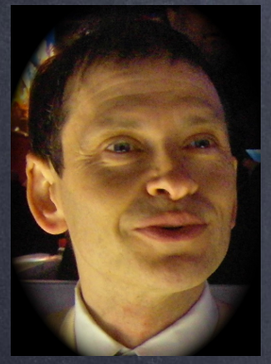
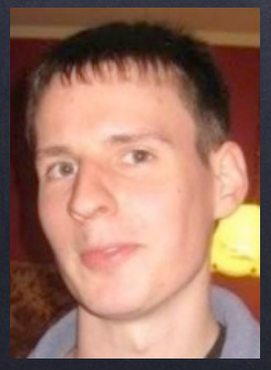
Attaining Grace in Teaching Programming

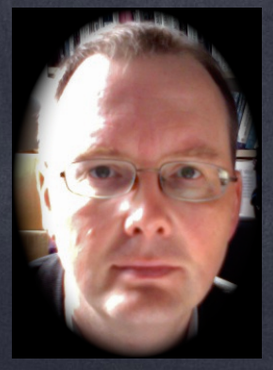


Andrew Black

Kim Bruce



Michael Homer



James Noble

gracelang.org

Time for a New Language for Novices

- Java nearly 20 years old, Python older
- State of the art has advanced
  - patches look like ... patches
- Too much overhead in popular languages
  - public static void main(String[] args)

Grace User Model

- First year students in OO CS1 or CS2
  - objects early or late,
  - static or dynamic types,
  - functionals first or scripting first or ...
- Second year students
- Faculty & TAs — assignments and libraries
- Researchers wanting an experimental vehicle
- Language Designers wanting a good example

Grace Goals

- Integrate proven new ideas in programming languages into a simple o-o language.
- Gracefully represent key concepts underlying o-o programming in a way that can be easily explained.
- Allow students to focus on the essential, rather than the accidental, difficulties of programming, problem solving and system modeling.

We are in the dog food business

User model:
Beginning
students

Customer:
experienced
instructors

The consumer is not the customer

Grace Fundamentals

- Everything is an object
- Simple dynamic method dispatch
- Single inheritance
- Types are interfaces (classes ≠ types)
  - Types come after objects
- Blocks are first-class closures

Advanced Features

- Pattern Matching
- Extensible via Libraries (control & data)
  - Modules as objects
- Dialects to
  - expand (vocabulary, not syntax)
  - provide initialization, and
  - restrict language (enforce constraints)

"Hello World" in Grace

"Hello World" in Grace

```
print "Hello World!"
```

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(“212F is "+(toCelsius(212))+
                  " Celsius");
   }
}
```

Java vs. Grace

```
method toCelsius(f:Number) -> 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

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```

Grace Example

```
// reads numbers from in stream returns the average
method average(in : InputStream) -> Number {
    var total := 0
    var count := 0
    while { ! in.atEnd } do {
        count := count + 1
        total := total + in.readNumber
    }
    if (count == 0) then { 0 }
                    else { total / count }
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Types optional

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```

Simple "method request"

- Like Smalltalk and Self:
  - no type-dependent 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 trying to learn not to say "message-send" or "method call".)

Uniform reference to attributes

```
theObject.x
    // could be method request or variable access

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

```
{ var x':Number := 3
{ method x -> Number { x' }                  // public
{ method x:= (newX:Number) { x' := newX }    // public
```

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 { i : Number -> print(i) }
// multi-part method name
```

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

```
welcomeAction.apply
```

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

Constructing Objects

Object constructors

```
object {
    def x : Number = 2
    def y : Number = 3
    method distanceTo(other : Point) -> Number {
        ((x - other.x)^2 + (y - other.y)^2).sqrt }
}
```

Object constructors

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}
```

x	2
y	3
distanceTo(_)	...

Classes

```
class x (x': Number) y (y': Number) -> Point {
    def x : Number = x'
    def y : Number = y'
    method distanceTo (other : Point) -> Number {
        ((x - other.x)^2 + (y - other.y)^2).sqrt }
}
```

Classes

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}
```

x(_)y(_)

Classes

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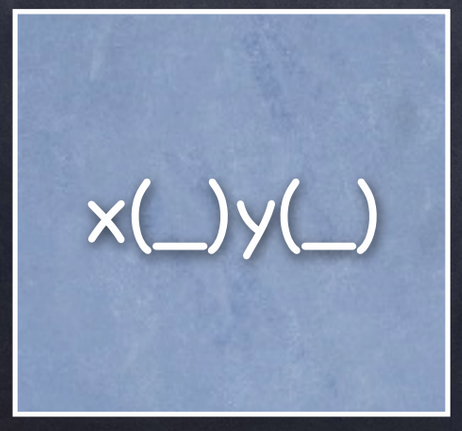

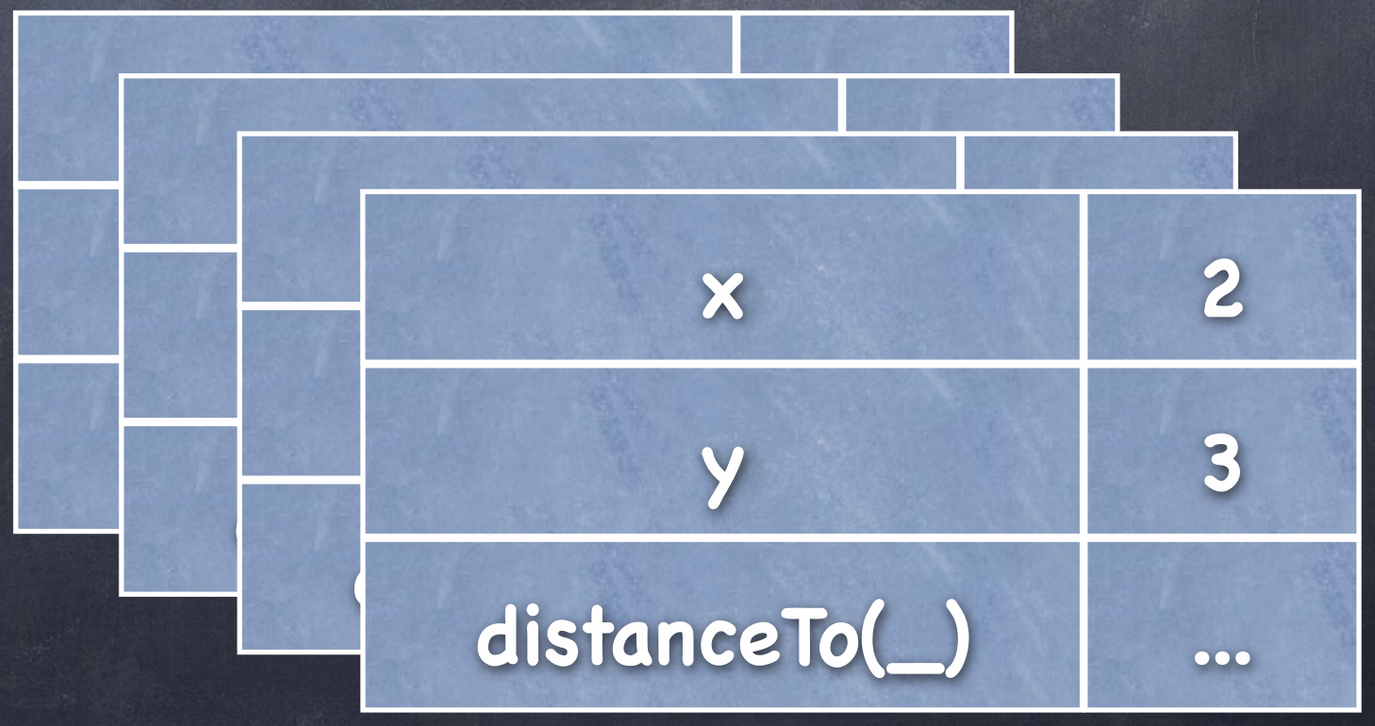

Classes are Factory Methods

