represents integers of any size.

```
>> 5.class
=> Integer

>> 11 ** 111
=> 393176952871725354905341733868827567047616076641З
5852855034678556753487133293648186980649622260361388
994869790176611

>> (3 ** 33_000).to_s.size
=> 15746

>> (3 ** 33_000_000).bit_length
(irb):115: warning: in a**b, b may be too big
NoMethodError (undefined method `bit_length' for
Infinity:Float)
```

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 **Integer**s produces an **Integer**.

```
>> 2/3
=> 0

>> _.class
=> Integer
```

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

```
>> 10 / 5.1
=> 1.9607843137254903

>> 10 % 4.5
=> 1.0

>> _.class
=> Float
```

Numbers, continued

Ruby has a **Complex** type.

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

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

>> Complex 'i'


> >> _ * _
```

Numbers, continued

There's **Rational**, too.

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

>> it * 300



>> Rational 0.5



>> Rational 0.6



>> Rational 0.015625
```

Sidebar: Fixnum and Bignum—RIP

With 2.2.4 on lectura, integers in the range -2^{62} to $2^{62}-1$ were 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
```

LHtLaL:
Explore boundaries!

```
>> x.class          => Fixnum

>> x += 1           => 4611686018427387904

>> x.class          => Bignum

>> x -= 1           => 4611686018427387903

>> x.class          => Fixnum
```

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 Integer)
```

The methods **to_i**, **to_f**, and **to_s** are used to convert values to **Integer**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 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
```

Arrays, continued

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
```

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
```

TODO: show intercalation!

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]]
```

Speculate: Will the following work?

```
>> [1,2] < [3,4]
```

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 Integer with String failed)
```

Comparing arrays, continued

At hand:

```
>> ["sixty",20,"two"].sort
ArgumentError (comparison of Integer with String 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:

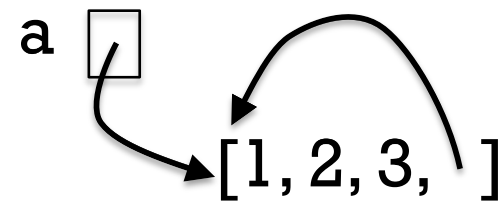
```
>> a = [1,2,3]

>> a.push a

>> a.size

>> a[-1]

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




```
>> a << 10

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

Control Structures

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".

From my Python notes:

```
>>> list(map(bool, [False, None, [], {}, "", set(), 0, 0.0]))
[False, False, False, False, False, False, False, False]
```

PHP 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 metacharacters.
- Knowing the full set of truthy/falsy rules for a language.

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

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

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

Will it work?

```
Traceback (most recent call last):
```

What's the problem?

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?

`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 cannot 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, indentation is never significant in Ruby.

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"?

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
```

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

```
>> ! 1
```

```
>> ! nil
```

```
>> ! (1 || 2)
```

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

```
>> ![nil]
```

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.

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?

break and **next**

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
```

TODO: DROP THIS SLIDE
Expand previous slide,
Including for c in "abc"

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?

Execution:

```
>> hello
Hello!
=> nil
>>
```

Contrast with Python:

```
>>> hello()
Hello!
>>>
```

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**:

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

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

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

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

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

Testing methods with **irb**, continued

Let's include in **simple.rb** an "**r**" method that loads **simple.rb**:

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

def hello # new for example
   puts "Hello!"
end

def r
   load "simple.rb"
end
```

```
$ irb -r ./simple.rb
>> add 3,4
=> 7
>> hello
Hello!
[...edit simple.rb...]
>> r
=> true
>> add 3,4
add called...
=> 7
>> hello
Hello! (v2)
```

After loading **simple.rb** once with **irb**, we can edit in a different window and then reload **simple.rb** by just typing **r**.

Where's the class?!

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

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
=> [:r, :add, :hello]
```

self has three more private methods after loading **simple.rb**.

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

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

Imagine a ***wrap*** method that can be used in three ways:

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

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

>> wrap _, "|"
=> "|<abc>|"
```

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

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

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
Python	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 Python's **print** can accept any number of arguments.

Imagine a Ruby method that can be called with any number of arguments:

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

Implementation:

```
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>

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...

