Context-oriented Programming

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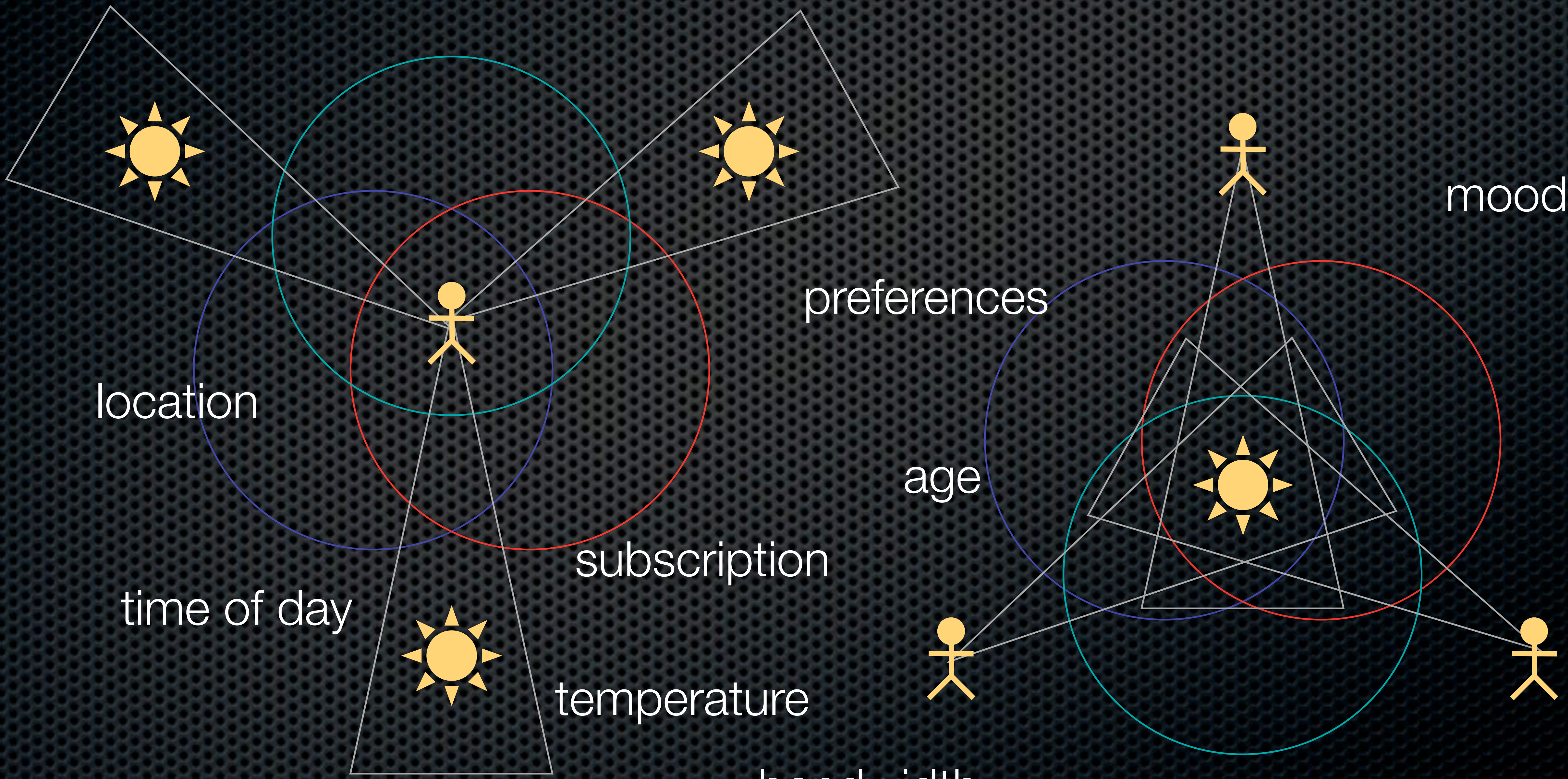
Context?

everything computationally accessible



Introduction to OOP.

```
class Rectangle {
  int x, y, width, height;
  void draw() { ... }
}

class Person {
  String name, address, city, zip;
  void display() { ... }
}
```

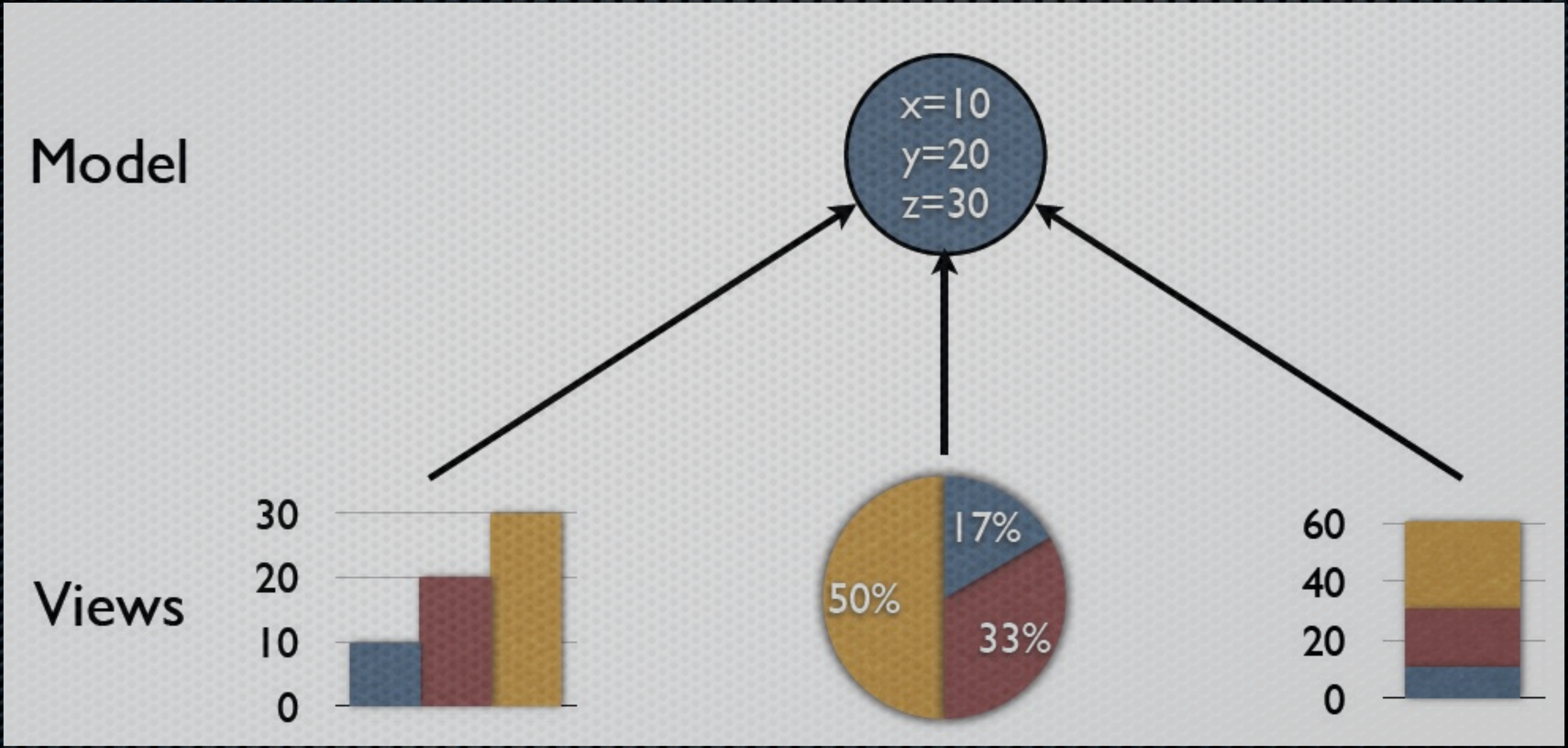
Context-independent behavior.

```
class Person {

    String name;

    void display () {
      println(name);
    }

}
```

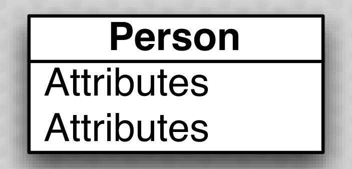
Context-dependent behavior.

```
class Person {

    String name, address, zip, city;

    void display (... printAddress, printCity ...) {
      println(name);
      if (printAddress) { println(address); }
      if (printCity) { println(zip); println(city); }
    }

}
```

Model-View-Controller.



Increased Complexity.



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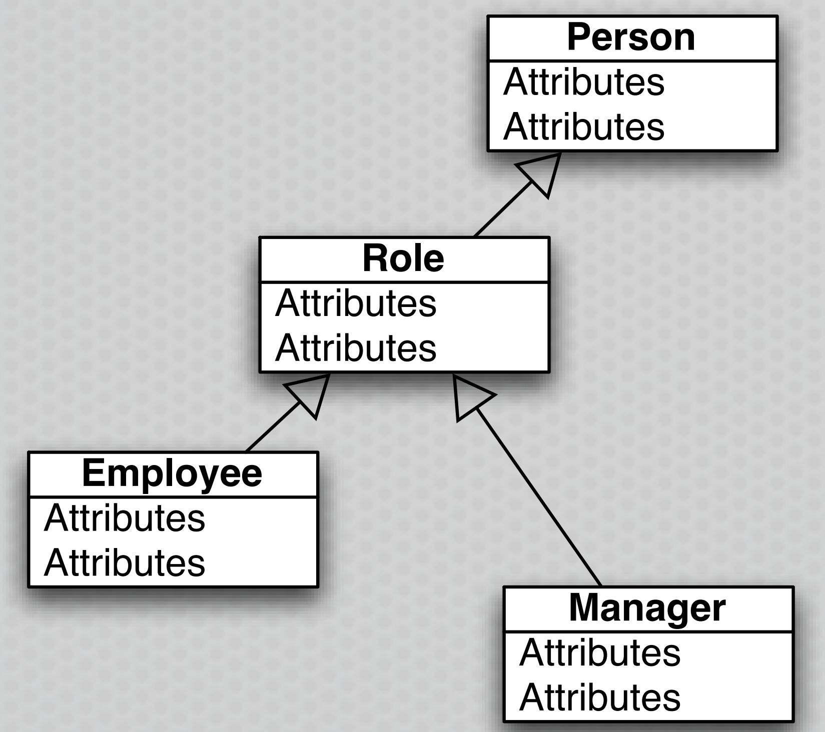
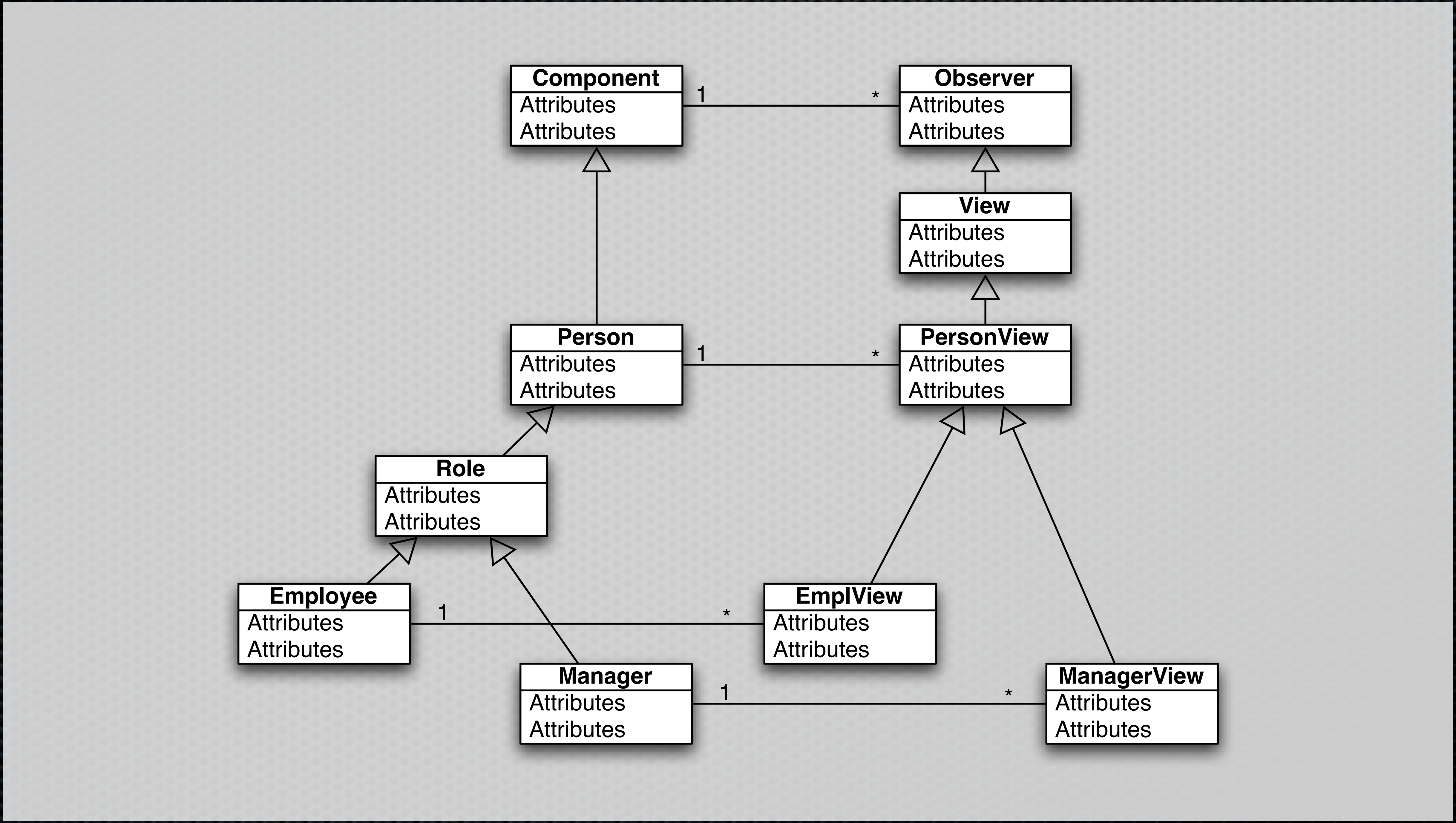


