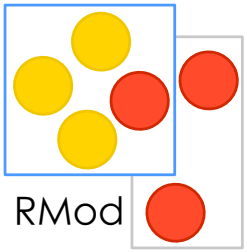

Studying a Minimal Object-Oriented Kernel

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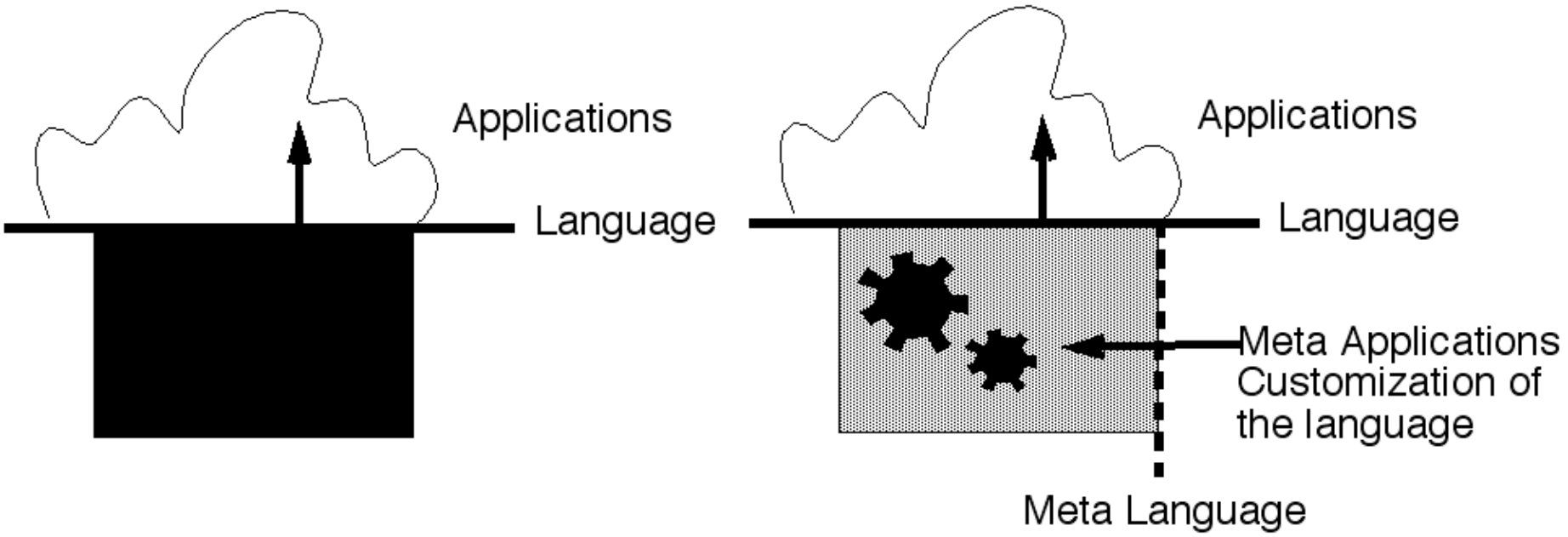
Goals

- Classes as objects
- Object and Class classes
- Semantics of inheritance
- Semantics of super and self
- Instantiation vs. Inheritance
- Allocation and Initialization
- Build your own language

Outline

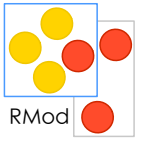
- Classes as objects
- ObjVlisp in 5 postulates
- Instance Structure and Behavior
- Class Structure
- Message Passing
- Object allocation & Initialization
- Class creation
- Inheritance Semantics
- Bootstrapping

Context: Can we customise languages?



Real Cases

Nichimem (3D) corp saved 15 years of development by changing the semantics of CLOS to be close to the one Flavor.



Classes as Objects?

"The difference between classes and objects has been repeatedly emphasized. …, these concepts belong to different worlds: the program text only contains classes; at run-time, only objects exist.

…

This is not the only approach. One of the subcultures of object-oriented programming, influenced by Lisp and exemplified by Smalltalk, views ***classes as object themselves, which still have an existence at run-time***."

B. Meyer Object-Oriented Software Construction

Understanding instantiation

What is the relationship between

- an instance and its class?
- a class and its metaclass?
- a metaclass and its metametaclass?

What is the difference between described-by and instances of?

Metaclasses

One of the possible meta-entities (method, instance variables,…)

Support language extension

They may control

- Inheritance
- Internal representation of the objects (listes, vecteurs, hash-table, ...)
- Instance variable access

Roadmap

- Classes as objects
- ***ObjVlisp in 5 postulates***
- Instance Structure and Behavior
- Class Structure
- Message Passing
- Object allocation & Initialization
- Class creation
- Inheritance Semantics
- Bootstrapping

Why ObjVlisp?

- Minimal (only two classes)
- ObjVlisp self-described: definition of Object and Class
- Unified: Only one kind of object: a class is an object and a metaclass is a class that creates classes
- Simple: can be implemented with less than 300 lines of Scheme or 30 Smalltalk methods.
- Equivalent of Closette (Art of MetaObject Protocol, G. Kiczales)

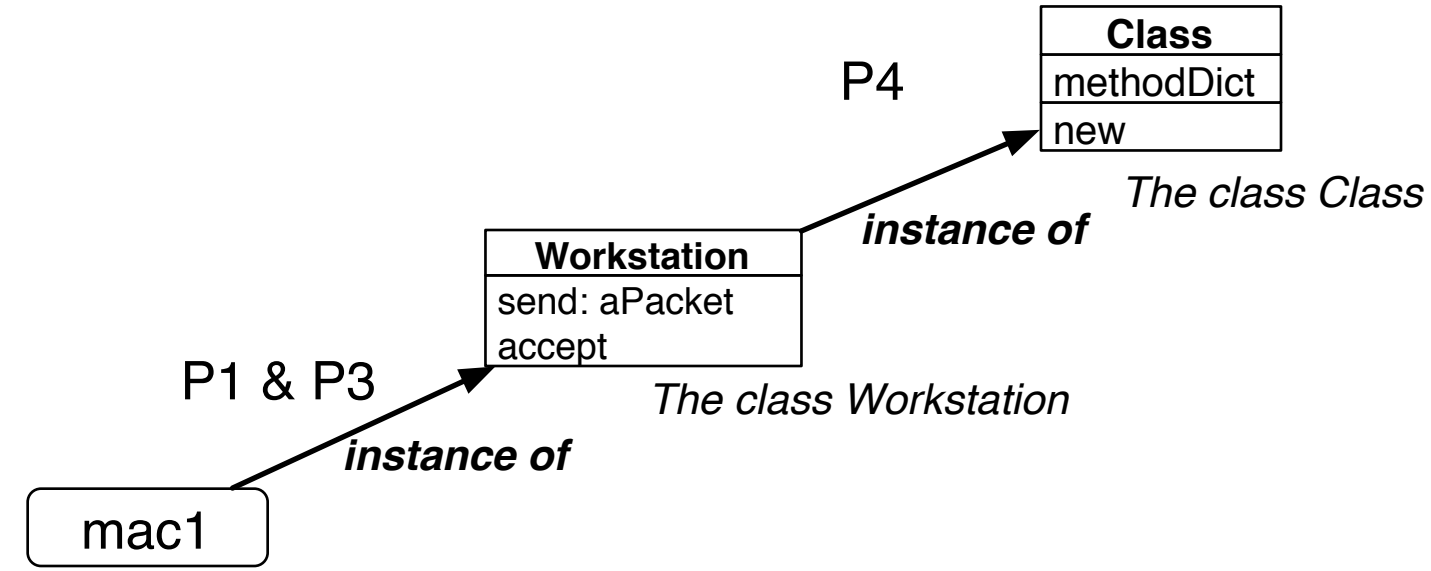
ObjVlisp Postulates (I)

- P1: An object represents a piece of knowledge and a set of capabilities.

- P3: Every object belongs to a class that specifies its data (slots or instance variables) and its behavior. Objects are created dynamically from their class.

- P4: Following P3, a class is also an object therefore instance of another class *its metaclass* (that describes the behavior of a class).

ObjVLisp Postulates (II)




```
| mac1 |
mac1 := Workstation new name: #mac1
```

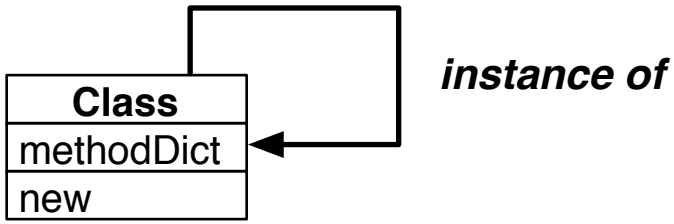

RMod

Infinite Recursion

- A class is an object therefore instance of another class its metaclass that is an object too instance of a metametaclass that is an object too instance of another a metametametaclass.....

Stopping the Infinite Recursion

- To stop this potential infinite recursion
  - Class is the initial class and metaclass
  - Class is instance of itself
  - All other metaclasses are instances of Class



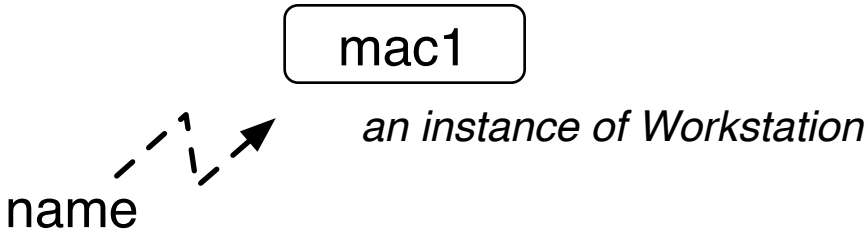
The class Class

RMod

ObjVlisp 2nd Postulate

- P2: Message passing is the only means to activate an object

[object selector args]



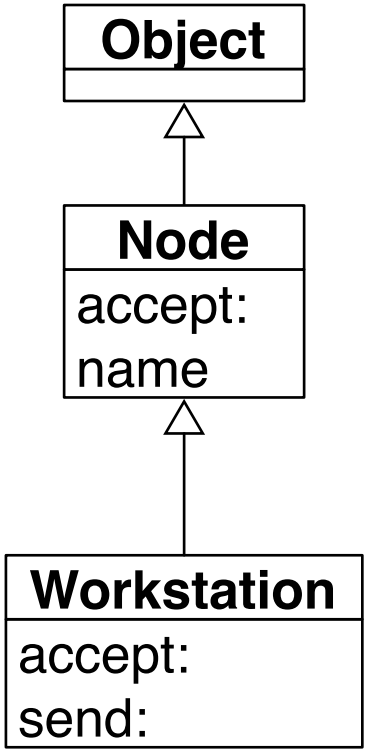

```
| mac1 |
mac1 := Workstation new name: #mac1.
mac1 name
```


RMod

ObjVlisp 5th Postulate

- P5: A class can be defined as a subclass of one or many other classes.

- We only implement single inheritance



RMod

Unifying Class/Instance

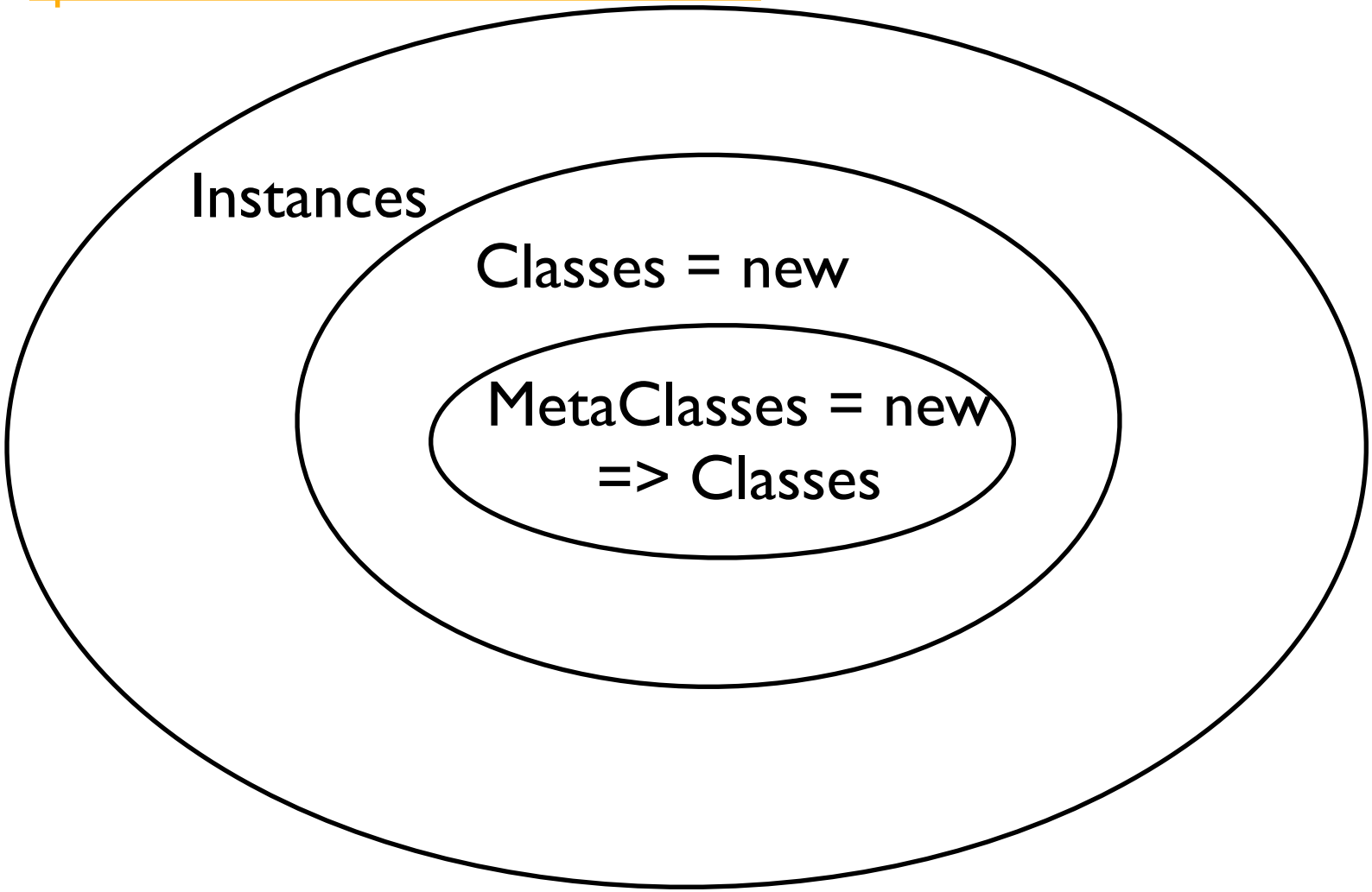
- Every object is instance of a class
- A class is an object instance of a metaclass (P4)
  But all the objects are not classes
- Only one kind of objects without distinction between classes and final instances.