```
method x (x': Number) y (y': Number) -> Point {
    object {
        def x : Number = x'
        def y : Number = y'
        method distanceTo(other:Point)->Number {
            ((x - other.x)^2 + (y - other.y)^2).sqrt }
    }
}
```

Inheritance

```
class x (x': Number) y (y': Number)
                        colour (c' : Colour) {
    inherits x (x') y (y')
    def c : Colour is public = c'
}
```

More on inheritance later!

Implicit initialization

- Object & class expressions can contain executable code

```
object {
    def x : Number = 2
    def y : Number = 3
    print "Just set x to {x}"
    method distanceTo(other : Point) -> Number {
       ((x - other.x)^2 + (y - other.y)^2).sqrt }
    print "I'm {self.distanceTo(origin)} from origin"
}
```

Classes

- Classes are an implementation concept
- Inheritance via object extension
- Classes are not types

Types

- Types are for classification
  - Types logically come after objects, not before
  - Structural, Gradual, Optional

```
type Point = {
        x -> Number
        y -> Number
        distanceTo (other:Point) -> Number
    }
```

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

Ask me about:

- (the missing) null pointer exceptions
- Pattern matching
- Blocks as partial functions
- Exceptions
- Modules as Objects
- Unit tests
- Dialects for:
  - resticting the language
  - extending the labguage
- Teaching Experience
- Graphics
- How you can help

No null pointer exceptions!

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- Accessing uninitialized variable is an error

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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) ≡ x : A ∨ x : B
- Algebraic constructors:
  - T1 & T2: intersection, conforms to T1 and T2
    - Used to extend types
    - E.g., type ColorPoint = Point & {c -> Color}
  - union and subtraction available, but rarely used
- Type parameters don't need variance annotations

Match - Case

```
match ( x )                          // x : 0 | String | Student

 // match against a constant
    case { 0 -> print("Zero") }

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

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

Blocks as partial functions

```
var blk := { n : Number -> n * 2 }
blk.apply 2
   // -> 4
blk.match 2
   // -> SuccessfulMatch(4)
blk.apply "text"
   // Runtime error: wanted Number, got String
blk.match "text"
   // -> FailedMatch("text")
```

match (s)
case p_1
case p_2

Pattern-matching through method dispatch

s:Scrutinee

p:Pattern

match (s)
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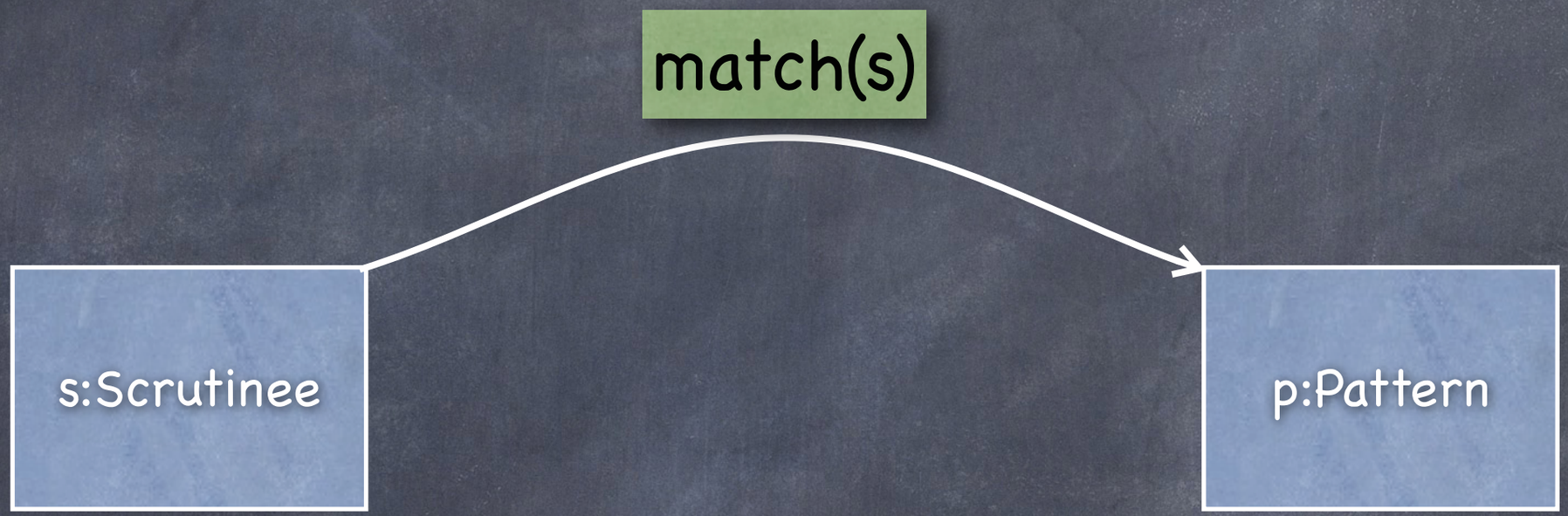
Pattern-matching through method dispatch



