CMSC 330: Organization of Programming Languages

Introduction to Ruby
Last Lecture

- Many types of programming languages
  - Imperative, functional, logical, OO, scripting
- Many programming language attributes
  - Clear, orthogonal, natural...
- Programming language implementation
  - Compiled, interpreted
Clickers improve student engagement


Using clickers to improve student engagement and performance class.
Addison S\textsuperscript{1}, Wright A, Milner R.

Author information

Abstract
Students say

ren
@reennnn__

Clickers are the invention of satan I'm convinced.
5:45 PM - 26 Nov 2012 · San Diego, CA, United States

Rachel Paddock
@RachelPaddock

Whoever invented clickers.... I despise you.
11:33 AM - 29 Nov 2012

Cait Corf
@caitcorf

BUT WHY MUST I BE SO STUPID?! The only reason I stayed is because it this class has I clickers,guess what I forgot to bring to class today?
12:18 PM - 15 Mar 2013
Ruby is an object-oriented, imperative scripting language

• “I wanted a scripting language that was more powerful than Perl, and more object-oriented than Python. That's why I decided to design my own language.”

• “I believe people want to express themselves when they program. They don't want to fight with the language. Programming languages must feel natural to programmers. I tried to make people enjoy programming and concentrate on the fun and creative part of programming when they use Ruby.”

– Yukihiro Matsumoto (“Matz”)
Books on Ruby

- Earlier version of Thomas book available on web
  - See course web page
Applications of Scripting Languages

- Scripting languages have many uses
  - Automating system administration
  - Automating user tasks
  - Quick-and-dirty development

- Major application

Text processing
% wc *
271 674 5323 AST.c
100 392 3219 AST.h
117 1459 238788 AST.o
1874 5428 47461 AST_defsc.c
1375 6307 53667 AST_defsh.h
371 884 9483 AST_parent.c
810 2328 24589 AST_print.c
640 3070 33530 AST_types.h
285 846 7081 AST_utils.c
59 274 2154 AST_utils.h
50 400 28756 AST_utils.o
866 2757 25873 Makefile
270 725 5578 Makefile.am
866 2743 27320 Makefile.in
38 175 1154 alloca.c
2035 4516 47721 aloctypes.c
86 350 3286 aloctypes.h
104 1051 66848 aloctypes.o

...
Climate Data for IAD in August, 2005

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Raw Census 2000 Data for DC

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A Simple Example

Let’s start with a simple Ruby program

ruby1.rb:

```ruby
# This is a ruby program
x = 37
y = x + 5
print(y)
print("\n")
```

% ruby -w ruby1.rb
42
%

%
Language Basics

- Comments begin with #, go to end of line
- Variables need not be declared
- No special main() function or method
- Line break separates expressions (can also use ";") to be safe
Run Ruby, Run

There are several ways to run a Ruby program

• **ruby -w filename** – execute script in *filename*
  ✓ tip: the -w will cause Ruby to print a bit more if something bad happens
  ✓ Ruby filenames should end with ‘.rb’ extension

• **irb** – launch interactive Ruby shell
  ✓ Can type in Ruby programs one line at a time, and watch as each line is executed
    irb(main):001:0> 3+4
    => 7
  ✓ Can load Ruby programs via load command
    • Form: load *string*
    • String must be name of file containing Ruby program
    • E.g.: load ‘foo.rb’

➤ Ruby 1.9.3 is installed on linuxlab, Grace clusters
Run Ruby, Run (cont.)

- **fxri** – launch standalone interactive Ruby shell
Suppose you want to run a Ruby script as if it were an executable (e.g. “double-click”, or as a command)

- Windows
  - Must associate .rb file extension with ruby command
  - If you installed Ruby using the Windows installer, this was done automatically
  - The Ruby web site has information on how to make this association
Suppose you want to run a Ruby script as if it were an executable (cont.)

- *nix (Linux / Unix / etc.)

```ruby
#!/usr/local/bin/ruby -w
print("Hello, world!\n")
```

- The first line ("shebang") tells the system where to find the program to interpret this text file
- Must chmod u+x filename first, or chmod a+x filename so everyone has exec permission
- Warning: Not very portable: Depends on location of Ruby interpreter
  - /usr/local/bin/ruby vs. /usr/bin/ruby vs. /opt/local/bin/ruby etc.
Creating Ruby Programs

- As with most programming languages, Ruby programs are text files.
  - Note: there are actually different versions of “plain text”! E.g. ASCII, Unicode, Utf-8, etc.
  - You won’t need to worry about this in this course.

