7. Understanding Metaclasses

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Roadmap

- Metaclasses in 7 points
- Indexed Classes
- Class Instance Variables
- Class Variables
- Pool Dictionaries

Metaclasses in 7 points

1. Every object is an instance of a class
2. Every class eventually inherits from Object
3. Every class is an instance of a metaclass
4. The metaclass hierarchy parallels the class hierarchy
5. Every metaclass inherits from Class and Behavior
6. Every metaclass is an instance of Metaclass
7. The metaclass of Metaclass is an instance of Metaclass

Adapted from Goldberg & Robson, *Smalltalk-80 — The Language*

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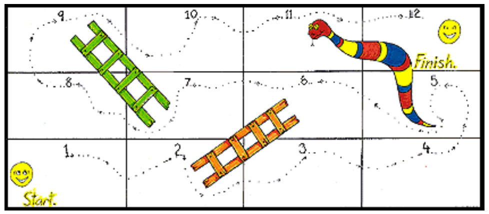
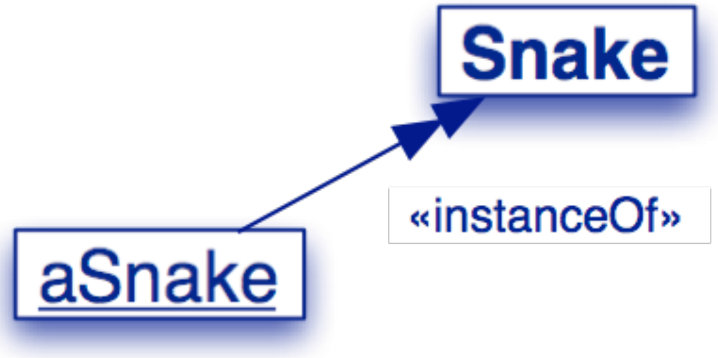
1. Every object is an instance of a





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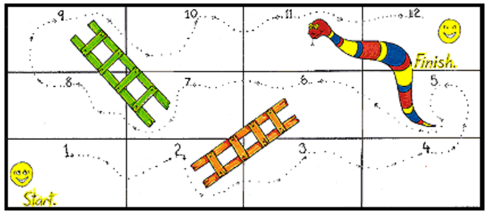
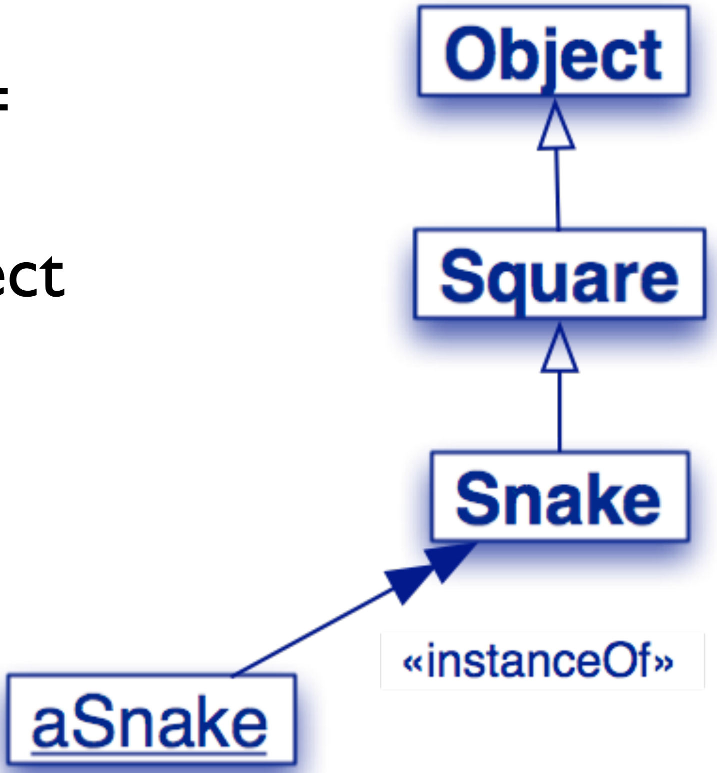
2. Every class inherits from Object

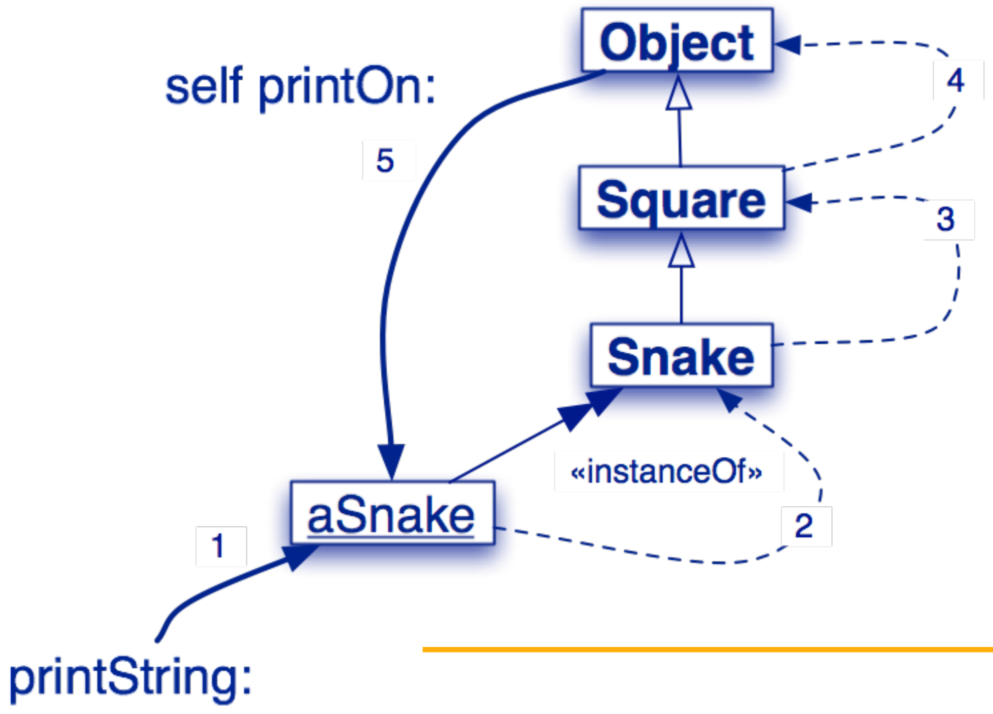
Every object is-an Object =
The class of every object
ultimately inherits from Object





The Meaning of is-a

- When an object receives a message, the method is looked up in the method dictionary of its class, and, if necessary, its superclasses, up to Object



Responsibilities of Object

- **`Object`**
  - represents the common object behavior
    - error-handling, halting …
  - all classes should inherit ultimately from `Object`