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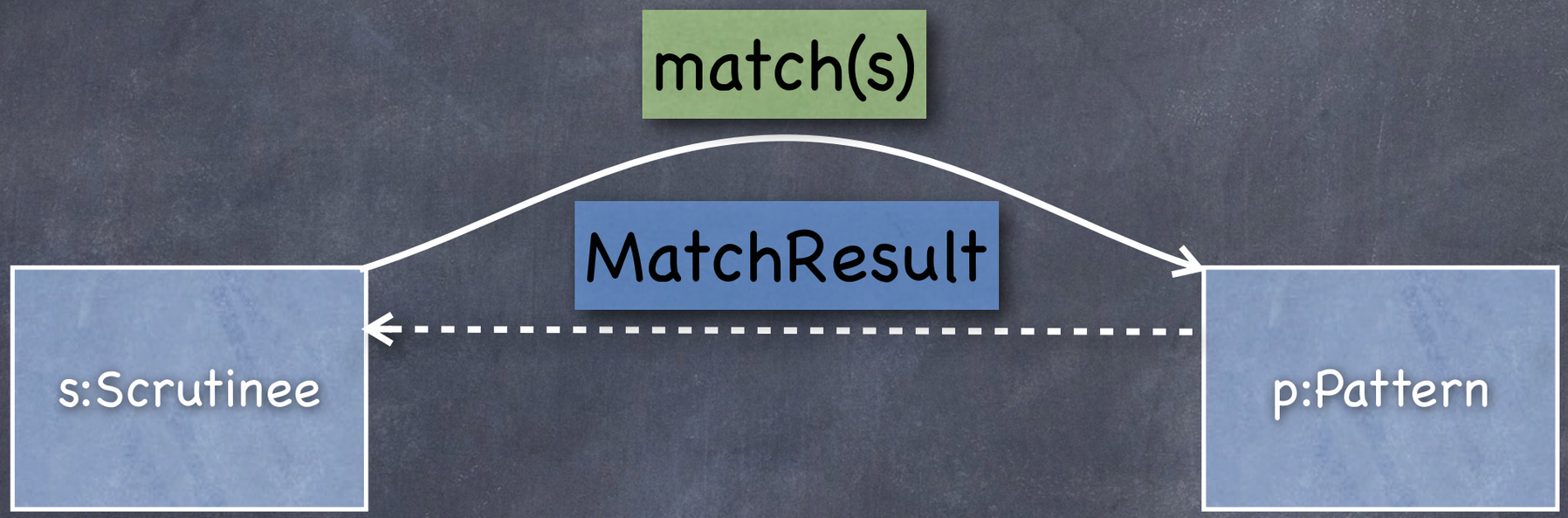

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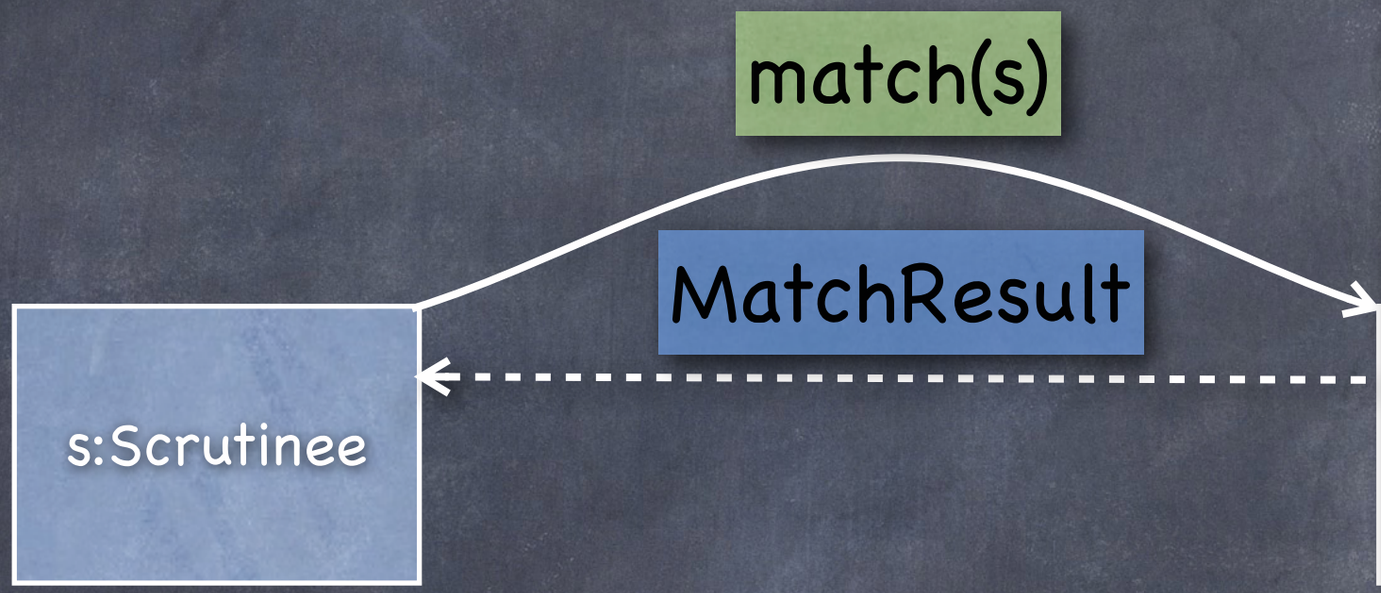
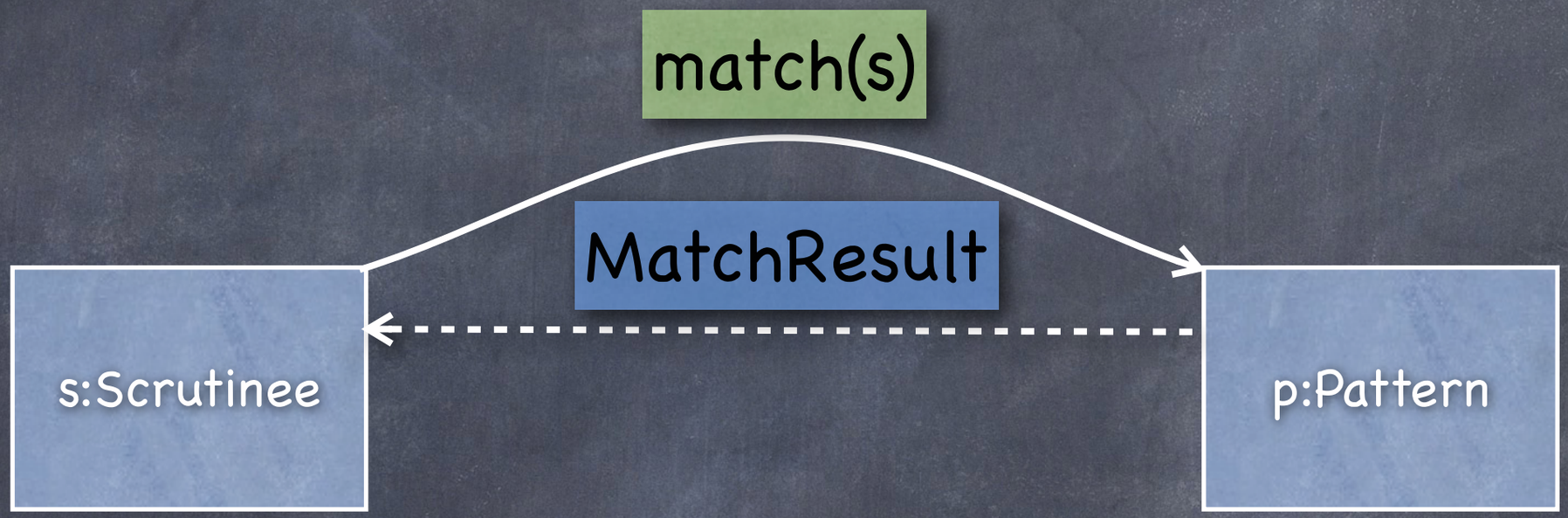