- To create a Ruby program, you can use your favorite text editor, e.g.
  - notepad++ (free, much better than notepad)
  - emacs (free, infinitely configurable)
  - vim
  - Eclipse (see web page for plugin instructions)
  - Many others
Explicit vs. Implicit Declarations

- Java and C/C++ use explicit variable declarations
  - Variables are named and typed before they are used
    - int x, y; x = 37; y = x + 5;

- In Ruby, variables are implicitly declared
  - First use of a variable declares it and determines type
    - x = 37; y = x + 5;
      - x, y exist, will be integers
  - Ruby allows multi-assignment, too
    - x,y = 37, 5; y += x
      - x,y = 37,x+5 would have failed; x was not yet assigned
### Tradeoffs?

<table>
<thead>
<tr>
<th>Explicit Declarations</th>
<th>Implicit Declarations</th>
</tr>
</thead>
<tbody>
<tr>
<td>More text to type</td>
<td>Less text to type</td>
</tr>
<tr>
<td>Helps prevent typos</td>
<td>Easy to mistype variable name</td>
</tr>
<tr>
<td>Forces programmer to document types</td>
<td>Variable not held to a fixed type (could imagine variable declarations without types)</td>
</tr>
</tbody>
</table>
Getting started

- All classes examples will be posted on the course schedule webpage.
Everything is an object

In Ruby:
- All values are references to objects
- Objects communicate via method calls
- Each object has its own (private) state
- Every object is an instance of a class
- An object’s class determines the object’s behavior
  - How it handles method calls
  - Class contains method definitions

- Java/C#/etc. similar but do not follow (1) (e.g., numbers, null) and allow objects to have non-private state
Everything is an Object

- In Ruby, everything is an object
  - (-4).abs
    - integers are instances of Fixnum
  - 3 + 4
    - infix notation for “invoke the + method of 3 on argument 4”
  - "programming".length
    - strings are instances of String
  - String.new
    - classes are objects with a new method
  - 4.13.class
    - use the class method to get the class for an object
    - floating point numbers are instances of Float
Classes and Objects

- Class names begin with an uppercase letter
- The “new” method creates an object
  - \( s = \text{String.new} \) creates a new String and makes \( s \) refer to it
- Every class inherits from Object
Objects and Classes

- Objects are data
- Classes are types (the kind of data which things are)
- But in Ruby, classes themselves are objects!

<table>
<thead>
<tr>
<th>Object</th>
<th>Class (aka type)</th>
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<tbody>
<tr>
<td>10</td>
<td>Fixnum</td>
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<tr>
<td>-3.30</td>
<td>Float</td>
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<tr>
<td>&quot;CMSC 330&quot;</td>
<td>String</td>
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<tr>
<td>String.new</td>
<td>String</td>
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<tr>
<td>['a', 'b', 'c']</td>
<td>Array</td>
</tr>
<tr>
<td>Fixnum</td>
<td>Class</td>
</tr>
</tbody>
</table>

- Fixnum, Float, and String are objects of type Class
  - So is Class itself!
Two Cool Things to Do with Classes

- Since classes are objects, you can manipulate them however you like
  - Here, the type of `y` depends on `p`
    - Either a String or a Time object

- You can get names of all the methods of a class
  - `Object.methods`
    - `=> ["send", "name", "class_eval", "object_id", "new", "autoload?", "singleton_methods", ... ]`

```ruby
if p then
  x = String
else
  x = Time
End
y = x.new
```
The nil Object

- Ruby uses a special object `nil`
  - All uninitialized fields set to `nil` (@ prefix used for fields)
    ```ruby
    irb(main):004:0> @x
    => nil
    ```
  - Like NULL or 0 in C/C++ and null in Java
- `nil` is an object of class `NilClass`
  - It’s a singleton object – there is only one instance of it
    - `NilClass` does not have a `new` method
  - `nil` has methods like `to_s`, but not other methods
    ```ruby
    irb(main):006:0> nil + 2
    NoMethodError: undefined method `+' for nil:NilClass
    ```
Defining Your Own Classes

