Grace

An Object-Oriented Language for Novices


Andrew Black
Portland State U


Kim Bruce
Pomona College


James Noble
Victoria U. Wellington

Why?

Assumption: Programming Languages Matter

- You are going to teach object-oriented programming to 1st year students.
- Following Aristotle (and Brooks):
  - What are the *essential* difficulties you must teach?
  - What are the *accidental* difficulties imposed by the language you choose?
- How will you and your students divide your time?

Which language?

- ECOOP 2010: we don't like the available options
  - Java, Scala, C++, C# and other "professional" languages — too complex for teaching
  - Smalltalk — no static types
  - Python — inconsistent method syntax, no encapsulation, "accidental" declarations ...
- All available options emphasize the *accidental*
- Group decision: design a modern object-oriented language specifically for teaching

Java has, but Grace does not:

1 Type-based overloading of methods.
2 `null`
3 Primitive data — int, boolean, char, byte, short, long, float, double.
4 Classes (as built-in non-objects).
5 Packages (as built-in non-objects).
6 Constructors (as distinct from methods) and `new`.
7 Object initializers (code in a class enclosed in { and })
8 import * — introduction of names invisibly.
9 Operations on variables, like `x++` meaning `x := x + 1`.
10 Multiple numeric types (so that, for example, `3.0` and `3` are different).
11 Numeric literals with `F` and `L`.
12 Integer arithmetic defined to wrap.
13 == as a built-in operation on objects.

14 static variables.
15 static methods.
16 static initializers.
17 final.
18 private (which is much more complicated than most people realize, since it interacts with the type system).
19 C-style for loops.
20 switch statements.
21 Class-types.
22 Packages
23 Package-based visibility.
24 Arrays (as a special built-in construct with their own special syntax and type rules).
25 Required semicolons.
26 () in method requests that take no parameters.
27 public static void main(String[] args) — necessary to run your code.
28 Object with “functional interfaces” treated as λ-expressions.

Grace has:

1. multi-part method names if(_)then(_)else(_)
2. String interpolation: "The value of x is {x}"
3. Object expressions
4. Nested objects (lexical scope)
5. Closures w/correct scope
6. Operators defined as methods
7. match(_)case(_)... statement for examining variant types

Best of 20th Century-Technology

- Closures
- Assertions, unit testing, traces, and tools for finding errors
- High-level constructs for concurrency
- Support for immutable data
- Parameterized types (done right)
  e.g., `List⟦String⟧`

Talk Outline

- Meta-babble
- Quick Overview, terminology
- Objects and methods
- Classes
- λ-expressions
- Program and module structure
- Dialects
- Types
- Pattern-matching
- Exceptions
- Concurrency
- Teaching with Grace
- Dialects

Grace Fundamentals

- Everything is an object
- Simple method dispatch
- Single inheritance
- Types are interfaces (classes ≠ types)
    - Pedagogically, types come *after* objects
- Blocks: { syntax for λ-expressions }
- Extensible via libraries (control & data)

Grace Example

```
method average(in : InputStream) → Number {
    // reads numbers from stream and averages them
    var total := 0
    var count := 0
    while { ! in.atEnd } do {
        count := count + 1
        total := total + in.readNumber
    }
    if (count == 0) then { return 0 }
    total / count
}
```

Grace Example

```
method average(in : InputStream) → Number {
    // reads numbers from stream and averages them
    var total := 0
    var count := 0
    while { ! in.atEnd } do {
        count := count + 1
        total := total + in.readNumber
    }
    if (count == 0) then { return 0 }
    total / count
}
```

What questions do you have?

One true "method request"

- Like Smalltalk and Self:
  - no static overloading
- a "method request" names the target, the method, and provides the arguments
- "dynamic dispatch" selects the correspondingly-named method in the receiver
- "method execution" occurs in the receiver

(We're learning *not* to say "message-send" or "method call".)

Method Requests

```
aPerson.printOn(outputStream)

printOn(outputStream)                    // implicit receiver

((x + y) > z) && q.not               // operators are methods

while { ! in.atEnd } do { print (in.readNumber) }
                                     // multi-part method name
```

Constructing Objects

Object constructors

```
object {
  def x : Number is public = 2
  def y : Number is public = 3
  method distanceTo(other : Point) → Number {
    ((x - other.x)^2 + (y - other.y)^2)^(1/2) }
}
```

x	2
y	3
distanceTo(Point)	...