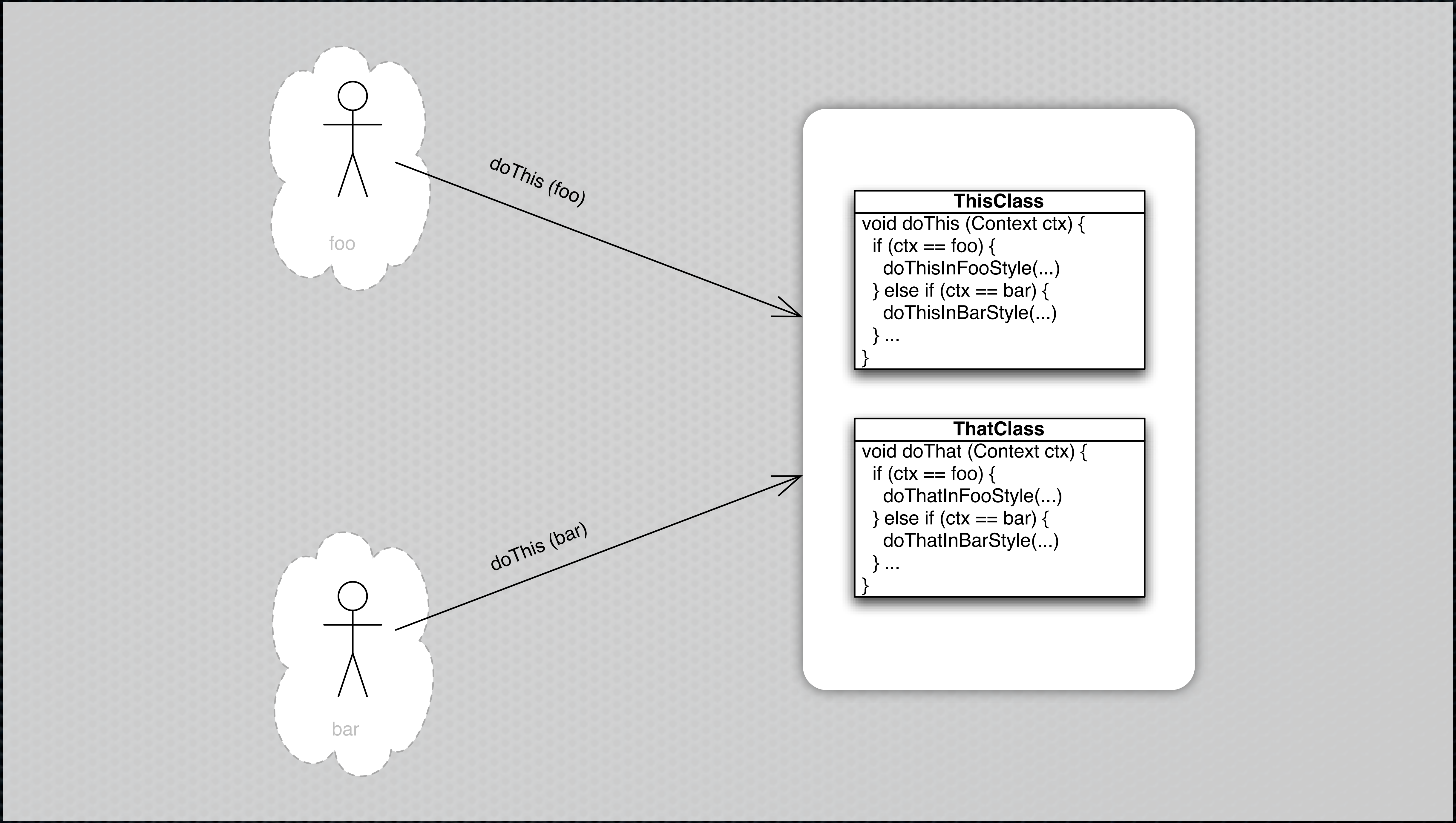
Increased Complexity.



Manual Context Orientation.

- Context-dependent behavior
  spread over several classes!
- Secondary classes required just for plumbing!
- Basic notion of OOP broken:
  Objects don’t know how to behave!

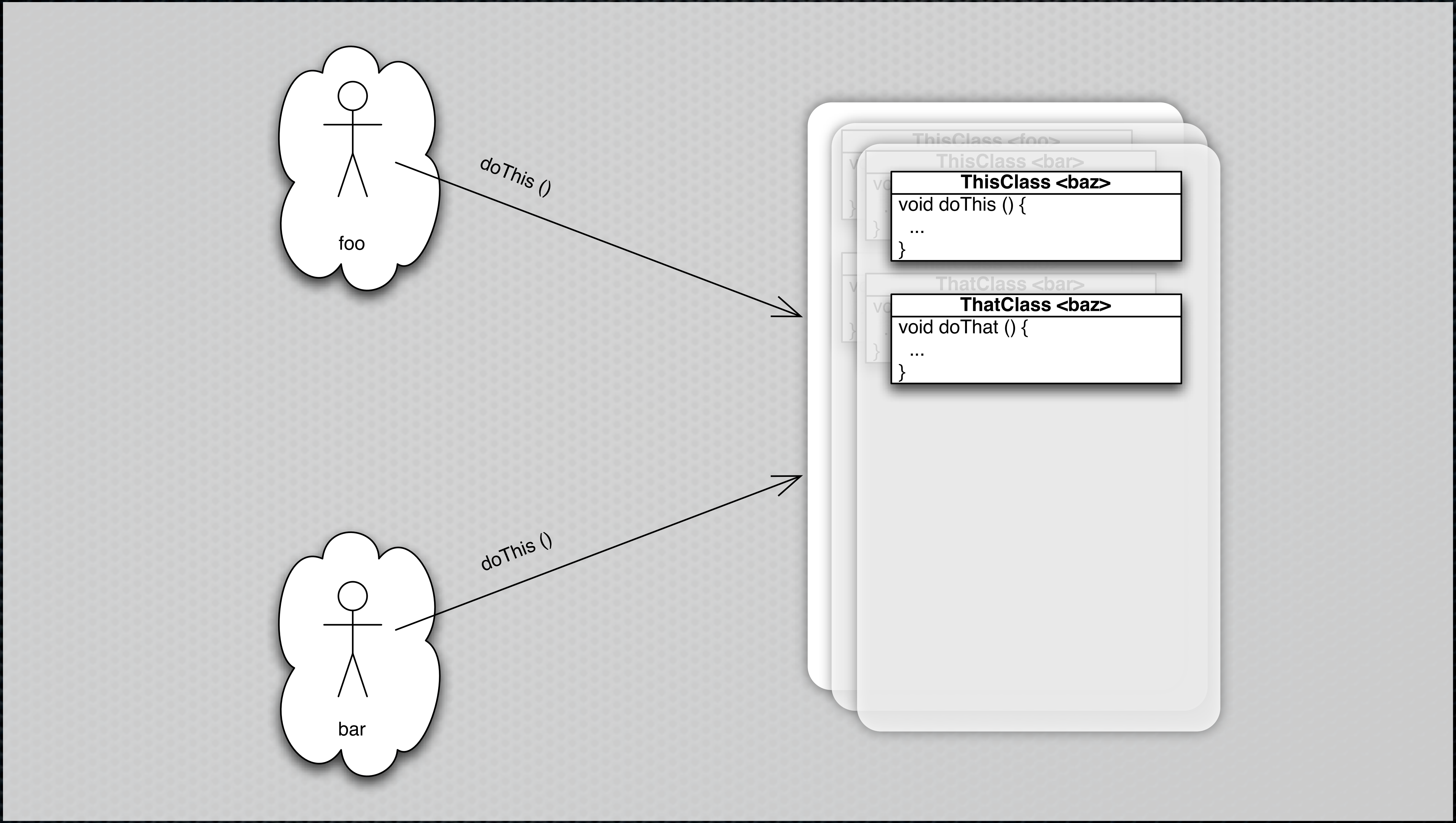
Context-oriented Programming.



```
void doThis (Context ctx) {
  if (ctx == foo) {
    doThisInFooStyle(...)
  } else if (ctx == bar) {
    doThisInBarStyle(...)
  } ...
}
```

```
void doThat (Context ctx) {
  if (ctx == foo) {
    doThatInFooStyle(...)
  } else if (ctx == bar) {
    doThatInBarStyle(...)
  } ...
}
```

Context-oriented Programming.



Context-oriented Programming.