match does different things in different patterns:

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

```
match (s)
case p1
case p2
```

Pattern-matching through method dispatch



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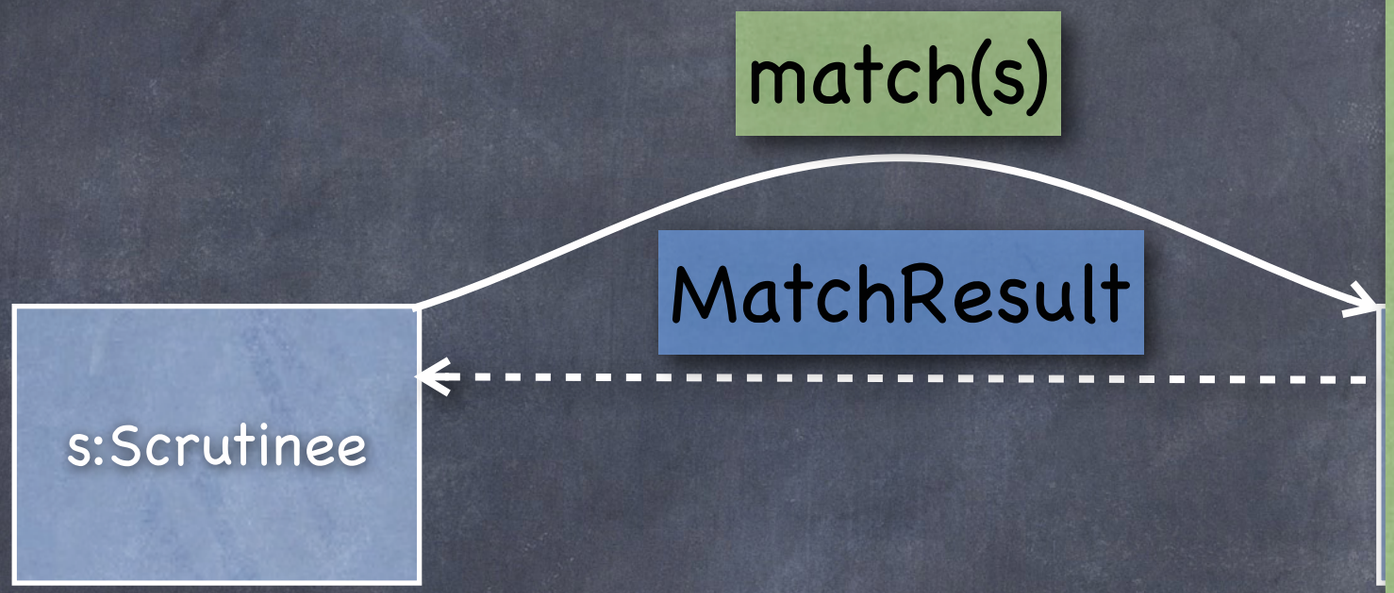
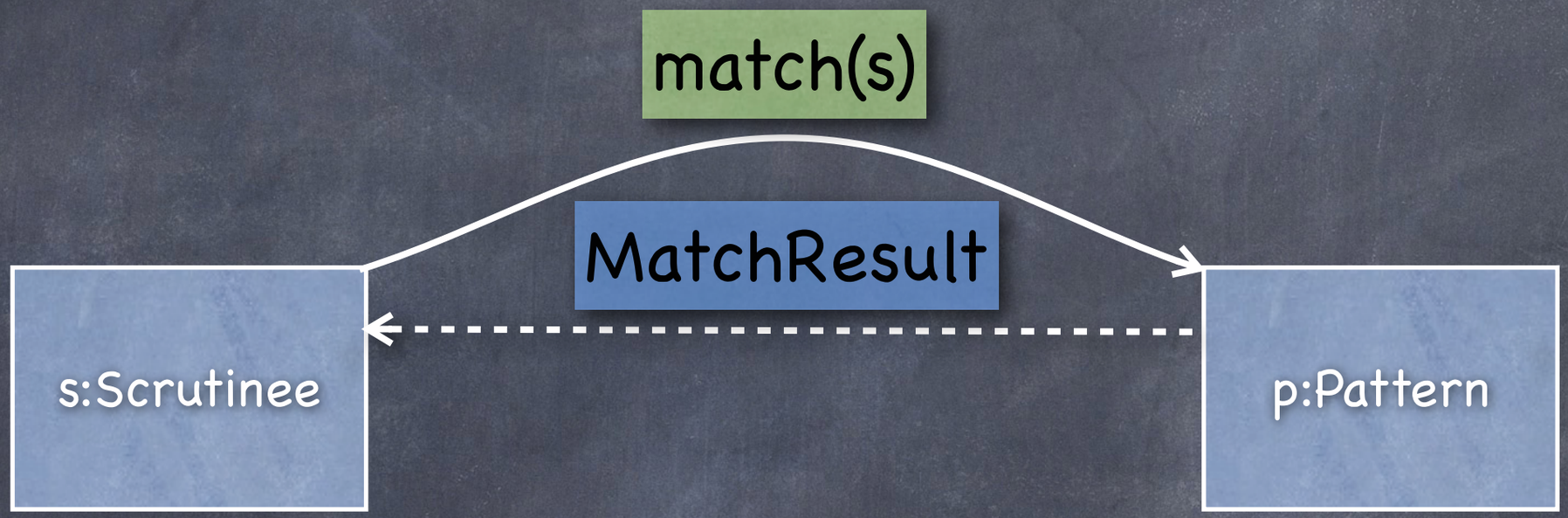