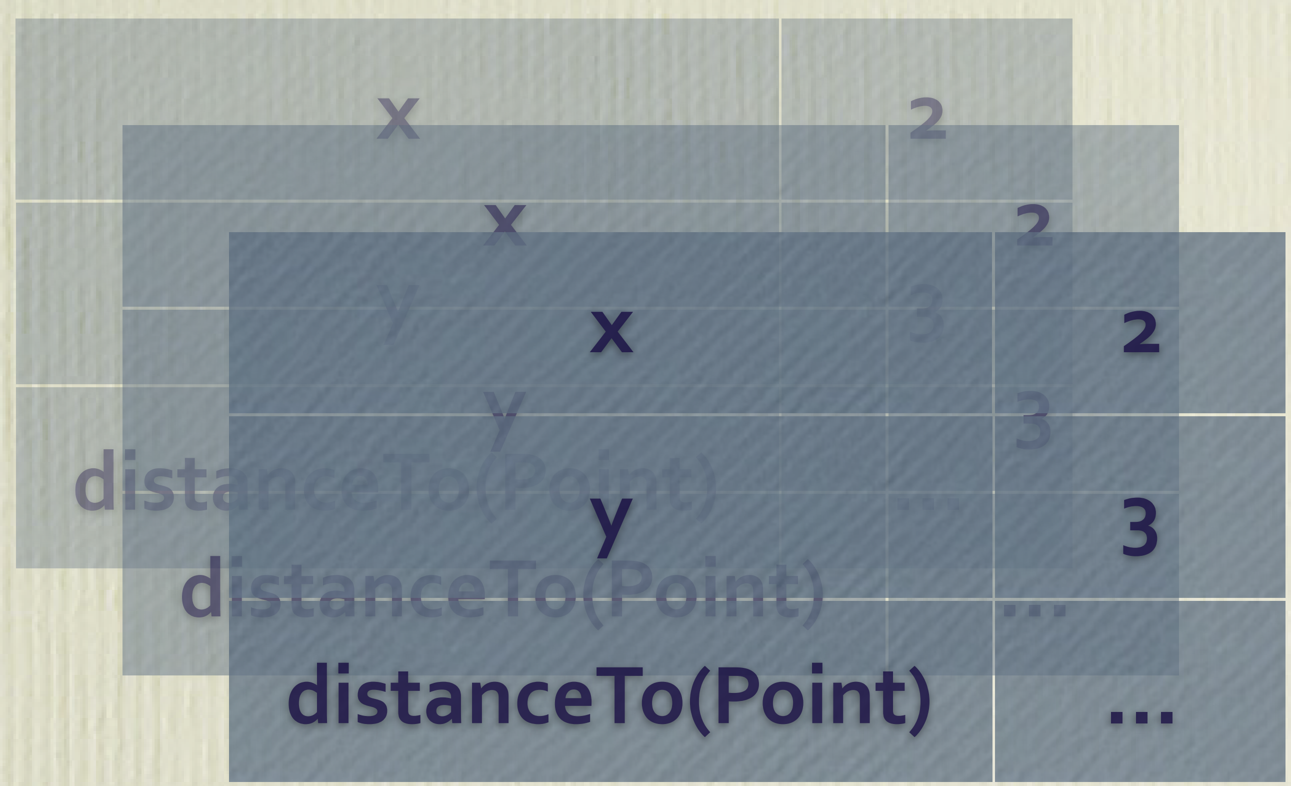
Object constructors

```
object {
  def x : Number is public = 2
  def y : Number is public = 3
  method distanceTo(other : Point) → Number {
    ((x - other.x)^2 + (y - other.y)^2)^(1/2) }
}
```

x	2
y	3
distanceTo(Point)	...

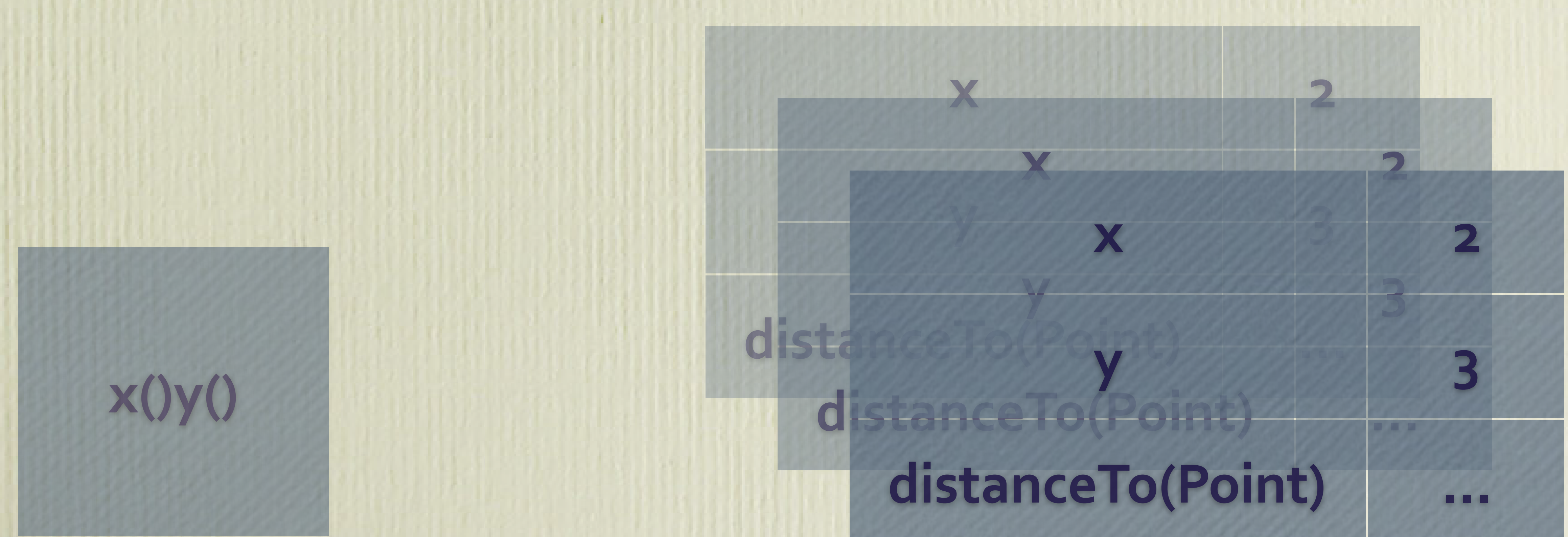
Classes

```
class x(x′: Number)y(y′: Number) → Point {
    def x : Number is public = x′
    def y : Number is public = y′
    method distanceTo(other : Point) → Number {
        ((x - other.x)^2 + (y - other.y)^2)^(1/2) }
}
```