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

  def add_x(x)
    @x += x
  end

  def to_s
    return "(" + @x.to_s + "," + @y.to_s + ")"
  end
end

p = Point.new(3, 4)
p.add_x(4)
puts(p.to_s)
No Access To Internal State

- Instance variables (with @) can be directly accessed only by instance methods
- Outside class, they require **accessors**:

  A typical getter
  ```ruby
def x
    @x
  end
```

  A typical setter
  ```ruby
def x= (value)
    @x = value
  end
```

- Very common, so Ruby provides a shortcut

  ```ruby
class ClassWithXandY
  attr_accessor "x", "y"
end
```

  Says to generate the x= and x and y= and y methods
No Method Overloading in Ruby

- Thus there can only be one `initialize` method
  - A typical Java class might have two or more constructors
  - You can code up your own overloading by using a variable number of arguments, and checking at runtime the number/types of arguments
- Ruby does issue an exception or warning if a class defines more than one `initialize` method
  - But last `initialize` method defined is the valid one
Recall classes begin with an uppercase letter

**inspect** converts any instance to a string

```ruby
irb(main):033:0> p.inspect
=> "#<Point:0x54574 @y=4, @x=7>"
```

The **to_s** method can be invoked implicitly

- Could have written `puts(p)`
  - Like Java’s `toString()` methods
Inheritance

- Recall that every class inherits from `Object`

```ruby
class A  ## < Object
    def add(x)
        return x + 1
    end
end

class B < A
    def add(y)
        return (super(y) + 1)
    end
end

b = B.new
puts(b.add(3))
```

```
b.is_a? A  # true
b.instance_of? A  # false
```
super( ) in Ruby

Within the body of a method

• Call to super( ) acts just like a call to that original method
• Except that search for method body starts in the superclass of the object that was found to contain the original method
Methods in Ruby

Methods are declared with def...end

```ruby
def sayN(message, n)
i = 0
while i < n
    puts message
    i = i + 1
end
return i
end
```

```
x = sayN("hello", 3)
puts(x)
```

List parameters at definition
May omit parens on call
Invoke method
Like print, but adds newline

Methods should begin with lowercase letter and be defined before they are called. Variable names that begin with uppercase letter are constants (only assigned once).
Method Return Values

- Value of the return is the value of the last executed statement in the method
  - These are the same:

```python
def add_three(x)
    return x+3
end
```

- Methods can return multiple results (as a list)

```python
def dup(x)
    return x,x
end
```
Terminology

- **Formal parameters**
  - Parameters used in the body of the method
  - `def sayN(message, n)` in our example

- **Actual parameters**
  - Arguments passed in to the method at a call
  - `x = sayN("hello", 3)` in our example
What is a Program?

In C/C++, a program is...
- A collection of declarations and definitions
- With a distinguished function definition
  - \texttt{int main(int argc, char *argv[])} \{ ... \}
- When you run a C/C++ program, it’s like the OS calls \texttt{main(...)}

In Java, a program is...
- A collection of class definitions
- With some class (say, \texttt{MyClass}) containing a method
  - \texttt{public static void main(String[] args)}
- When you run \texttt{java MyClass}, the main method of class \texttt{MyClass} is invoked
A Ruby Program is...

- The class **Object**
  - When the class is loaded, any expressions not in method bodies are executed

```ruby
def sayN(message, n)
  i = 0
  while i < n
    puts message
    i = i + 1
  end
  return i
end

x = sayN("hello", 3)
puts(x)
```

defines a method of **Object**

invokes `self.sayN`

invokes `self.puts` (part of **Object**)
Ruby is Dynamically Typed

- Recall we don’t declare types of variables
  - But Ruby does keep track of types at run time
    
    ```ruby
    x = 3; x.foo
    NoMethodError: undefined method 'foo' for 3:Fixnum
    ```

- We say that Ruby is **dynamically typed**
  - Types are determined and checked at run time

- Compare to C, which is **statically typed**

```ruby
# Ruby
x = 3
x = "foo"  # gives x a
    # new type
```

```c
/* C */
int x;
x = 3;
x = "foo"; /* not allowed */
```
Types in Java and C++

- Are Java and C++ statically or dynamically typed?
  - A little of both
  - Many things are checked statically
    
    ```java
    Object x = new Object();
    x.println("hello");  // No such method error at compile time
    ```
  - But other things are checked dynamically
    
    ```java
    Object o = new Object();
    String s = (String) o;  // No compiler warning, fails at run time
    // (Some Java compilers may be smart enough to warn about above cast)
    ```
## Tradeoffs?