Instance/Class (Metaclass)

- Sole difference is the ability to respond to the creation message: ***new***. Only a class knows how to deal with it.

- A ***metaclass*** is only a class that generates classes

Instance/Class/Metaclass

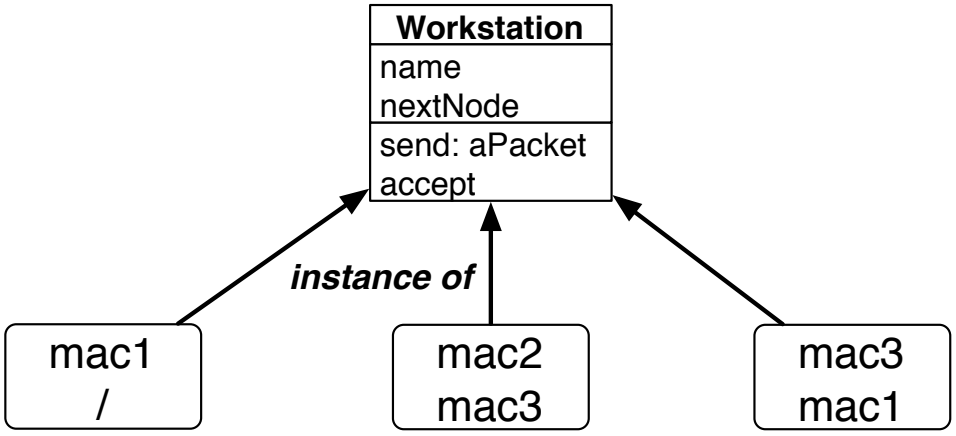


RoadMap

- Classes as objects
- ObjVlisp in 5 postulates
- ***Instance Structure and Behavior***
- Class Structure
- Message Passing
- Object allocation & Initialization
- Class creation
- Inheritance Semantics
- Bootstrapping

Instance Structure

- Instance variables
  - an ordered sequence of instance variables ***defined*** by a class
  - ***shared*** by all instances
  - values ***specific*** to each instance



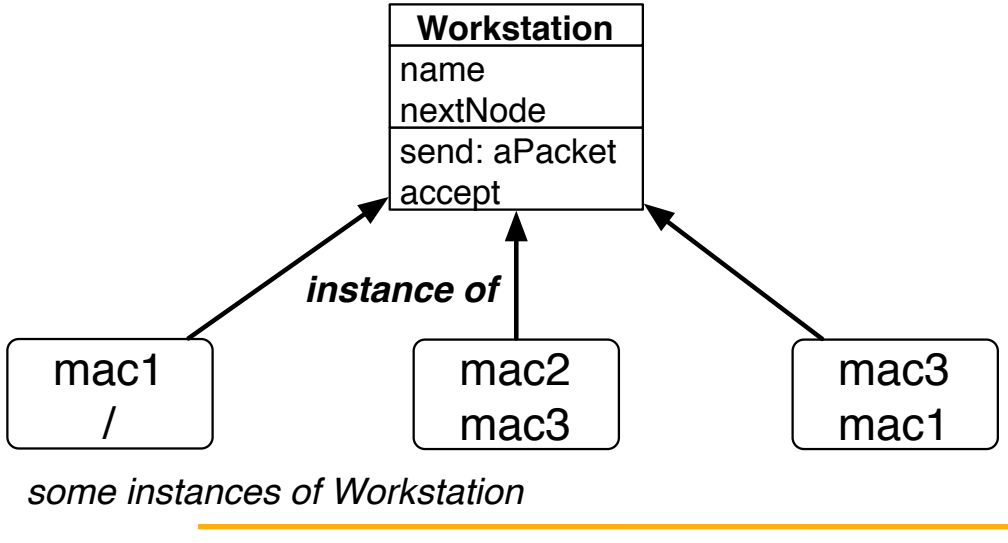
some instances of Workstation

RMod

Instance Structure

In particular, every object possesses an instance variable ***class*** *(inherited from Object) that points to its class*

mac1 class
>>> Workstation



Instance Behavior

A method

- belongs to a class
- defines the behavior of ***all the instances*** of the class
- is stored into a dictionary that associates a key (the method selector) and the method body

Instance Behavior

The method dictionary of a class is the value of the instance variable ***methodDict*** *defined on the metaclass* ***Class***.

Method implementation choices

- Let's use a pharo block
- name -> [:objself | objself unary: #name]

- no direct access to instance variables

RoadMap

- Classes as objects
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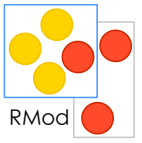
Class as an Object

- How would you represent a class?
- What state do you need to represent a class?



Class as an Object

As an instance factory the Class has 4 instance variables that describe a class:

- ***name*** the class name
- ***superclass*** its superclass (we limit to single inheritance)
- ***i-v*** the list of its instance variables
- ***methodDict*** a method dictionary

Class as an Object

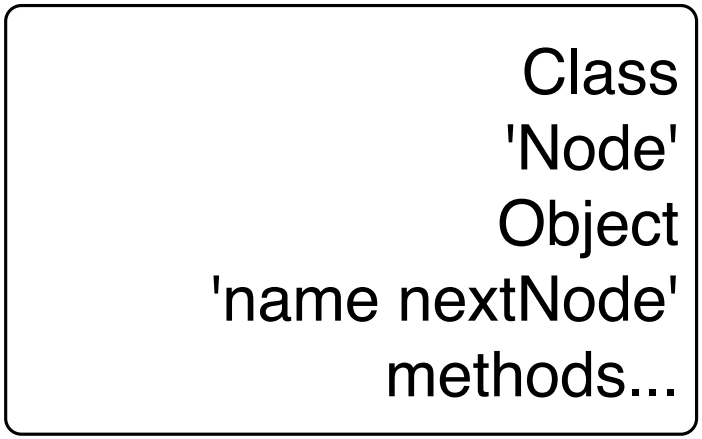
- Workstation class -> Class

- A class possesses the instance variable ***class*** inherited from Object that refers to its class (the metaclass that creates it).

- Class value: an identifier of the class of the instance

Class Node as Object

The class Node



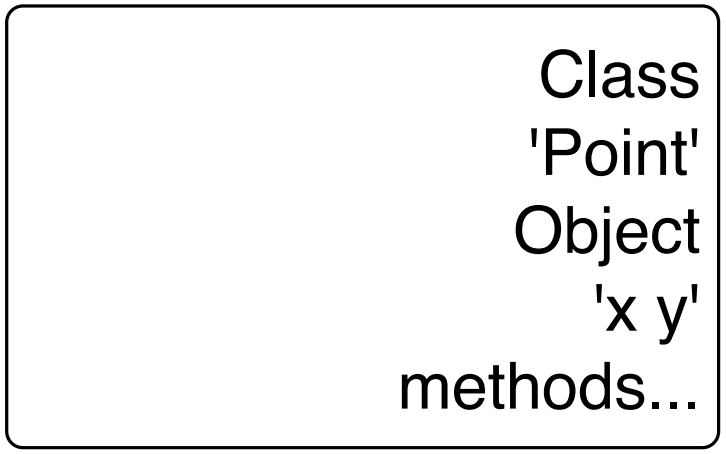
is instance of Class
named Node
inherits from Object
has instance variables
defines some methods

- Node is instance of class Class because we can create instances of Node sending it the message new

RMod

Class Point as Object

The class Point

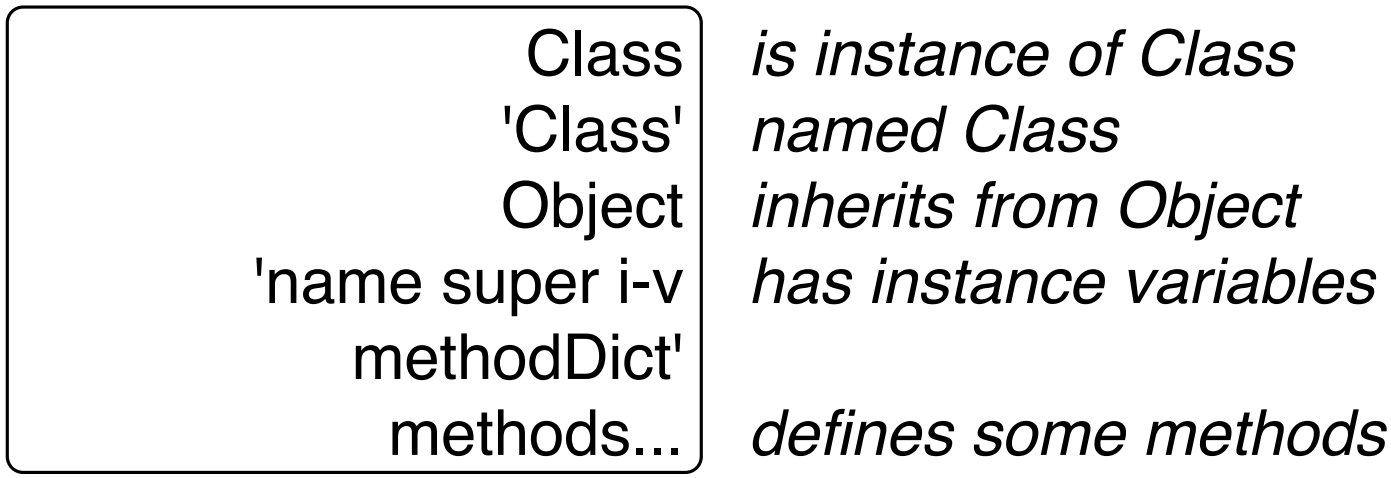


is instance of Class
named Point
inherits from Object
has instance variables
defines some methods

RMod

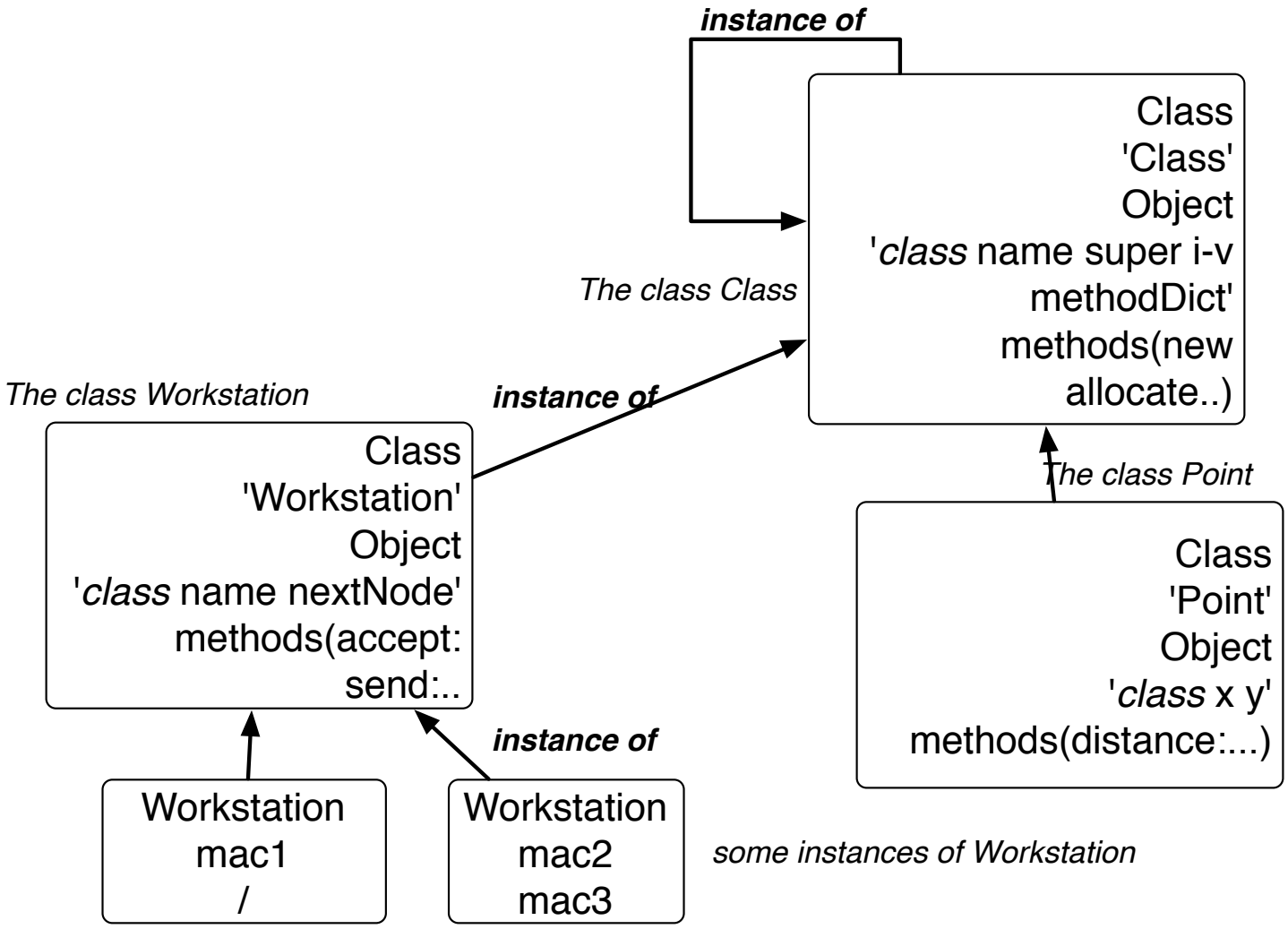
The class Class

The class Class



RMod

Instances...