- Several language extensions...
  (ContextL, ContextS, ContextR, ContextPy, ContextJ, ...)
- Here: ContextL, based on the
  Common Lisp Object System (CLOS).

root layer

```
(define-layered-class person
  ((name :initarg :name
         :layered-accessor person-name)))

(define-layered-function display (object))

(define-layered-method display ((object person))
  (print (person-name object)))
```

root layer

```
(define-layered-class person
  ((name :initarg :name
         :layered-accessor person-name))

(define-layered-function display (object))

(define-layered-method display ((object person))
  (print (person-name object)))
```

employment layer

```
(deflayer employment)

(define-layered-class employer :in-layer employment ()
  ((name :initarg :name
              :layered-accessor employer-name)))

(define-layered-class person :in-layer employment ()
  ((employer :initarg :employer
                    :layered-accessor person-employer)))

(define-layered-method display
  :in-layer employment :after ((object person))
  (display (person-employer object)))
```

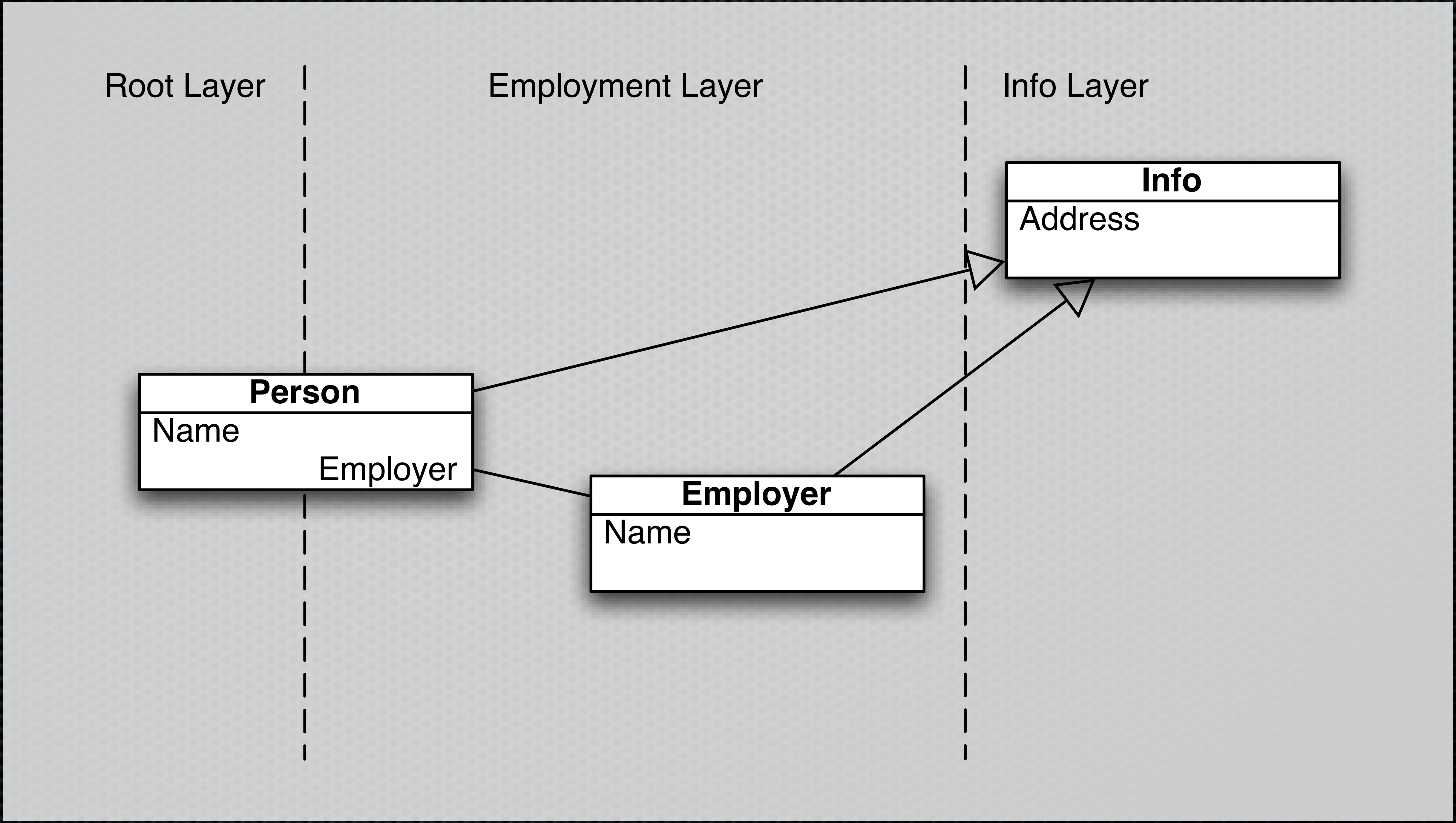
root layer

employment layer

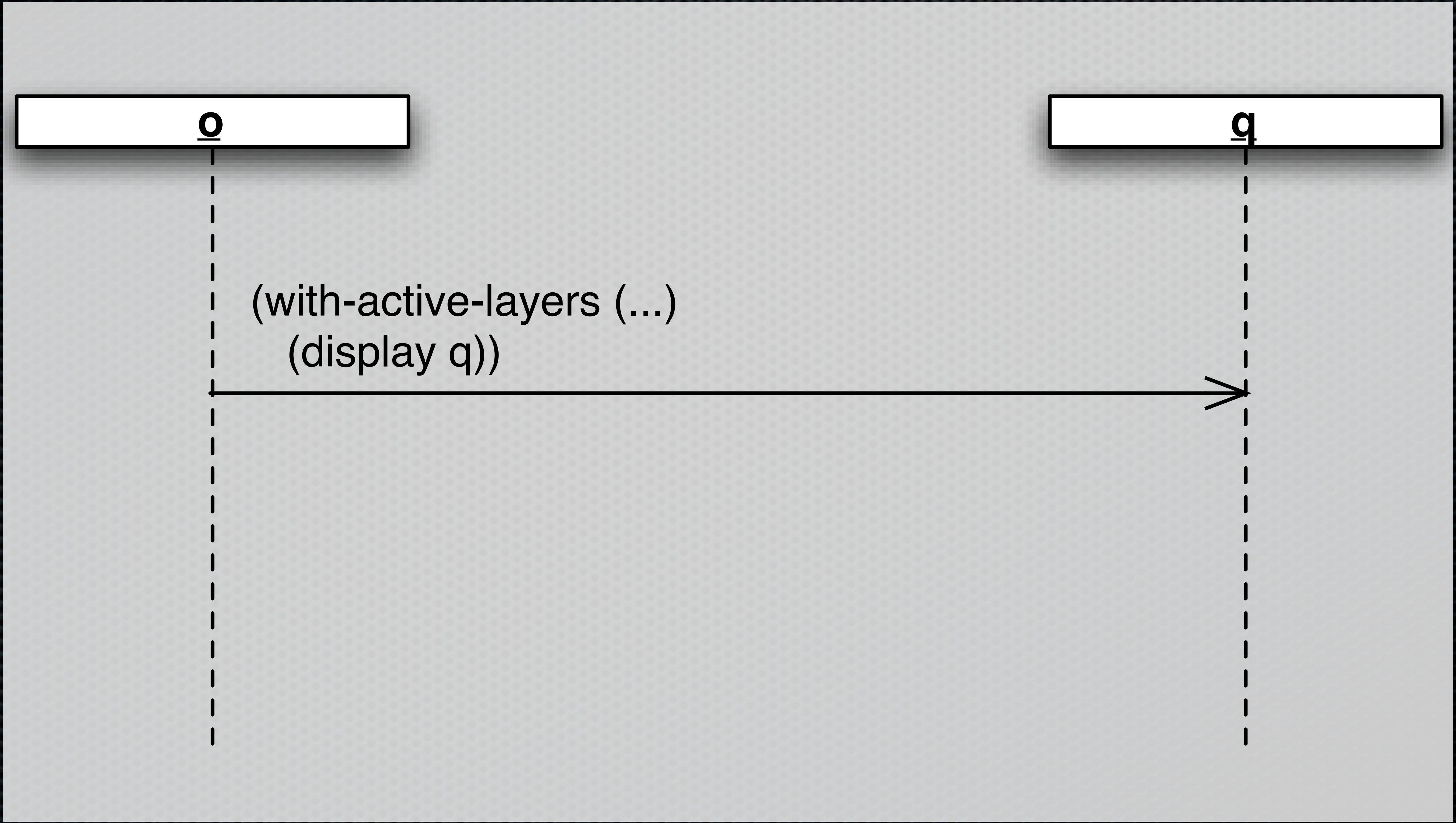
info layer

```
(deflayer info)

(define-layered-class info-mixin :in-layer info ()
   ((address :initarg :address
                  :layered-accessor address)))

(define-layered-method display
   :in-layer info :after ((object info-mixin))
   (print (address object)))

(define-layered-class person :in-layer info (info-mixin)
   ())
(define-layered-class employer :in-layer info (info-mixin)
   ())
```

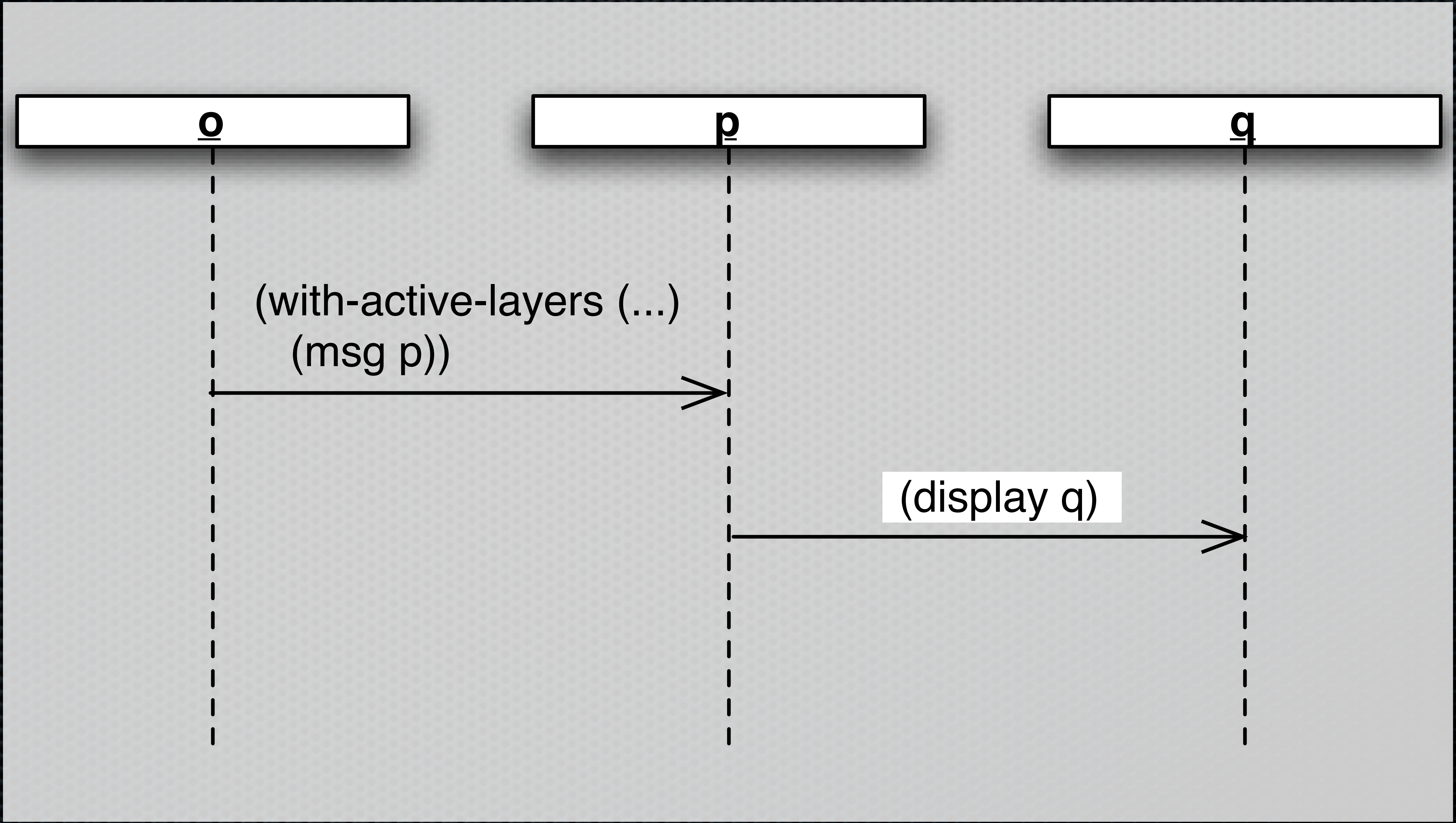
Example Classes.



