



## CSE341: Programming Languages

### Lecture 21 Dynamic Dispatch Precisely, and Manually in Racket

Dan Grossman  
Spring 2016

## Dynamic dispatch

### Dynamic dispatch

- Also known as *late binding* or *virtual methods*
- Call `self.m2()` in method `m1` defined in class `c` can *resolve to* a method `m2` defined in a subclass of `c`
- Most unique characteristic of OOP

Need to define the semantics of *method lookup* as carefully as we defined *variable lookup* for our PLs

Spring 2016

CSE341: Programming Languages

2

## Review: variable lookup

Rules for “looking things up” is a key part of PL semantics

- ML: Look up *variables* in the appropriate environment
  - Lexical scope for closures
  - *Field names* (for records) are different: not variables
- Racket: Like ML plus `let`, `letrec`
- Ruby:
  - Local variables and blocks mostly like ML and Racket
  - But also have instance variables, class variables, methods (all more like record fields)
    - Look up in terms of `self`, which is special

Spring 2016

CSE341: Programming Languages

3

## Using self

- `self` maps to some “current” object
- Look up instance variable `@x` using object bound to `self`
- Look up class variables `@@x` using object bound to `self.class`
- Look up methods...

Spring 2016

CSE341: Programming Languages

4

## Ruby method lookup

The semantics for method calls also known as message sends

`e0.m(e1, ..., en)`

1. Evaluate `e0`, `e1`, ..., `en` to objects `obj0`, `obj1`, ..., `objn`
  - As usual, may involve looking up `self`, variables, fields, etc.
2. Let `c` be the class of `obj0` (every object has a class)
3. If `m` is defined in `c`, pick that method, else recur with the superclass of `c` unless `c` is already `Object`
  - If no `m` is found, call `method_missing` instead
    - Definition of `method_missing` in `Object` raises an error
4. Evaluate body of method picked:
  - With formal arguments bound to `obj1`, ..., `objn`
  - With `self` bound to `obj0` -- this implements dynamic dispatch!

Note: Step (3) complicated by *mixins*: will revise definition later

Spring 2016

CSE341: Programming Languages

5

## Punch-line again

`e0.m(e1, ..., en)`

To implement dynamic dispatch, evaluate the method body with `self` mapping to the *receiver* (result of `e0`)

- That way, any `self` calls in body of `m` use the receiver's class,
  - Not necessarily the class that defined `m`
- This much is the same in Ruby, Java, C#, Smalltalk, etc.

Spring 2016

CSE341: Programming Languages

6

## Comments on dynamic dispatch

- This is why `distFromOrigin2` worked in `PolarPoint`
- More complicated than the rules for closures
  - Have to treat `self` specially
  - May seem simpler only if you learned it first
  - Complicated does not necessarily mean inferior or superior

## Static overloading

In Java/C#/C++, method-lookup rules are similar, but more complicated because > 1 methods in a class can have same name

- Java/C/C++: Overriding only when number/types of arguments the same
- Ruby: same-method-name always overriding

Pick the “best one” using the *static* (!) types of the arguments

- Complicated rules for “best”
- Type-checking error if there is no “best”

Relies fundamentally on type-checking rules

- Ruby has none

## A simple example, part 1

In ML (and other languages), closures are closed

```
fun even x = if x=0 then true else odd (x-1)
and odd x = if x=0 then false else even (x-1)
```

So we can shadow `odd`, but any call to the closure bound to `odd` above will “do what we expect”

- Does not matter if we shadow `even` or not

```
(* does not change odd - too bad; this would
   improve it *)
fun even x = (x mod 2)=0
```

```
(* does not change odd - good thing; this would
   break it *)
fun even x = false
```

## A simple example, part 2

In Ruby (and other OOP languages), subclasses can change the behavior of methods they do not override

```
class A
  def even x
    if x==0 then true else odd (x-1) end
  end
  def odd x
    if x==0 then false else even (x-1) end
  end
end
class B < A # improves odd in B objects
  def even x ; x % 2 == 0 end
end
class C < A # breaks odd in C objects
  def even x ; false end
end
```

## The OOP trade-off

Any method that makes calls to overridable methods can have its behavior changed in subclasses even if it is not overridden

- Maybe on purpose, maybe by mistake
- Observable behavior includes calls-to-overridable methods
- So *harder* to reason about “the code you’re looking at”
  - Can avoid by disallowing overriding
    - “private” or “final” methods
- So *easier* for subclasses to affect behavior without copying code
  - Provided method in superclass is not modified later

## Manual dynamic dispatch

Now: Write Racket code with little more than pairs and functions that *acts like* objects with dynamic dispatch

Why do this?