RMod

The class Class

- Initial metaclass
- Defines the behavior of all the ***metaclasses***
- Defines the behavior of all the ***classes***

RoadMap

- Classes as objects
- ObjVlisp in 5 postulates
- Instance Structure and Behavior
- Class Structure
- ***Inheritance and its Semantics***
- Object allocation & Initialization
- Class creation
- Bootstrapping

Inheritance

- **incremental** class definition

Two kinds of inheritance

Static for the state

- subclasses get superclass state
- *At compilation time* ***(class-creation time)***

Dynamic for behavior

- inheritance tree walked ***at run-time***

Instance Variable Inheritance

- Static for the instances variables
- Done once at the class creation

- When C is created, its instance variables are the union of the instance variables of its superclass with the instance variables defined in C.

- final-instance-variables (C) =

    OrderedUnion (iv (super C)),

        local-instance-variables(C))

Object minimal structure

Object defines the instance variable ***class***
so that any object can know its class

- *(10@10) class -> Point*
- *Point class -> Class*

RMod

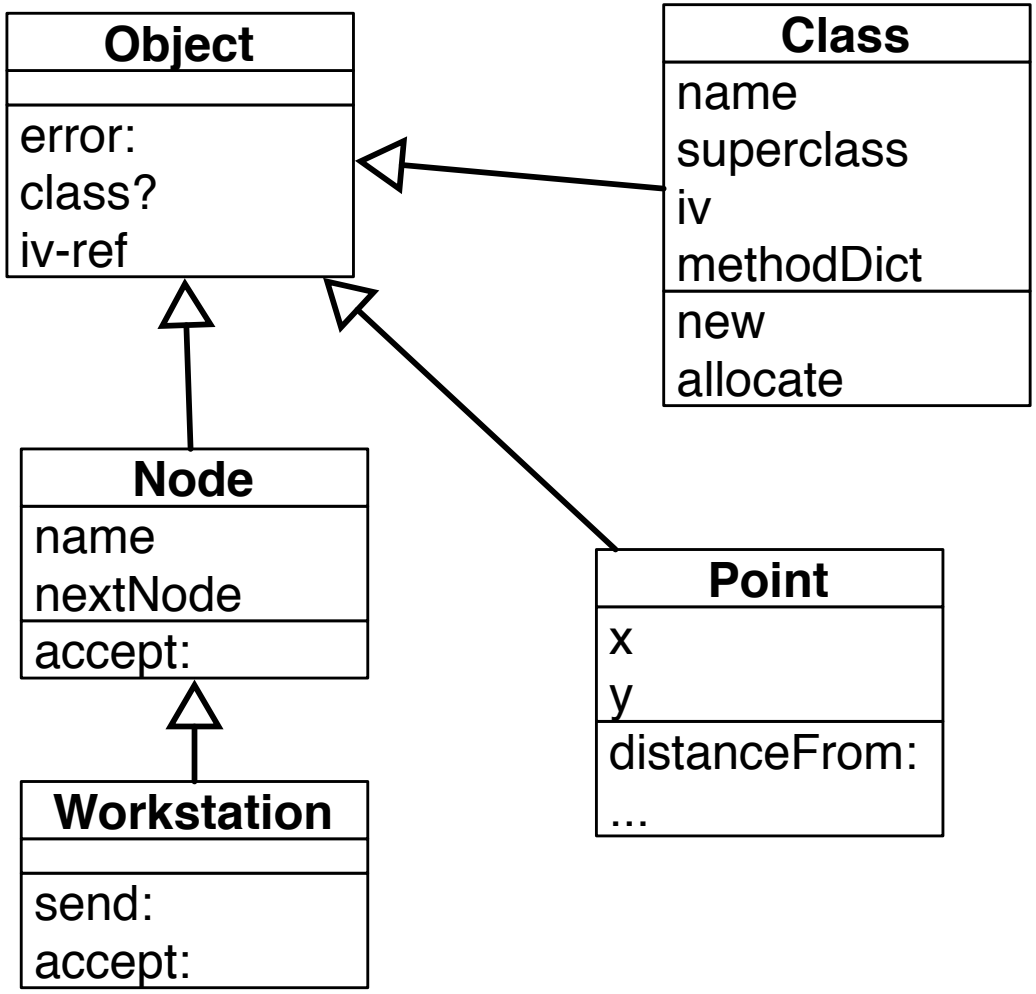
Inheritance Graph

- ***Object*** is the root of the hierarchy.

- a Workstation is an object (should at least understand the minimal behavior), so ***Workstation*** inherits from ***Object***

- a class is an object so ***Class*** inherits from ***Object***
- In particular, class instance variable is inherited from Object class.

Inheritance Graph



Object: Minimal Shared Behavior

- Represents the common behavior shared by all the objects:
  - classes
  - final instances

- Every object knows its class: class instance variable

- Methods:
  - initialize (instance variable initialization)
  - error, class, metaclass?, class?
  - iv-set, iv-ref (meta operations)

Method Inheritance

Walks through the inheritance graph between classes using the super instance variable

lookup (selector class receiver):

if the method is found then return it

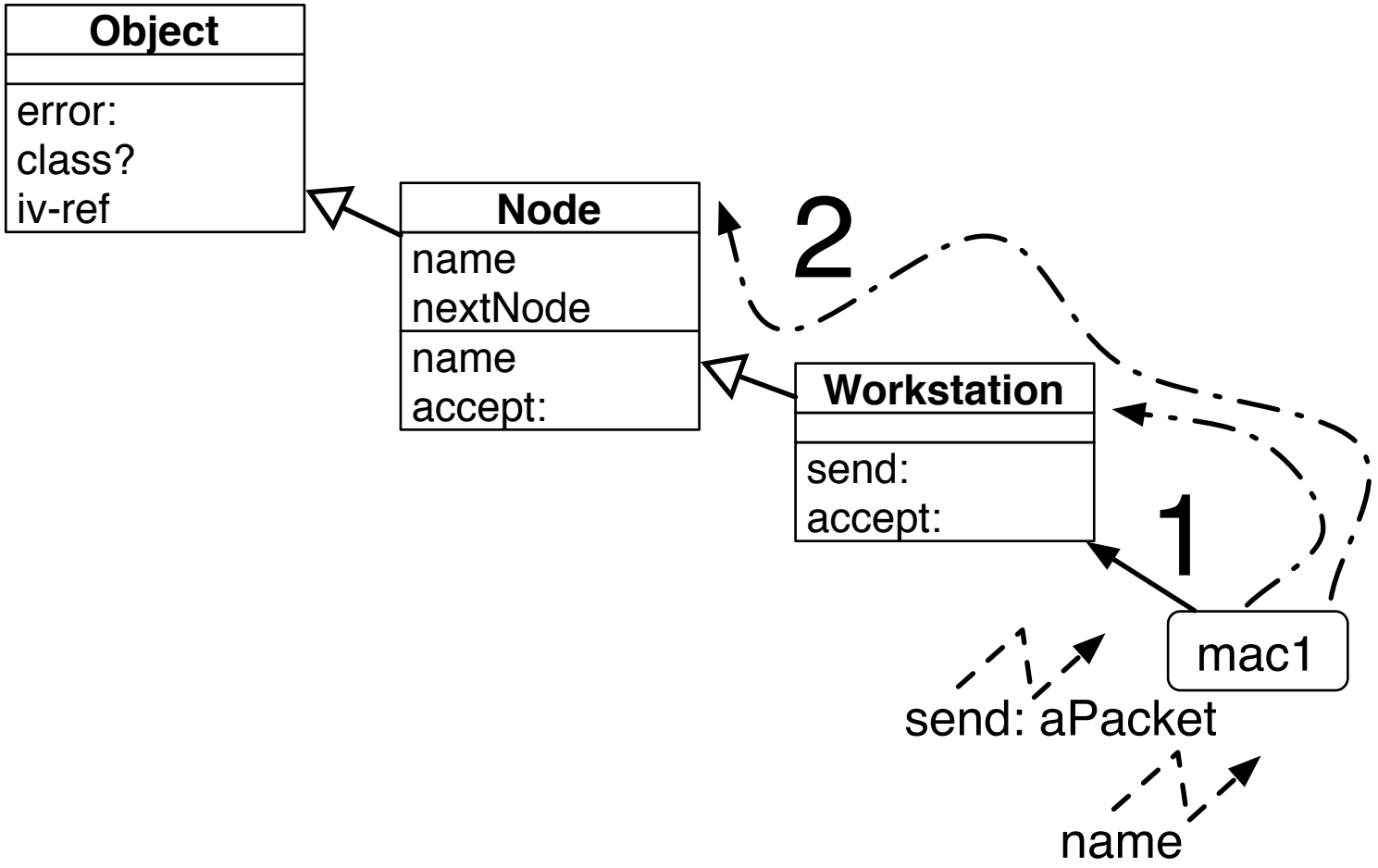
else if class == Object

then [receiver error selector]

else lookup (selector super(class) receiver)

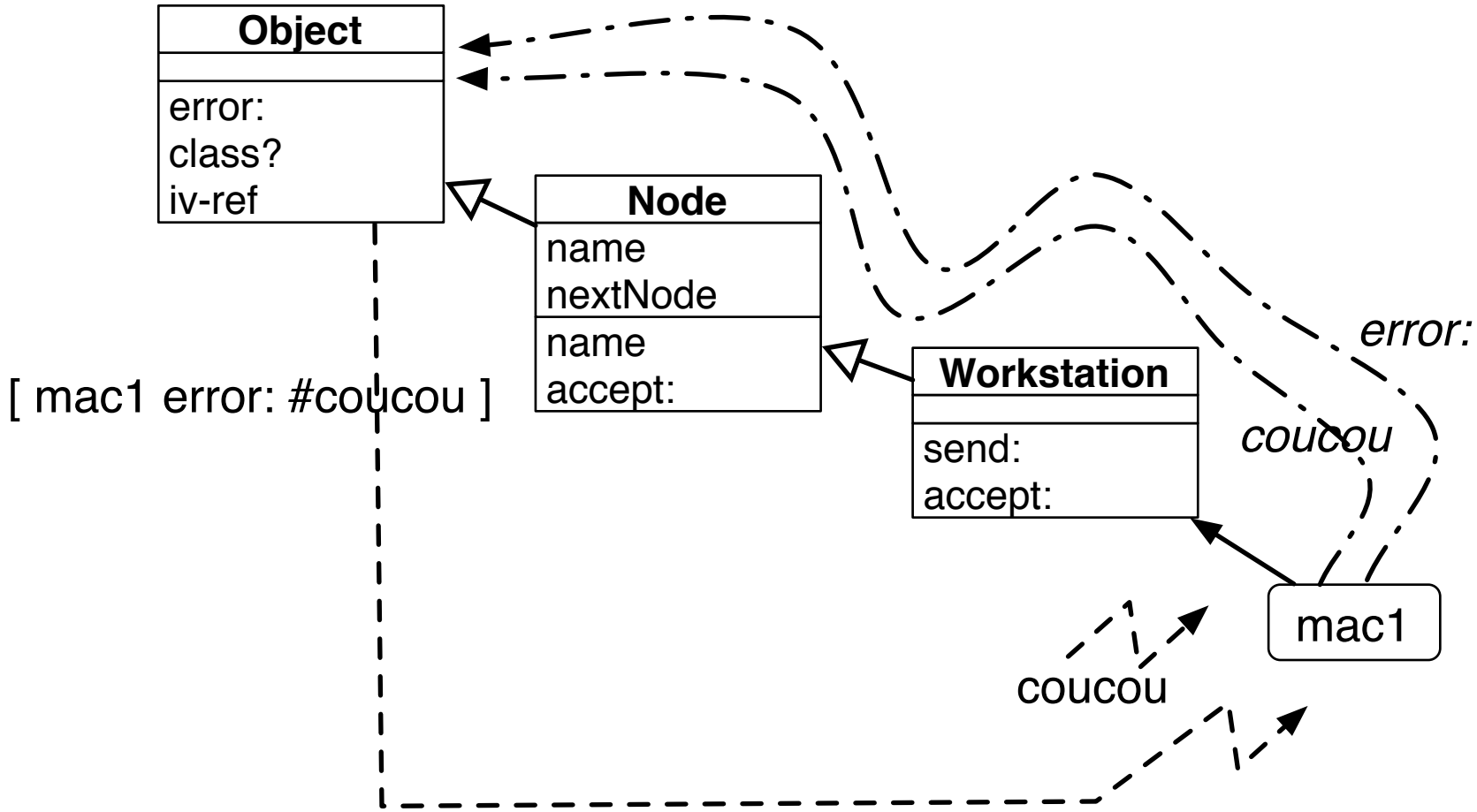
the error method can be specialized to handle the error.