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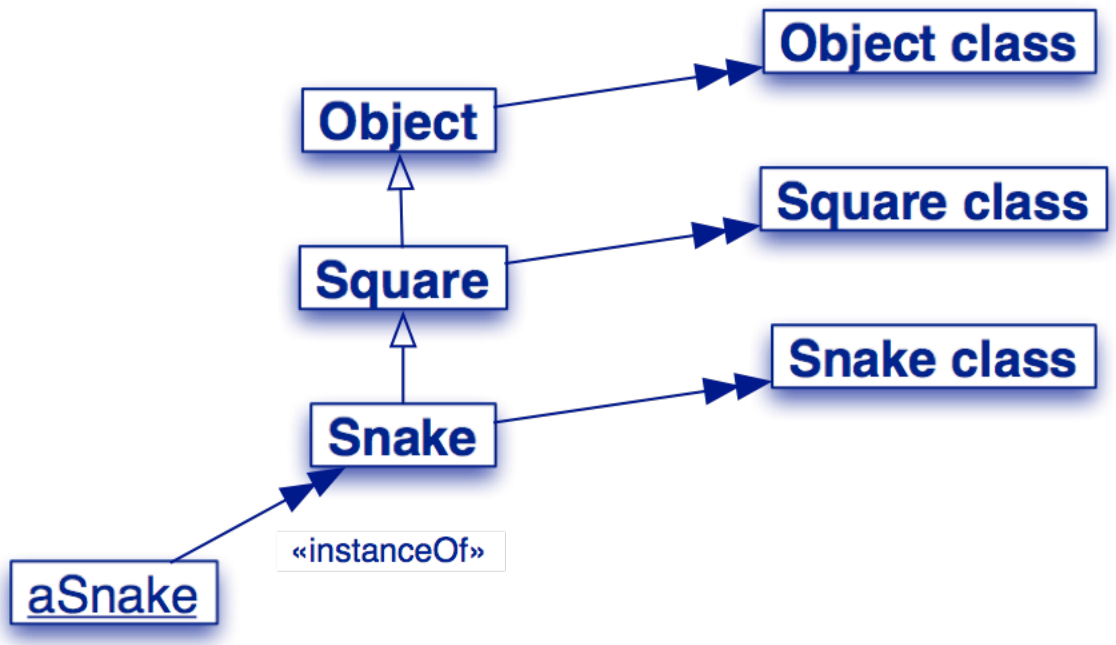
3. Every class is an instance of a

- Classes are objects too!
  - Every class X is the unique instance of its metaclass, called X class



Metaclasses are implicit

- There are no explicit metaclasses
  - Metaclasses are created implicitly when classes are created
  - No sharing of metaclasses (unique metaclass per class)

Metaclasses by Example

```
Square allSubclasses
Snake allSubclasses

Snake allInstances
Snake instVarNames

Snake back: 5
Snake selectors

Snake canUnderstand: #new
Snake canUnderstand: #setBack:
```

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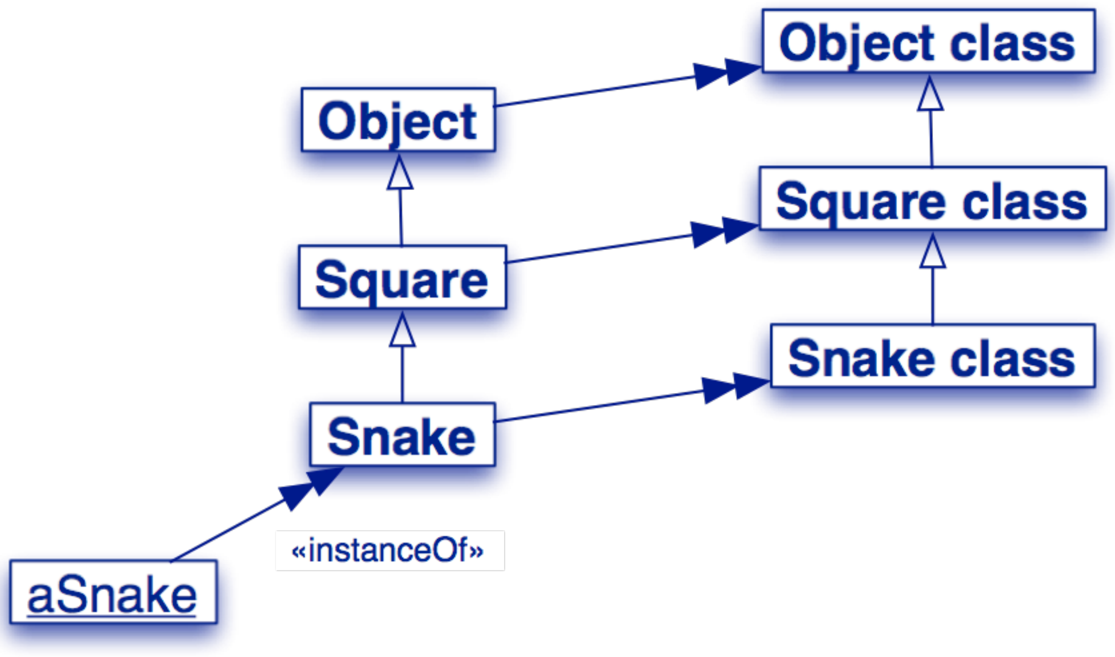
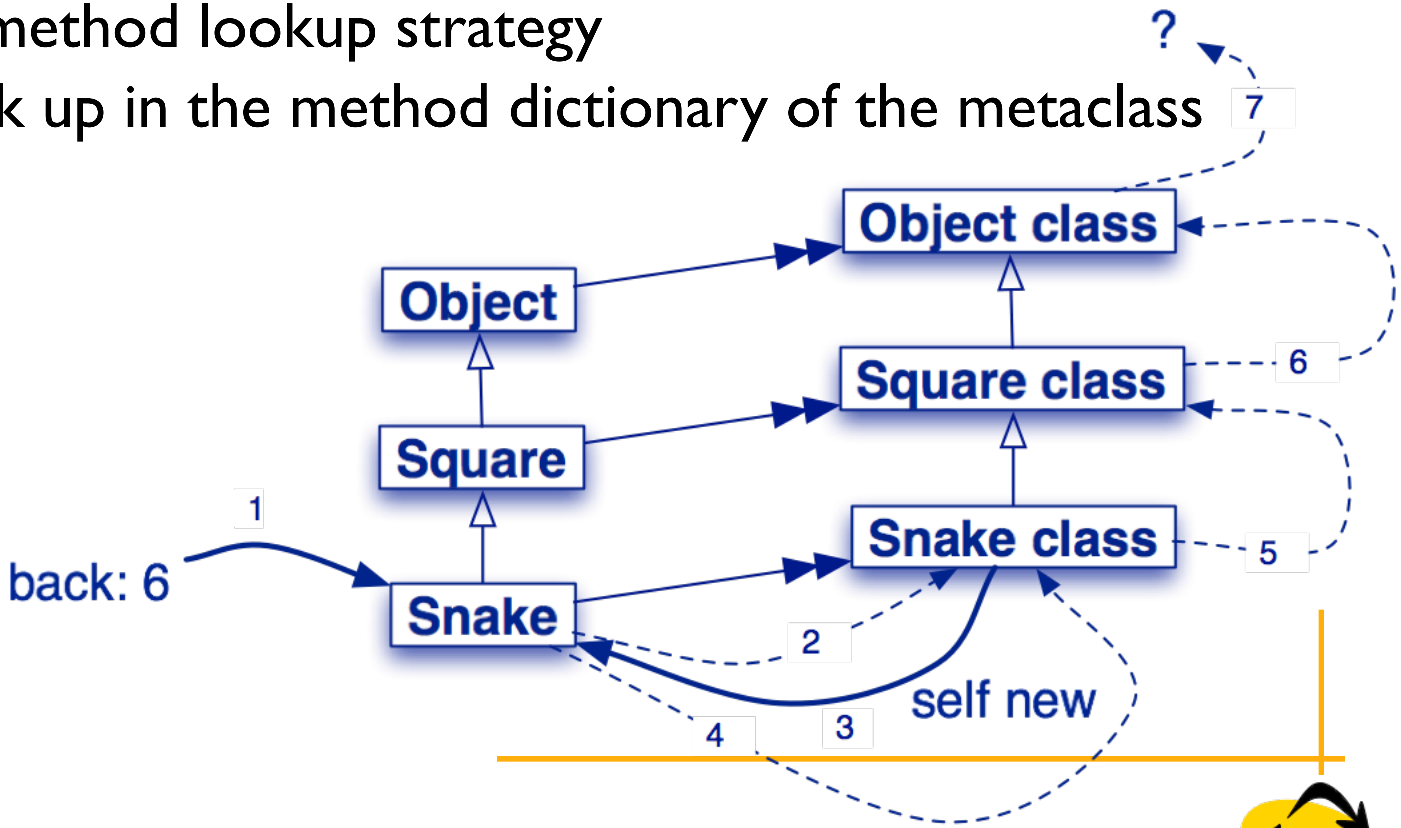
4. The metaclass hierarchy