Layer Activation.



Layer Activation.



Demo.

Essential Concepts.

- Behavioral Variations: new or modified behavior.
- Layers: group related behavioral variations.
- Activation: dynamic activation/deactivation of layers.
- Context: any computationally accessible information.
- Scoping: explicit control of effect of layer activation.

Success Stories.

- Project for Hungarian government
  + Gathering data from communes for budget planning
  + Requires context-dependencies in the web GUI
  + Started in July ‘07, in active use since November ‘07
  + Apache + Steel Bank Common Lisp + PostgreSQL
  + 4000 registered users
  + Average 300 online, more than 500 at peak times

Success Stories.

- Lisp on Lines
  + Web application framework (similar to Ruby on Rails)
  + Used for commercial website
- Ordina Belgium
  + Competence Center for
    Advanced Planning & Scheduling
  + Context-aware Security Guard Assistant

The Figure Editor Example.

- Hierarchy of simple and composite graphical objects.
- Changing positions of graphical objects
  triggers updates on the screen.
- Used to motivate aspect-oriented programming.
  (“jumping aspects”)

root layer

```
(define-layered-class point (figure-element)
  ((x :initarg :x :layered-accessor point-x)
   (y :initarg :y :layered-accessor point-y)))

(define-layered-method move ((elm point) dx dy)
  (incf (point-x elm) dx)
  (incf (point-y elm) dy))

(define-layered-class line (figure-element)
  ((p1 :initarg :p1 :layered-accessor line-p1)
   (p2 :initarg :p2 :layered-accessor line-p2)))

(define-layered-method move ((elm line) dx dy)
  (move (line-p1 elm) dx dy)
  (move (line-p2 elm) dx dy))
```

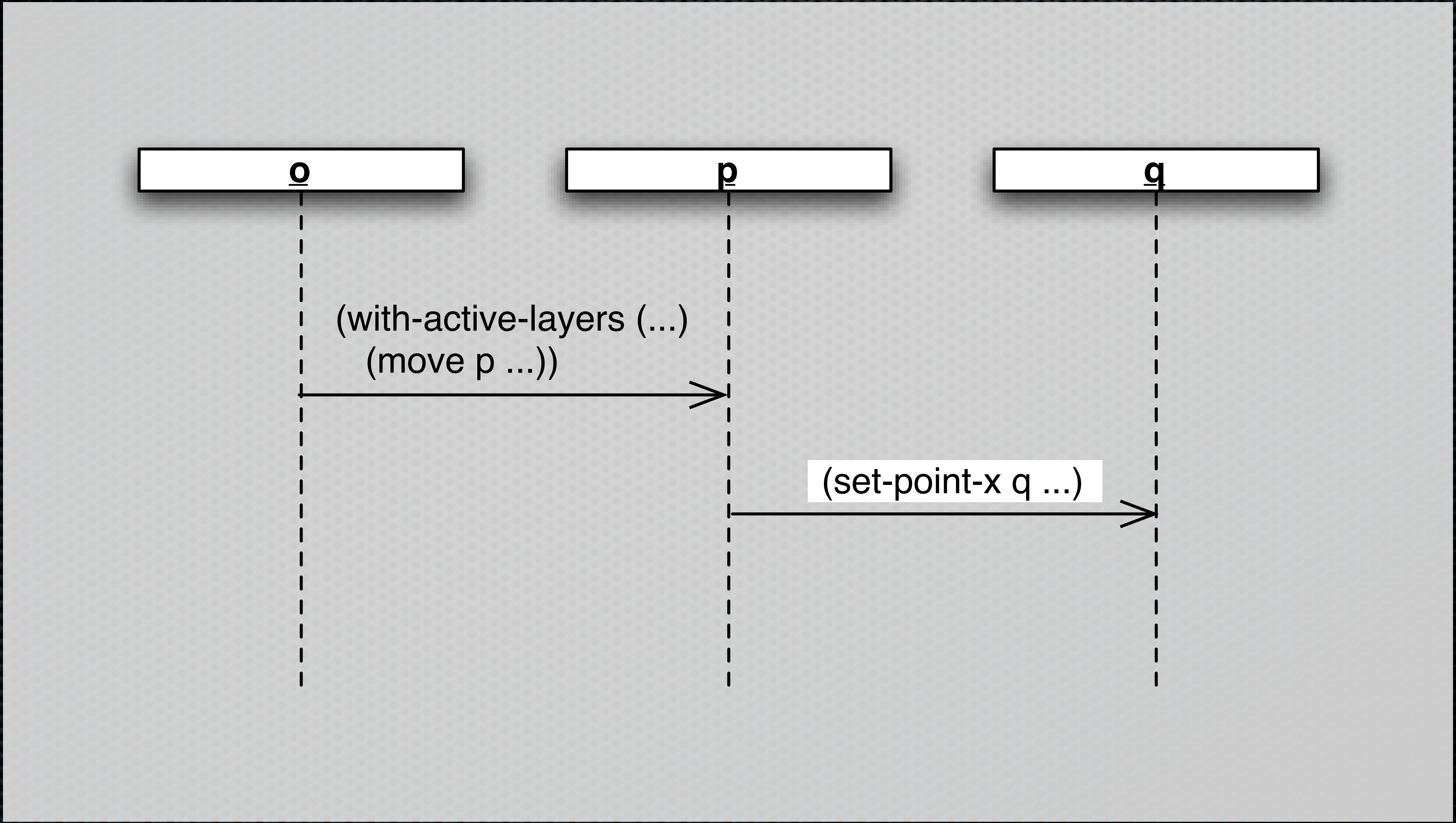
root layer

```
(define-layered-class point (figure-element)
  ((x :initarg :x :layered-accessor point-x)
   (y :initarg :y :layered-accessor point-y)))

(define-layered-method move ((elm point) dx dy)
  (incf (point-x elm) dx)
  (incf (point-y elm) dy))

(define-layered-class line (figure-element)
  ((p1 :initarg :p1 :layered-accessor line-p1)
   (p2 :initarg :p2 :layered-accessor line-p2)))

(define-layered-method move ((elm line) dx dy)
  (move (line-p1 elm) dx dy)
  (move (line-p2 elm) dx dy))
```

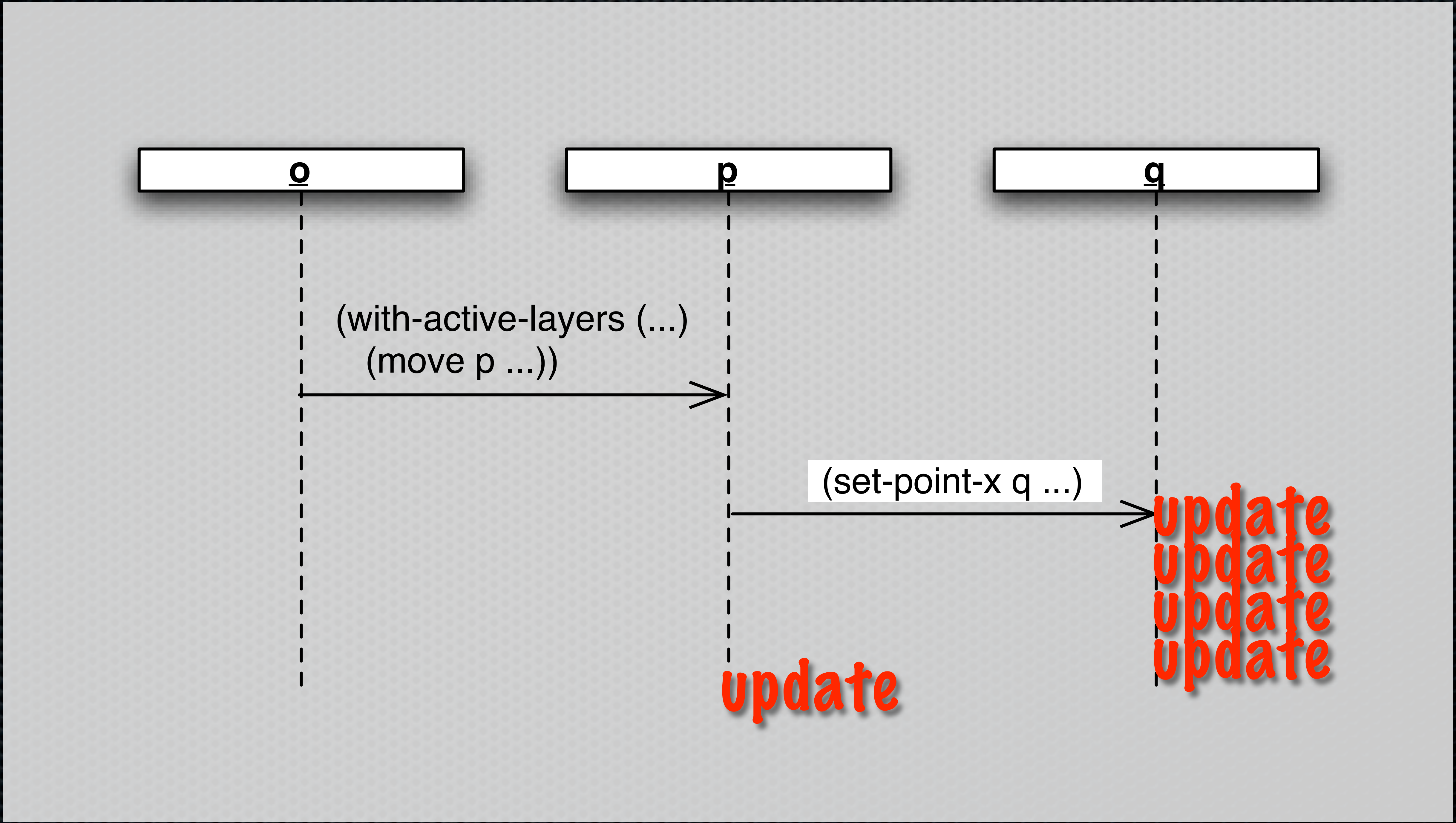
display layer

```
(deflayer display-layer)

(define-layered-method move
  :in-layer display-layer :after
  ((elm figure-element) dx dy)
  (update display elm))

(define-layered-method set-point-x
  :in-layer display-layer :after
  ((elm point) new-x)
  (update display elm))

... same for set-point-y, set-line-p1, set-line-p2 ...
```