- (Racket actually has classes and objects available)

- Demonstrates how one language’s *semantics* is an idiom in another language
- Understand dynamic dispatch better by coding it up
  - Roughly how an interpreter/compiler might

Analogy: Earlier optional material encoding higher-order functions using objects and explicit environments

## Our approach

Many ways to do it; our code does this:

- An "object" has a list of field pairs and a list of method pairs

```
(struct obj (fields methods))
```

- Field-list element example:

```
(mcons 'x 17)
```

- Method-list element example:

```
(cons 'get-x (lambda (self args) ...))
```

Notes:

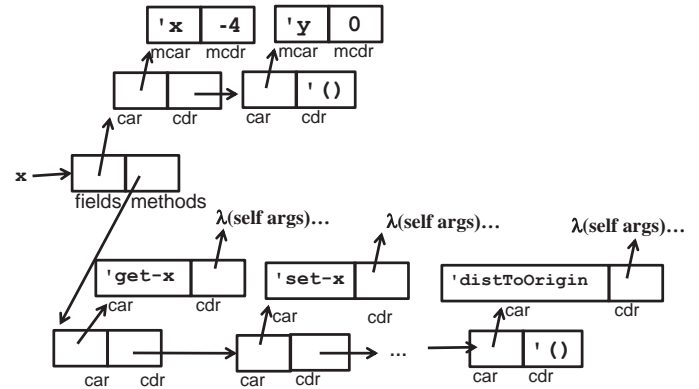
- Lists sufficient but not efficient
- Not class-based: object has a list of methods, not a class that has a list of methods [could do it that way instead]
- Key trick is lambdas taking an extra **self** argument
  - All "regular" arguments put in a list **args** for simplicity

Spring 2016

CSE341: Programming Languages

13

## A point object bound to **x**



Spring 2016

CSE341: Programming Languages

14

## Key helper functions

Now define plain Racket functions to get field, set field, call method

```
(define (assoc-m v xs)
  ...) ; assoc for list of mutable pairs

(define (get obj fld)
  (let ([pr (assoc-m fld (obj-fields obj))])
    (if pr (mcd r pr) (error ...))))

(define (set obj fld v)
  (let ([pr (assoc-m fld (obj-fields obj))])
    (if pr (set-mcdr! pr v) (error ...))))

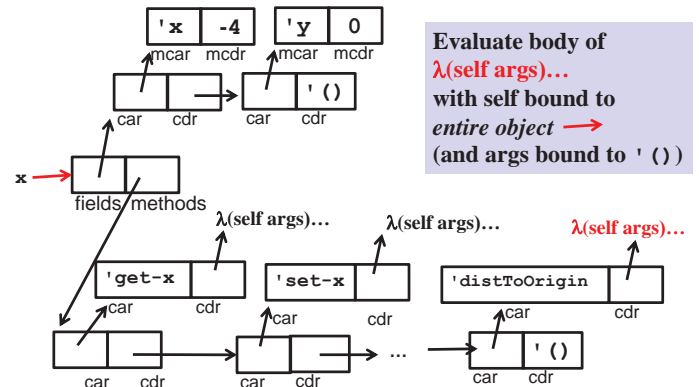
(define (send obj msg . args)
  (let ([pr (assoc msg (obj-methods obj))])
    (if pr ((cdr pr) obj args) (error ...))))
```

Spring 2016

CSE341: Programming Languages

15

## (send x 'distToOrigin)



Spring 2016

CSE341: Programming Languages

16

## Constructing points

- Plain-old Racket function can take initial field values and build a point object
  - Use functions **get**, **set**, and **send** on result and in "methods"
  - Call to self: (send self 'm ...)
  - Method arguments in **args** list

```
(define (make-point _x _y)
  (obj
    (list (mcons 'x _x)
          (mcons 'y _y))
    (list (cons 'get-x (λ(self args) (get self 'x)))
          (cons 'get-y (λ(self args) (get self 'y)))
          (cons 'set-x (λ(self args) (...)))
          (cons 'set-y (λ(self args) (...)))
          (cons 'distToOrigin (λ(self args) (...))))))
```

Spring 2016

CSE341: Programming Languages

17

## "Subclassing"

- Can use **make-point** to write **make-color-point** or **make-polar-point** functions (see code)
- Build a new object using fields and methods from "super" "constructor"
  - Add new or overriding methods to the *beginning* of the list
    - **send** will find the first matching method
  - Since **send** passes the entire receiver for **self**, dynamic dispatch works as desired

Spring 2016

CSE341: Programming Languages

18

## *Why not ML?*

- We were wise not to try this in ML!
- ML's type system does not have subtyping for declaring a point type that "is also a" point type
  - Workarounds possible (e.g., one type for all objects)
  - Still no good type for those `self` arguments to functions
    - Need quite sophisticated type systems to support dynamic dispatch if it is not *built into the language*
- In fairness, languages with subtyping but not generics make it analogously awkward to write generic code