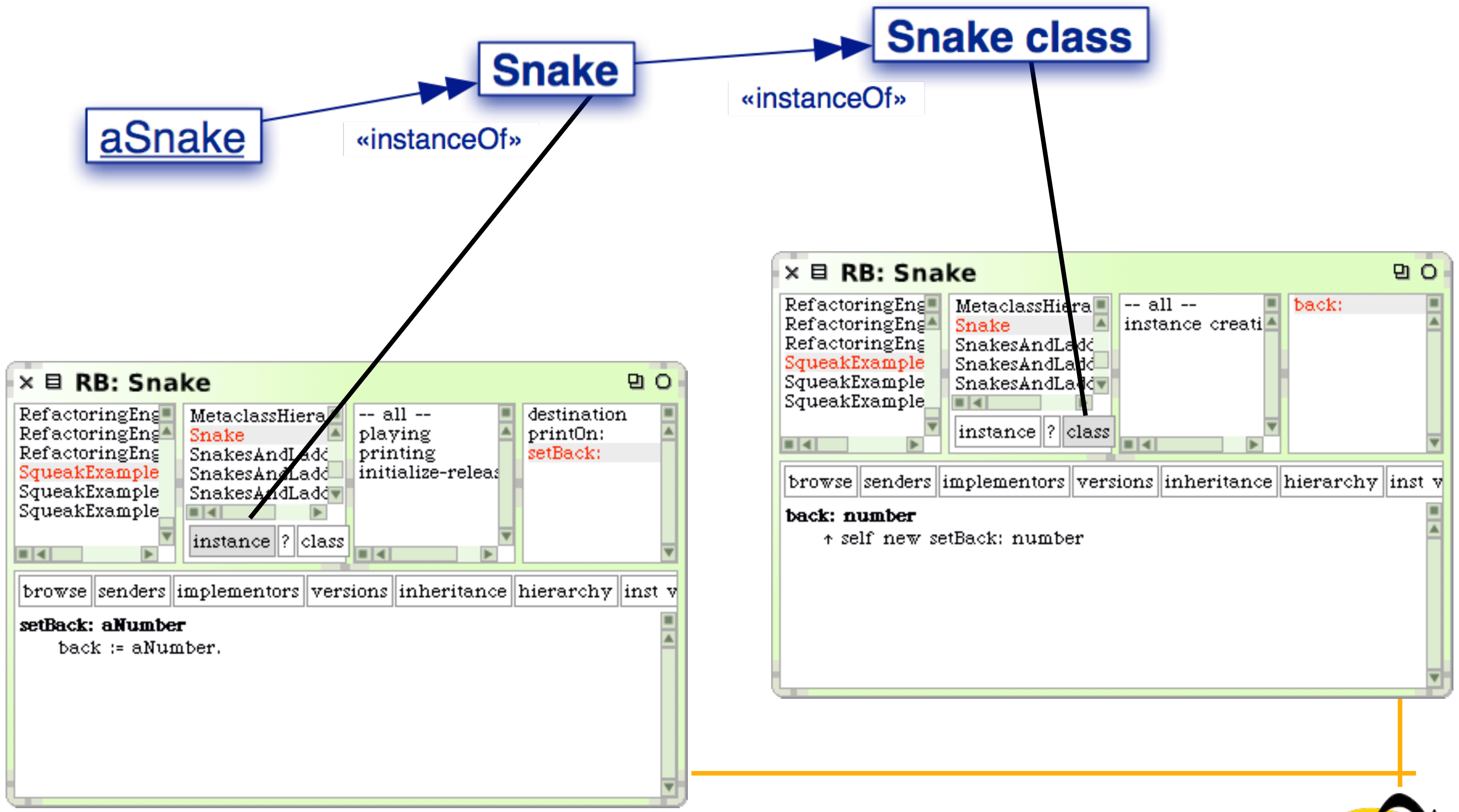


Uniformity between Classes and Objects

- Classes are objects too, so …
  - Everything that holds for objects holds for classes as well
  - Same method lookup strategy
    - Look up in the method dictionary of the metaclass



About the Buttons



```
setBack: aNumber
    back := aNumber.
```

```
back: number
    ↑ self new setBack: number
```