Classes

```
class x(x′: Number)y(y′: Number) → Point {
   def x : Number is public = x′
   def y : Number is public = y′
   method distanceTo(other : Point) → Number {
      ((x - other.x)^2 + (y - other.y)^2)^(1/2) }
}
```



Classes

- A Class is a shorthand for a factory method: a method that returns the result of an object constructor.

```
method x(x′: Number)y(y′: Number) → Point {
    return object {
        def x : Number is public = x′
        def y : Number is public = y′
        method distanceTo(other:Point)→Number {
            ((x - other.x)^2 + (y - other.y)^2)^(1/2) }
    }
}
```

Class: Summary

```
class x(x′)y(y′)  {
  def x is public = x′
  def y is public = y′
  method distanceTo other → {
    ((x - other.x)^2 + (y - other.y)^2)^(1/2) }
}
```

```
method x(x′)y(y′) {
   return object {
      def x is public = x′
      def y is public = y′
      method distanceTo(other) → {
         ((x - other.x)^2 + (y - other.y)^2) ^(1/2) }}
}
```

Inheritance

```
class x(x:Number) y(y:Number) colour(c:Colour) {
  inherit cartesianPoint.x(x)y(y)
  def color : Colour is public = c
}
```

- Objects created by x(_)y(_)colour(_) have:
  - all the methods of aCartesianPoint.x(_)y(_), plus
  - methods colour and colour:=(_)

Uniform reference to attributes

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theObject.x

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```
// could be a request of a method, or access
// to a public variable: theObject knows which
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```

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var x:Number := 3                    // confidential variable
var x:Number is public := 3          // public variable
```

Uniform reference to attributes

```
theObject.x
    // could be a request of a method, or access
    // to a public variable: theObject knows which

var x:Number := 3                       // confidential variable
var x:Number is public := 3             // public variable

var x′:Number := 3                      // confidential
method x → Number { return x′ }         // public
method x:= (newX:Number) →Done { x′ := newX }  // public
```

Uniform reference to attributes

```
theObject.x
    // could be a request of a method, or access
    // to a public variable: theObject knows which

var x:Number := 3                          // confidential variable
var x:Number is public := 3                    // public variable

var x′:Number := 3                             // confidential
method x → Number { return x′ }       // public
method x:= (newX:Number) →Done { x′ := newX }  // public

method helper(…)→Done is confidential {…}
                                          // confidential method
```

λ-expressions

"Lambdas are relegated to relative obscurity until Java makes them popular by not having them."

James Iry

Grace has λs. We call them "blocks":

```
for (1..10) do {                    // multi-part method name
      i → print(i)
}
```

Blocks

- Blocks are objects that represent functions
  - **{ this is a block }** — a λ-expression
  - blocks create objects that mimic functions (like Smalltalk)

```
def welcomeAction := { print "Hello" }
```

```
welcomeAction.apply
```

```
object { method apply
            { print "Hello" } }
```

Examples

Examples

```
if (x == 3) then ( print "3" )
                    // type error
```

Examples

```
if (x == 3) then ( print "3" )
                  // type error

if (x == 3) then   print "3"
```

Examples

```
if (x == 3) then ( print "3" )
                    // type error

if (x == 3) then {print "3"}
                    // no implicit call-by-name
```

Examples

```
if (x == 3) then ( print "3" )
                        // type error

if (x == 3) then {print "3"}
                        // no implicit call-by-name

block.apply             // these are different!
```

Examples

```
if (x == 3) then ( print "3" )
                    // type error

if (x == 3) then {print "3"}
                    // no implicit call-by-name

block.apply         // these are different!
block               // application is never implicit
```

Program Structure & Modules

a whole Grace Program

```
print "Hello World"
```

a whole Grace Program

```
def graceModule378 = object {
        print "Hello World"
}
```

a whole Grace Program

```
def graceModule378 = object {

        print "Hello World"

}
```

every Grace file defines a module

Modules are Objects

in a file called *collections.grace* :