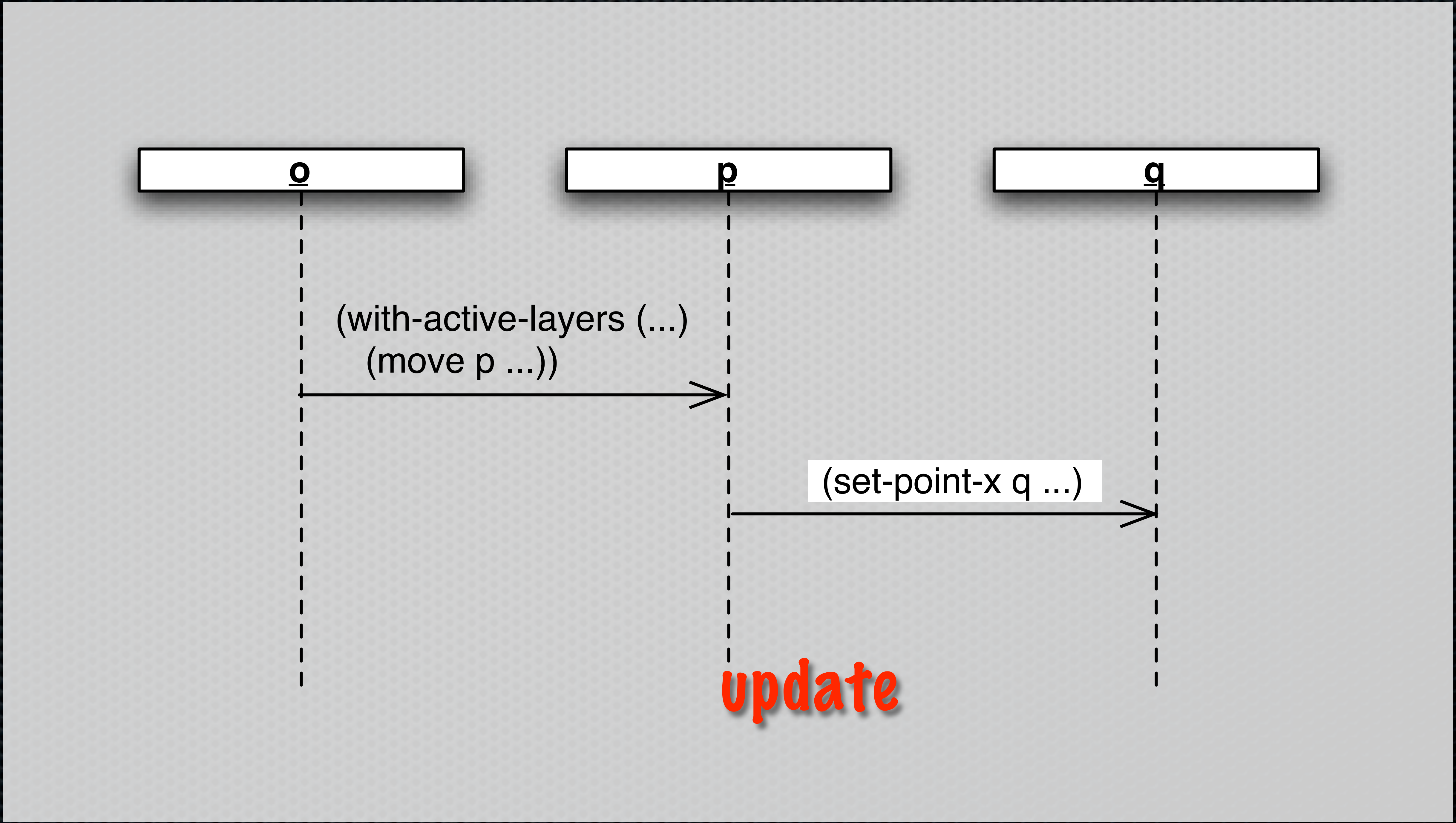
Layer Activation.



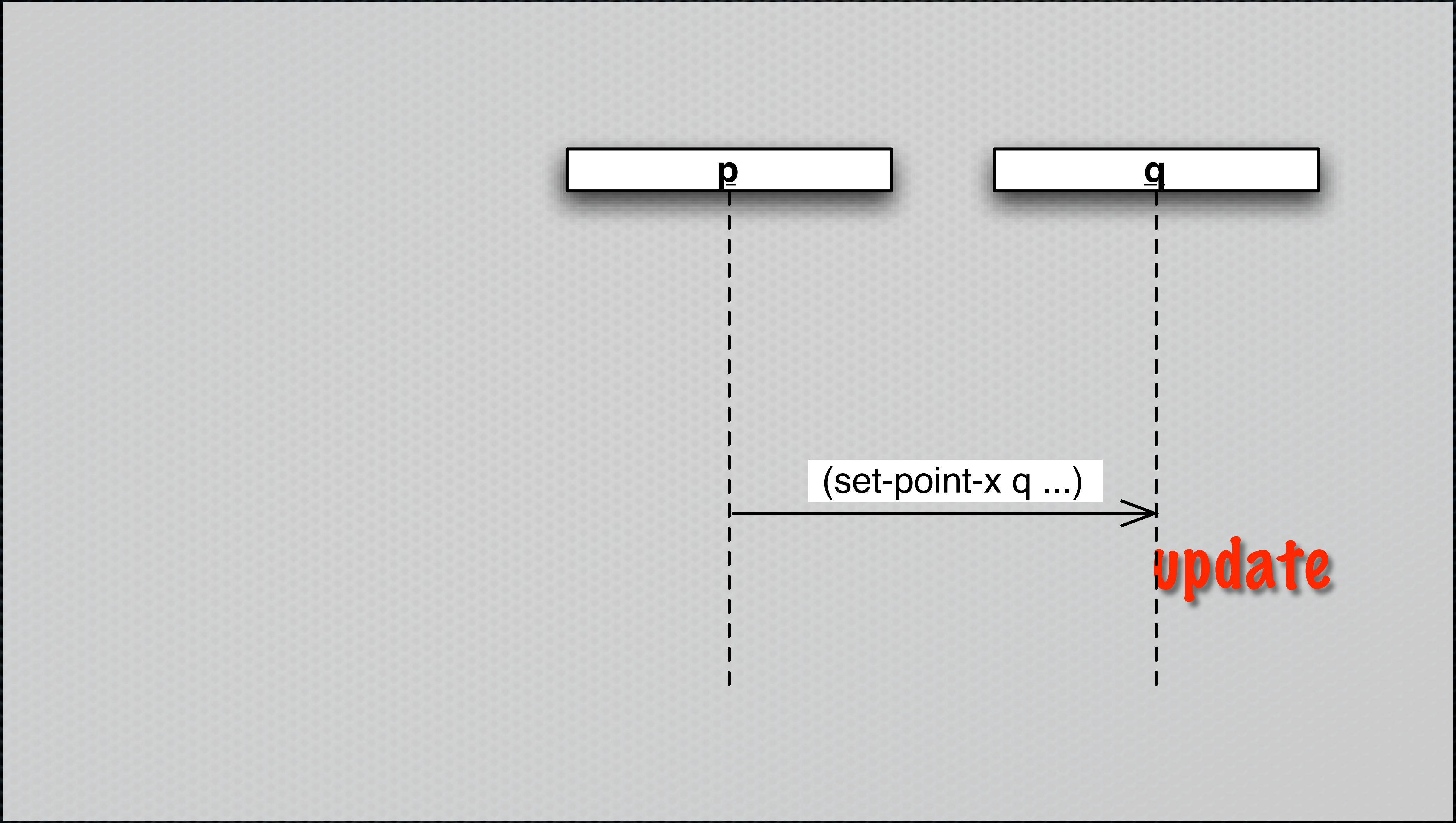
When to update?



When to update?



When to update?

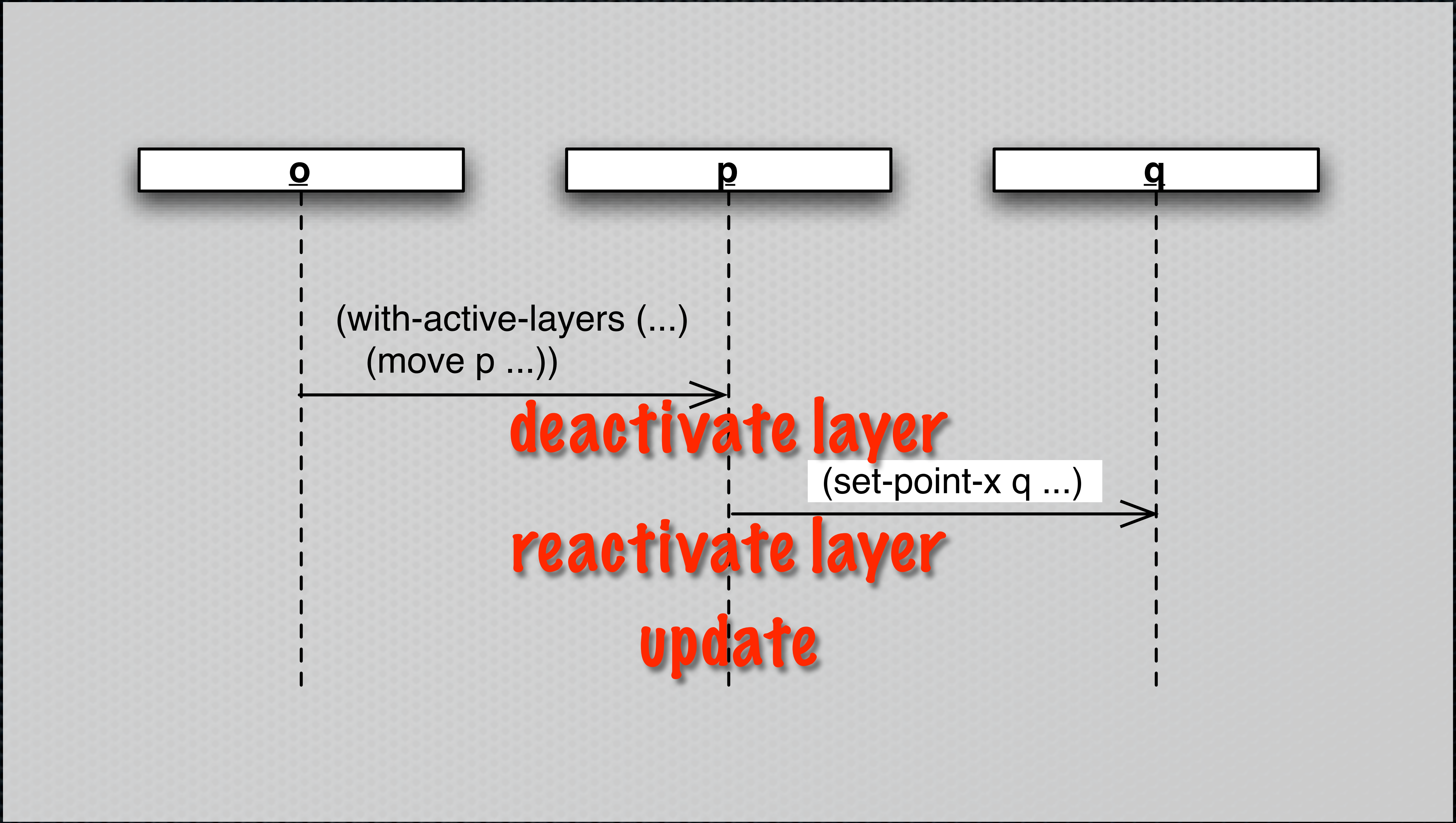


only top-level moves

DisplayUpdating v4

```
aspect DisplayUpdating {

  pointcut move(FigureElement fe):
    target(fe) &&
    (call(void FigureElement.moveBy(int, int)) ||
     call(void Line.setP1(Point))              ||
     call(void Line.setP2(Point))              ||
     call(void Point.setX(int))                ||
     call(void Point.setY(int)));

  pointcut topLevelMove(FigureElement fe):
    move(fe) && !cflowbelow(move(FigureElement));

  after(FigureElement fe) returning: topLevelMove(fe) {
    Display.update(fe);
  }
}
```

Update depends on context!



root layer

```
(define-layered-class point (figure-element)
  ((x :initarg :x :layered-accessor point-x)
   (y :initarg :y :layered-accessor point-y)))

(define-layered-method move ((elm point) dx dy)
  (incf (point-x elm) dx)
  (incf (point-y elm) dy))

(define-layered-class line (figure-element)
  ((p1 :initarg :p1 :layered-accessor line-p1)
   (p2 :initarg :p2 :layered-accessor line-p2)))

(define-layered-method move ((elm line) dx dy)
  (move (line-p1 elm) dx dy)
  (move (line-p2 elm) dx dy))
```

display layer

```
(deflayer display-layer)

(define-layered-method move
  :in-layer display-layer :around
  ((elm figure-element) dx dy)
  (with-inactive-layers (display-layer)
     (call-next-method))
  (update display elm))

... same for set-point-x, set-point-y, set-line-p1, set-line-p2 ...
```