Metaclasses in 7 points

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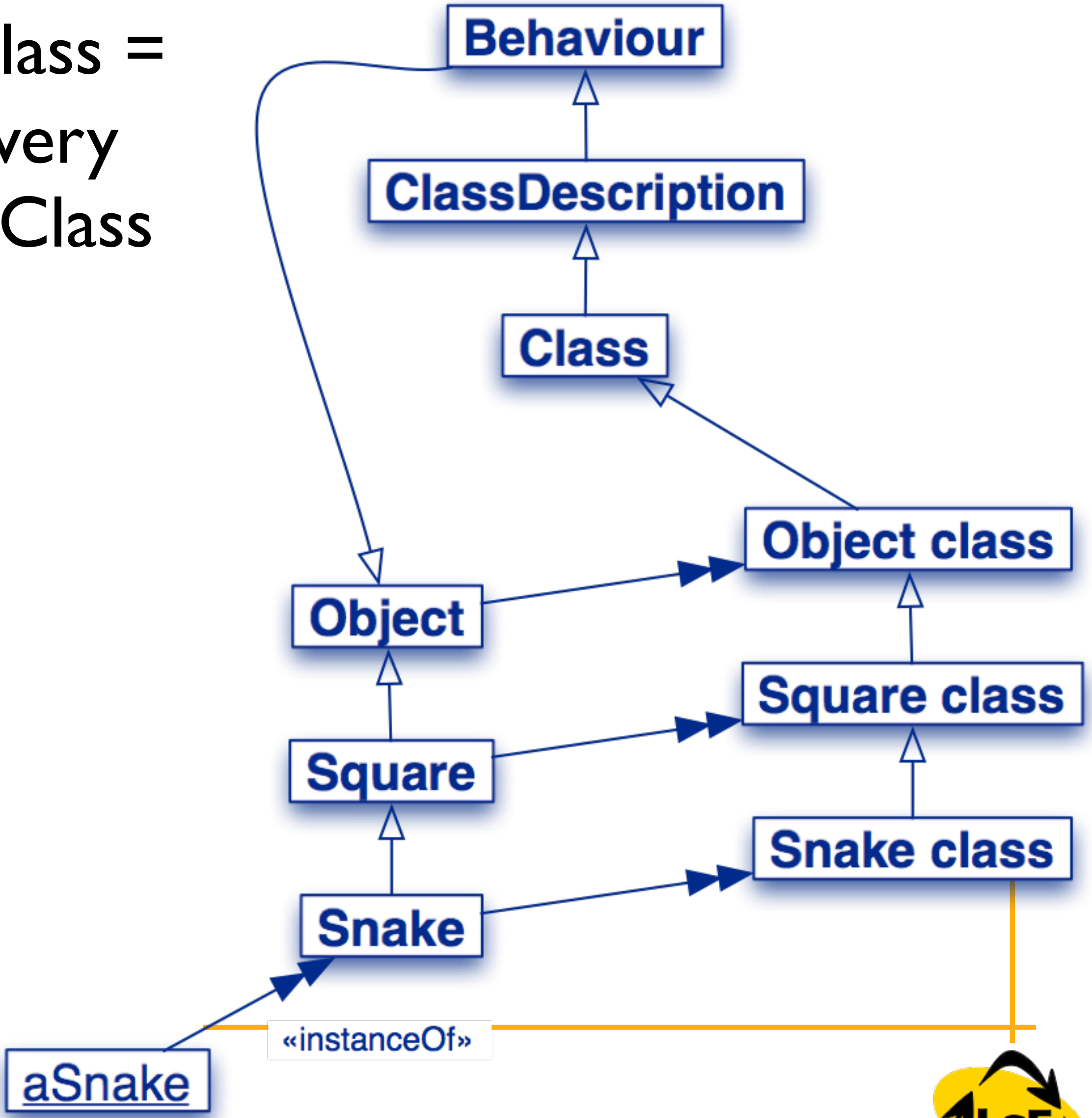
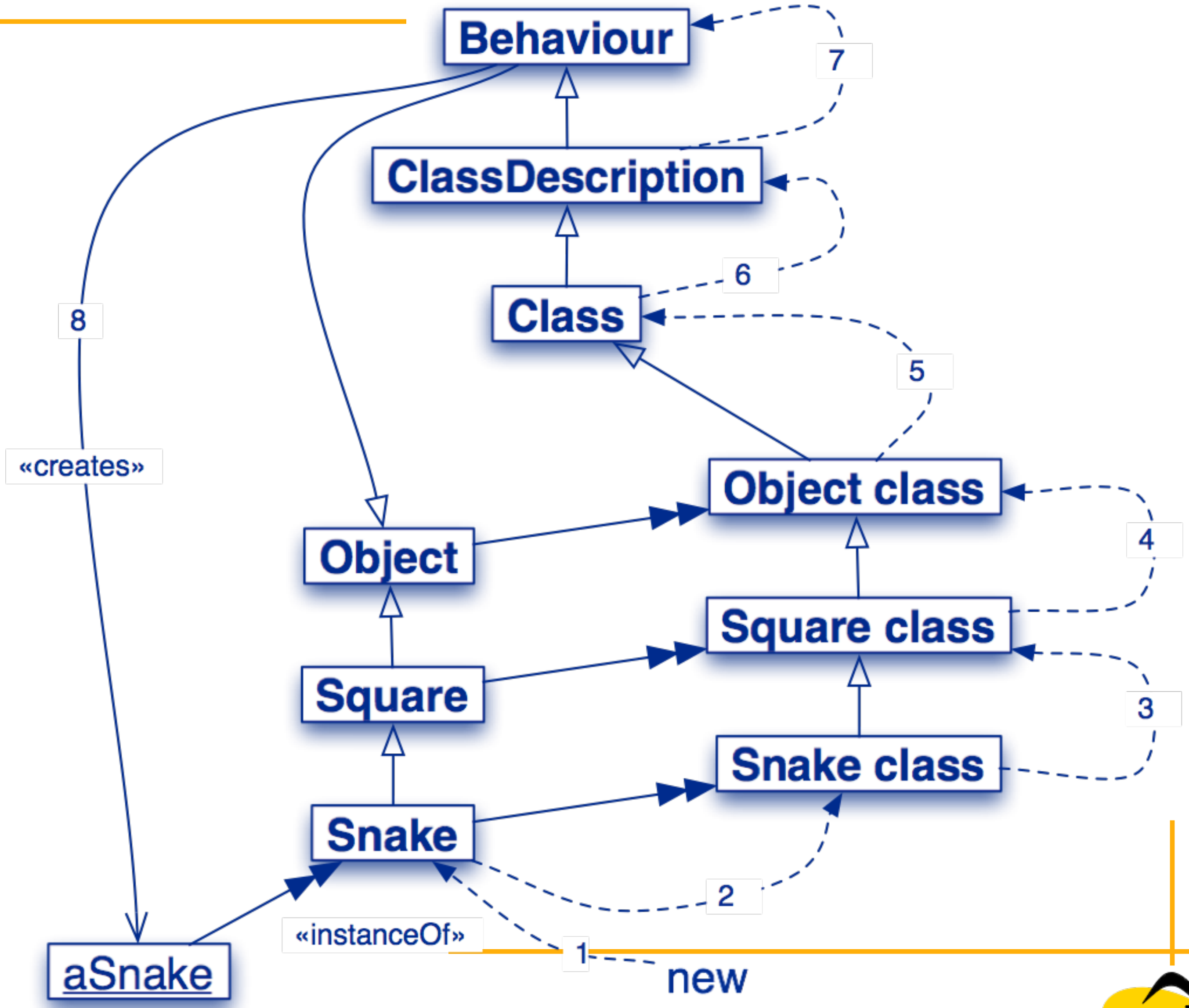
5. Every metaclass inherits from Class and Behavior

- Every class is-a Class = The metaclass of every class inherits from Class



Where is new defined?



Responsibilities of Behavior

`Behavior`

Minimum state necessary for objects that have instances.

Basic interface to the compiler.

State:

class hierarchy link, method dictionary, description of instances (representation and number)

Methods:

creating a method dictionary, compiling method

instance creation (new, basicNew, new:, basicNew:)

class hierarchy manipulation (superclass:, addSubclass:)

accessing (selectors, allSelectors, compiledMethodAt:)

accessing instances and variables (allInstances, instVarNames)

Responsibilities of ClassDescription

`ClassDescription`

adds a number of facilities to basic Behavior:

- named instance variables
- category organization for methods
- the notion of a name (abstract)
- maintenance of Change sets and logging changes
- most of the mechanisms needed for fileOut

`ClassDescription` is an abstract class: its facilities are intended for inheritance by the two subclasses, `Class` and `Metaclass`.

