

XOTcl – Tutorial

1.5.1

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Introduction



Language Overview

XOTcl [Neumann and Zdun 2000a] is an extension to the object-oriented scripting language OTcl [Wetherall and Lindblad 1995] which itself extends Tcl [Ousterhout 1990] (Tool Command Language) with object-orientation. XOTcl is a value-added replacement for OTcl and does not require OTcl to compile.

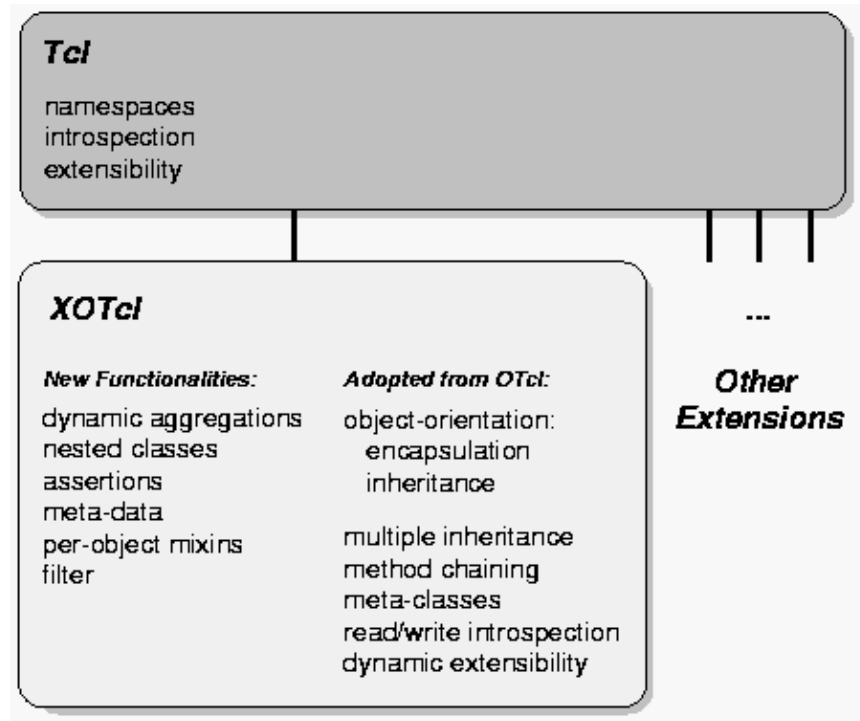
XOTcl runs in the `tclsh` and provides a few extension commands. These are offered in a Tcl namespace `::xotcl`, and can be imported into the current namespace to reduce typing and improve readability. All Tcl commands remain available (and are also applicable on the extension constructs).

A central property of Tcl is, that it uses strings solely for the representation of data. Internally it uses an dynamic type system with automatic conversion (which enables efficient type handling). For that reason all components (e.g. written in C) once integrated in Tcl automatically fit together and the components can be reused in unpredicted situations without change. The evolving *component frameworks* provide a high degree of code reuse, rapid application development, and ease of use. The application developer may concentrate on the application task solely, rather than investing efforts in fitting components together. Therefore, in certain applications scripting languages like Tcl are very useful for a fast and high-quality development of software (see [Ousterhout 1998] for more details).

Tcl is equipped with appropriate functionalities for the easy gluing of components, like dynamic typing, dynamic extensibility, and read/write introspection. OTcl is an object-oriented extension to Tcl, which encourages a Tcl-like programming style and is composed of language constructs with properties similar to Tcl. It offers an object-orientation with encapsulation of data and operation without protection mechanisms and single and multiple inheritance. Furthermore it enables to change the relationships dynamically, offers read/write introspection, has a three level class system based on meta-classes and offers method chaining. These abilities are integrated in XOTcl with only slight changes to OTcl visible to the programmer.

The XOTcl extension aims at complexity and adaptability issues that may occur in context of large (object-oriented) software structures and in the context of component glueing. In particular we added the following support:

- *Filters* as a means of abstractions over method invocations to implement large program structures, like design patterns.
- *Mixin Classes*, as a means to give an object or a classes' instances access to several different supplemental classes, which may be changed dynamically.
- *Dynamic Object Aggregations*, to provide dynamic aggregations through nested namespaces.
- *Nested Classes*, to reduce the interference of independently developed program structures.
- *Assertions*, to reduce the interface and the reliability problems caused by dynamic typing and, therefore, to ease the combination of components.
- *Forwarders*, to delegate calls efficiently to other objects or classes.
- *Slots*, to manage values of instance variables with a common interface.
- *Meta-data and Automatic Documentation*, to enhance self-documentation of objects and classes.