match does different things in different patterns:

- ...
- destructuring patterns can extract "fields" from scrutinee

Pattern-matching through method dispatch



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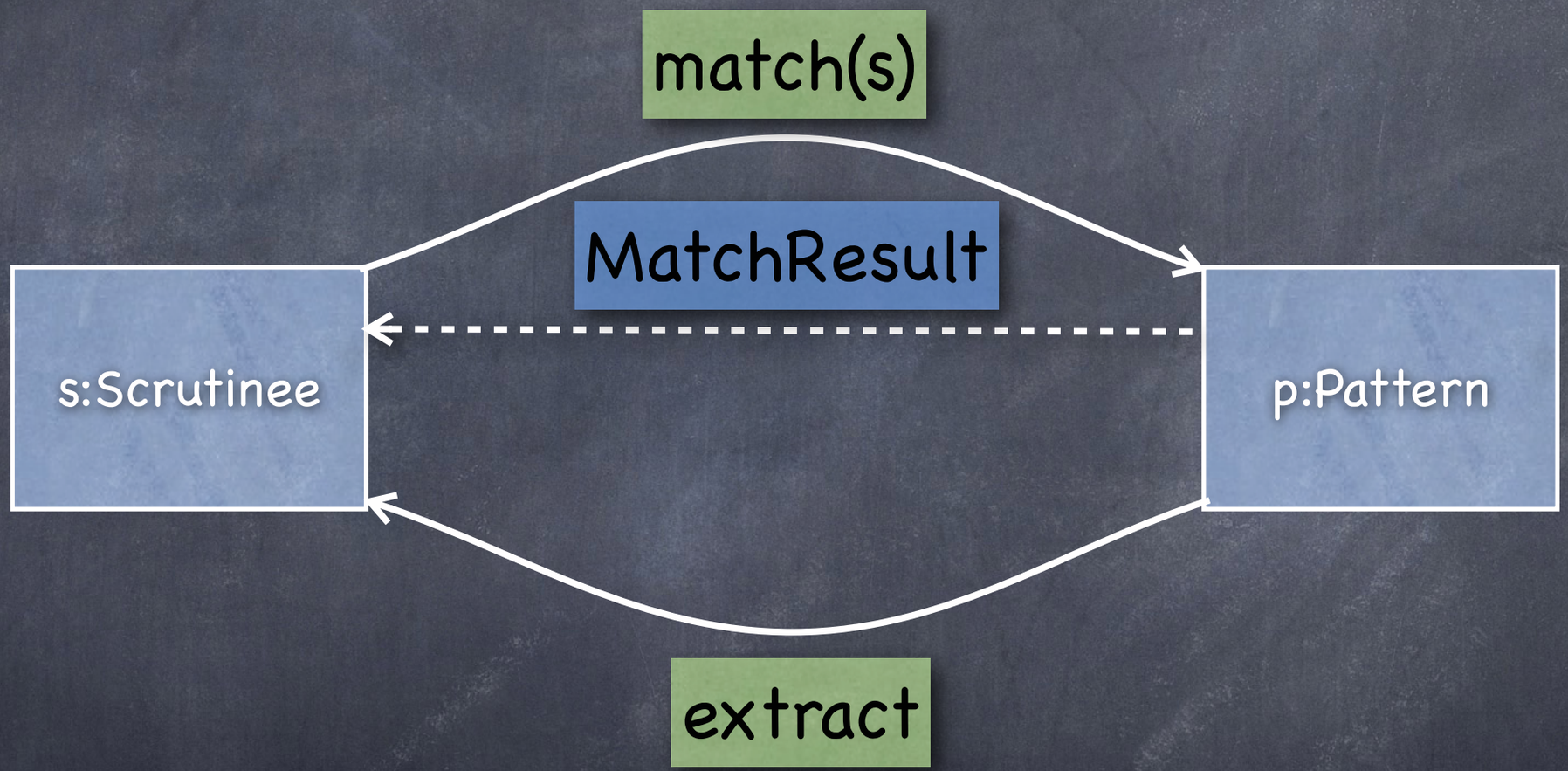