Responsibilities of Class

`Class`

- represents the common behavior of all classes
  - name, compilation, method storing, instance variables …
- representation for classVariable names and shared pool variables (`addClassVarName:`, `addSharedPool:`, `initialize`)
- `Class` inherits from `Object` because `Class` is an `Object`
  - *`Class`* knows how to create instances, so all metaclasses should inherit ultimately from *`Class`*

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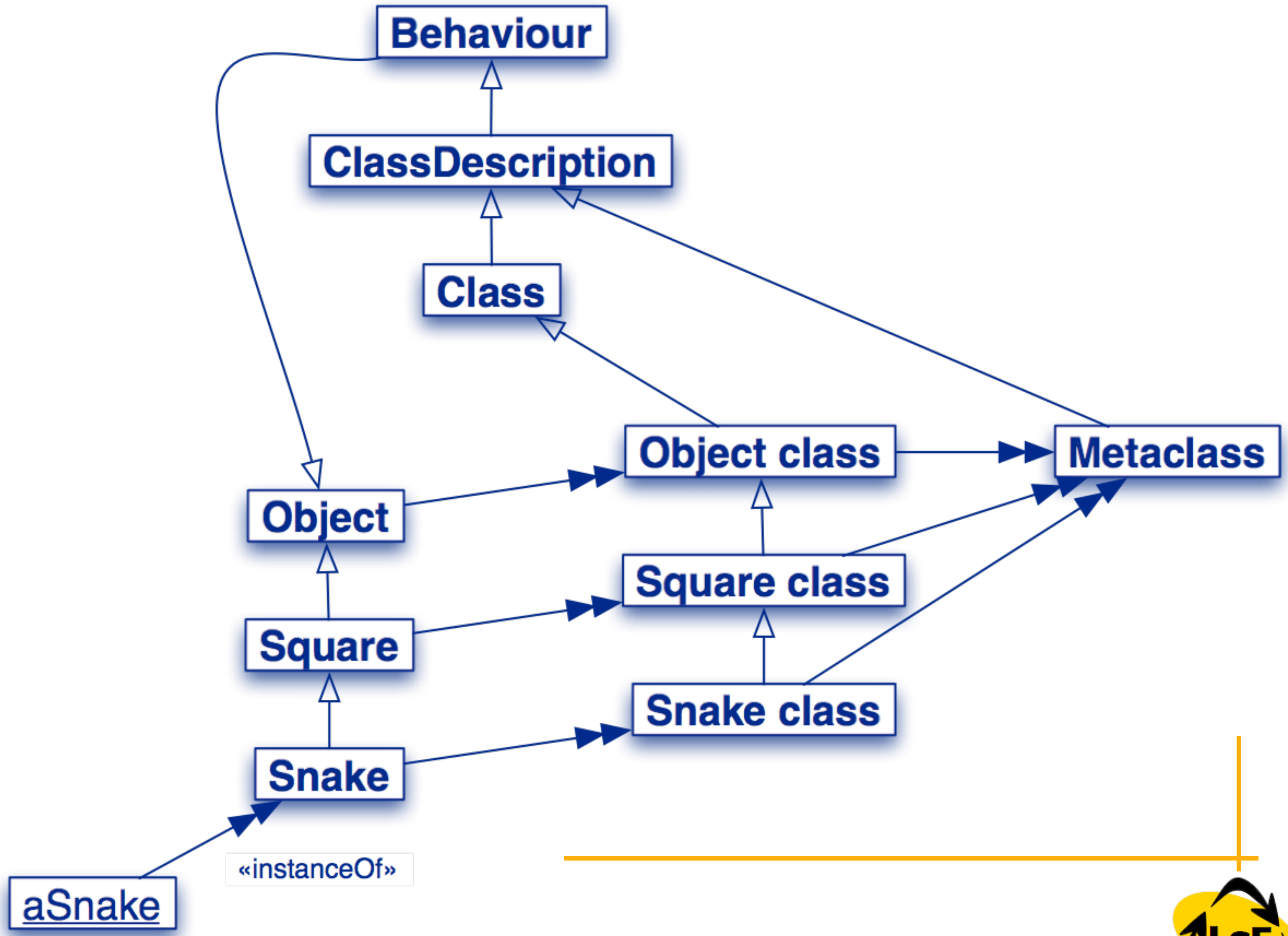
6. Every metaclass is an instance



Metaclass Responsibilities

`Metaclass`

- Represents common metaclass Behavior
  - instance creation (subclassOf:)
  - creating initialized instances of the metaclass's sole instance
  - initialization of class variables
  - metaclass instance protocol (name:inEnvironment:subclassOf:....)
  - method compilation (different semantics can be introduced)
  - class information (inheritance link, instance variable, ...)

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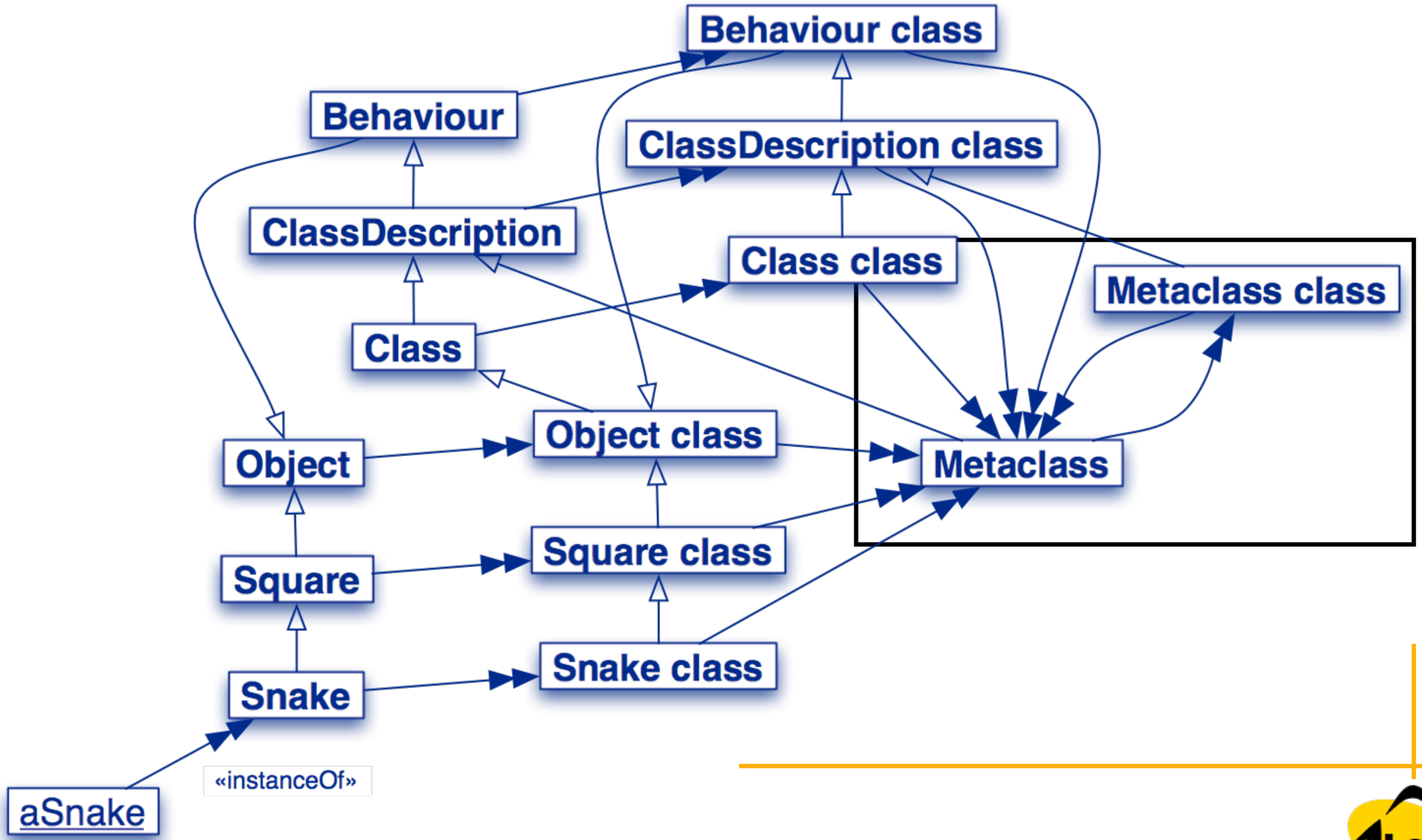
7. The metaclass of Metaclass is an