```
def list is public = object { … }
def set is public = object { … }
def dictionary is public = object { … }
```

Modules are Objects

in a file called *bingoGame.grace*:

```
import "collections" as coll
def set = coll.set
def bingoCard = set.with "Free Space"
    …
```

Recall "collections.grace"

```
def list is public = object { … }
def set is public = object { … }
def dictionary is public = object { … }
```

```
def list is public = object { … }
def set is public = object { … }
def dictionary is public = object { … }
```

import "collections" as coll

```
def list is public = object { … }
def set is public = object { … }
def dictionary is public = object { … }
```

```
import "collections" as coll
```

```
def list is public = object { … }
def set is public = object { … }
def dictionary is public = object { … }
```

import "collections" as coll

```
def temp917 = object {
    def list is public = object { … }
    def set is public = object { … }
    def dictionary is public = object { … }
}
```

import "collections" as coll

```
def temp917 = object {

        def list is public = object { … }

        def set is public = object { … }

        def dictionary is public = object { … }

}

def coll = temp917
```

Example: importing a module

in a file called bingoGame.grace :

```
import "collections" as coll
def set = coll.set
def bingoCard = set.with "Free Space"
    ...
```

Example: importing a module

in a file called bingoGame.grace :

```
def coll = temp917
def set = coll.set
def bingoCard = set.with "Free Space"
    ...
```

Dialects

- "Outermost" object: defines methods without explicit receiver
  - *e.g.,* turtle graphics, loops with invariants, TDD
- Top level code of dialect runs before module in the dialect
  - *e.g.* initialize canvas, turtle ...
- Dialect runs checker over AST of module in the dialect
  - Can generate new errors, such as missing type annotations, use of [ ] or match()case() ...

Dialects can define control methods

```
// dialect = outermost enclosing object
method do (action: Block) unless (c: Boolean) {
    if ( c ) then  ( action.apply )
}
method repeat (n : Number) times (a : Block) {
    (1..n).do { _ → a.apply }

object {
        // your program here; sends messages to
        // implicit receiver outer
}
```

Types

- Types classify objects
  - Type come *after* objects, not before
  - Structural, Gradual, Optional

```
type Point = interface {
    x → Number
    y → Number
    distanceTo (other:Point) → Number
}
```

- Interfaces are sets of method signatures
- Types can take types as parameters (a.k.a. Generics)

No null pointer exceptions!

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- No null

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- No null
- *Accessing* uninitialized variable is an error

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- No null
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- Define objects for empty lists, empty trees, etc., *and give them appropriate behavior*

No null pointer exceptions!

- No null
- *Accessing* uninitialized variable is an error
- Define objects for empty lists, empty trees, etc., *and give them appropriate behavior*

```
def emptyList = object {
    method length { 0 }
    method isEmpty { true }
    method head {
        noValue.raise "can't take the head of an empty list"
    }
    method tail { … }
}
```

Type Operations

- Variants: Point | nil, Leaf⟦X⟧ | Node⟦X⟧
  - $x : (A | B) \equiv x : A \vee x : B$
- Algebraic constructors:
  - T_1 & T_2: intersection, conforms to T_1 and T_2
    - Used to extend types
  - $T_3 + T_4$: union, conforms to T_3 or T_4
  - $T_5 - T_6$: structural subtraction, T_5 without T_6
- Type parameters don't need variance annotations

Match – Case