Figure 1: Language Extensions of XOTcl

Introductory Overview Example: Soccer Club

To give you an impression of the language before we go into the details of the language construct, we present in this section a simple, introductory example. It shall demonstrate the basic language constructs on the example of a soccer club (the full code can be found in the `xotcl/src/scripts/soccerClub.xotcl` file. All the characters in this example are fictitious, and any resemblance to actual persons, living or deceased, is coincidental.

In XOTcl we do not have to provide a file description as a comment, but we can use the `@` object, which is used generally to provide any kind of information, meta-data, and documentation on a running program. Here, we just give a file description. Then the `makeDoc.xotcl` tool can automatically document the program file for us.

```
@ @File {
  description {
    This is a simple introductory example for the language XOTcl.
    It demonstrates the basic language constructs on the example of
    a soccer club.
  }
}
```

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All things and entities in XOTcl are objects, a special kind of objects are classes. These define common properties for other objects. For a soccer club, we firstly require a common class for all kinds of members.

Common to all members is that they have a name. Common properties defined across all instances of a class are called 'parameter' in XOTcl. In this example the instance variable `name` will be initialized by default with an empty string.

```
Class ClubMember -parameter {{name ""}}
```

A special club member is a `Player`. Derived classes can be build with inheritance (specified through `superclass`). `Players` may have a `playerRole` (defaults to `NONE`).

```
Class Player -superclass ClubMember -parameter {{playerRole NONE}}
```

Other club member types are `trainers`, `player-trainers`, and `presidents`:

```
Class Trainer -superclass ClubMember
Class President -superclass ClubMember
```

The `PlayerTrainer` uses multiple inheritances by being both a `player` and a `trainer`:

```
Class PlayerTrainer -superclass {Player Trainer}
```

Now we define the `SoccerTeam` class:

```
Class SoccerTeam -parameter {name location type}
```

We may add a `player`. This is done by a method. Instance methods are in XOTcl defined with `instproc`. All club members are aggregated in the team (denoted by `::` namespace syntax).

```
SoccerTeam instproc newPlayer args {
  # we create a new player who is part of the soccer team
  # "eval" is needed to pass the provided arguments to the call of new
  eval Player new -childof [self] $args
}
```

A `player` can be transferred to another team. The `player` object does not change internally (e.g. the `playerRole` stays the same). Therefore we move it to the destination team.

```
SoccerTeam instproc transferPlayer {playername destinationTeam} {
  # We use the aggregation introspection option children in order
  # to get all club members
  foreach player [my info children] {
    # But we only remove matching playernames of type "Player". We do
    # not want to remove another club member type who has the same
    # name.
    if {[${player} istype Player] && [${player} name] == $playername} {
      # We simply 'move' the player object to the destination team.
      # Again we use a unique autaname in the new scope
      $player move [set destinationTeam]::[$destinationTeam autaname player%02d]
    }
  }
}
```

Finally we define two convenience to print the members/players to the stdout with `puts`.

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```
SoccerTeam instproc printMembers {} {
    puts "Members of [my name]:"
    foreach m [my info children] {puts "  [$m name]"}
}
SoccerTeam instproc printPlayers {} {
    puts "Players of [my name]:"
    foreach m [my info children] {
        if {[ $m istype Player]} {puts "  [$m name]"}
    }
}
```

Now let us build to example soccer team objects.

```
SoccerTeam chelsea -name "Chelsea FC" -location "Chelsea"
SoccerTeam bayernMunich -name "F.C. Bayern München" -location "Munich"
```

With `addPlayer` we can create new aggregated player objects

Let us start some years in the past, when "Franz Beckenbauer" was still a player.

```
set fb [bayernMunich newPlayer -name "Franz Beckenbauer" \
    -playerRole PLAYER]
```

`playerRole` may not take any value. It may either be `NONE`, `PLAYER`, or `GOALY` ... such rules may be given as assertions (here: an `instinvar` gives an invariant covering all instances of a class). In XOTcl the rules are syntactically identical to `if` statements:

```
Player instinvar {
    {[my playerRole] == "NONE" ||
     [my playerRole] == "PLAYER" ||
     [my playerRole] == "GOALY"}
}
```

If we break the invariant and turn assertions checking on, we should get an error message:

```
$fb check all
if {[catch {$fb set playerRole SINGER} errMsg]} {
    puts "CATCHED EXCEPTION: playerRole has either to be NONE, PLAYER, or TRAINER"
    # turn assertion checking off again and reset to PLAYER
    $fb check {}
    $fb set playerRole PLAYER
}
```

But soccer players may play quite different, orthogonal roles. E.g. Franz Beckenbauer was also a singer (a remarkably bad one). However, we can not simply add such orthogonal, extrinsic extensions with multiple inheritance or delegation. Otherwise we would have either to build a lot of unnecessary helper classes, like `PlayerSinger`, `PlayerTrainerSinger`, etc., or we would have to build such helper objects. This either leads to an unwanted combinatorial explosion of class or object number

Here we can use a per-object mixin, which is a language construct that expresses that a class is used as a role or as an extrinsic extension to an object.

First we just define the `Singer` class.