<table>
<thead>
<tr>
<th>Static types</th>
<th>Dynamic types</th>
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<tbody>
<tr>
<td>More work when coding</td>
<td>Less work when coding</td>
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<tr>
<td>Helps prevent some subtle errors</td>
<td>Can use objects incorrectly and not discover until run time</td>
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<tr>
<td>Fewer programs type check</td>
<td>More programs type check</td>
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Style

- Names of methods that return a boolean should end in `?`

- Names of methods that modify an object’s state should end in `!`

Example: suppose `x = [3,1,2]` (this is an array)

- `x.member? 3` returns true since 3 is in the array `x`
- `x.sort` returns a new array that is sorted
- `x.sort!` modifies `x` in place
Control Statements in Ruby

- A control statement is one that affects which instruction is executed next
  - We’ve seen two so far in Ruby
    - while and method call
  - Ruby also has conditionals

```ruby
if grade >= 90 then
    puts "You got an A"
elsif grade >= 80 then
    puts "You got a B"
elsif grade >= 70 then
    puts "You got a C"
else
    puts "You’re not doing so well"
end
```
Ruby Conditionals Must End!

- All Ruby conditional statements must be terminated with the `end` keyword.

Examples

- `if grade >= 90 then
  puts "You got an A"
end`

- `if grade >= 90 then
  puts "You got an A"
else
  puts "No A, sorry"
end`
What is True?

- The **guard** of a conditional is the expression that determines which branch is taken.

  ```
  if grade >= 90 then
  ...
  ```
  
  Guard

- The **true** branch is taken if the guard evaluates to anything except:
  - false
  - nil

- **Warning to C programmers:** 0 is **not** false!
Yet More Control Statements in Ruby

- **unless** cond then stmt-f else stmt-t end
  - Same as “if not cond then stmt-t else stmt-f end”

```ruby
unless grade < 90 then
  puts "You got an A"
else unless grade < 80 then
  puts "You got a B"
end
```

- **until** cond body end
  - Same as “while not cond body end”

```ruby
until i >= n
  puts message
  i = i + 1
end
```
Using If and Unless as Modifiers

- Can write if and unless after an expression
  - puts "You got an A" if grade >= 90
  - puts "You got an A" unless grade < 90

- Why so many control statements?
  - Is this a good idea? Why or why not?
    - **Good**: can make program more readable, expressing programs more directly. In natural language, many ways to say the same thing, which supports brevity and adds style.
    - **Bad**: many ways to do the same thing may lead to confusion and hurt maintainability (if future programmers don’t understand all styles)
Arrays and Hashes

- Ruby data structures are typically constructed from Arrays and Hashes
  - Built-in syntax for both
  - Each has a rich set of standard library methods
  - They are integrated/used by methods of other classes
Arrays of objects are instances of class `Array`

- Arrays may be heterogeneous
  
  ```ruby
  a = [1, "foo", 2.14]
  ```

- C-like syntax for accessing elements, indexed from 0
  
  ```ruby
  x = a[0]; a[1] = 37
  ```

Arrays are **growable**

- Increase in size automatically as you access elements
  
  ```ruby
  irb(main):001:0> b = []; b[0] = 0; b[5] = 0; puts b.inspect
  [0, nil, nil, nil, nil, 0]
  ```

- `[ ]` is the empty array, same as `Array.new`
Arrays can also shrink

- Contents shift left when you delete elements
  
  ```ruby
  a = [1, 2, 3, 4, 5]
a.delete_at(3)  # delete at position 3; a = [1,2,3,5]
a.delete(2)    # delete element = 2; a = [1,3,5]
  ```