```
match ( x )                                   // x : o | String | Student

    // match against a constant
  case { o → print("Zero") }

    // typematch, binding a variable
  case { s : String → print(s) }

    // destructuring match, binding variables ...
  case { Student(name, id) → print (name) }
```

Pattern-matching through method dispatch

match (s)
case p_1
case p_2

Pattern-matching through method dispatch

match (s)
case p_1
case p_2

Pattern-matching through method dispatch

match...case

match (s)
case p_1
case p_2

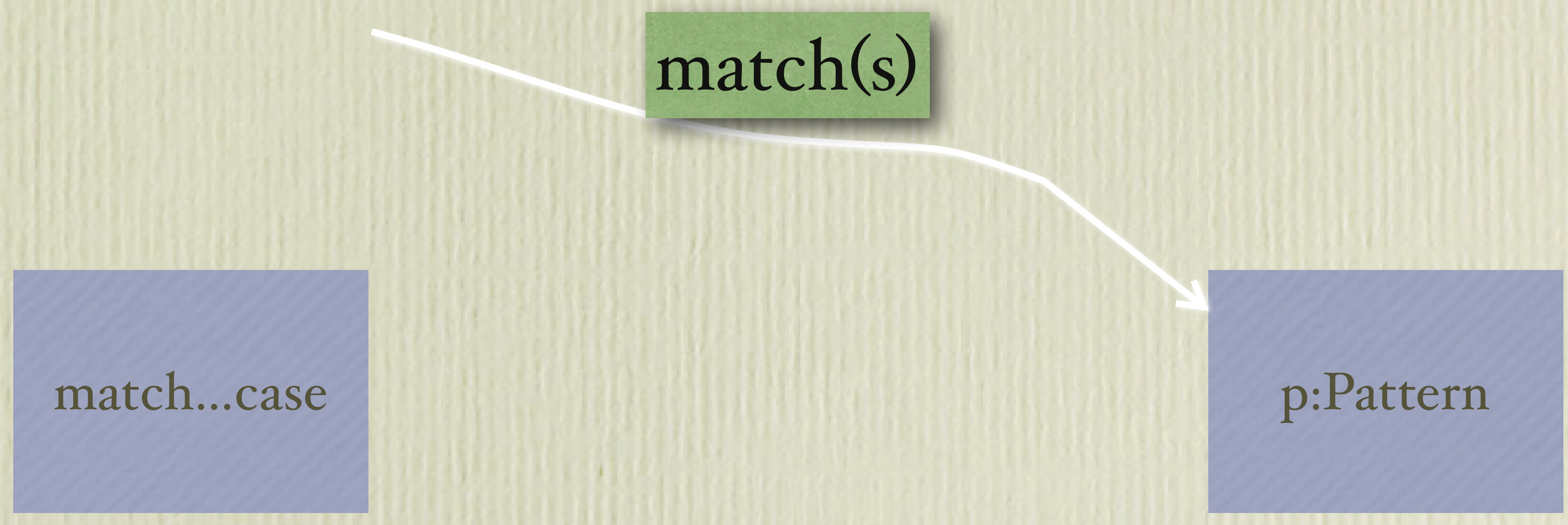
Pattern-matching through method dispatch

match...case

p:Pattern

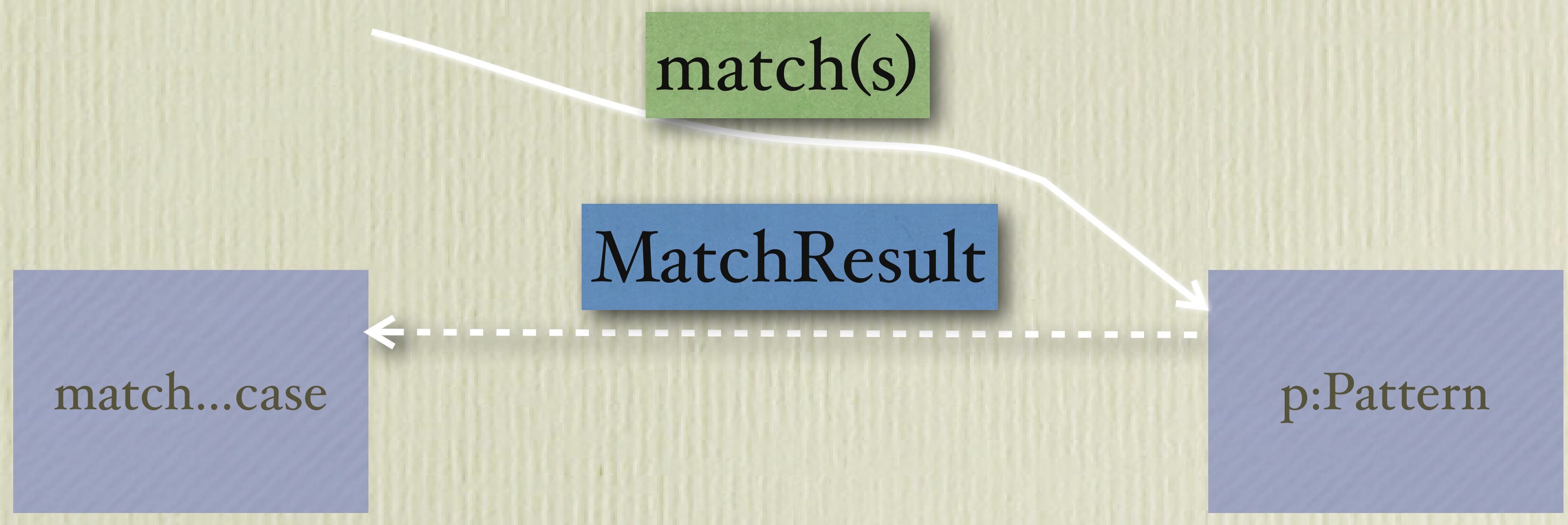
match (s)
case p_1
case p_2

