CSE341: Programming Languages

Lecture 21
Dynamic Dispatch Precisely, and Manually in Racket

Dan Grossman
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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 \textit{method lookup} as carefully as we defined \textit{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
\[ e_0 \cdot m(e_1, \ldots, e_n) \]

1. Evaluate \( e_0, e_1, \ldots, e_n \) to objects \( \text{obj}_0, \text{obj}_1, \ldots, \text{obj}_n \)
   - As usual, may involve looking up \textit{self}, variables, fields, etc.
2. Let \( \text{C} \) be the class of \( \text{obj}_0 \) (every object has a class)
3. If \( m \) is defined in \( \text{C} \), pick that method, else recur with the superclass of \( \text{C} \) unless \( \text{C} \) is already \texttt{Object}
   - If no \( m \) is found, call \texttt{method_missing} instead
     - Definition of \texttt{method_missing} in \texttt{Object} raises an error
4. Evaluate body of method picked:
   - With formal arguments bound to \( \text{obj}_1, \ldots, \text{obj}_n \)
   - With \texttt{self} bound to \( \text{obj}_0 \) -- this implements dynamic dispatch!

Note: Step (3) complicated by \textit{mixins}: will revise definition later
Punch-line again

e0.m(e1,\ldots, en)

To implement dynamic dispatch, evaluate the method body with \texttt{self} mapping to the \textit{receiver} (result of \texttt{e0})

- That way, any \texttt{self} calls in body of \texttt{m} use the receiver's class,  
  - Not necessarily the class that defined \texttt{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 the 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

```ml
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

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

```ml
(* 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

```ruby
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

\[(\text{struct obj (fields methods)})\]

– Field-list element example:

\[(\text{mcons 'x 17})\]

– Method-list element example:

\[(\text{cons 'get-x (lambda (self args) ...))})\]

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 \textit{self} argument
  – All “regular” arguments put in a list \textit{args} for simplicity
A point object bound to \( \mathbf{x} \)

\[
\begin{array}{c|c}
\text{'x} & -4 \\
\text{mcar} & \text{mcdr}
\end{array} 
\quad \begin{array}{c|c}
\text{'y} & 0 \\
\text{mcar} & \text{mcdr}
\end{array}
\]

\[
\begin{array}{c|c}
\text{car} & \text{cdr}
\end{array} 
\quad \begin{array}{c|c}
\text{car} & \text{cdr}
\end{array}
\]

\(\text{x}\) →

\[
\begin{array}{c|c}
\text{fields} & \text{methods}
\end{array}
\]

\(\lambda(\text{self args})\)...

\[
\begin{array}{c|c}
\text{'get-x} & \\
\text{car} & \text{cdr}
\end{array}
\]

\(\lambda(\text{self args})\)...

\[
\begin{array}{c|c}
\text{'set-x} & \\
\text{car} & \text{cdr}
\end{array}
\]

\(\lambda(\text{self args})\)...

\[
\begin{array}{c|c}
\text{'distToOrigin} & \\
\text{car} & \text{cdr}
\end{array}
\]

\[
\begin{array}{c|c}
\text{car} & \text{cdr}
\end{array} 
\quad \begin{array}{c|c}
\text{car} & \text{cdr}
\end{array}
\]

\(\lambda(\text{self args})\)...

\[
\begin{array}{c|c}
\text{car} & \text{cdr}
\end{array}
\]
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)

Evaluate body of \( \lambda(\text{self args}) \ldots \) with self bound to entire object (and args bound to ' () )
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

```racket
(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