- Can use arrays to model stacks and queues
  
  ```ruby
  a = [1, 2, 3]
a.push("a")     # a = [1, 2, 3, "a"]
x = a.pop        # x = "a"
a.unshift("b")  # a = ["b", 1, 2, 3]
y = a.shift      # y = "b"
  ```

**note:** `push`, `pop`, `shift`, and `unshift` all permanently modify the array.
Iterating Through Arrays

- It's easy to iterate over an array with `while`

```ruby
a = [1,2,3,4,5]
i = 0
while i < a.length
  puts a[i]
i = i + 1
end
```

- Looping through all elements of an array is very common
  - And there’s a better way to do it in Ruby

The **Array** class also has an **each** method

- Takes a code block as an argument

```ruby
a = [1,2,3,4,5]
a.each { |x| puts x }
```

code block delimited by `{ }`'s or `do...end`

We’ll consider code blocks generally a bit later
Ranges

- 1..3 is an object of class Range
  - Integers between 1 and 3 inclusively
- 1…3 also has class Range
  - Integers between 1 and 3 but not including 3 itself.
- Not just for integers
  - ‘a’..'z' represents the range of letters ‘a’ to ‘z’
  - 1.3…2.7 is the continuous range [1.3,2.7)
  - (1.3...2.7).include? 2.0 #=> true
- Discrete ranges offer the each method to iterate
  - And can convert to an array via to_a; e.g., (1..2).to_a
Other Useful Control Statements

```ruby
for elt in [1, "math", 3.4]
  puts elt.to_s
end

for i in (1..3)
  puts i
end

(1..3).each { |elt|
  puts elt
}

IO.foreach(filename)
{ |x|
  puts x
}

IO.foreach(filename)
{ |x|
  puts x
}

while i>n
  break
  next
  puts message
  redo
end

case x
  when 1, 3..5
    code block
  when 2, 6..8
    does not need
    break
end
```
More Data-driven Control Statements

Ruby function to print all even numbers from 0 up to (but not including) some given number $x$

```ruby
def even(x)
  for i in (0…x)
    if i % 2 == 0
      puts i
    end
  end
end
```

```ruby
def even(x)
  x.times { |i|
    if i % 2 == 0
      puts i
    end
  }
end
```

```ruby
def even(x)
  0.upto(x-1) { |i|
    if i % 2 == 0
      puts i
    end
  }
end
```
Standard Library: Hash

- A hash acts like an associative array
  - Elements can be indexed by any kind of values
  - Every Ruby object can be used as a hash key, because the Object class has a hash method

- Elements are referred to using [ ] like array elements, but Hash.new is the Hash constructor

```ruby
italy["population"] = 58103033
italy["continent"] = "europe"
italy[1861] = "independence"
```
Hash (cont.)

- Hash methods
  - values returns array of a hash’s values (in some order)
  - keys returns an array of a hash’s keys (in some order)

- Iterating over a hash

```ruby
italy.keys.each { |k|
  print "key: ", k, " value: ", italy[k]
}

italy.each { |k,v|
  print "key: ", k, " value: ", v
}
```
Hash (cont.)

Convenient syntax for creating literal hashes

- Use \{ key => value, ... \} to create hash table

```ruby
credits = {
  "cmsg131" => 4,
  "cmsg330" => 3,
}

x = credits["cmsg330"]  # x now 3
credits["cmsg311"] = 3
```
Mixins

- Another form of code reuse is “mix-in” inclusion
  - `include A “inlines” A’s methods at that point`
    - Referred-to variables/methods captured from context
    - In effect: it adds those methods to the current class

```ruby
class OneDPoint
  attr_accessor “x”
  include Comparable
  def <=>(other)# used by Comparable
    if @x < other.x then return -1
      elsif @x > other.x then return 1
    else return 0
    end
  end
end
```

```ruby
p = OneDPoint.new
p.x = 1
q = OneDPoint.new
q.x = 2
x < y # true
puts [y,x].sort
# prints x, then y
```
Global Variables in Ruby

Ruby has two kinds of global variables

- Class variables beginning with `@@` (static in Java)
- Global variables across classes beginning with `$`

```ruby
class Global
  @@x = 0
  def inc
    @@x = @@x + 1; $x = $x + 1
  end
  def get
    return @@x
  end
end
```

```ruby
$x = 0
Global.inc
$x = $x + 1
Global.inc
puts(Global.get)
puts($x)
```

define a class ("singleton") method
Ruby has a special set of global variables that are implicitly set by methods.