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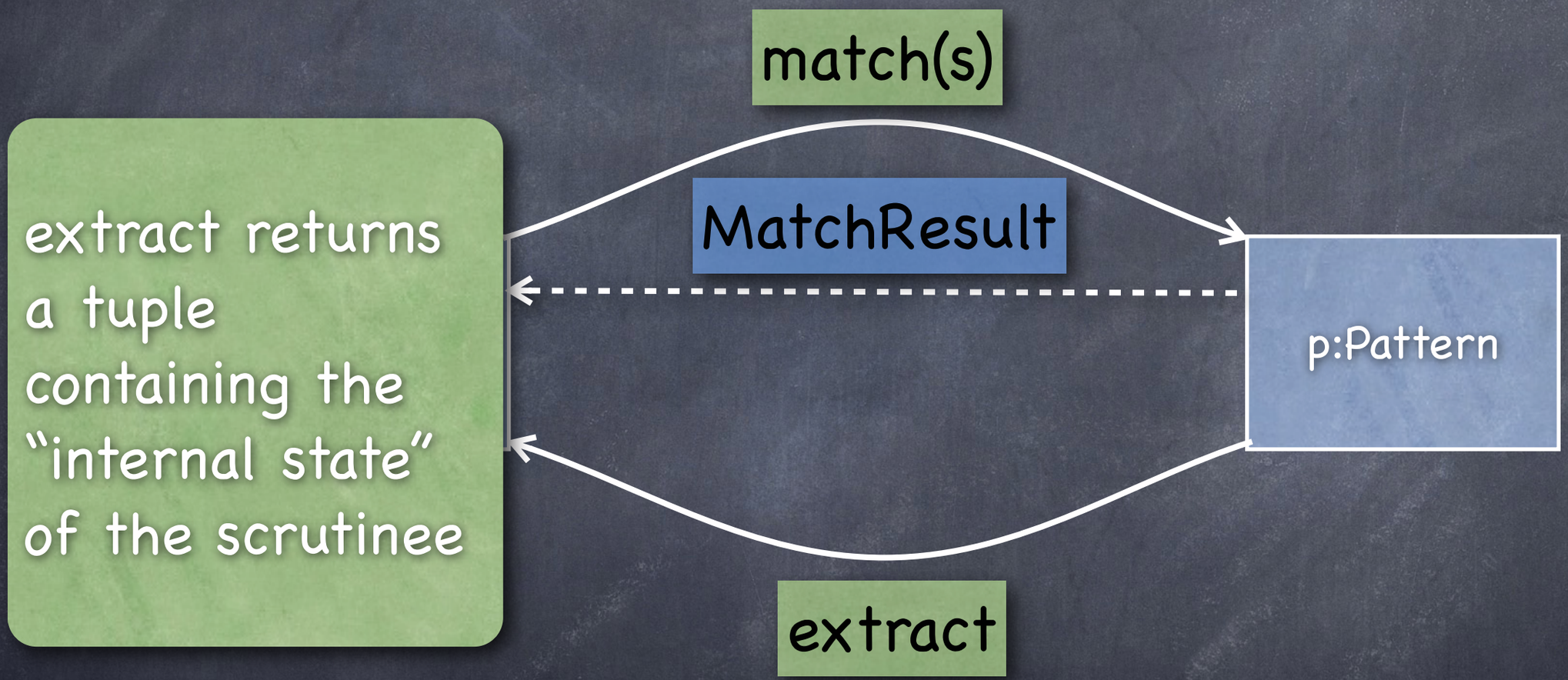

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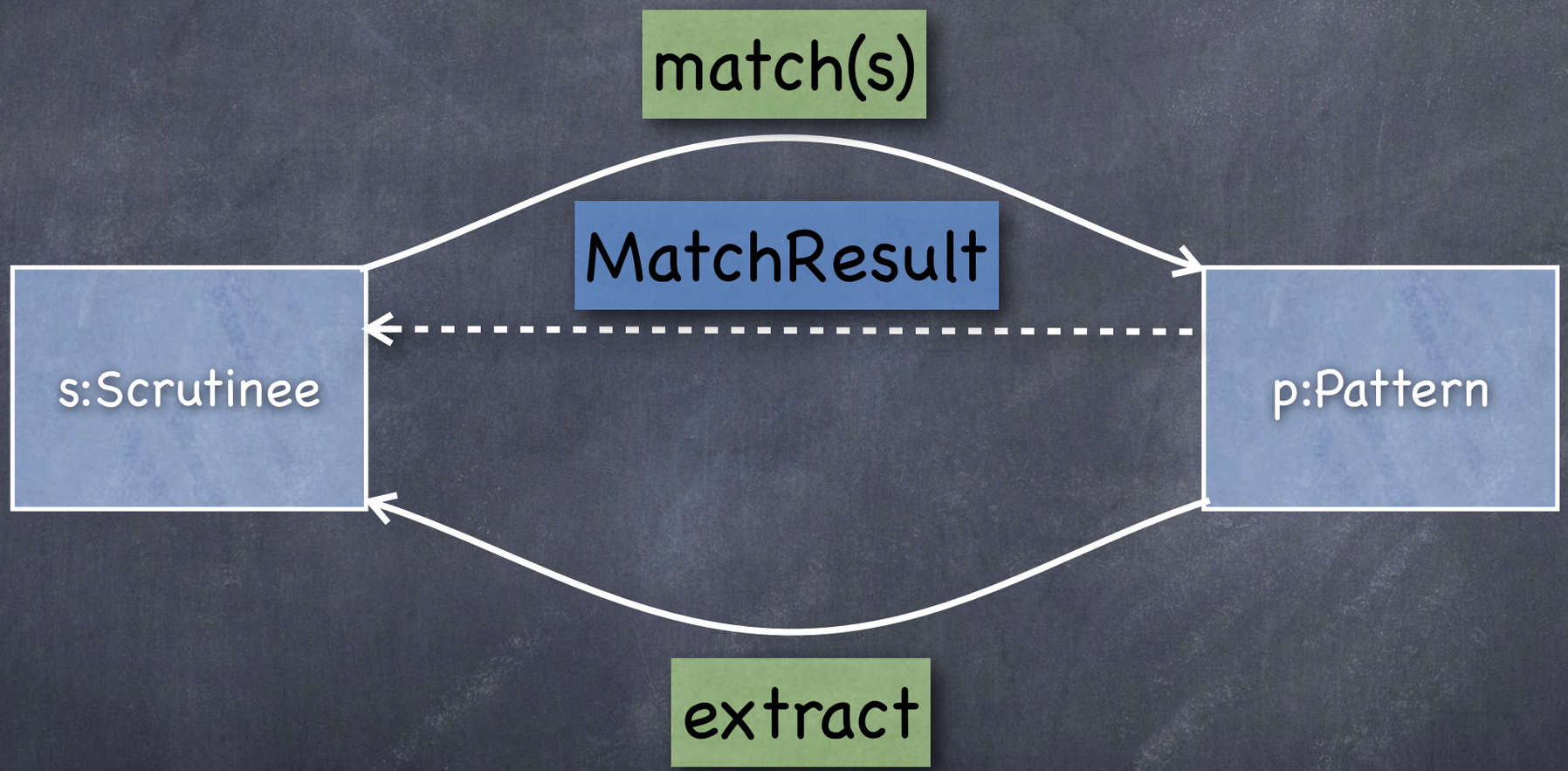