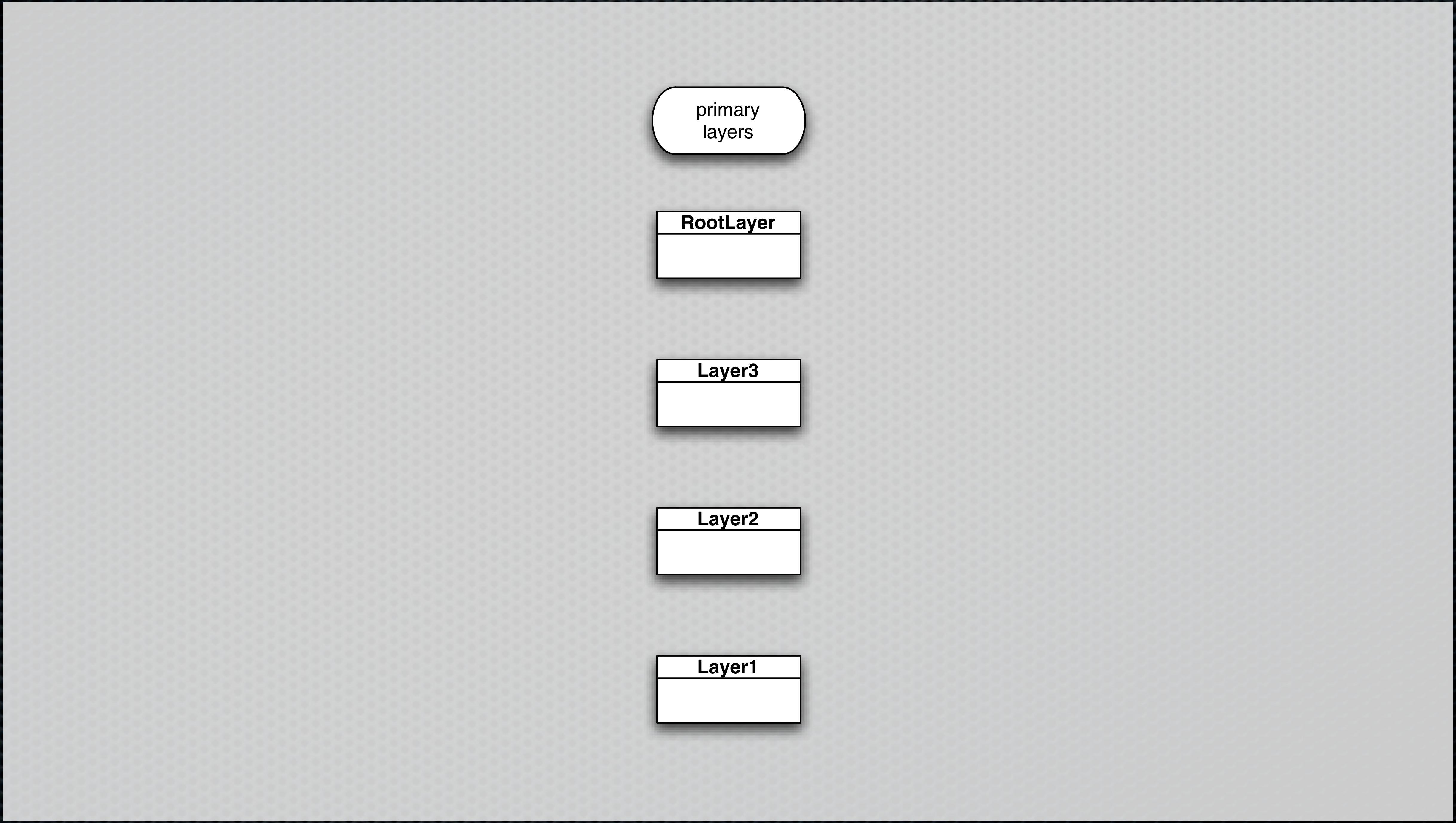
root layer

display layer

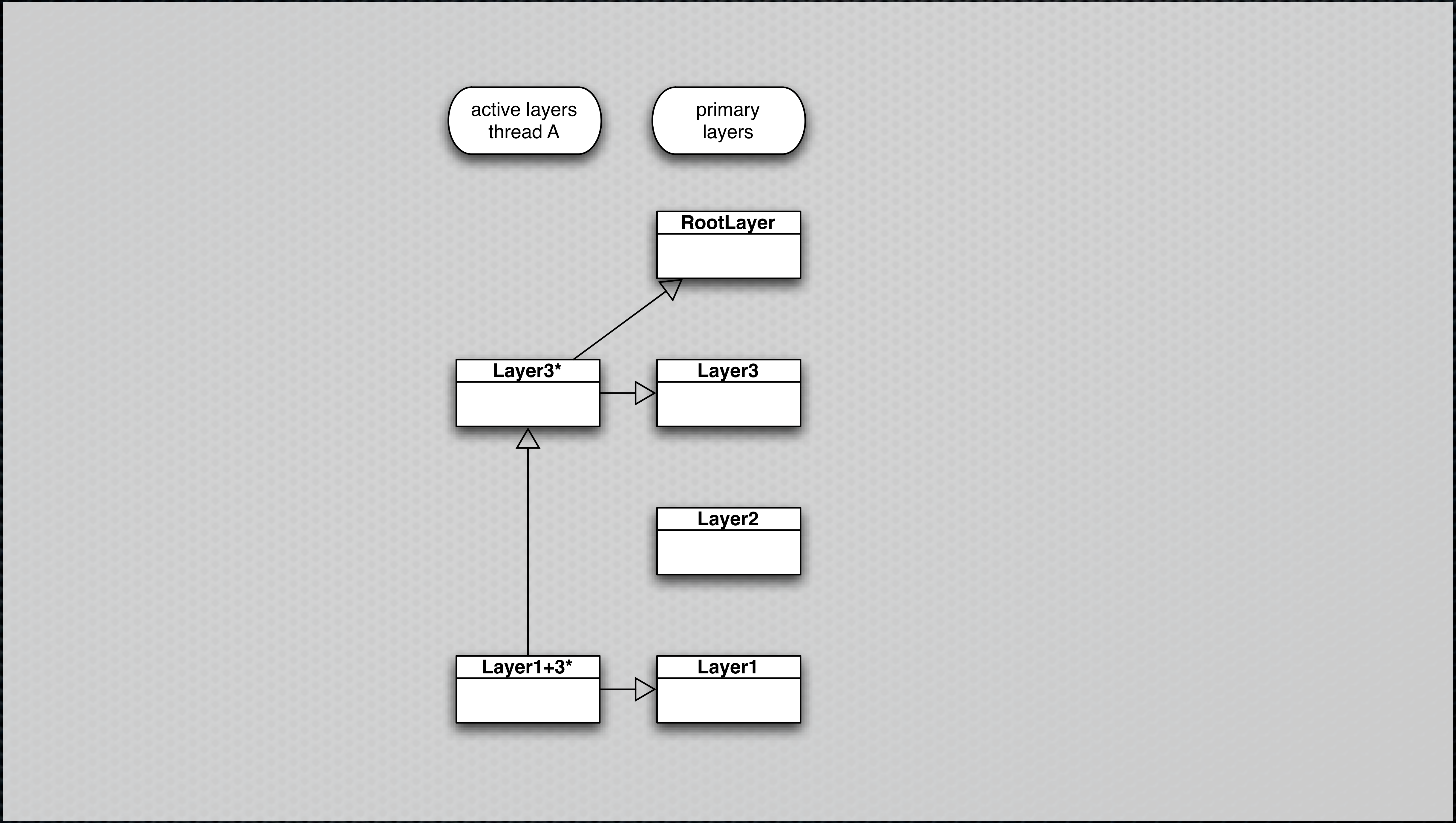
```
(deflayer display-layer)

(defun call-and-update (change-function object)
  (with-inactive-layers (display-layer)
    (funcall change-function)))
  (update display object))

(define-layered-method move
  :in-layer display-layer :around
  ((elm figure-element) dx dy)
  (call-and-update (function call-next-method) elm))

(define-layered-method layered-slot-set
  :in-layer display-layer :around
  ((elm figure-element) writer)
  (call-and-update writer elm))
```

...but can this be implemented efficiently?

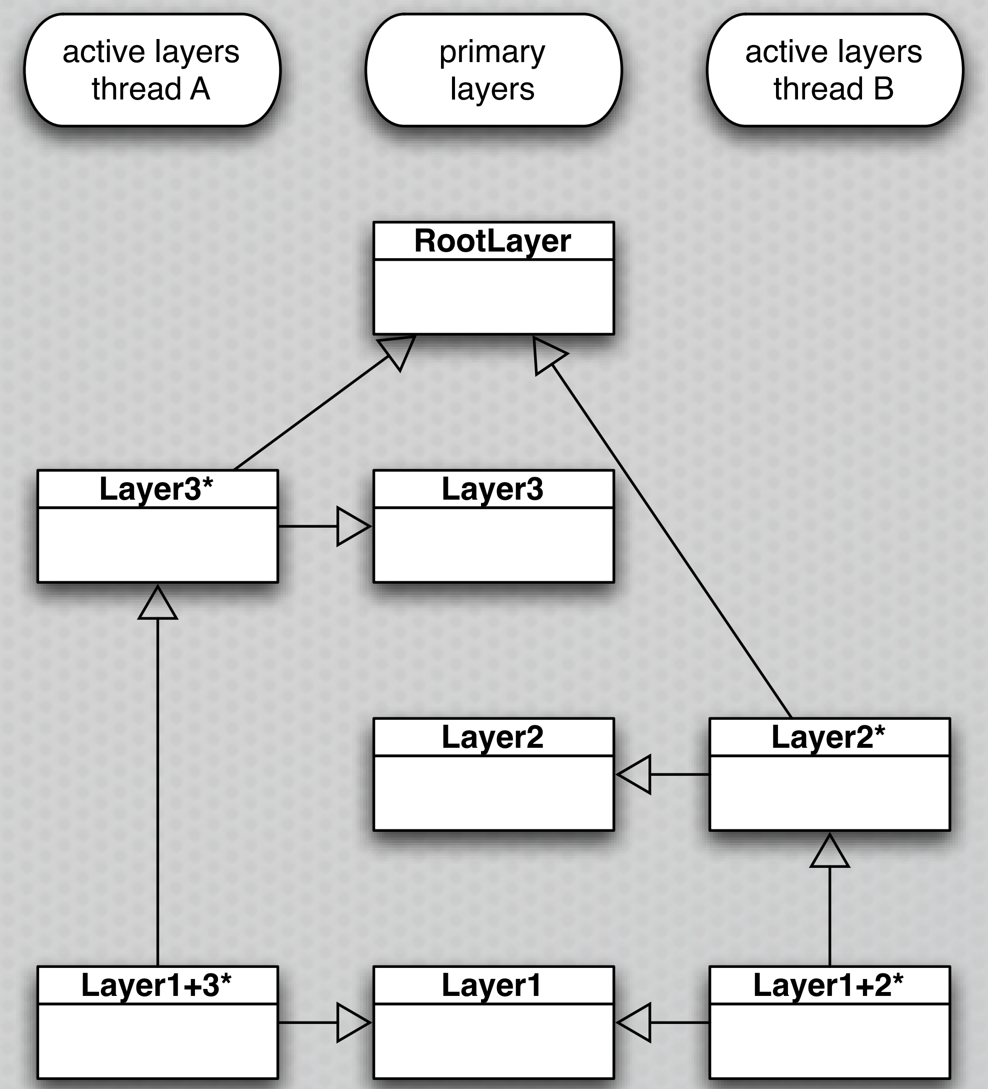
Layers as classes.



Layers as classes.



Layers as classes.