Lookup (I)



RMod

Lookup (II)

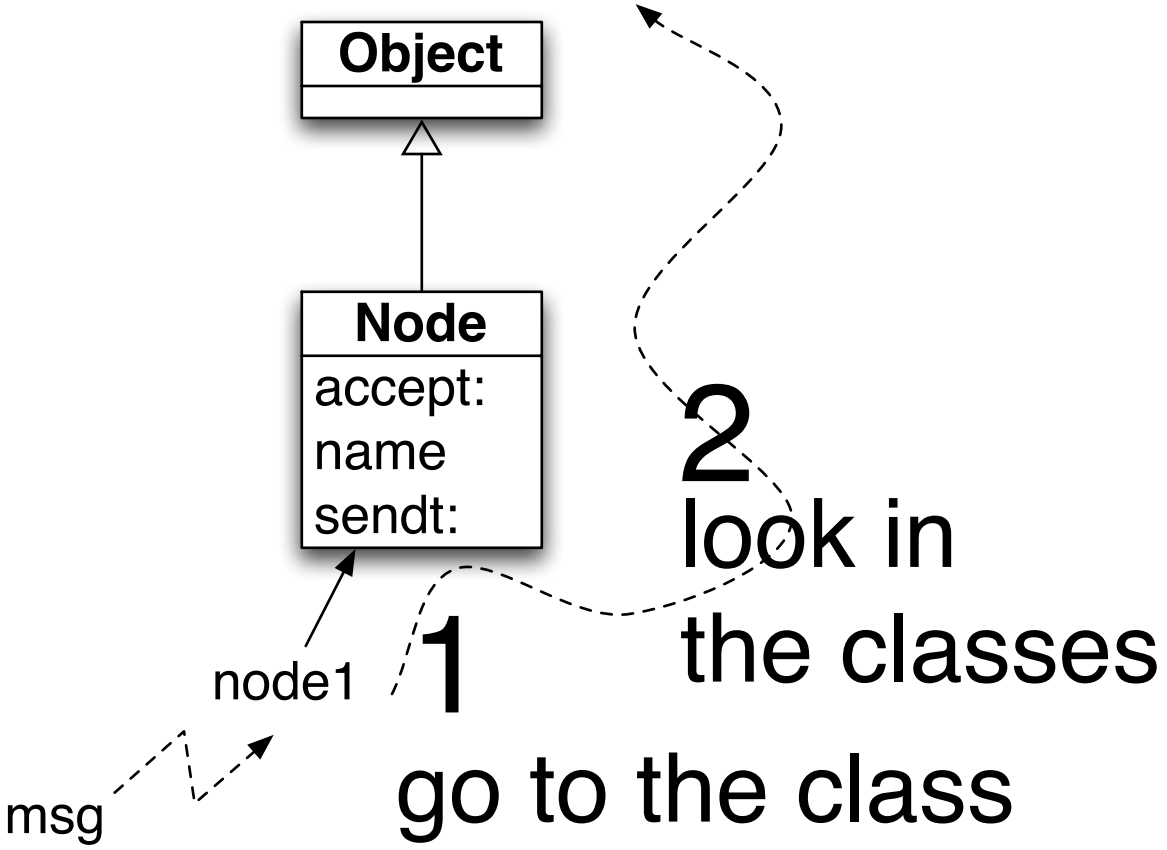


RMod

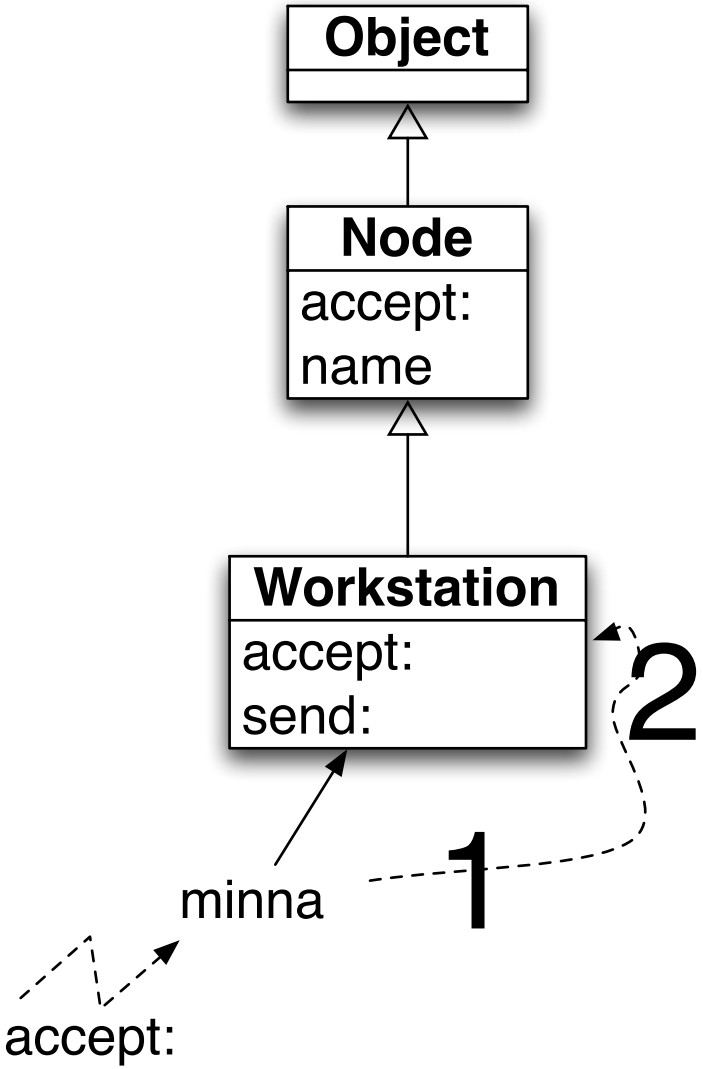
Method Lookup

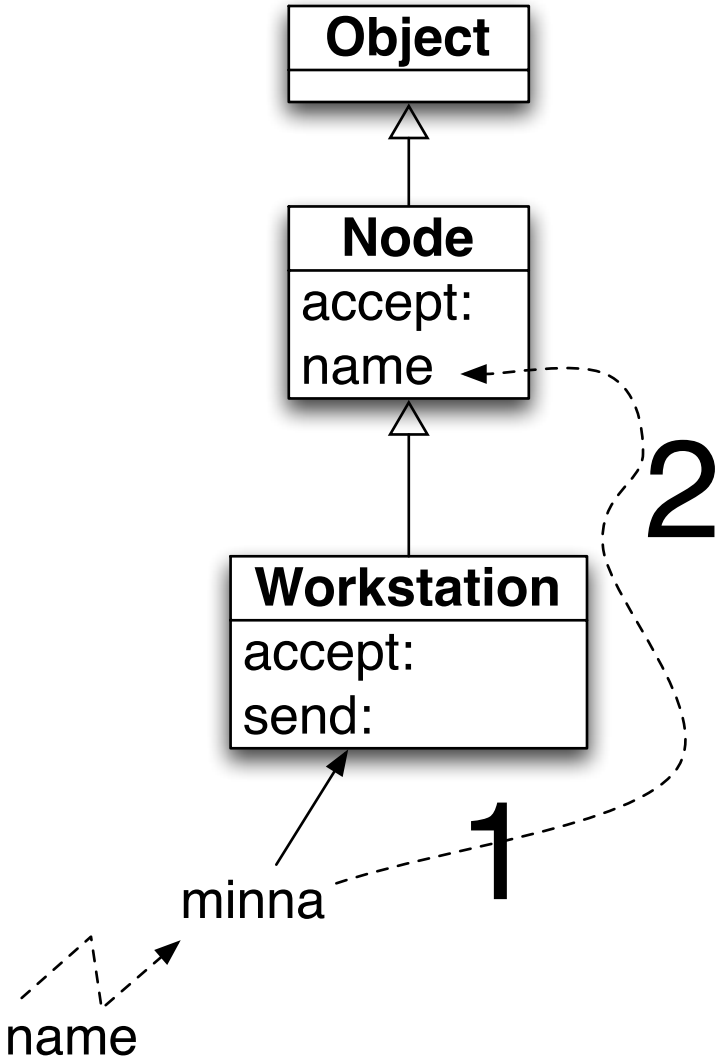
- Two steps process
- 1: The lookup starts in the ***CLASS*** of the ***RECEIVER***.
- 2: If the method is defined in the method dictionary, it is returned.
- 3: Otherwise the search continues in the superclasses of the receiver's class. If no method is found and there is no superclass to explore (class Object), this is an ERROR

Lookup: class and inheritance



Some Cases


Object
Node
accept:
name
Workstation
accept:
send:
2
minna
1
accept:


Object
Node
accept:
name
2
Workstation
accept:
send:
minna
1
name

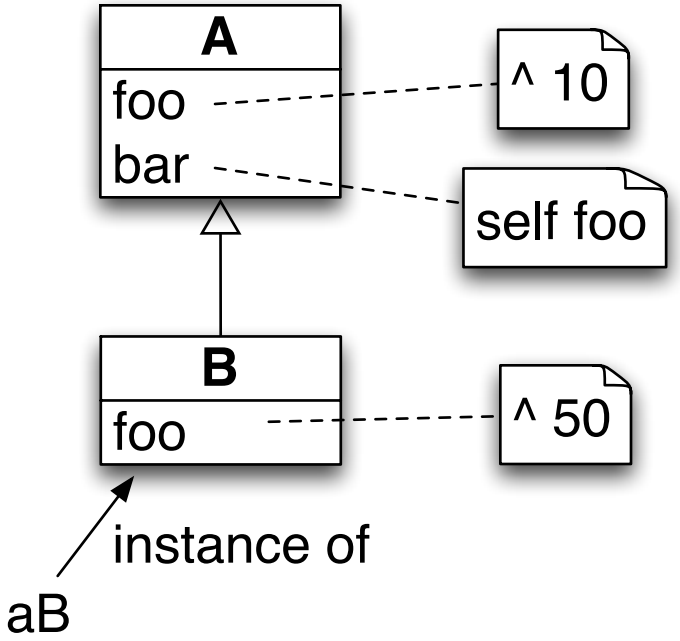
Method Lookup starts in Receiver Class

A new foo

B new foo

A new bar

B new bar



Method Lookup starts in Receiver Class

aB foo

(1) aB class => B

(2) Is foo defined in B?

(3) Foo is executed -> 50

aB bar

(1) aB class => B

(2) Is bar defined in B?

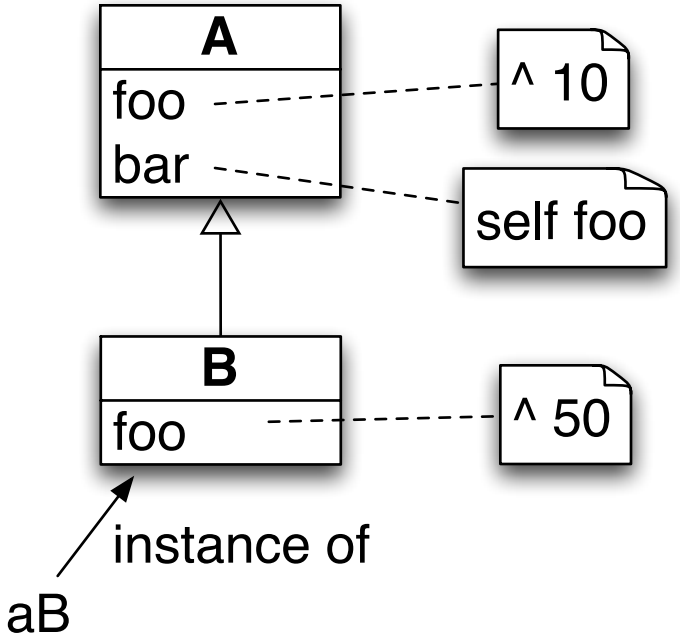
(3) Is bar defined in A?