TODO: irb –r ./main3.rb
(next slide, too)

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

Here's a technique that lets a program run normally with **ruby** but not 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 (>> $0 => "irb")
- **$,** 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: ruby-doc.org/core-2.7.0/doc/globals_rdoc.html.

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

<u>Ordinary variables are local to the method in which they're created</u>.

```
% 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' for
main:Object (NameError)
```

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):9: warning: already initialized constant MAX_ITEMS
(irb):8: warning: previous definition of MAX_ITEMS was here
=> 200
```

Modifying an object referenced by a constant does not 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?

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).

Type Checking

"The Java programming language is a *statically typed* language, which means that every variable and every expression has a type that is known at compile time."

-- *The Java Language Specification, Java SE 17 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.out.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.
- What would a similar Python program do?

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 know that 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 "not allowed" 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
- Invoking a method with the wrong number of arguments
- Forgetting a **`return`** at the end of a method that returns a value
- Misspelling the name of a method (true?)

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?

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?
=> Integer

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

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

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

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 never detected.

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

An example of a typing-related trade-off in execution time:

- C spends zero time during execution checking types.
- Java checks types during execution only in certain cases.
- Languages with dynamic typing check types on every operation, at least conceptually.

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.

REPLACEMENTS!
Discard 133-157 in the prior set!

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.

Two examples of Ruby's **for** loop:

for i in 1..20 do ***...statements...*** **end**

for word in line.split do ***...statements...*** **end**

for only requires the "**in**" expression to produce an object that has an **each** method.

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.*

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>

Consider this method:

```
def double x
    x * 2           # think of this as x.*(2)
end
```

What operation(s) does **double** require that **x** support?

Duck typing, continued

```
>> double 10

>> double "abc"

>> double [1,2,3]

>> double Rational(3)

>> double 1..10
```

For reference:

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

- Is it good or bad that **double** operates on so many different types?
- Is **double** polymorphic?

Duck typing, continued

Here's ***wrap*** from slide 98. 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

Should a method check the type of parameters?

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

What does the following suggest?

```
>> double(Complex 'i')
RuntimeError (Can't double a Complex!)
```

-
-

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

Duck typing, continued

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

Does the following Java method exemplify duck typing?

```
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

In Ruby, an *iterator* is a method that can invoke a *block*.

One of the many iterators in the **Array** class is **each**. Example:

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

What's the block in this case?

How many times is the block invoked?

What is `|e|`? Is it required?

What does **Array#each** return?

Iterators and blocks, continued

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

However, with some iterators the value returned is of principle interest.

See if you can predict what the following iterators do.

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

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

>> [5,4,10,7].inject([[0,0]]) {|a, e| a + [[e, a[-1][1]+e]]}
```

What do these remind you of?

Iterators and blocks, continued

We can use **[30, 20, 10, 40].sort** to sort an array but we can also call **Array#sort** with a block:

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

Speculate: What values is **sort** passing to the block?

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 does **Array#sort** do if not given a block?

```
>> "a longer try first".split.sort
```

TODO: maybe a good example would be to make [3,"5"].sort work

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** iterator 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-2.7.0/Enumerable.html**

Numeric iterators

```
>> 3.times { puts "Ding!" }
Ding!
Ding!
Ding!
=> 3

>> 3.downto(1) {|i| puts i }
3
2
1
=> 3

>> 1.step(2,Rational(1,3)) {|i| puts i}
```

Some **String** iterators

In Ruby 1.9, **String** lost its **each** method!

```
>> "abc".each { |c| puts c }
```

Use **each_char** instead:

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

Any ideas about the behavior of the following?

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

Sidebar: Iterate with **each** or use a **for** loop?

Which is better? This,

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

or this?

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

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.

The opening brace or do for a block must be on the same line as the iterator invocation.

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
```

Let's 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\n".split  => ["10", "20", "30"]`
- `"10".to_i               => 10`

sumnums.rb solution

One solution:

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

Or, if you can't let go of Haskell...

```
nums = STDIN.read.split.map {|s| s.to_i }
total = nums.inject(0) {|sum,e| sum + e }
n = nums.size
printf(...) if n != 0
```

Scoping rules with blocks

If a variable isn't created before a block, it is local to the block.

```
[7,1,3].each {|e| x = e * 2; ...}
puts x            # x is undefined here!
```

If a variable is created before a block, references inside the block apply to that outer variable.

```
x = 5
[7,1,3].each {|e| x = e * 2; ...}
puts x            # prints 6
```

We can follow a block's parameter(s) with a list of block-local variables.

```
x = 5; y = 6
[7,1,3].each {|e; x, y| ... x = 10; y = 20; ...} # best practice
puts [x,y]        # prints [5,6]
```

You can try the above cases and more with **blockscope2.rb**.