Navigating the metaclass

```
MetaclassHierarchyTest>>testHierarchy
	"The class hierarchy"
	self assert: Snake superclass = Square.
	self assert: Square superclass = Object.
	self assert: Object superclass superclass = nil. "skip ProtoObject"
	"The parallel metaclass hierarchy"
	self assert: Snake class name = 'Snake class'.
	self assert: Snake class superclass = Square class.
	self assert: Square class superclass = Object class.
	self assert: Object class superclass superclass = Class.
	self assert: Class superclass = ClassDescription.
	self assert: ClassDescription superclass = Behavior.
	self assert: Behavior superclass = Object.
	"The Metaclass hierarchy"
	self assert: Snake class class = Metaclass.
	self assert: Square class class = Metaclass.
	self assert: Object class class = Metaclass.
	self assert: Class class class = Metaclass.
	self assert: ClassDescription class class = Metaclass.
	self assert: Behavior class class = Metaclass.
	self assert: Metaclass superclass = ClassDescription.
	"The fixpoint"
	self assert: Metaclass class class = Metaclass.
```

Roadmap

> Metaclasses in 7 points
> **Indexed Classes**
> Class Instance Variables
> Class Variables
> Pool Dictionaries

Two ways to represent objects

- Named or indexed instance variables
  - Named: `name` of `GamePlayer`
  - Indexed: `#(Jack Jill) at: 1`
- Or looking at them in another way:
  - Objects with pointers to other objects
  - Objects with arrays of bytes (word, long)
  - Difference for efficiency reasons:
    - arrays of bytes (like C strings) are faster than storing an array of pointers, each pointing to a single byte.

Different methods to create classe

Indexed	Named Instance Variables	Definition Method
No	Yes	`#subclass:` ...
Yes	Yes	`#variableSubclass:` ...
Yes	No	`#variableByteSubclass:` ...

> See the subclass creation protocol of `Class`

> Constraints

- *Pointer classes* defined using `#subclass:` support any kind of subclasses
- *Byte classes* defined using `#variableSubclass:` can only have: `variableSubclass:` or `variableByteSubclass:` subclasses

Testing methods

- See testing protocols of `Behavior`:
  - #isPointers, #isBits, #isBytes, #isFixed, #isVariable
  - #kindOfSubclass

```
Object allSubclasses select: [:class | class isBytes]
```

Testing methods

> See testing protocols of `Behavior`:
  - #isPointers, #isBits, #isBytes, #isFixed, #isVariable
  - #kindOfSubclass

```
Object allSubclasses select: [:class | class isBytes]
```

```
a Set(ByteArray MwSynchronizationWrapper
MwBlockMethodWrapper ExternalAddress MCMockClassH
LargeNegativeInteger LargePositiveInteger ByteSymbol
MwCountMethodWrapper MwTimeMethodWrapper
MwMethodWrapper MwBlockHandlerMethodWrapper
ByteString MwCalledMethodWrapper UUID
CompiledMethod)
```

Defining Indexed Classes

Example — instantiating an Array:

```
Array new: 4
```

```
#(nil nil nil nil)
```

```
ArrayedCollection variableSubclass: #Array
    instanceVariableNames: ''
    classVariableNames: ''
    poolDictionaries: ''
    category: 'Collections-Arrayed'
```

```
#(1 2 3 4) class isVariable
```

```
true
```

Defining an Indexed Class

```
Object variableSubclass: #IndexedObject
     instanceVariableNames: ''
     classVariableNames: ''
     poolDictionaries: ''
     category: ''
```

```
(IndexedObject new: 2)
     at: 1 put: 'Jack';
     at: 2 put: 'Jill';
     at: 1
```

```
'Jack'
```

Indexed Classes / Instance

An indexed variable is implicitly added to the list of instance variables

- Only one indexed instance variable per class
- Access with at: and at:put:
  - NB: answers the value, not the receiver

Subclasses should also be indexed

Roadmap

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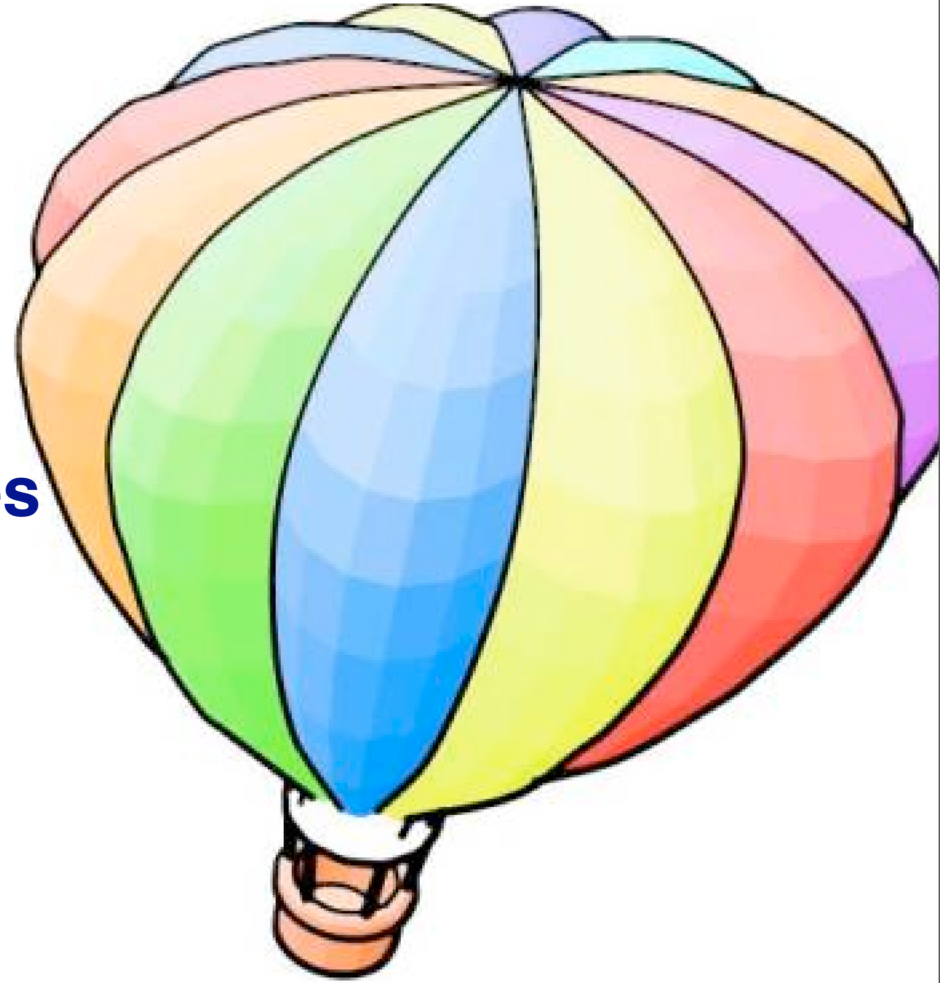
- **Class Instance Variables**
- Class Variables
- Pool Dictionaries



