PAUL G. ALLEN SCHOOL OF COMPUTER SCIENCE & ENGINEERING

CSE341: Programming Languages

Lecture 21
Dynamic Dispatch Precisely,
and Manually in Racket

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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

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

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…

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

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.

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)
```

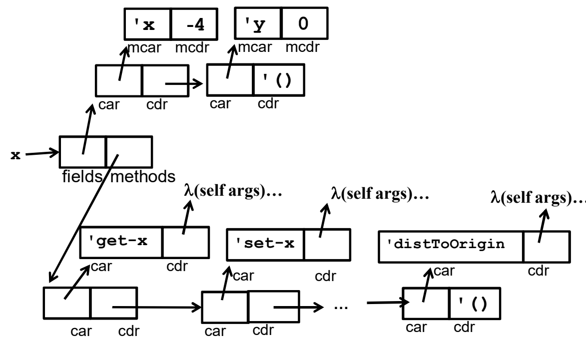
- Method-list element example:

```
(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

A point object bound to `x`

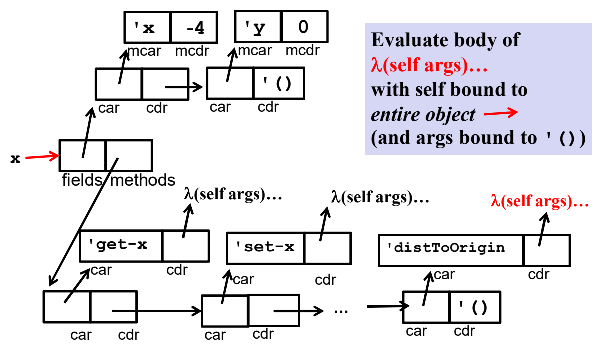


Key helper functions

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 (mcdr 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 …))))
```


`(send x 'distToOrigin)`



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)(…))))))
```


"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

Why not ML?

- We were wise not to try this in ML!
- ML's type system does not have subtyping for declaring a polar-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