(4) bar executed

(5) Self class => B

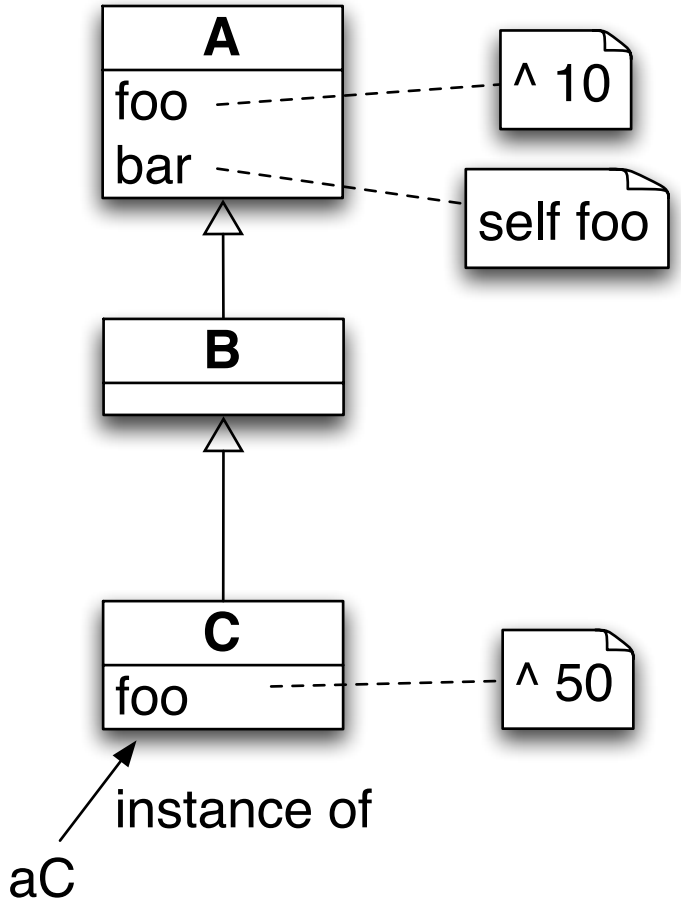
(6) Is foo defined in B

(7) Foo is executed -> 50



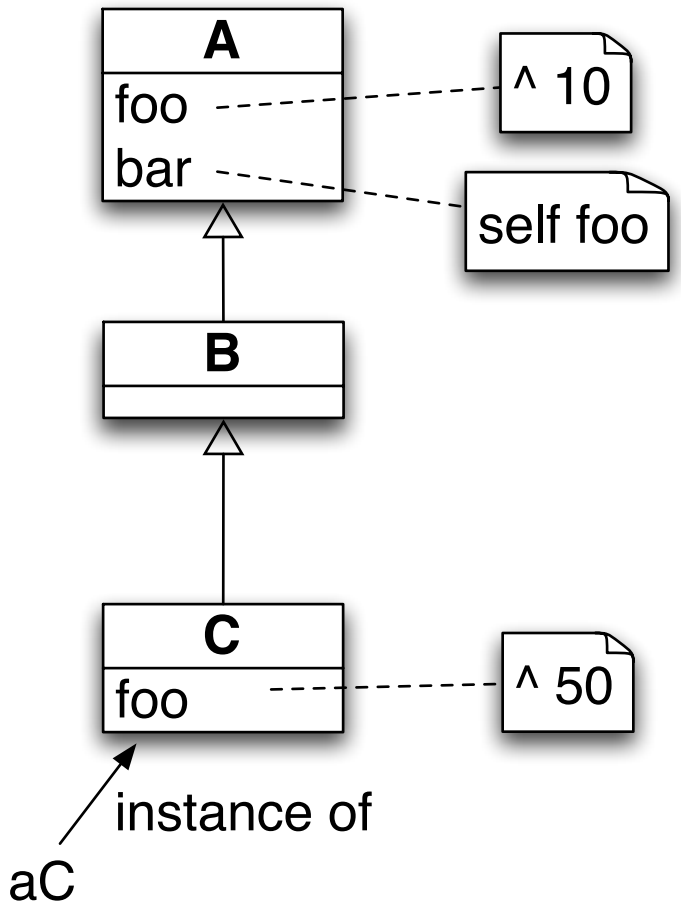
self **always** represents the receiver

- A new foo
- ->
- B new foo
- ->
- C new foo
- ->
- A new bar
- ->
- B new bar
- ->
- C new bar
- ->



self **always** represents the receiver

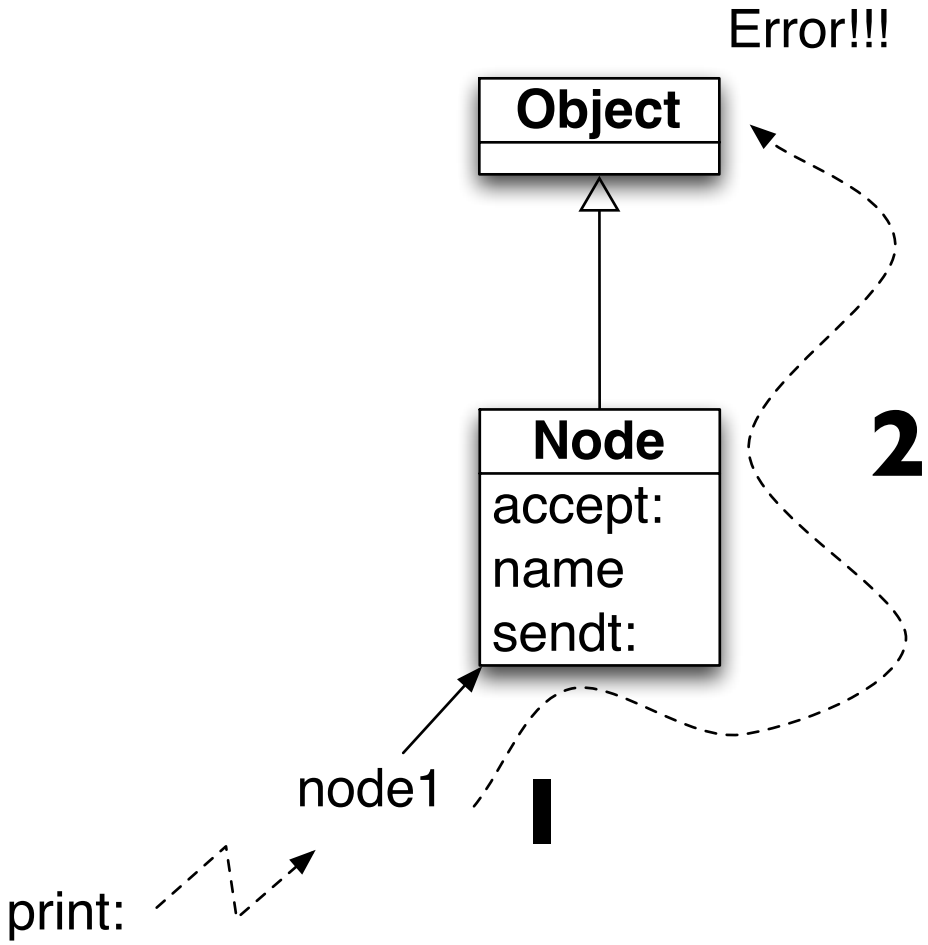
- A new foo
- -> 10
- B new foo
- -> 10
- C new foo
- -> 50
- A new bar
- -> 10
- B new bar
- -> 10
- C new bar
- -> 50



When message is not found

- If no method is found and there is no superclass to explore (class Object), a new method called #doesNotUnderstand: is sent to the receiver, with a representation of the initial message.

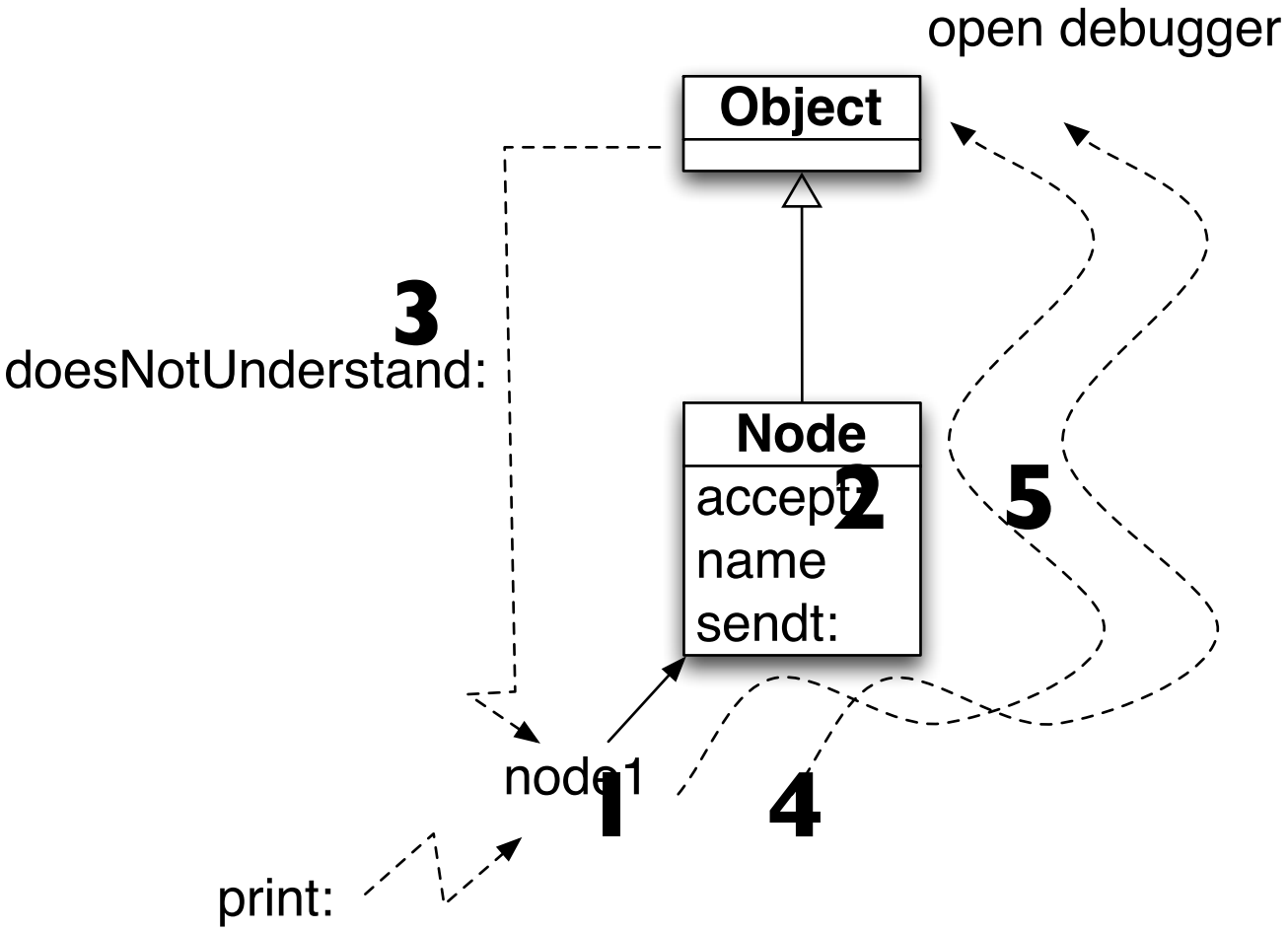
Graphically…



…in Smalltalk

- node1 print: aPacket
  - node is an instance of Node
  - print: is looked up in the class Node
  - print: is not defined in Node > lookup continues in Object
  - print: is not defined in Object => lookup stops + exception
  - message: node1 doesNotUnderstand: #(#print aPacket) is executed
  - node1 is an instance of Node so doesNotUnderstand: is looked up in the class Node
  - doesNotUnderstand: is not defined in Node => lookup continues in Object
  - doesNotUnderstand: is defined in Object => lookup stops + method executed (open a dialog box)

Graphically…



Roadmap

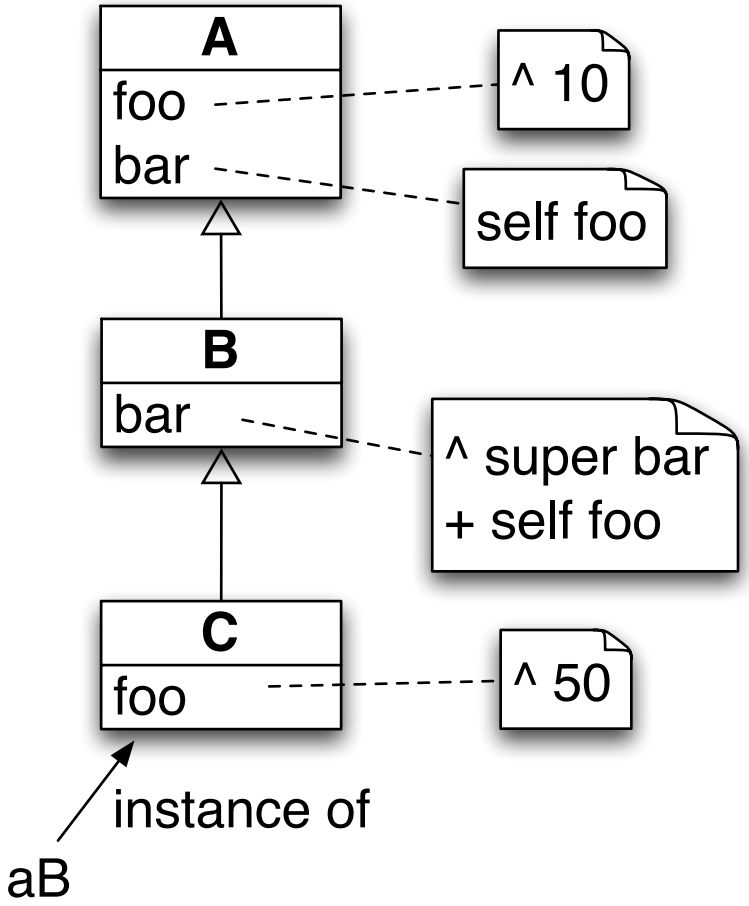
- Inheritance
- Method lookup
- ***Self/super difference***

The semantics of super

- Like self, ***super*** is a pseudo-variable that refers to the ***receiver*** of the message.
- It is used to invoke overridden methods.
- When using self, the lookup of the method begins in the class of the receiver.
- When using super, the lookup of the method begins in the ***superclass of the class of the method containing*** the super expression