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 }
```

Both invoke blocks 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.

```
>> [1,2,4,5].all? { |n| n.odd? }          => false
```

Invokes block with each element in turn; each block result contributes to final result of **true** or **false**, possibly short-circuiting.

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

Invokes block to determine membership in final result.

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

Invokes block an arbitrary number of times; each block result guides further computation towards final result.

The **Hash** class

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
```

Hash, continued

At hand:

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

Subscripting with a key fetches the associated value.

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

What will happen with a non-existent key?

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

Hash, continued

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
```

Here's the literal syntax with key/value pairs:

```
>> h = {"i" => 7, "a" => [3,1,5], "s" => "test"}
```

The value associated with a key can be changed in various ways:

```
>> h["i"] += 3

>> h["a"].unshift 11

>> h["s"] << "er"

>> h
=> {"i"=>10, "a"=>[11, 3, 1, 5], "s"=>"tester"}
```

A contrast with Python

Python:

```
>>> d = {}

>>> d[[10,20,30]] = 3
TypeError: unhashable type: 'list'

>>> d[d] = d
TypeError: unhashable type: 'dict'
```

Ruby:

```
>> h = {}

>> h[[10,20,30]] = 3

>> h[h] = h
```

(Ralph Griswold felt strongly that this should work!)

```
>> h
=> {[10, 20, 30]=>3, {...}=>{...}}
```

A hash to work with:

```
>> 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]}
```

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"]
=> [1, 2]

>> 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!)

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
```

tally.rb, continued

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

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

At hand:

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

Solution:

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

Notes:

- The minus in the format **%-7s** left-justifies, in a field of width seven.
- As a shortcut for easy alignment, the column headers are put at the start of the array, as a fake key/value pair.
- We use **%5s** instead of **%5d** to format the counts and accommodate "**Count**", too. (This works because **%s** causes **to_s** to be invoked on the value being formatted.)
- A next step might be to size columns based on content.

More on **Hash** sorting

- By default, key/value pairs are sorted by keys.
- We can override that behavior with a block.
- The block is repeatedly invoked with two key/value pairs, like `["be", 2]` and `["or", 1]`.

How does the following block affect the sort?

```
counts.sort do
    |a,b|
    r = b[1] <=> a[1]
    if r != 0 then r  else a[0] <=> b[0] end
end
=> [["be", 2], ["to", 2], ["not", 1], ["or", 1]]
```

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!)

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
```

A **Hash.new** pitfall

Let's build a hash where the keys are word lengths and the values are lists of words with that length.

For the words

```
"it", "and", "or"
```

we'd want

```
{2=>["it", "or"], 3=>["and"]}
```

First attempt:

```
>> h = Hash.new []    # Our hope: The initial value for each
                      # key will be an empty list.

>> ["it", "and", "or"].each {|w| h[h.size] << w }

>> h
=> {}
```

A **Hash.new** pitfall, continued

Solution:

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

>> ["it", "and", "or"].each {|w| h[w.size] << w }

>> h
=> {2=>["it", "or"], 3=>["and"]}
```

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?

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.

Counter, continued

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*!)

An instance variable comes into existence when it is assigned to. 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:

- Only an object's methods can access its instance variables.
  (An object's instance variables cannot be accessed by any other object.)

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:

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
```

<u>Common error</u>: 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     => #<X:0x0000010117aaa0 @x=1, @y=1>
```

Addition of methods

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

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

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

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

Now we add 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 **Integer** and **String**.

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

Addition of methods, continued

Here is **random.rb**:

```
class Integer
   def rand
     Kernel.rand(self)+1
   end
end

class String
   def rand
     self[size.rand-1]     # Uses Integer.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

With **eval** we could write a method that adds methods to **Integer**:

```
>> units("foot/feet=1,yard(s)=3,mile(s)=5280")

>> 10.yards.in_feet
=> 30.0

>> units("second(s)=1,minute(s)=60,hour(s)=3600,day(s)=86400")

>> (1.day + 9.hours + 45.minutes).in_days
=> 1.40625
```

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"
```

Sidebar, continued

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?