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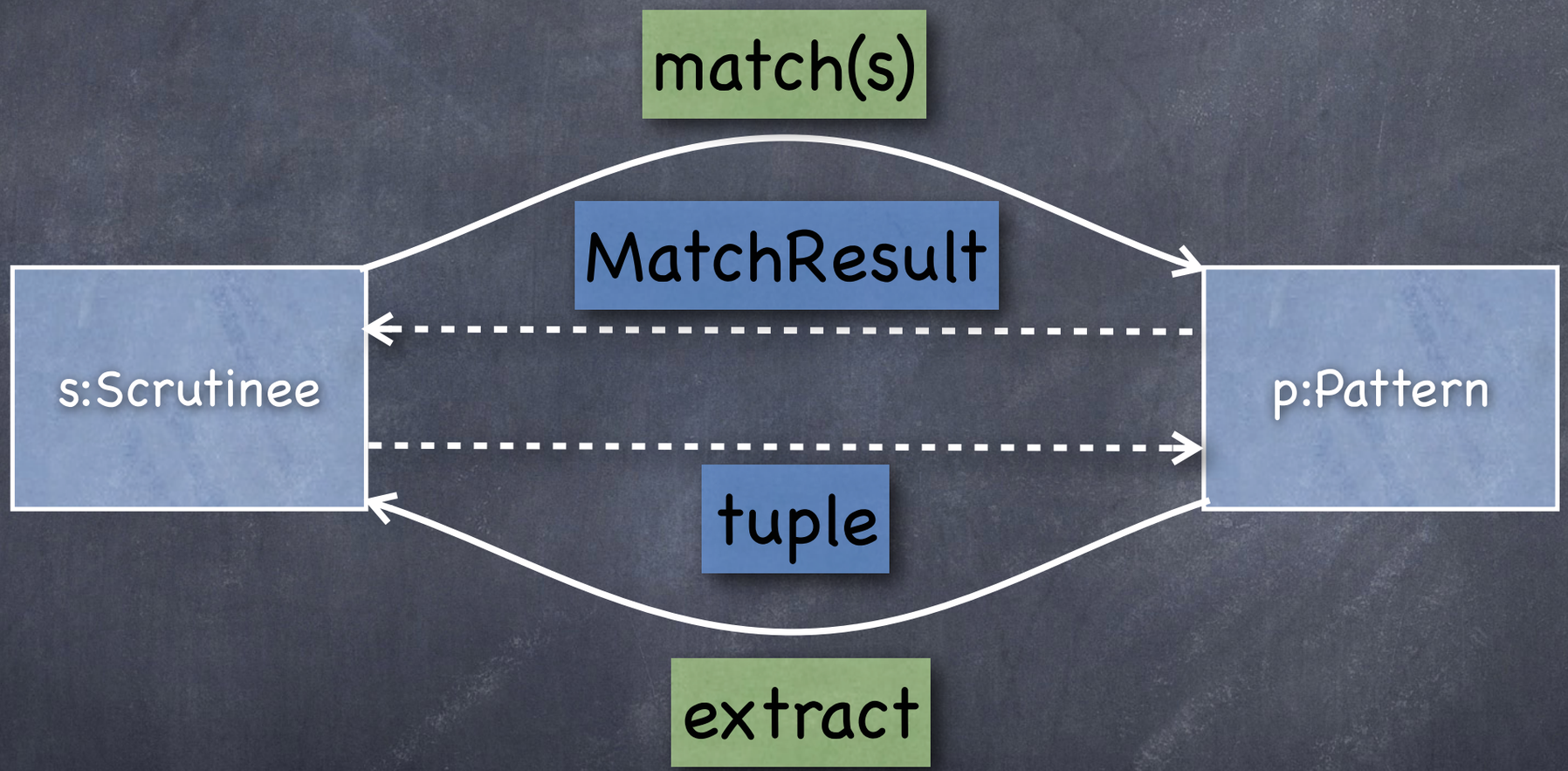

Exceptions

Exceptions as Patterns

```
def myError = Error.refine "MyError"

def negativeError =  myError.refine "NegativeError"
try {
    ...
        negativeError.raise "{value} < 0"
    ...
} catch {e: negativeError ->
            print "be more positive: {e}"
} catch {e: Error -> print "Unexpected Error: {e}"
}
```

a whole Grace Program

```
print "Hello World"
```

a whole Grace Program

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

a whole Grace Program

```
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```

every Grace file defines a module

Modules are Objects

in a file called collections.grace :

```
def aList is public = object { ... }
def anArray is public = object { ... }
def aSet is public = object { ... }
def aDictionary is public = object { ... }
```

Interpreting “Import”

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

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```
def temp917 = object {
    def aList is public = object { … }
    def anArray is public = object { … }
    def aSet is public = object { … }
    def aDictionary is public = object { … }
}
```

Modules are Objects

in a file called bingoGame.grace :