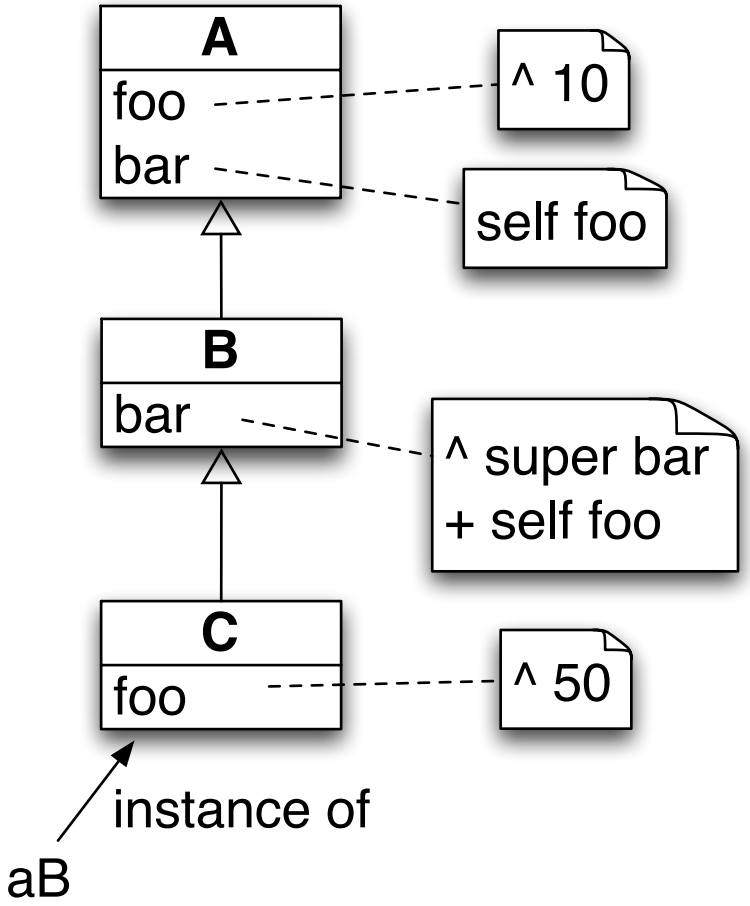
super *changes* lookup starting class

- A new foo
- A new bar
- B new foo
- B new bar
- C new foo
- C new bar



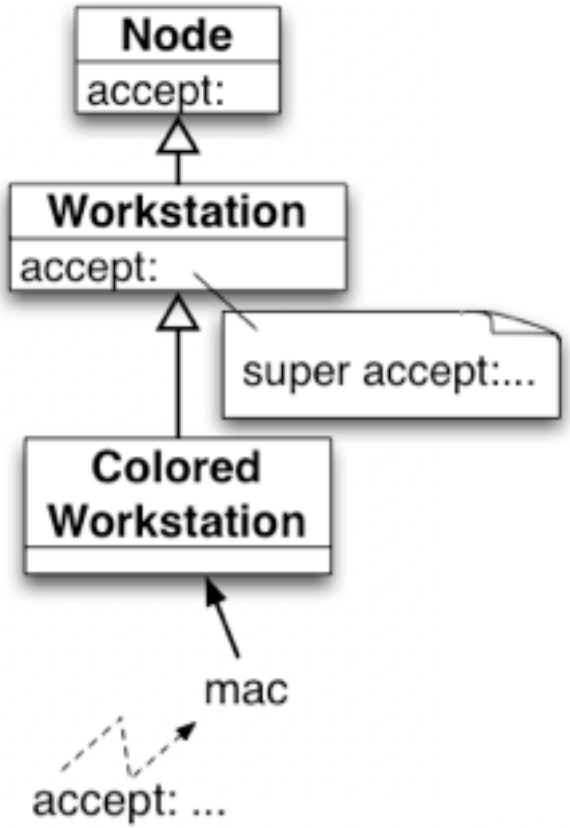
super *changes* lookup starting class

- A new bar
- -> 10
- B new bar
- -> 10 + 10
- C new bar
- -> 50 + 50



super is NOT the superclass of the receiver

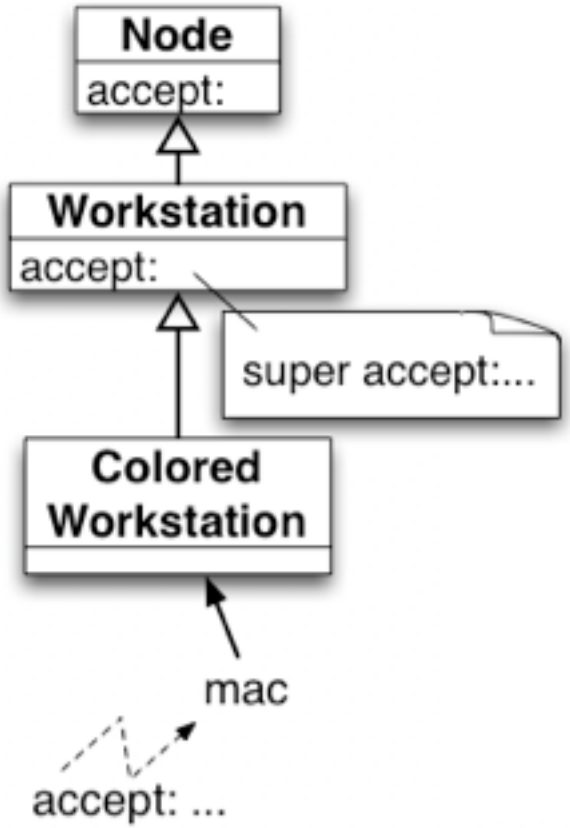
Suppose the WRONG hypothesis: *"The semantics of super is to start the lookup of a method in the superclass of the receiver class"*



super is NOT the superclass of the receiver

mac is instance of ColoredWorkStation
Lookup starts in ColoredWorkStation
Not found so goes up...

accept: is defined in Workstation
    lookup stops
    method accept: is executed
Workstation>>accept: does a super send
Our hypothesis: start in the super of the class of the receiver
=> superclass of class of a ColoredWorkstation is ... **Workstation !**



Therefore we look in workstation ***again***!!!

Dynamic vs. Static

- self is dynamic:
  - Using self the lookup of the method begins in the class of the receiver.
  - Bound at execution-time
- super is static:
  - Using super the lookup of the method begins in the superclass of the class of the method containing the super expression (not in the superclass of the receiver class).
  - Bound at compile-time

RoadMap

- Classes as objects
- ObjVlisp in 5 postulates
- Instance Structure and Behavior
- Class Structure
- Message Passing
- ***Object allocation & Initialization***
- Class creation
- Inheritance Semantics
- Bootstrapping

Object Creation

- Creation of **instances** of the class Point
  - [Point new :x 24 :y 6]
  - [Point new]
  - [Point new :y 10 :y 15]

- Creation of the **class** Point instance of Class
  - [Class new
    :name 'Point'
    :super 'Object'
    :i-v #(x y)
    :methods (x ...display ...)
    ]

Object Creation: new

- Object Creation = initialisation O allocation

- Creating an instance is the composition of two actions:
  memory allocation: ***allocate*** method
  object initialisation: ***initialize*** method

RMod

Instance creation

- [aClass new args] =
  [[aClass allocate] initialize args]

- new creates an object: class or final instances
- new is a class method

RMod

Object Allocation

- Should return:
  - Object with empty instance variables
  - Object with an identifier to its class

- Done by the method *allocate* defined on the metaclass Class

- allocate method is a class method

Allocation Examples

[Point allocate]
-> #(Point nil nil) for x and y

[Workstation allocate]
->#(Workstation nil nil) for ‘name’ and ‘nextNode’

[Class allocate]
->#(Class nil nil nil nil nil) for name, super, iv, keywords and methodDict

Object Initialization

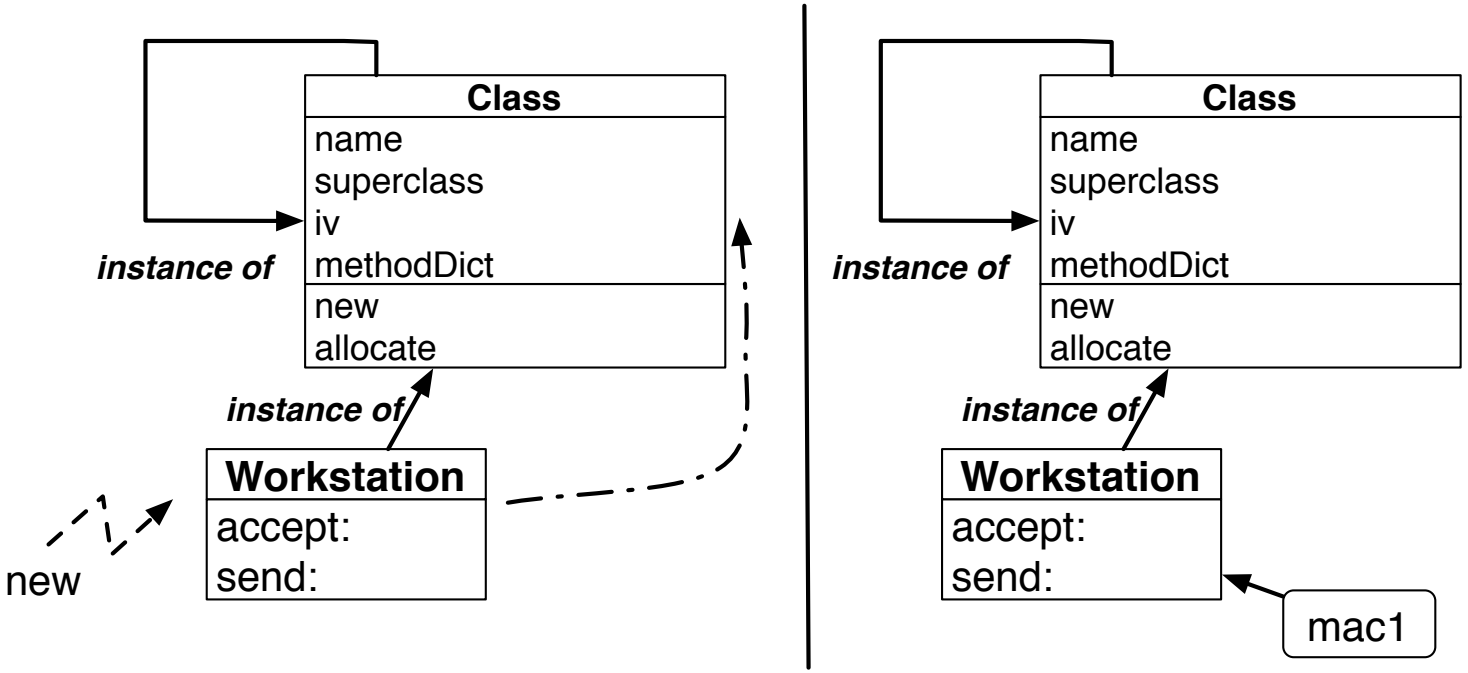
- To specify the value of the instance variables by means of keywords (:x ,:y) associated with the instances variables

- [Point new :y 6 :x 24]
  -> [#(Point nil nil) initialize (:y 6 :x 24)]
  -> #(Point 24 6)
- initialize: two steps
  - get the values specified during the creation. (y -> 6, x -> 24)
  - assign the values to the instance variables of the created object.

RMod

Instance Creation: Metaclass Role

Lookup method in the class of the receiver then we apply it to the receiver.