Pattern-matching through method dispatch



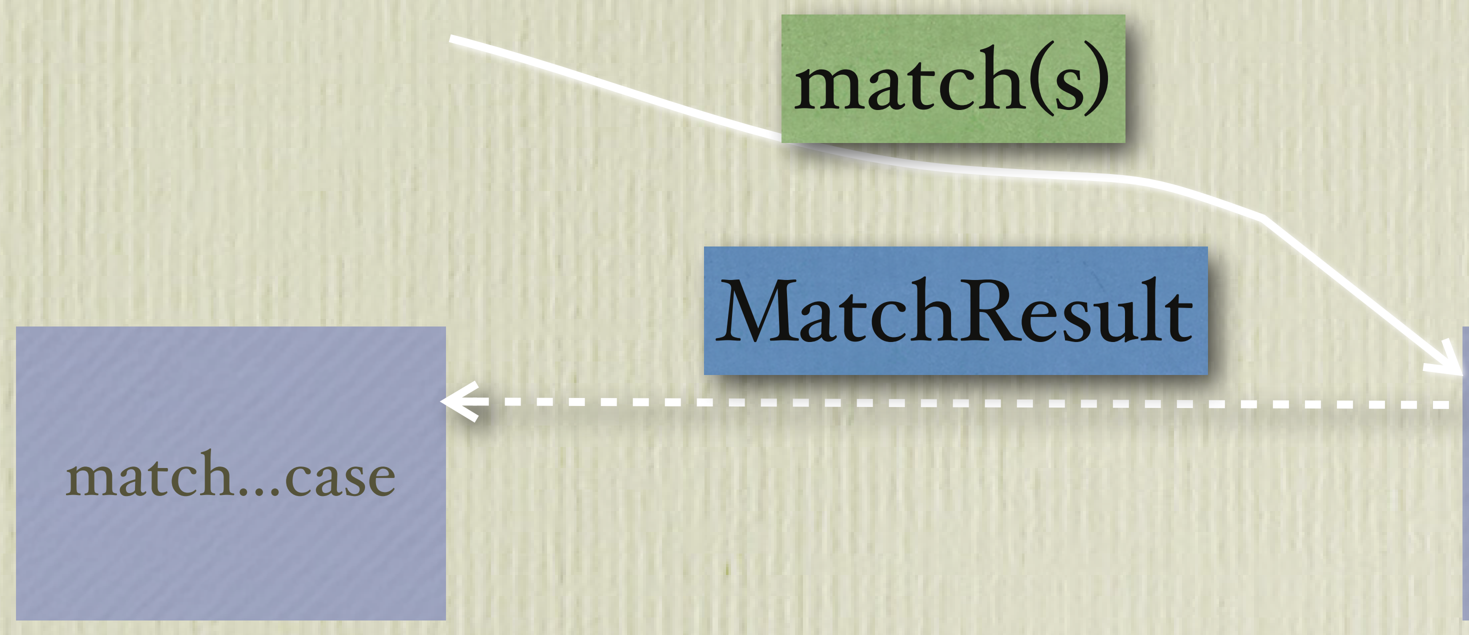
match (s)
case p_1
case p_2

Pattern-matching through method dispatch



match (s)
case p_1
case p_2

Pattern-matching through method dispatch

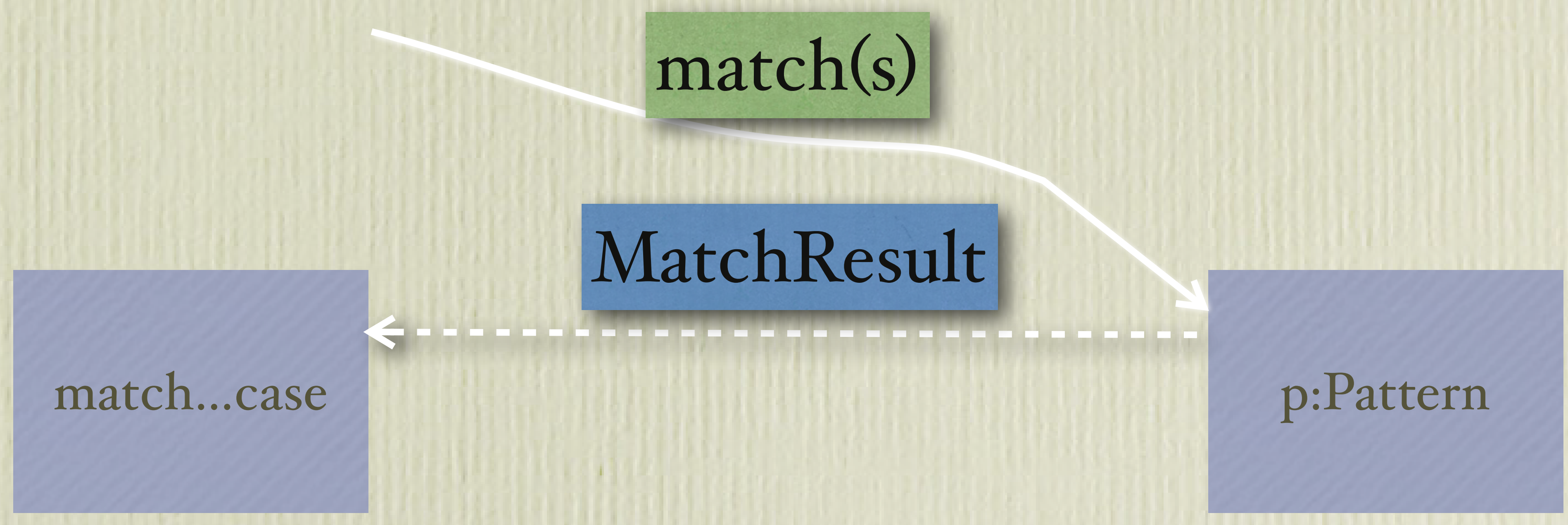


match does different things in different patterns:

- Type patterns ask s for its type
- Literal patterns check for =
- etc

match (s)
case p_1
case p_2

Pattern-matching through method dispatch



Teaching with Grace

Designed for Flexibility

- We are not trying to prescribe how to teach programming
- Grace tries to make it possible to teach in many styles, e.g.,

✓procedural first

✓objects first

✓turtle graphics

✓object-graphics

✓functional?

✓test-driven

Java vs. Grace