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

Modules are Objects

in a file called bingoGame.grace :

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

Dialects for Teaching

Dialects

- Allows methods without explicit receiver
  - e.g., loops with invariants
- Top-level code in dialect runs first
  - Initialize canvas, turtle initialization,...
- Run an included checker over AST
  - Can exclude code
  - e.g., require type annotations, invariants
  - Pluggable static typing as part of dialect

Dialects Simple to Use

```
dialect "simpleControl"

// your program here;

// Uses constructs of dialect
```

Dialects

```
In Module  "simpleControl":

    method if (c) then (t : Block) else (f : Block) {
        c.ifTrue ( t ) else ( f )
    }
    ...
method while (c : Block) do (a : Block) {
    if (c) then {
        a.apply
        while (c) do (a) }
}
```

Dialects provide outer scope

```
object {     // outermost enclosing object
   method if (c) then (t : Block) else (f : Block) {
       c.ifTrue ( t ) else ( f )
   }
       ...
   method while (c : Block) do (a : Block) {
       if (c) then { a.apply; while (c) do (a) }
   }

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

What Was Tricky?

Inheritance in Grace

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- Key concept in OO languages

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Inheritance in Grace

- Key concept in OO languages
- Grace treats objects as primitive,
  - Classes as syntactic sugar
- How to define inheritance from object?
- Abadi-Cardelli punted
  - though talked about delegation
  - defined inheritance for classes only

A Taste of Theory

- Semantics of OO languages
  - Classes are generators of fixed points (Cook, ...)
    - Contain "pre-methods" (parameterized on self)
  - Objects are the fixed points (give meaning to self!!)
    - Methods have self baked in.

A Taste of Theory

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    - Contain "pre-methods" (parameterized on self)
  - Objects are the fixed points (give meaning to self!!)
    - Methods have self baked in.
- Inheritance on classes
  - Copy (pre)methods from superclass
  - Add/replace (pre)methods from subclass
  - Super is collection of (pre)methods from superclass.

Initialization of Fields for New Objects

- Allocate space for all features
- Run initializers for superclasses
- Run initializers for subclass

Tricky Bits

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  - Request method with self as parameter
  - E.g., register graphics object on canvas

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- Initialization can request methods on self
- Object can be released into wild before initialization completed
  - Request method with self as parameter
  - E.g., register graphics object on canvas
- Issues:
  - What is meaning of self during initialization?
  - Initialize with original method, or with override?
    - C++ vs Java semantics

Inheriting from Objects

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  - Clone?
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  - What kind of clone?

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- Inheriting methods is same
  - Actually keep pre-methods, not methods
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- How to initialize inherited fields?
  - Clone?
  - Should everything support cloning?
  - What kind of clone?

Rejected delegation as too complex for novices

Our Solution

- Allow inheritance from new objects only
- To create object by inheritance
  - Create method suite as before
  - Allocate space for fields
  - Run initialization code for creating super-object
    - but on new object
  - Run initialization code for sub-object

Issues

- Works fine when inheriting from classes
- With objects, not so nice:
  - Write clone-like methods if want to inherit
  - What about immutable objects ?
    - Why write clone when no initialization??
- Is there a better solution?

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  - What about immutable objects ?
    - Why write clone when no initialization??
- Is there a better solution?
- Simplest solution for immutable objects:
  - Change superobject to a class

Modules and Types

```
import "x" as x                  // keep types
import "x" as x : Dynamic        // throw types away

import "xSpec" as xSpec          // separate spec and impl
import "xImpl" as x : xSpec.T

import "xSpec" as spec           // I conform to external spec
assertType<spec.T>(self)

type ExpectedType = { ... }      // import confirms to local
spec
import "x" as x : ExpectedType
```

Asynchrony & Parallelism

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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

Turtle graphics

```
dialect "logo"

def length = 150
def diagonal = length * 2.sqrt
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

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        turnRight(90)
    }
}
```

sample programs/house.grace

objectdraw Graphics

```
dialect objectdraw

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

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

Unit testing dialect

```
dialect "minitest"

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

testSuiteNamed "temperature conversion" with {

    test "zero" by {
        assert(toCelsius(32)) shouldBe (0)
    }
```

```
    test "Boiling" by {
        assert(toCelsius(212)) shouldBe (100)
    }
    test "Alaska" by {
        assert(toCelsius(-40)) shouldBe (-40)
    }
    test "TooCold" by {
        assert{toCelsius(-500)} shouldRaise (Error)
    }
}
```

GUnit/GUnit project/f2c minitest.grace

Exciting output:

Download f2c.grace Search Delete

```
1  dialect "minitest"
2
3  method toCelsius(f:Number) {
4      if (f < -459.4) then { Error.raise "{f}°F is below absolute zero" }
5      (f - 32) * (5 / 9)
6  }
7
8  testSuiteNamed "temperature conversion" with {
9
10     test "zero" by {
11         assert(toCelsius 32) shouldBe 0
12     }
13     test "Boiling" by {
14         assert(toCelsius 212) shouldBe 100
15     }
16     test "Alaska" by {
17         assert(toCelsius(-40)) shouldBe (-40)
18     }
19     test "TooCold" by {
20         assert{toCelsius(-500)} shouldRaise (Error)
21     }
22 }
23
```

Run ▶

```
temperature conversion: 4 run, 0 failed, 0 errors
```

Schedule

- 2011: 0.1, 0.2 and 0.5 language releases, hopefully prototype implementations
  - 3 implementations in progress
- 2012 0.8 language spec, mostly complete implementations
- 2014 0.9 language spec, reference implementation, experimental classroom use
- 2014 1.0 language spec, robust implementations, textbooks, initial adopters for CS1/CS2
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- 2016? ready for general adoption?

Help!

- Supporters
- Programmers
- Implementers
- Library Writers
- IDE Developers
- Testers
- Spec critics
- Teachers
- Students
- Tech Writers
- Textbook Authors
- Blog editors
- Community Builders

No conclusions —
we aren't done yet

Questions

Comments

Suggestions

Brickbats

Workshop at ECOOP this summer

http://gracelang.org

http://web.cecs.pdx.edu/~grace/minigrace/exp/