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
>> 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     # :x is a Symbol.  "x" would work.
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: `3 + "4"` is `7` (addition); `3 || "4"` is `"34"` (concatenation)

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 rectangle addition:

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

Let's try it...

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

>> c = a + b

>> a
```

What's the problem?

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                        => 5 x 2 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                   => 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 <u>mutable</u>—we can change the meaning of expressions.

If we wanted to be sure that a program never used integer addition, we could do this:

```
class Integer
   def + x
      raise "boom!"
   end
end
```

Contrast:

- C++ is extensible, but not mutable.
- 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**.

Shape, continued

```
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.

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"
```

A <u>trivial</u> **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 arbitrarily large.
- If **vs** is a **VString**, **vs[pos]** and **vs[pos,len]** produce **String**s.
- **VString#size** works.
- **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 9!

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..]
   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..]
   end
end
```

Previous version:

```
module Haskell
   def Haskell.head(a)
      a[0]
   end

   def Haskell.tail(a)
      a[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:

```
>> Integer.ancestors
=> [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]

>> Integer.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.

<u>If a class implements **each** and includes **Enumerable** then all those methods become available to instances of the class.</u>

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"]]
```

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 **include 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
```

Some things I threw out when I was panicked…

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
```

Racket:

```
> (+ 3/4 1/3 1/5)         => 77/60
```

Icon:

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

Levels of support

A language's support for a feature 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

- Ruby has **Complex '2+3i'** (but Racket allows just **2+3i**)
- Java and Python have classes for working with REs.
  Python does have raw strings—**re.match(r"\w+\(\d+\)", ...)**
- C and Icon have function libraries for working with REs.

"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?

Partial 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"
```

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?

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

"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 arbitrarily large integers

Small, medium or large:

- Support for operator overloading?
- Support for object-oriented programming?

  Classes: An Abstract Data Type Facility for the C Language
- 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)
```

I got an OK to add string invocation to Icon.

Why did Ralph choose to allow this feature?

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]
```

Parallel assignment, continued

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. (!)

In conclusion...

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 then "T"; else "H";end,
                d.strftime("%m/%d/%y"), n)
        n += 1
    end
    d += incs[pos % 2]
    pos += 1
end  # classdays.rb
```

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 how to write iterators (slides 261-275 in **ruby.pdf**)
- Work with regular expressions in Ruby (slides 276-326 in **ruby.pdf**)
- Learn about **lambda**s, blocks as explicit parameters, and **call**.
- Do some metaprogramming with *hooks* like **method_missing**, **included**, and **inherited**.
- Experiment with internal Domain Specific Languages (DSLs).
- Look at how Ruby on Rails puts Ruby features to good use.
- Take a peek at BDD (Behavior-Driven Development) with Cucumber or RSpec.

Writing Iterators

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.

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:

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

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

Calling **simple** without a block produces an error on the first **yield**:

```
>> 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.

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
```

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
```

yield, continued

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**

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

Here is a trivial iterator to show the mechanics:

```
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 }

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?

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?

Iterator Block

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

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

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

Which is better?

Regular Expressions

A little theory

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

The Chomsky hierarchy of languages looks like this:

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

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

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

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.

- A regular language can also be described by a regular expression.

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
```

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/) }
```

Great idea: 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("A1b33s4ax1", /.[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 fall22

- 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 R_1 and R_2 are regular expressions then R_1R_2 is a regular expression.
In other words, juxtaposition is the concatenation operation for REs.

There are also postfix operators on regular expressions.

If **R** is a regular expression, then...

R* matches zero or more occurrences of **R**

R+ matches one or more occurrences of **R**

R? matches zero or one occurrences of **R**

All have higher precedence than juxtaposition.

*****, **+**, and **?** are commonly called *quantifiers* but PA doesn't use that term.

The *, +, and ? quantifiers

At hand:

R* matches <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 **`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.

TODO: Example: C has relatively few rules but they must be well-understood.

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 <u>strings of interest</u> instead of <u>what separates them</u>, **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(" }   ",                    )
=> "<< }   >>"
```

Using **grep**, print lines in Ruby source files that are exactly three characters long.

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.