Class Instance Variables

- Class are objects too
  - Instances of their metaclass
    - Methods looked up in the method dictionary of their metaclass
  - Can also define instance variables

- When a metaclass defines a new instance variable, then its instance (a Class) gets a new variable
  - I.e., in addition to `subclass`, `superclasses`, `methodDict`…

- Use class instance variables to represent the private state of the class

Example: the Singleton

A class having only one instance

We keep the unique instance created in an instance

```
WebServer class
      instanceVariableNames: 'uniqueInstance'

WebServer class>>new
      self error: 'Use uniqueInstance to get the unique
instance'

WebServer class>>uniqueInstance
   uniqueInstance isNil
         ifTrue: [uniqueInstance := self basicNew initialize].
   ^ uniqueInstance
```

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- Class Instance Variables
- **Class Variables**
- Pool Dictionaries

Class Variable = Shared Variable

To share information amongst all instances of a class, use a “class variable”

- Shared and directly accessible by all the instances of the class and subclasses
- Accessible to both instance and class methods
- Begins with an uppercase letter

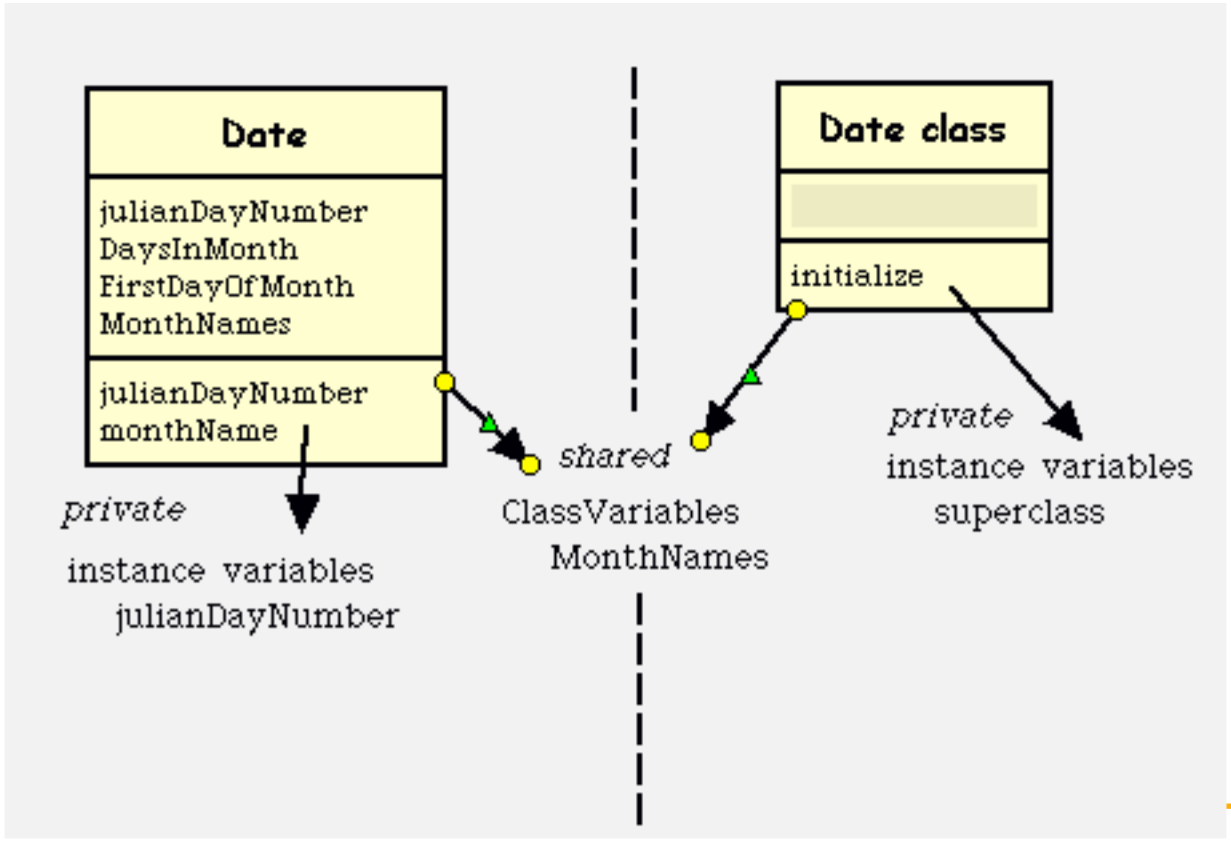
Initializing class variables

Class variables should be initialized by an initialize method on the class side

```
Magnitude subclass: #Date
   instanceVariableNames: 'julianDayNumber '
   classVariableNames: 'DaysInMonth FirstDayOfMonth
                 MonthNames SecondsInDay WeekDayNames '
   poolDictionaries: ''
   category: 'Kernel-Magnitudes'

Date class>>initialize
       ...
       WeekDayNames := #(Sunday Monday ...).
       MonthNames := #(January February ... ).
       DaysInMonth := #(31 28 31 30 31 30 31 31 30 31 30 31).
```

ClassVariables vs. Instance



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> Metaclasses in 7 points
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> Class Variables
> **Pool Dictionaries**

Pool Dictionaries

A Pool Dictionary is a shared variable

- Begins with a uppercase letter.
- Shared by a group of classes not linked by inheritance.