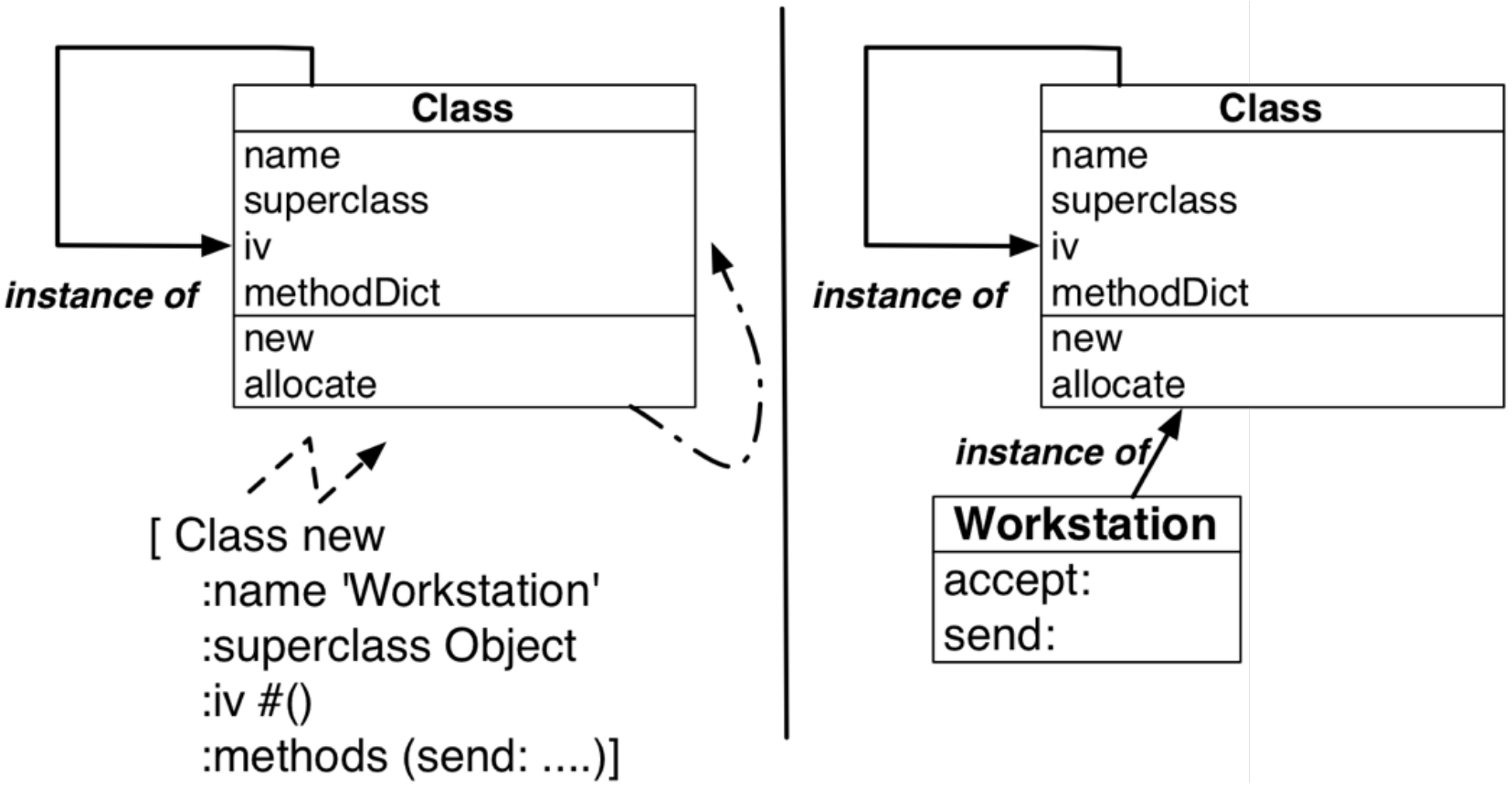


RoadMap

- Classes as objects
- ObjVlisp in 5 postulates
- Instance Structure and Behavior
- Class Structure
- Message Passing
- Object allocation & Initialization
- ***Class creation***
- Inheritance Semantics
- Bootstrapping

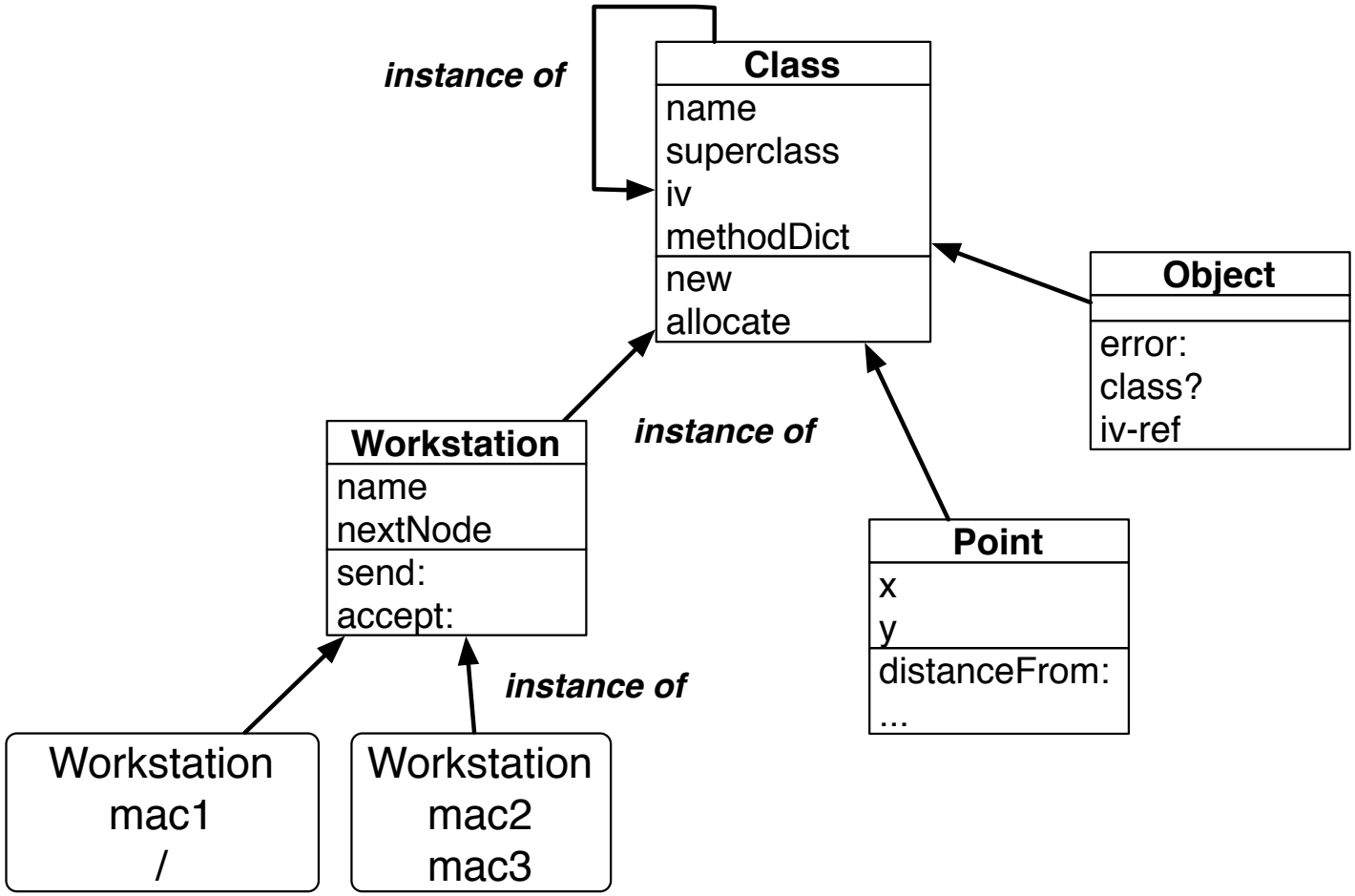
Class Creation

Look in the *class of the receiver*



RMod

Instantiation Graph

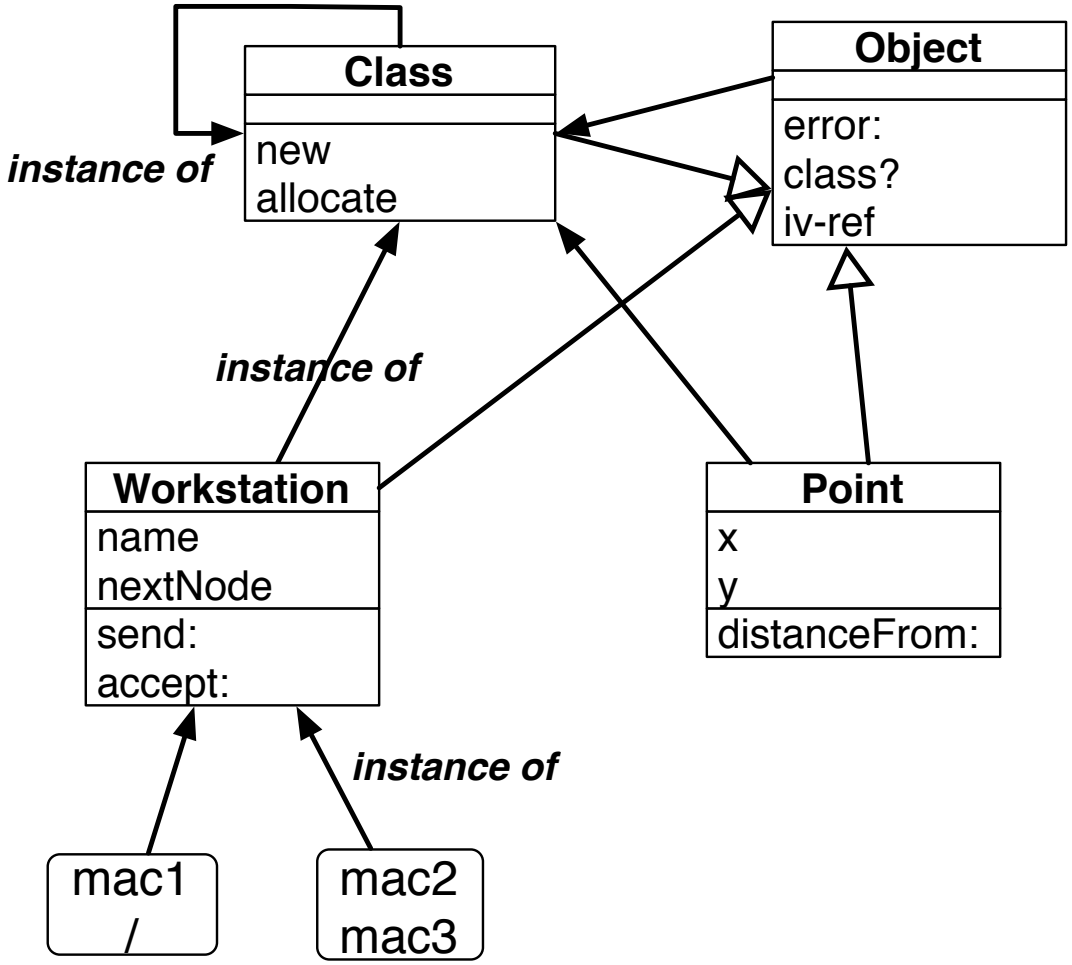


RMod

Instantiation Graph

- ***Class*** is the root of instantiation graph
- ***Object*** is a class that represents the minimal behavior of an object
- ***Object*** is a class so it is instance of ***Class***

A Simple Kernel



RMod

Examples

Abstract Classes

- The rule to define a new metaclass is to make it inherit from a previous one
- Prb. Abstract classes should not create instances
- Sol. Redefine the new method

Metaclass Use

[***Abstract*** new :name 'Node' :super 'Object' ….]

[Node new]
>>> Cannot create instance of class Node

[***Abstract*** new :name Abstract-Stack :super Object ....]

RMod

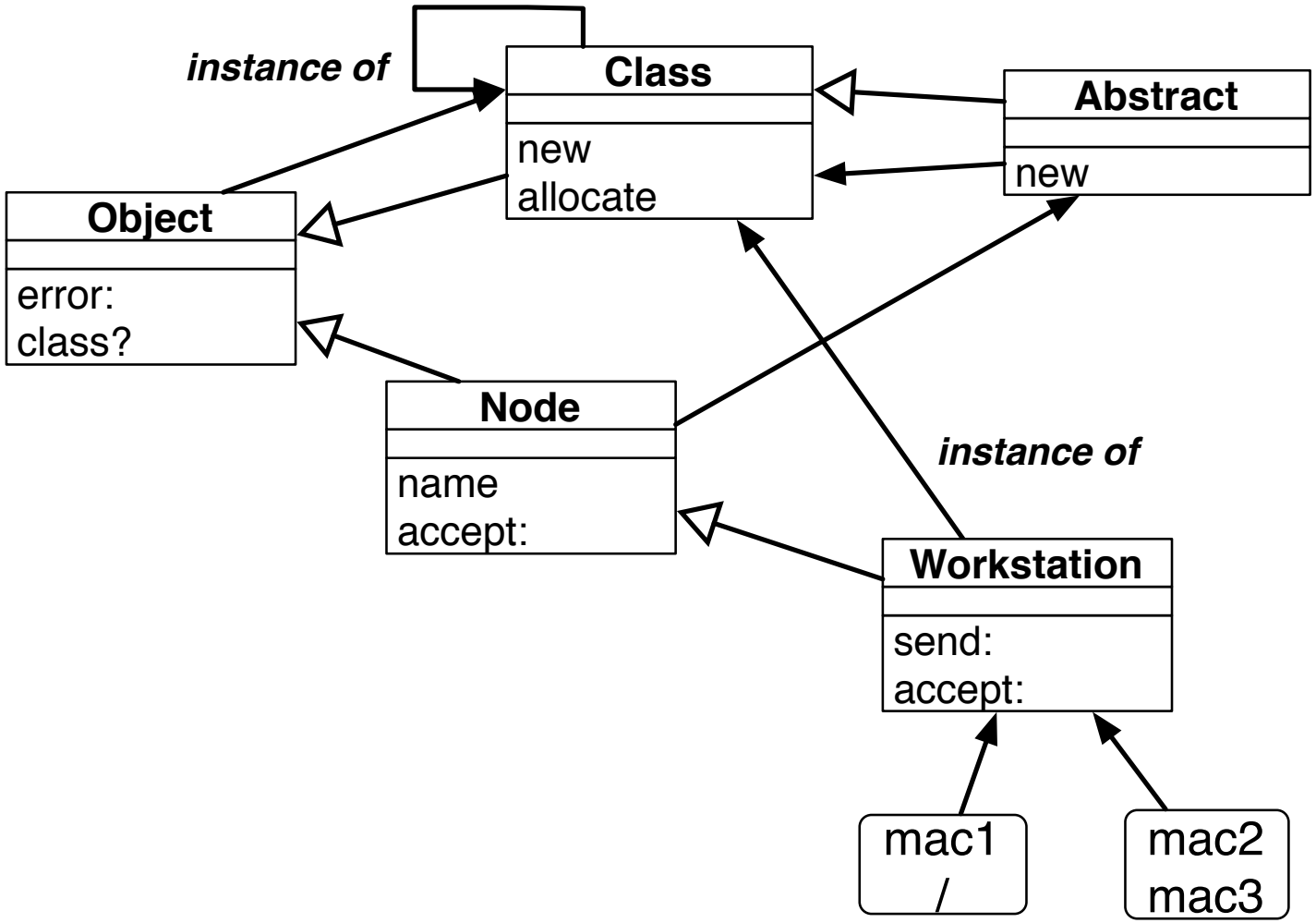
Metaclass Definition

- [Class new
  :name 'Abstract'
  :super 'Class'
  :methods
  (new (lambda (self initargs)
  (self error "Cannot create instance
  of class %s" self name))]