The most insidious one: \$_

- Last line of input read by gets or readline

Example program

```ruby
gets    # implicitly reads input line into \$_
print   # implicitly prints out \$_
```

Using \$_ leads to shorter programs

- And confusion
- We suggest you avoid using it
Creating Strings in Ruby

- Substitution in double-quoted strings with `#{ }`
  - `course = "330"; msg = "Welcome to #{course}"`
  - "It is now #{Time.now}"'
  - The contents of `#{ }` may be an arbitrary expression
  - Can also use single-quote as delimiter
    - No expression substitution, fewer escaping characters

- Here-documents
  ```ruby
  s = <<END
      This is a text message on multiple lines
      and typing \n is annoying
  END
  ```
Creating Strings in Ruby (cont.)

- Ruby also has `printf` and `sprintf`
  - `printf("Hello, %s\n", name);`
  - `sprintf("%d: %s", count, Time.now)`
    - Returns a string

- The `to_s` method returns a `String` representation of a class object
The **String** class has many useful methods

- `s.length` # length of string
- `s1 == s2` # structural equality (string contents)
- `s = "A line\n"; s.chomp` # returns "A line"
  - Return new string with s's contents except newline at end of line removed
- `s = "A line\n"; s.chomp!`
  - Destructively removes newline from s
  - *Convention:* methods ending in `!` modify the object
  - *Another convention:* methods ending in `?` observe the object
- "r1\nr2\nr4".each_line { |rec| puts rec }
  - Apply code block to each newline-separated substring
Consider these three examples again

- All involve searching in a string for a certain pattern
- What if we want to find more complicated patterns?
  - Find first occurrence of "a" or "b"
  - Split string at tabs, spaces, and newlines
Object Copy vs. Reference Copy

Consider the following code

- Assume an object/reference model like Java or Ruby
  - Or even two pointers pointing to the same structure

```plaintext
x = "groundhog" ; y = x
```

Which of these occur?

- Object copy
- Reference copy

```
x (reference) → "groundhog" (object)

y → "groundhog"
```

```
x (reference) → "groundhog" (object)

y → "groundhog"
```
Object Copy vs. Reference Copy (cont.)

For

- Ruby and Java would both do a reference copy

```
x = "groundhog" ; y = x
```

But for

- Ruby would cause an object copy
- Unnecessary in Java since Strings are immutable

```
x = "groundhog"
y = String.new(x)
```
Physical vs. Structural Equality

Consider these cases again:

If we compare $x$ and $y$, what is compared?

- The references, or the contents of the objects they point to?

If references are compared (physical equality) the first would return false but the second true.

If objects are compared both would return true.
String Equality

- In Java, \( x == y \) is physical equality, always
  - Compares references, not string contents
- In Ruby, \( x == y \) for strings uses structural equality
  - Compares contents, not references
  - \( == \) is a method that can be overridden in Ruby!
  - To check physical equality, use the \texttt{equal?} method
    - Inherited from the \texttt{Object} class
- It’s always important to know whether you’re doing a reference or object copy
  - And physical or structural comparison
## Comparing Equality

<table>
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<tr>
<th>Language</th>
<th>Physical equality</th>
<th>Structural equality</th>
</tr>
</thead>
<tbody>
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<td><strong>Java</strong></td>
<td><code>a == b</code></td>
<td><code>a.equals(b)</code></td>
</tr>
<tr>
<td><strong>C</strong></td>
<td><code>a == b</code></td>
<td><code>*a == *b</code></td>
</tr>
<tr>
<td><strong>Ruby</strong></td>
<td><code>a.equal?(b)</code></td>
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<td><code>a == b</code></td>
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<td><code>(equal? a b)</code></td>
</tr>
<tr>
<td><strong>Visual Basic .NET</strong></td>
<td><code>a Is b</code></td>
<td><code>a = b</code></td>
</tr>
</tbody>
</table>
Summary

- Scripting languages
- Ruby language
  - Implicit variable declarations
  - Dynamic typing
  - Many control statements
  - Classes & objects
  - Strings