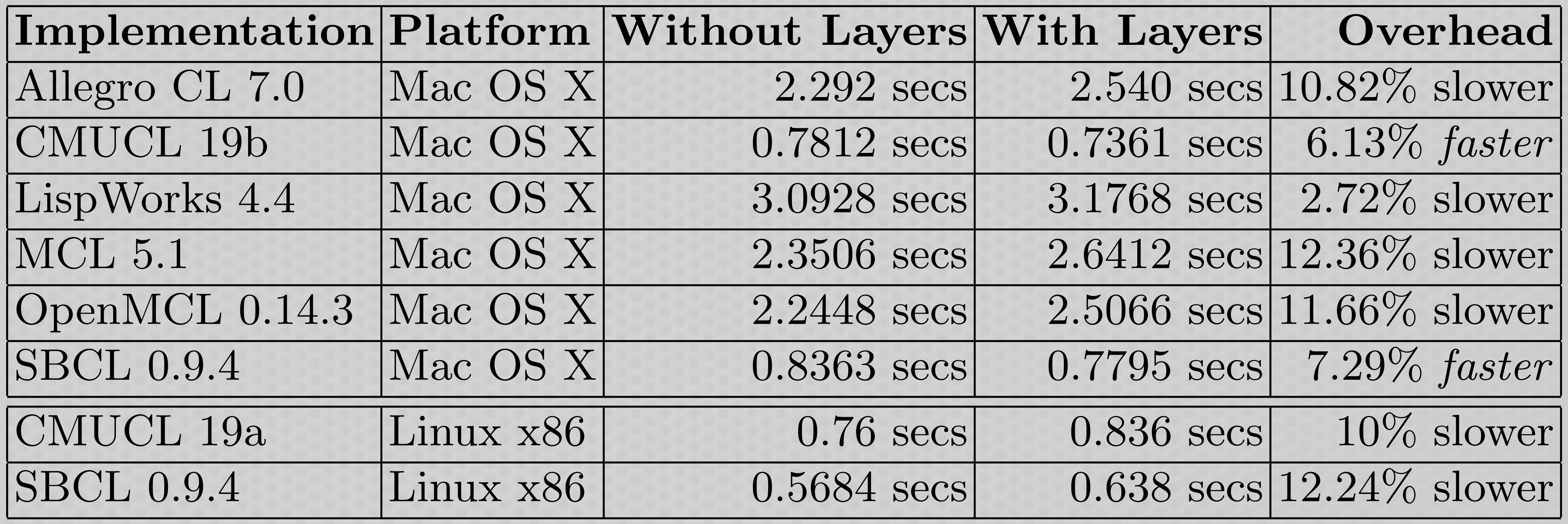
Layers passed via another implicit argument.

- obj.msg(x, y, z) => obj.msg(object, x, y, z)
- (move elm x y) => (move layers elm x y)
- Methods are dispatched on layers,
  and possibly on further arguments.

Key ingredients.

- Layer combinations via multiple inheritance.
- Layered dispatch via multiple dispatch.
- Efficient caches for layers (in ContextL).
- Efficient method dispatch (in CLOS).

Benchmark results.



Implementation	**Platform**	**Without Layers**	**With Layers**	**Overhead**
Allegro CL 7.0	Mac OS X	2.292 secs	2.540 secs	10.82% slower
CMUCL 19b	Mac OS X	0.7812 secs	0.7361 secs	6.13% *faster*
LispWorks 4.4	Mac OS X	3.0928 secs	3.1768 secs	2.72% slower
MCL 5.1	Mac OS X	2.3506 secs	2.6412 secs	12.36% slower
OpenMCL 0.14.3	Mac OS X	2.2448 secs	2.5066 secs	11.66% slower
SBCL 0.9.4	Mac OS X	0.8363 secs	0.7795 secs	7.29% *faster*
CMUCL 19a	Linux x86	0.76 secs	0.836 secs	10% slower
SBCL 0.9.4	Linux x86	0.5684 secs	0.638 secs	12.24% slower

Layer dependencies.

-
  ```
  (deflayer phone-tariff)

  (define-layered-method start-phone-call
    :in-layer phone-tariff :after (number)
    ... record start time ...)

  (define-layered-method end-phone-call
    :in-layer phone-tariff :after ()
    ... record end time & determine cost ...)
  ```
- What if there are several alternative phone tariffs?

Layer inheritance.

-
  ```
  (deflayer phone-tariff)

  (define-layered-method start-phone-call
     :in-layer phone-tariff :after (number)
     ... record start time ...)
  ```

-
  ```
  (deflayer phone-tariff-a (phone-tariff))
  (deflayer phone-tariff-b (phone-tariff))
  ```
- ...allows sharing of common behavior.
  But this is not enough:
  Tariff a and b should be mutually exclusive!

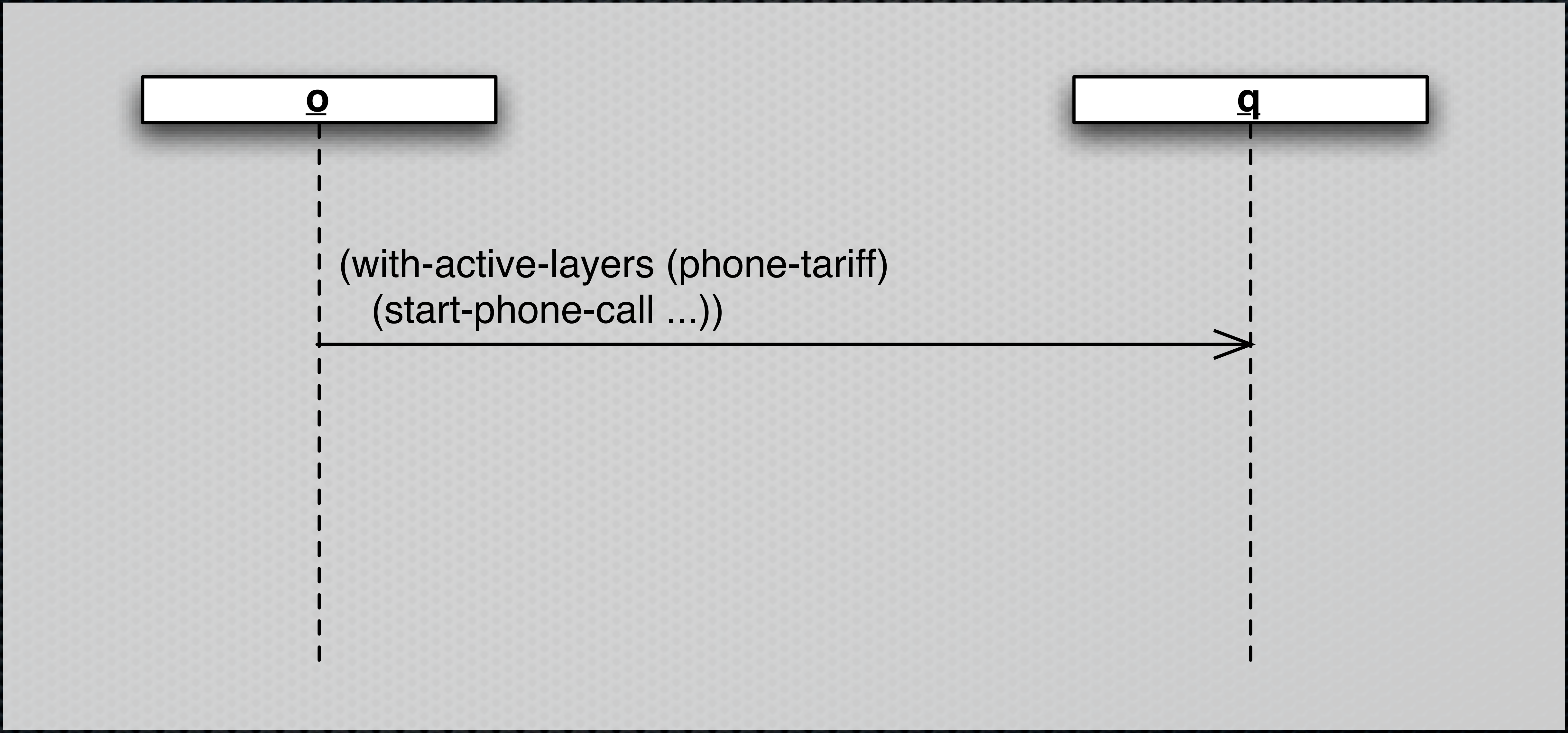
Layers as metaobjects.

- Reflection =
  introspection and intercession.
- Metaobject protocols =
  OOP-style organization of the reflective API.
- Here: Layers are instances of layer metaobject classes.

Intercession of layer activation.

-
  ```
  (defclass tariff-base-layer-class (standard-layer-class)
    ())

  (deflayer phone-tariff () ()
    (:metaclass tariff-base-layer-class))
  ```

Intercession of layer activation.



- Internally calls (adjoin-layer-using-class <phone-tariff> ...)

Intercession of layer activation.

-
  ```
  (defclass tariff-base-layer-class (standard-layer-class)
    ())

  (deflayer phone-tariff () ()
    (:metaclass tariff-base-layer-class))
  ```

-
  ```
  (define-layered-method adjoin-layer-using-class
    ((layer tariff-base-layer-class) active-layers)
    (if (layer-active-p ‘phone-tariff active-layers)
      active-layers
      (let ((tariff (ask-user “Select tariff ...”)))
        (adjoin-layer tariff active-layers))))
  ```

Layer dependencies.

- Conditional or unconditional blocking
  of layer activations.
- Inclusion dependencies:
  Activation of a layer requires activation of another.
- Exclusion dependencies:
  Activation of a layer requires deactivation of another.
- Also: dependencies on layer deactivation.

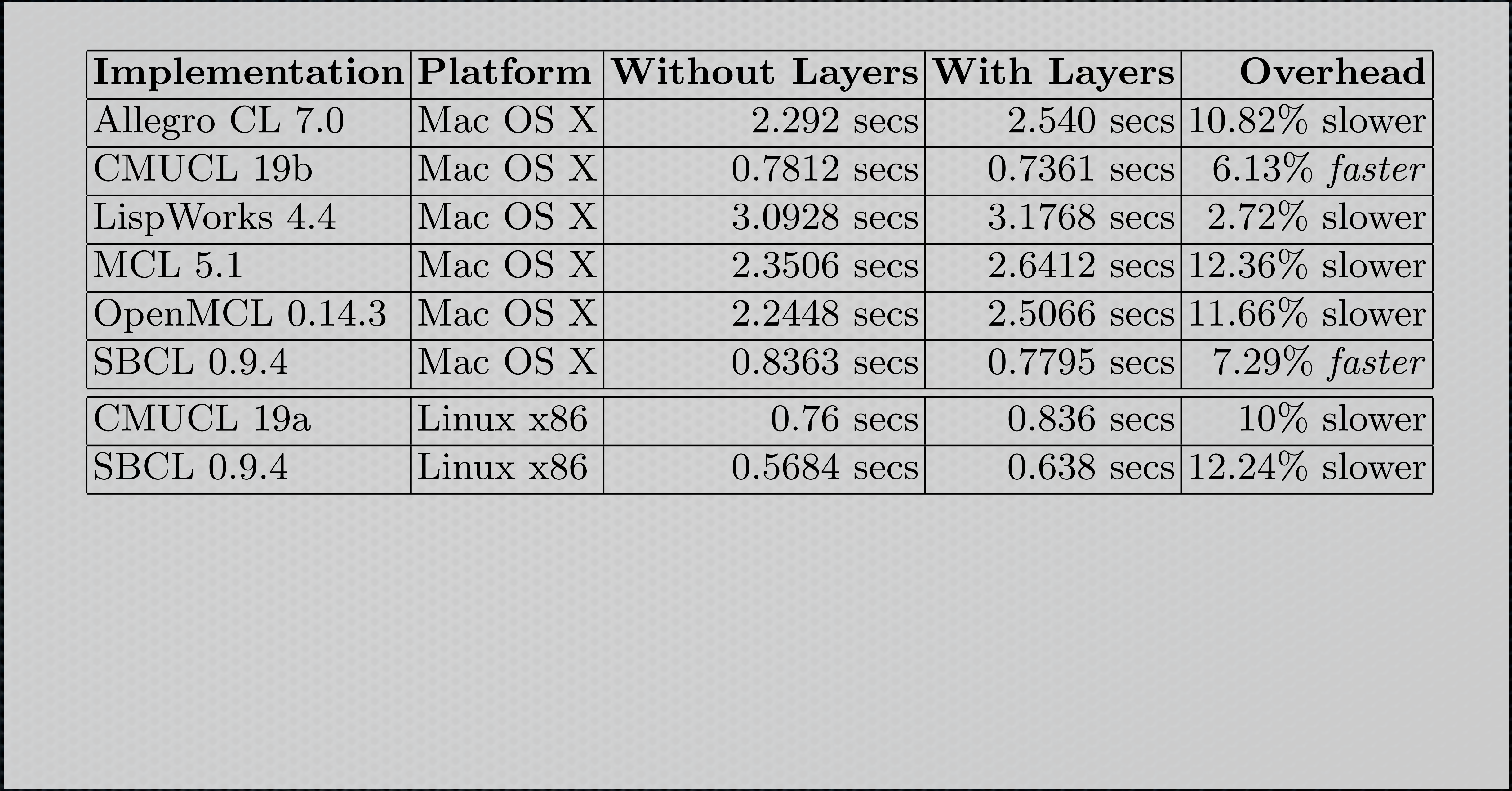
Efficiency.