- Abstract is a class: It is instance of ***Class***

- Abstract define class behavior: It inherits from ***Class***

Complete Picture



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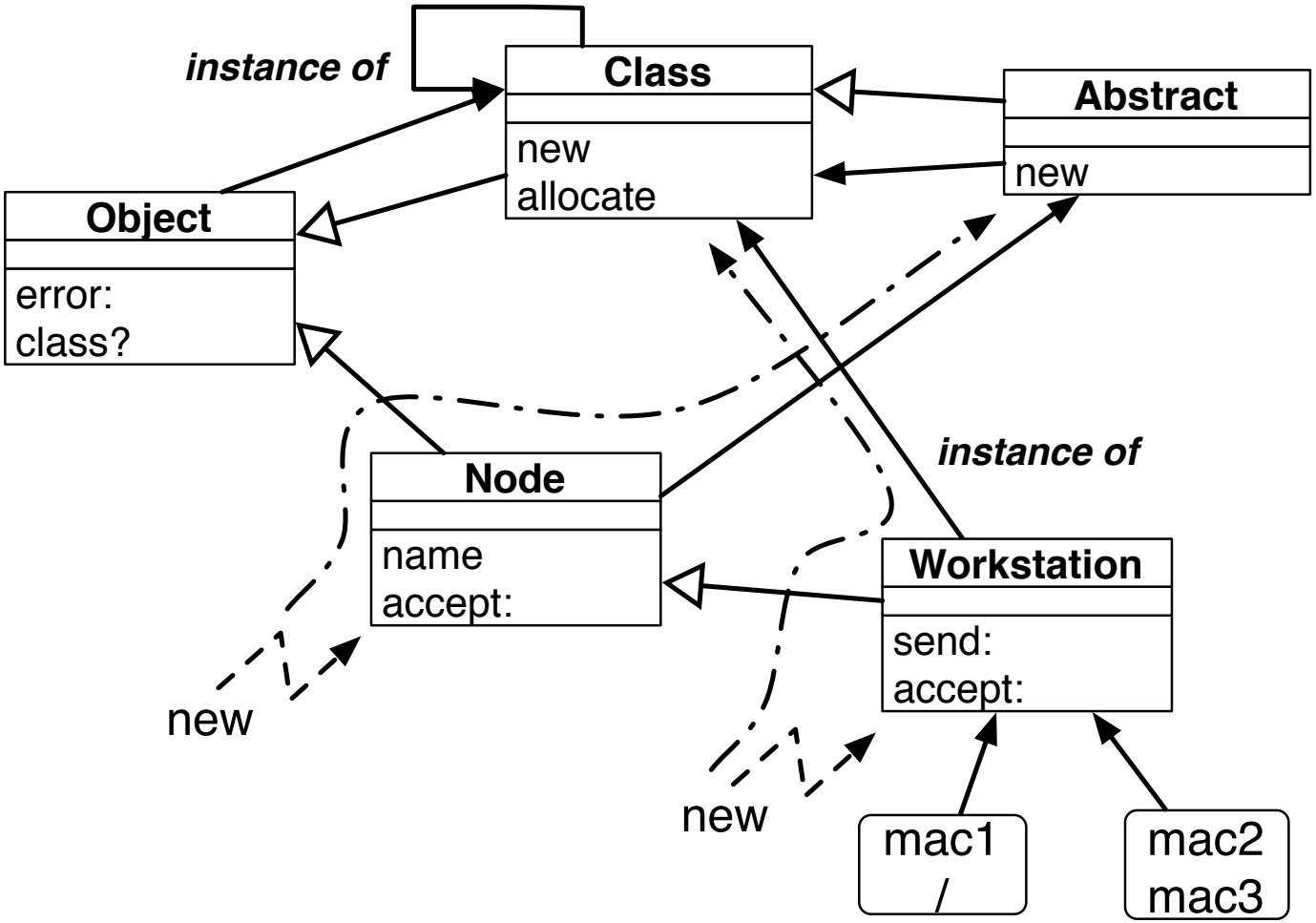
Method Lookup



RMod

RoadMap

- Classes of objects
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- ***Some points***
- Bootstrapping


RMod

Class initialization

- initialize is defined on both classes ***Class*** and ***Object***

- on ***Object*** values are extracted from initarg list and assigned to the allocated instance

  [#(Point nil nil) initialize (:y 6 :x 24)]
  => #(Point 6 24)

- Initialize is looked up in class of #(Point nil nil): ***Point***
- Then in its superclass: ***Object***

Class initialization

[Class new *:name 'Point' :super Object :i-v (x y)*...]
[#(Class nil nil nil...) initialize (*:name Point :super Object :i-v (x y)*…]

(1) a class as an *object* (executing initialize method)

[#(Class 'Point' Object (x y) nil #(x: (mkmethod...) y: (mkmethod ...)]

(2) inheritance of instance variables,
keyword definition,
class declaration to the env
[#(Class Point Object (*class* x y) (:x :y) #(x: (...) y: (...)]

About the 6th Postulate

6th Postulate: class variable of anObject = instance variable of anObject's class

Example:

Pig color is always pink

Pig class

name super i-v ... **color**

So class variables are shared by all the instances of a class.

Why the 6th is wrong!

Semantically class variables are not instance variables of object'class!

Instance variable of metaclass should represent class information not instance information shared at the meta-level.

Metaclass information should represent classes not domain objects

Solution

A class possesses an instance variable that stores structure that represents instance ***shared-variable*** and their values.

[Class new
:name 'Pig' :super Object
:i-v (weigth name) ***:shared-var: #(color)***]

A class has the possibility to define shared variables

RMod

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- Bootstrapping

Recap: Class class

- Initial metaclass
- Reflective: its instance variable values describe instance variables of any classes in the system (itself too)
- Defines the behavior of all the classes
- Inherits from Object class
- Root of the instantiation graph
- Instance variables: name, super, iv, methodDict
- Some Methods
  - new, allocate, initialize (instance variable inheritance, keywords, method compilation)
  - class?, subclass-of?

Recap: Object class

- Defines the behavior shared by all the objects of the system
- Instance of Class
- Root of the inheritance tree: all the classes inherit directly or indirectly from Object
- Its instance variable: class
- Its methods:
- initialize (initialisation les variables d'instance), error, class, metaclass?, class?, iv-set, iv-ref

RoadMap

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- Recap
- ***Bootstrapping***

Bootstrapping

- Mandatory to have ***Class*** instance of itself
- Be lazy: Use as much as possible of the system to define itself
- Idea: Cheat the system so that it believes that ***Class*** already exists as instance of itself, then create ***Object*** and ***Class*** inherits from Object as normal classes

Three Steps Bootstrap

1- Manual creation of the instance that represents the class ***Class*** with

inheritance simulation (class instance variable from ***Object*** class)

only the necessary methods for the creation of the classes (new, allocate and initialize)

Creation of the class

Object [Class new :name 'Object'....]

definition of all the method of Object

Redefinition of ***Class***

[***Class*** new :name 'Class' :super ***Object***.....]

definition of all the methods of Class

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Summary

Classes are objects too

Instantiation = initialize(allocate())

Class is the instantiation root

Object is the inheritance root

One single method lookup for classes and instances

- first go to the class
- then follow inheritance chain

super and self are referring to the message receiver but super changes the method lookup

Implementation

#(#ObjPoint 10 20)

1 = classId
self offsetForClass

+.... ivs

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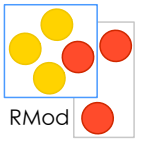
Structure of Classes

#(class name superclass ivs keys

#(#ObjClass #ObjPoint #ObjObject #(class x y) ....

```
lookupMethodInClass: class
    | currentClass dictionary found |
    <inline: false>
    self assert: class ~= objectMemory nilObject.
    currentClass := class.
    [currentClass ~= objectMemory nilObject]
        whileTrue:
        [dictionary := objectMemory fetchPointer: MethodDictionaryIndex ofObject:
currentClass.
        found := self lookupMethodInDictionary: dictionary.
        found ifTrue: [^currentClass].
        currentClass := self superclassOf: currentClass].
    "Cound not find a normal message -- raise exception #doesNotUnderstand:"
    self createActualMessageTo: class.
    messageSelector := objectMemory splObj: SelectorDoesNotUnderstand.
    self sendBreak: messageSelector + BaseHeaderSize
        point: (objectMemory lengthOf: messageSelector)
        receiver: nil.
    ^self lookupMethodInClass: class
```

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    self sendBreak: messageSelector + BaseHeaderSize
        point: (objectMemory lengthOf: messageSelector)
        receiver: nil.
    ^self lookupMethodInClass: class
```


```
ookupMethodInDictionary: dictionary
    "This method lookup tolerates integers as Dictionary keys to suoport
     execution of images in which Symbols have been compacted out."
    | length index mask wrapAround nextSelector methodArray |

    length := objectMemory fetchWordLengthOf: dictionary.
            ...
    index := SelectorStart + (mask bitAnd: ((objectMemory isIntegerObject: messageSelector)
                                ifTrue: [objectMemory integerValueOf: messageSelector]
                                ifFalse: [objectMemory hashBitsOf: messageSelector])).

    "It is assumed that there are some nils in this dictionary, and search will
     stop when one is encountered. However, if there are no nils, then wrapAround
     will be detected the second time the loop gets to the end of the table."
    wrapAround := false.
    [true] whileTrue:
        [nextSelector := objectMemory fetchPointer: index ofObject: dictionary.
         nextSelector = objectMemory nilObject ifTrue: [^ false].
         nextSelector = messageSelector ifTrue:
                [methodArray := objectMemory fetchPointer: MethodArrayIndex ofObject: dictionary.
            newMethod := objectMemory fetchPointer: index - SelectorStart ofObject:
          methodArray.
                ^true].
         index := index + 1.
         index = length ifTrue:
                [wrapAround ifTrue: [^false].
                 wrapAround := true.
                 index := SelectorStart]].
```

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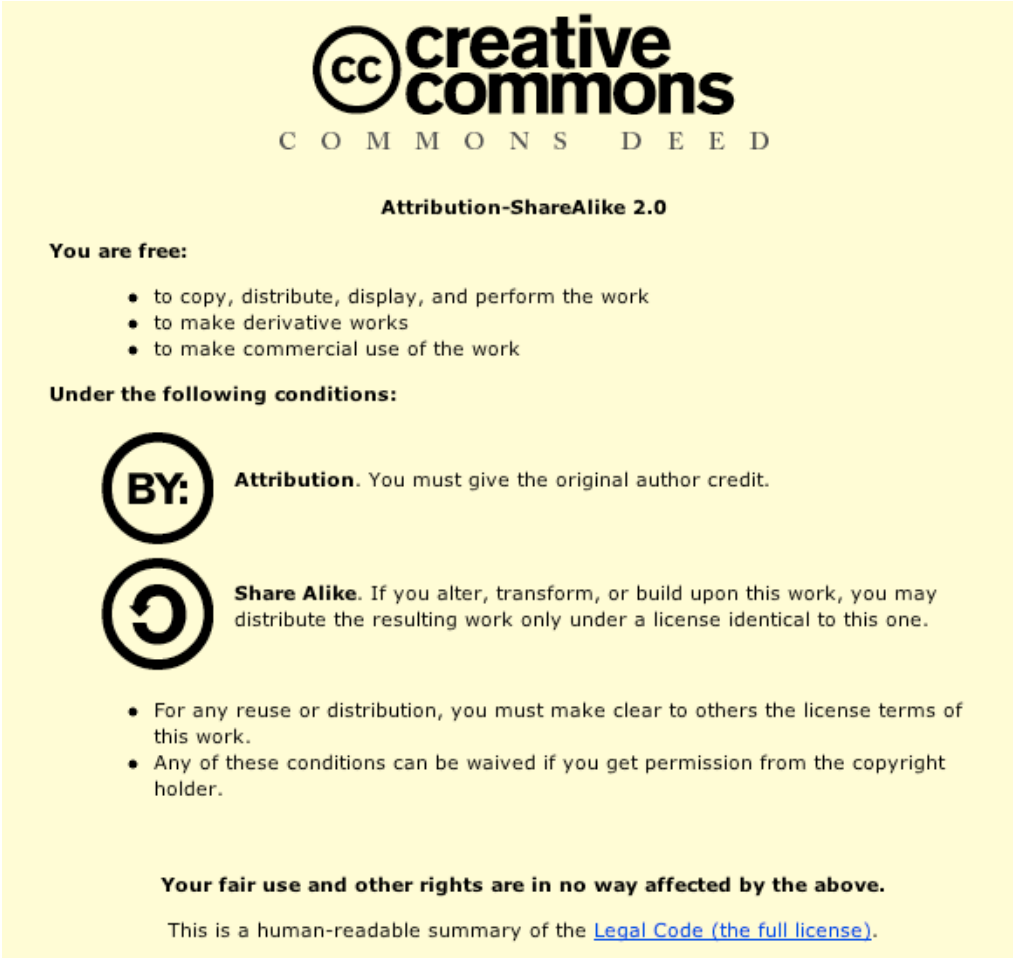

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