```
method toCelsius(f:Number) {
   if (f < -459.4) then {  Error.raise "{f}°F is below absolute zero"  }
   (f – 32) * (5 / 9)
}

print "212°F is {toCelsius(212)}°C"
```

Java vs. Grace

```
public class Celsius {

   public static double toCelsius(double f) {
      if (f < -459.4)  {
         throw new RuntimeException(
            f+"° Fahrenheit is below absolute zero");
      }
      return (f – 32.0) * (5.0 / 9.0);
   }

   public static void main(String[] args) {
        System.out.println("212°F is "+ toCelsius(212) + "°C");
   }
}
```

Java vs. Grace

```
public class Celsius {

    public static double toCelsius(double f) {
        if (f < -459.4)  {
            throw new RuntimeException(
              f+"° Fahrenheit is below absolute zero");
        }
        return (f – 32.0) * (5.0 / 9.0);
    }

    public static void main(String[] args) {
         System.out.println("212°F is "+ toCelsius(212) + "°C");
    }
}
```

Java vs. Grace

```
public class Celsius {

  public static double toCelsius(double f) {
    if (f < -459.4)  {
      throw new RuntimeException(
        f+"° Fahrenheit is below absolute zero");
    }
    return (f – 32.0) * (5.0 / 9.0);
  }

  public static void main(String[] args) {
     System.out.println("212°F is "+ toCelsius(212) + "°C");
  }
}
```

Java vs. Grace

```
public class Celsius {

  public static double toCelsius(double f) {
    if (f < -459.4)  {
      throw new RuntimeException(
        f+"° Fahrenheit is below absolute zero");
    }
    return (f – 32.0) * (5.0 / 9.0);
  }

  public static void main(String[] args) {
      System.out.println("212°F is "+ toCelsius(212) + "°C");
  }
}
```

Turtle graphics

```
dialect "logo"

def length = 150
def root2 = 2^0.5
def diagonal = length * root2
lineWidth := 2
square(length)
turnRight(45)
penUp
forward(diagonal)
turnLeft(90)
penDown
roof(diagonal/2)
```

```
method roof(slope) {
    lineColor := red
    forward(slope)
    turnLeft(90)
    forward(slope)
}

method square(len) {
    repeat 4 times {
        forward(len)
        turnRight(90)
    }
}
```

sample programs/house.grace

Turtle graphics

```
dialect "logo"

def length = 150
def root2 = 2^0.5
def diagonal = length * root2
lineWidth := 2
square(length)
turnRight(45)
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roof(diagonal/2)
```

```
method roof(slope) {
  lineColor := red
  forward(slope)
  turnLeft(90)
  forward(slope)
}

method square(len) {
  repeat 4 times {
    forward(len)
    turnRight(90)
  }
}
```

sample programs/house.grace

objectdraw Graphics

```
import "objectdraw" as od

object {
  inherit od.aGraphicApplication.size(400,400)
  var cloth             // item to be moved
  method onMousePress(mousePoint){
    cloth := od.aFilledRect.at(mousePoint)size(100,100)on(canvas)
    cloth.color := od.red
  }

  method onMouseDrag(mousePoint)→Done{
    cloth.moveTo(mousePoint)
  }
  startGraphics     // pop up window and start graphics
}
```

Functions and Unit tests

```
import "gUnit" as GU
method toCelsius(f:Number) {
   if (f < -459.4) then { Error.raise "{f}°F is below absolute zero" }
   (f - 32) * (5 / 9)
}

class forMethod(m) {
   inherit GU.aTestCase.forMethod(m)

   method testZero {
      assert(toCelsius(32)) shouldBe (0)
   }
   method testBoiling {
      assert(toCelsius(212)) shouldBe (100)
   }
```

```
    method testBoiling {
        assert(toCelsius(212)) shouldBe (100)
    }
    method testAlaska {
        assert(toCelsius(-40)) shouldBe (-40)
    }
    method testTooCold {
        assert{toCelsius(-500)} shouldRaise (Error)
    }
}

def tests = GU.aTestSuite.fromTestMethodsInClass(aTempTest)
tests.runAndPrintResults
```

gUnit/GUnit project/f2c.grace

Too Complicated!

- gUnit uses inheritance, methods, naming conventions, setup & teardown methods ...
- Instead, we have a TDD dialect, and a BDD dialect

Download linkedListTests.grace Help? Search Delete