- Goal: Only incur a cost when necessary.

-
  ```
  (define-layered-method adjoin-layer-using-class
     :in-layer block-managed-layers
     ((layer managed-layer-class) active-layers)
     (values active-layers t))
  ```

Benchmark results.

- Without reflective layer activation (JMLC ‘06).



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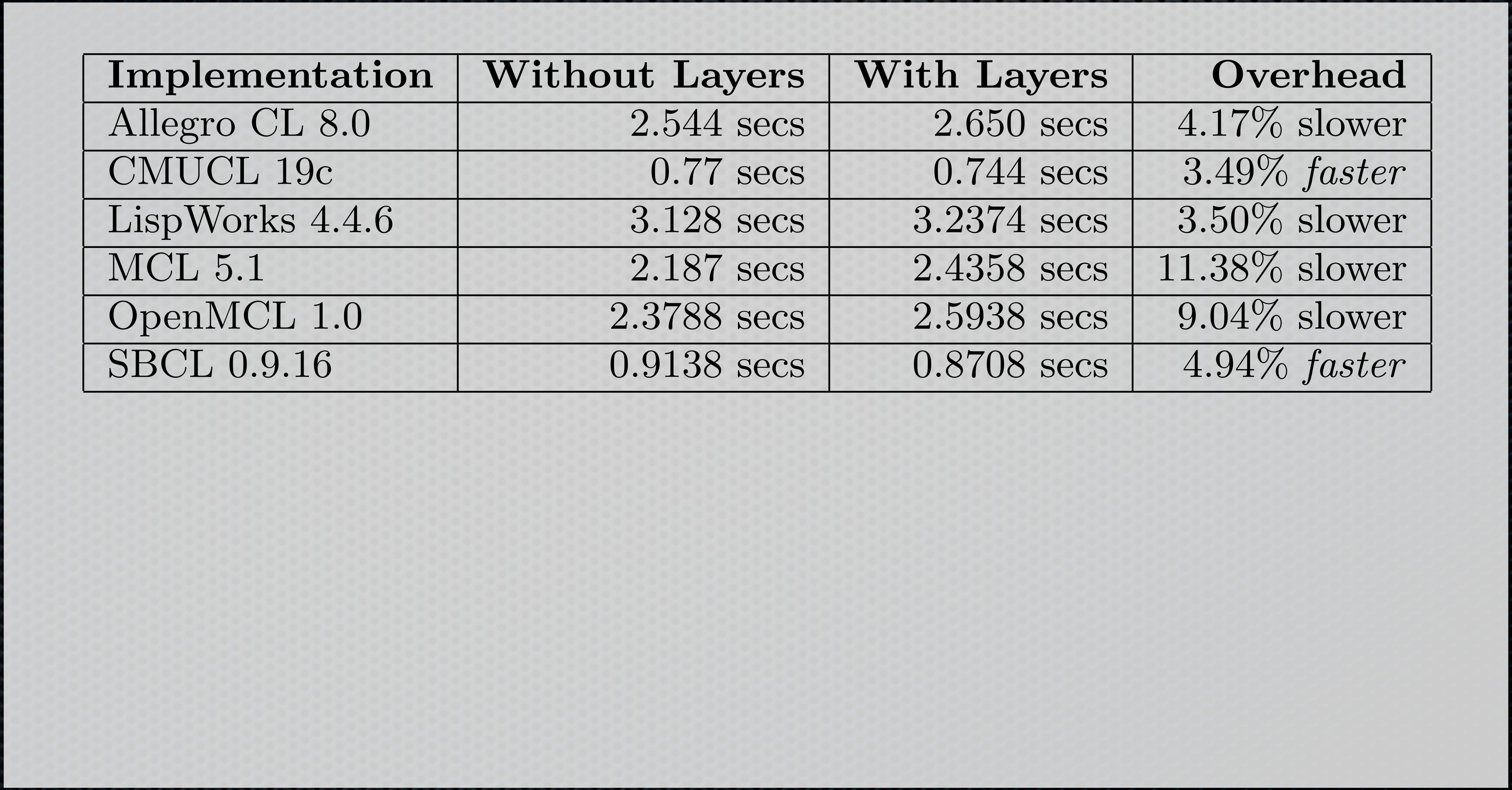
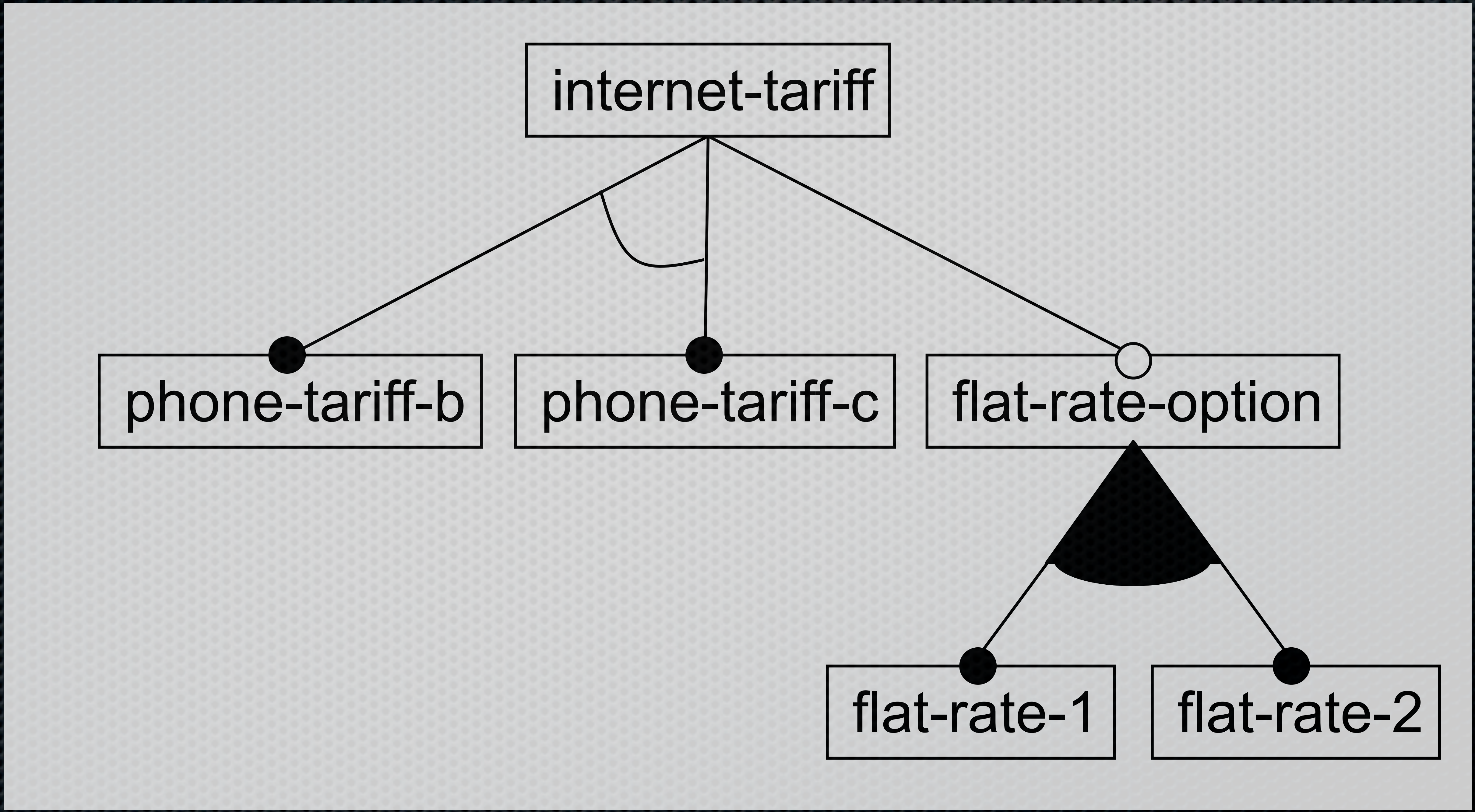
Benchmark results.

- With reflective layer activation (SAC PSC '07).



Implementation	**Without Layers**	**With Layers**	**Overhead**
Allegro CL 8.0	2.544 secs	2.650 secs	4.17% slower
CMUCL 19c	0.77 secs	0.744 secs	3.49% *faster*
LispWorks 4.4.6	3.128 secs	3.2374 secs	3.50% slower
MCL 5.1	2.187 secs	2.4358 secs	11.38% slower
OpenMCL 1.0	2.3788 secs	2.5938 secs	9.04% slower
SBCL 0.9.16	0.9138 secs	0.8708 secs	4.94% *faster*

Feature Diagrams to the rescue.



Summary.

- Context-oriented Programming provides
  + layers with partial classes and methods
  + that can be freely selected and combined
  + without interfering with other contexts.

Summary.

- COP is independent of source code organization.
  + Essential contribution is layer activation at runtime.
  + Beneficial to activate/deactivate layers anywhere.
- COP is compatible with a
  higher-order reflective programming style.

ContextL.

- Available for 6 major Common Lisp implementations.
- Implemented using the CLOS MOP.
- Apparently no serious runtime overhead!
- Source code with MIT/BSD-style license at http://common-lisp.net/project/closer/

Major achievements so far...

- **Language Construct for Context-oriented Programming - An Overview of ContextL**
  Dynamic Languages Symposium 2005 (with Robert Hirschfeld)
- **Efficient Layer Activation for Switching Context-dependent Behavior**
  Joint Modular Languages Conference 2006 (with Robert Hirschfeld & Wolfgang De Meuter)
- **Reflective Layer Activation in ContextL**
  ACM Symposium on Applied Computing 2007 (with Robert Hirschfeld)
- **Context-Oriented Domain Analysis**
  International and Interdisciplinary Conference on Modeling and Using Context 2007 (Brecht Desmet et al.)
- **Context-oriented Programming**
  Journal of Object Technology, March/April 2008 (with Robert Hirschfeld & Oscar Nierstrasz)
- **Filtered Dispatch**
  Dynamic Languages Symposium 2008 (with Charlotte Herzeel, Jorge Vallejos, Theo D'Hondt)
- **Context-oriented Software Transactional Memory in Common Lisp**
  Dynamic Languages Symposium 2009 (with Charlotte Herzeel & Theo D'Hondt)

COP Future Themes.

- Feature Diagrams
- Context-oriented Domain Analysis
- Distributed Context-oriented Programming
- Ambient Context-oriented Programming
- Filtered Dispatch / Predicate Dispatch
- Parallel Programming

Thank you!