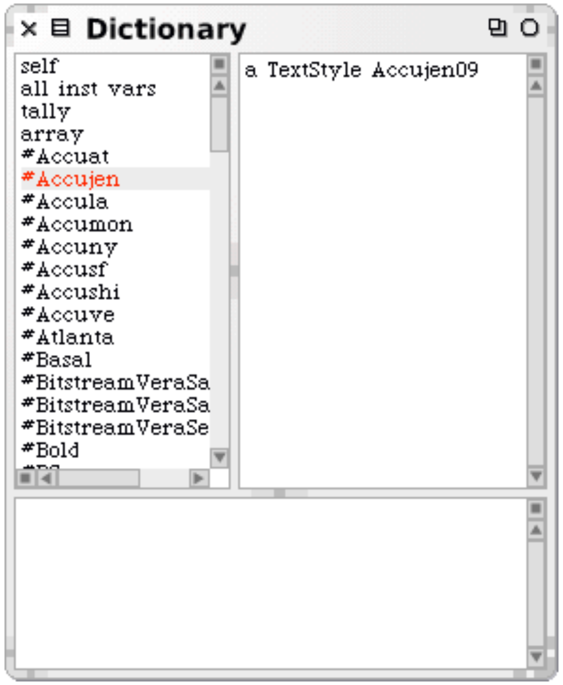
Each class possesses its own pool dictionary (containing pool variables).

- They are not inherited.

Don’t use them!

Examples of Pool Dictionaries

```
ArrayedCollection subclass: #Text
instanceVariableNames: 'string runs'
classVariableNames: ''
poolDictionaries: 'TextConstants'
category: 'Collections-Text'
```



```
self
all inst vars
tally
array
#Accuat
#Accujen
#Accula
#Accumon
#Accuny
#Accusf
#Accushi
#Accuve
#Atlanta
#Basal
#BitstreamVeraSa
#BitstreamVeraSa
#BitstreamVeraSe
#Bold
```

```
a TextStyle Accujen09
```

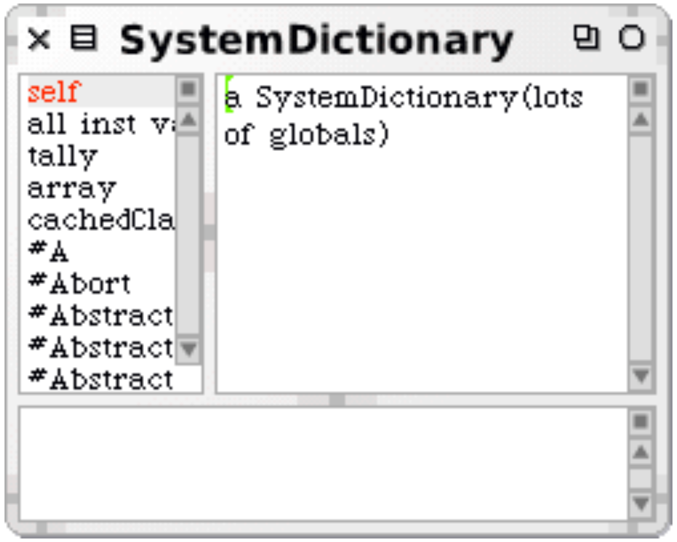
Elements stored into TextConstants like `Ctrl`, `CR`, `ESC`, `Space` can be directly accessed from all the classes like `ParagraphEditor`....

Hint: You can inspect any Pool Dictionary

Smalltalk System Dictionary

Pool Dictionaries are stored in the Smalltalk system dictionary

```
Smalltalk inspect
```



a SystemDictionary(lots of globals)

```
(Smalltalk at: #TextConstants) at: #ESC
```

```
$
```

Accessing globals

Use message-sending instead of directly accessing pool variables

```
stream nextPut: Lf "A pool variable visible to the class"
```

vs.

```
stream nextPut: Character lf
```

What you should know!

What does is-a mean?

What is the difference between sending a message to an object and to its class?

What are the responsibilities of a metaclass?

What is the superclass of Object class?

Where is new defined?

What is the difference between class variables and class instance variables?

Can you answer these questions?

Why are there no explicit metaclasses?
When should you override new?
Why don't metaclasses inherit from Class?
Are there any classes that don't inherit from Object?
Is Metaclass a Class? Why or why not?
Where are the methods class and superclass defined?
When should you define an indexed class?
Are Java static variables just like class variables or class instance variables?
Where is the SystemDictionary Smalltalk defined?

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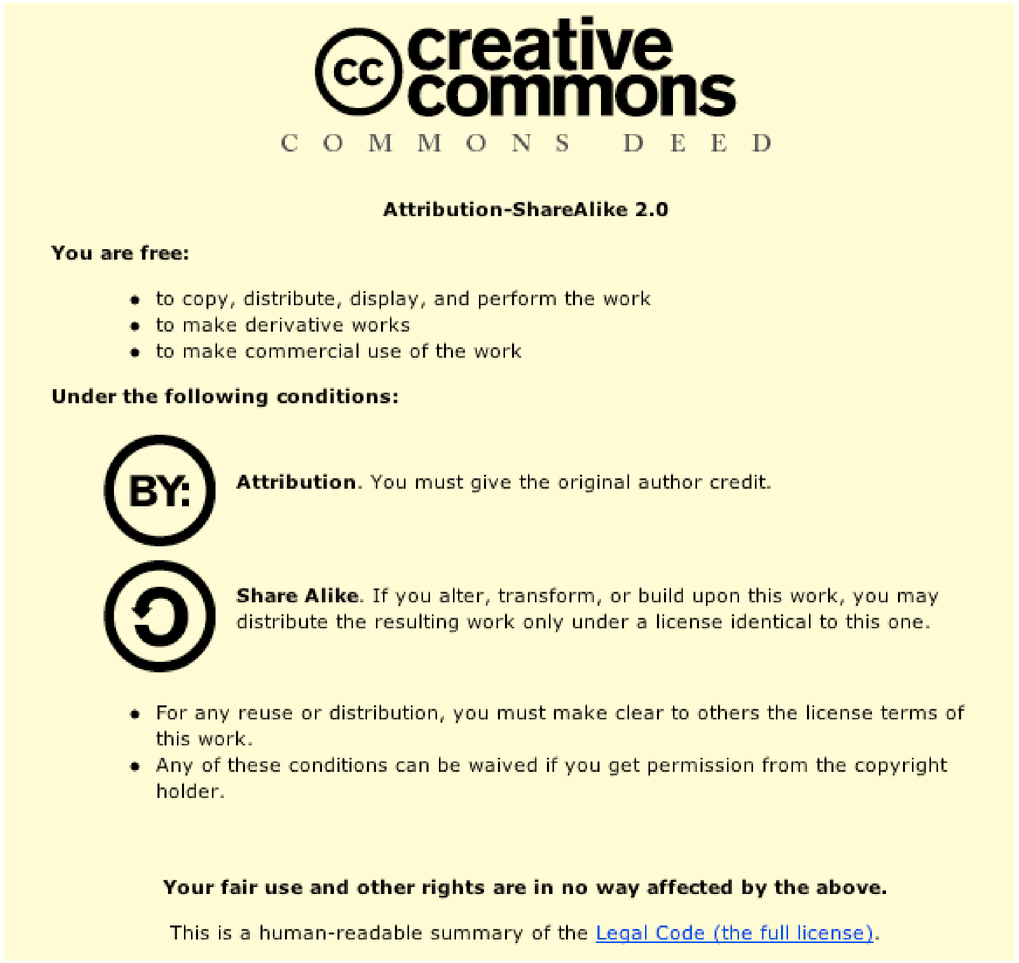
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