```
dialect "minitest"
import "sys" as sys
import "random" as random
import "unicode" as unicode
import "linkedListWithMergesort" as list

def start = sys.elapsedTime

testSuiteNamed "list tests" with {
    test "list.empty size" by {
        assert (list.empty.size) shouldBe 0
    }

    test "list.empty do" by {
        list.empty.do { each -> failBecause "list.empty.do did!" }
        assert (true)
    }

    test "list.empty asDebugString" by {
        assert (list.empty.asDebugString) shouldBe "⏚"
    }

    test "list.empty asString" by {
        assert (list.empty.asString) shouldBe "[]"
    }
```

Run ▶

```
list tests: 31 run, 0 failed, 0 errors
palindrome tests: 8 run, 0 failed, 0 errors
time taken: 0.169s
```

Download io_tests.grace Help? Search Delete

```
dialect "minispec"
import "date" as date
import "io" as io

def shortFile = io.open("io-specify-hi.txt","w")
shortFile.write "hi"
shortFile.close


describe "io" with {
    specify "read returns file contents" by {
        def fs = io.open("io-specify-hi.txt","r")
        expect (fs.read) toBe "hi"
    }
    specify "size returns file size" by {
        def fs = io.open("io-specify-hi.txt","r")
        expect (fs.size) toBe 2
    }
    specify "getline on empty file returns an empty string" by {
        def fileName = "aNewFile{date.now}.txt"
        def fs = io.open(fileName, "rw")        // create new empty file
        expect (fs.getline) toBe "" orSay "getline on empty file did not
            return empty string"
    }
    specify "getline on long file reads lines" by {
```

Run ▶

My plans for Rmod

- Implement Grace inside Pharo
  - Compile Grace to Pharo objects
  - interoperate with Pharo objects
  - challenge: implementing objects with lexical scope

```
method counterPair {
   var counter:Number := 0
   def countUp = object {
      method inc { counter := counter + 1 }
      method value { counter }
   }
   def countDown = object {
      method dec { counter := counter – 1 }
      method value { counter }
   }
   object {
      method up { countUp }
      method down { countDown }
   }
}
```

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method counterPair {
  var counter:Number := 0
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}
```

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  object {
    method up { countUp }
    method down { countDown }
  }
}
```

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method counterPair {
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    method value { counter }
  }
  def countDown = object {
    method dec { counter := counter – 1 }
    method value { counter }
  }
  object {
    method up { countUp }
    method down { countDown }
  }
}
```

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method counterPair {
   var counter:Number := 0
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      method inc { counter := counter + 1 }
      method value { counter }
   }
   def countDown = object {
      method dec { counter := counter – 1 }
      method value { counter }
   }
   object {
      method up { countUp }
      method down { countDown }
   }
}
```

```
method counterPair {
  var counter:Number := 0
  def countUp = object {
    method inc { counter := counter + 1 }
    method value { counter }
  }
  def countDown = object {
    method dec { counter := counter – 1 }
    method value { counter }
  }
  object {
    method up { countUp }
    method down { countDown }
  }
}
```

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    object {
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    }
}
```

Tentative Plan

- Build module compiler using SmaCC
    - Roughly follow design of existing Grace→JS compiler
- Generate Smalltalk source for ease of debugging
    - design Smalltalk representations for nested objects
- Later:
    - better IDE for Grace using Pharo
    - Generate bytecode rather than source

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- Example: perhaps I should generate the Pharo IR?

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- So: if you have opinions, suggestion, better ideas

  don't keep quiet!

- Example: perhaps I should generate the Pharo IR?

http://gracelang.org

http://www.cs.pdx.edu/~grace/ide

Classes in Grace

- ... generate objects:

```
class aSquareWithSide (s: Number) -> Square {
    var side: Number := s

    method area -> Number {
        side * side
    }

    method stretchBy (n: Number) -> Done {
        side := side + n
    }

    print "Created square with side {s}"
}
```

No separate constructors.

Type annotations can be omitted or included

Classes in Grace

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class aSquareWithSide (s: Number) -> Square {
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    }

    print "Created square with side {s}"
}
```

Create object with aSquareWithSide(20)

No separate constructors.

Type annotations can be omitted or included

Classes in Java

```
public class SquareWithSide implements Square {
    private int side;

    public SquareWithSide(int s) {
        side = s;
        System.out.println( "Created square with side” + s);
    }

    public int area() {
        return side * side;
    }

    public void stretchBy (int n) {
        side = side + n;
    }
}
```

Classes in Java

```
public class SquareWithSide implements Square {
    private int side;

    public SquareWithSide(int s) {
        side = s;
        System.out.println( "Created square with side" + s);
    }

    public int area() {
        return side * side;
    }

    public void stretchBy (int n) {
        side = side + n;
    }
}
```

Create object with
new SquareWithSide(20)

Side by Side

```
class aSquareWithSide (s: Number) -> Square {
    var side: Number := s

    method area -> Number {
       side * side
    }

    method stretchBy (n: Number) -> Done {
        side := side + n
    }

    print "Created square with side {s}"
}
```

```
public class SquareWithSide implements Square {
    private int side;

    public SquareWithSide(int s) {
        side = s;
        System.out.println( "Created square
                              with side” + s);
    }

    public int area() {
       return side * side;
    }

    public void stretchBy (int n) {
        side = side + n;
    }
}
```