```
Class Singer
Singer instproc sing text {
```


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```
puts "[my name] sings: $text, lala."  
}
```

Now we register this class as a per-object mixin on the player object:

```
$fb mixin Singer
```

And now Franz Beckenbauer is able to sing:

```
$fb sing "lali"
```

But Franz Beckenbauer has already retired. When a player retires, we have an intrinsic change of the classification. He *is* not a player anymore. But still he has the same name, is club member, and is a singer (brrrrrr).

Before we perform the class change, we extend the Player class to support it. I.e. the playerRole is not valid after class change anymore (we unset the instance variable).

```
Player instproc class args {  
  my unset playerRole  
  next  
}
```

Now we can re-class the player object to its new class (now Franz Beckenbauer is President of Bayern Munich).

```
$fb class President  
# Check that the playerRole isn't there anymore.  
if {[catch {$fb set playerRole} errMsg]} {  
  puts "CATCHED EXCEPTION: The player role doesn't exist anymore \  
    (as it should be after the class change)"  
}
```

But still Franz Beckenbauer can entertain us with what he believes is singing:

```
$fb sing "lali"
```

Now we define some new players for Bayern Munich:

```
bayernMunich newPlayer -name "Oliver Kahn" -playerRole GOALY  
bayernMunich newPlayer -name "Giovanne Elber" -playerRole PLAYER
```

If we enlist the players of Munich Franz Beckenbauer is not enlisted anymore:

```
bayernMunich printPlayers
```

But as a president he still appears in the list of members:

```
bayernMunich printMembers
```

Now consider an orthonogal extension of a transfer list. Every transfer in the system should be notified. But since the transfer list is orthogonal to SoccerTeams we do not want to interfere with the existing implementation at all. Moreover, the targeted kind of extension has also to work on all subclasses of SoccerTeam. Firstly, we just create the extension as an ordinary class:

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```
Class TransferObserver
TransferObserver instproc transferPlayer {pname destinationTeam} {
    puts "Player '$pname' is transfered to Team '[$destinationTeam name]'"
    next
}
```

Now we can apply the class as a per–class mixin, which functions exactly like a per–object mixin, but on all instances of a class and its subclasses. The `next` primitive ensures that the original method on `SoccerTeam` is called after notifying the transfer (with `puts` to `stdout`):

```
SoccerTeam instmixin TransferObserver
```

If we perform a transfer of one of the players, he is moved to the new club and the transfer is reported to the `stdout`:

```
bayernMunich transferPlayer "Giovanne Elber" chelsea
```

Finally we verify the transfer by printing the players:

```
chelsea printPlayers
bayernMunich printPlayers
```

Object and Class System



In XOTcl every object is associated with a class over the `class` relationship. Classes are special objects with the purpose of managing other objects. “Managing” means that a class controls the creation and destruction of its instances and that it contains a repository of methods (“`instprocs`”) accessible for the instances. Object–specific methods are called “`procs`”, instance methods are called “`instprocs`”.

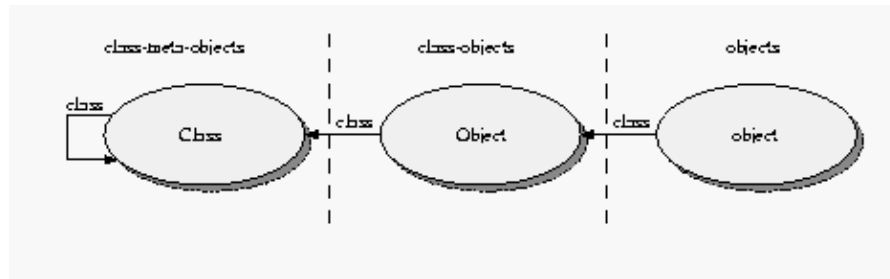
The instance methods common to all objects are defined in the root class `Object` (predefined or user–defined). Since a class is a special (managing) kind of object it is managed itself by a special class called “`meta–class`” (which manages itself). Meta–Classes are used to define classes and to provides methods for these. Most classes are defined by the predefined meta–class `Class`. One interesting aspect of meta–classes is that by providing a constructor pre–configured classes can be derived. Meta–classes can be used to instantiate large program structures, like some design patterns (see [\[Neumann and Zdun 1999a\]](#) for more details), where the meta–class may holds the generic parts of the structures. Since a meta–class is an entity of the program, it is possible to collect these entities in pattern libraries for later reuse easily (more details about meta–classes are given in a later [section](#)).

XOTcl supports single and multiple inheritance. Classes are ordered by the relationship `superclass` in a directed acyclic graph. The root of the class hierarchy is the class `Object`. A single object can be instantiated directly from this class. An inherent problem of multiple inheritance is the problem of name resolution, when for example two super–classes contain an instance method with the same name. XOTcl provides an intuitive and unambiguous approach for name resolution by defining the precedence order along a linear “`next–path`” incorporating the class and mixin hierarchies, which is modeled after CLOS. A method can invoke explicitly the shadowed methods by the predefined command `next`. When this command is executed a shadowed method is “mixed into” the execution of the current method. Method chaining without explicit naming of the targeted method is very important for languages supporting a dynamic class system, because one cannot always predict which classes are currently participating in the inheritance hierarchy at design time (often

necessary in inheritance models, like C++).

An important feature of all XOTcl objects is the read/write introspection. The reading introspection abilities of XOTcl are packed compactly into the `info` instance method which is available for objects and classes. All obtained information can be changed at run-time dynamically with immediate effect. Unlike languages with a static class concept, XOTcl supports dynamic class/superclass relationships. At any time the class graph may be changed entirely using the `superclass` method, or an object may change its class through the `class` method. This feature can be used for an implementation of a life-cycle or other intrinsic changes of object properties (in contrast to extrinsic properties e.g. modeled through roles and implemented through per-object and per-class mixins [Neumann and Zdun 1999c]). These changes can be achieved without losing the object's identity, its inner state, and its per-object behavior (procs and per-object mixins).

Figure 2: Object and Class System



Basic Functionalities



Objects

Initially XOTcl offers two new commands: `Object` and `Class`. They represent hooks to the features of the language. This section discusses both of them in detail and shows how they function in the context of XOTcl. Note, that even if most of this is compatible to OTcl, a few changes occur. For this reason, this section is no introduction to plain OTcl. The `Object` command provides access to the `Object` class, which holds the common features of all objects, and allows us to define new objects. Objects are always instances of classes, therefore, objects defined with the `Object` command are (initially) instances of the `Object` class. But since they have no user-defined type, they may be referred to as *singular objects*. As all other objects they may be specialized by object-operations and -data.

The object command has the following syntax:

```
Object objName ?args?
```

A command of this form is a short-cut for a message to the `create` instance method (forwarded automatically by the `unknown` mechanism, which is invoked every time the message dispatch system discovers an unknown message):

```
Object create objName ?args?
```

It creates a new object of type `Object` with the name `objName` (in fact it invokes a `create` call on the `Object` class). `objName` becomes a new command, which allows us to access the created object. Similar to the `Object` command it may be used like a normal Tcl-command (using sub-commands to access the object's methods). Therefore, this form of access is called *object-command* approach. A simple example is an object which holds the information of a kitchen. It is created by:

```
Object kitchen
```

An object creation calls the constructor `init` of the object's class. The destruction of an object is handled by the `destroy` instance method. The general syntax of `destroy` is:

```
objName destroy
```

E.g. the kitchen object is destroyed by:

```
kitchen destroy
```

To invoke a user-defined destruction process, it is possible to overload this instance method in every class derived from `object`.

Note that the destruction of an object is performed by the method `destroy` of `Object` (since every object is an instance of `Object`, every object can call `destroy`). When an application class overloads `destroy`, this method should contain a `next` in order to reach the base class and to actually destroy the object.

Data on Objects

The `Object` class provides a range of operations to manage objects, including those to manipulate data-structures on the objects. They are similar to the same-named Tcl-commands:

```
objName set varname ?value?  
objName unset v1 ?v2 ... vn?
```

The `set` instance method with given `value` option allows us to manipulate an object-variable's value or to create a new one, if the variable `varname` does not exist on the object so far. Without `value` option the `set` operation queries the variable and returns it's value, if the variable exists, otherwise it produces an error message. The `unset` operation deletes one or optionally a set of variables from an object. For example the `kitchen` object can store information on the color of the wall-paper by:

```
kitchen set wallPaperColor white
```

Similar to Tcl-variables the object variables are dynamical; they may be set at run-time when they are needed and unset when they become obsolete. E.g. the persons in the kitchen may be stored in an array. If there are no persons in the kitchen the array is deleted:

```
# Peter enters the kitchen to cook  
kitchen set persons(cook) Peter  
...  
# Marion enters the kitchen to take one of the seats  
kitchen set persons(seat1) Marion  
...  
# Both Peter and Marion leave the kitchen  
# the array is deleted by unset  
kitchen unset persons
```

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Since XOTcl variables are internally realized through Tcl-variables they may be treated like all Tcl-variables. For that reason they have all Tcl-variable abilities, including the possibility to handle them as lists or arrays (as seen in the last example). The `array` command of Tcl is mapped to an XOTcl-command directly. An object-oriented call to an object of the form

```
objName array option arrayName args
```

forwards its arguments to an `array` Tcl-command for the object's instance variable `arrayName`. It could be used like the same-named Tcl-command, e.g. the command

```
kitchen array names persons
```

returns all indexes currently stored in the `persons` array.

Similarly Tcl's `incr` command is mapped to the object system. A call with the syntax:

```
objName incr varName ?value?
```

increments `varName` with the given value (or without given value with 1).

Methods for Objects

Methods in XOTcl resemble Tcl-procedures. On objects one can define object-specific methods, called procs. Instance methods which are defined on classes are called instprocs. A new proc is defined using the `proc` instance method of the class `Object`:

```
objName proc name args body
```

The arguments of the `proc` instance method specify the name, the arguments as a Tcl-list, and the body of the new proc. All of them must be given, only one of `args` and `body` may be empty. An example proc would be a method to let persons enter the kitchen:

```
kitchen proc enter {name} {  
    [self] set persons($name) [clock seconds]  
}
```

Here the predefined `self` command is used in one of three possible ways, which allow us to access useful information when working with XOTcl-methods, these are in particular:

- `self`: returns the name of the object, which is currently in execution. This command is similar to `this` in C++. It is automatically generated on each object. If it is called from outside of an XOTcl method, it produces the error message "Can't find self".
- `self class`: the `self` command with the argument `class` returns the name of the class, which holds the currently executing instproc. Note, that this may be different to the class of the current object. If it is called from a proc it returns an empty string.
- `self proc`: the `self` command with the argument `proc` returns the name of the currently executing method (proc or instproc).

The method `enter` can be written in XOTcl as well with less syntactic overhead by using the predefined primitive `my` instead of `[self]`:

```
kitchen proc enter {name} {
```

```

    my set persons($name) [clock seconds]
}

```

Note, that there is a difference to the realization of these object informations to OTcl. XOTcl uses commands in order to make XOTcl-methods compatible to Tcl-procedures and accessible via namespace-paths. OTcl uses the three variables `self`, `class` and `proc`, which are filled automatically with proper values by the interpreter each time a method is called. To gain backwards compatibility XOTcl can be compiled with `-DAUTOVARS` to provide these variables additionally. By default this option is turned off.

Each XOTcl-method has its own scope for definition of local variables for the executing method. In most cases when a method uses object-variables, it is likely that the programmer wants to make one or more of these variables part of the method's scope. Then the Tcl-command for variable handling, like `set`, `lindex`, `array`, ... work also on these variables. The `instvar` instance method links a variable to the scope of an executing method. It has the syntax:

```
objName instvar v1 ?v2 ... vn?
```

It makes the variables `v1 ... vn`, which must be variables of the object, part of the current method's scope. A special syntax is:

```
objName instvar {varName aliasName} ...
```

for one of the variables. This gives the variable with the name `varName` the alias `aliasName`. This way the variables can be linked to the methods scope, even if a variable with that name already exists in the scope. Now the `enter` method can be adapted slightly and a `leave` method can be added, which uses Tcl's `info` command to check whether the named person is in the object's `persons` array. To demonstrate the alias-syntax this is done with the `persons` array and the alias `p`.

```

kitchen proc enter {name} {
    my instvar persons
    set persons($name) [clock seconds]
}

kitchen proc leave {name} {
    my instvar {persons p}
    if {[info exists p($name)]} {
        puts "$name leaves after [expr {[clock seconds]-$p($name)}] seconds"
        unset p($name)
    } else {
        puts "$name is not in the room"
    }
}

```

A method defined via `proc` can be deleted by `proc` using an empty argument list and an empty body. The following example deletes the method `enter`:

```
Room proc enter {} {}
```

Information about Objects

XOTcl offers reading and writing introspection. The reading introspection abilities are packed compactly into the `info` instance method which is available for objects and classes (there are special `info` options for object aggregations, nested classes, mixins, filters, meta-data and assertions, which are explained separately in the following sections). The `info` instance method's options, from the view of an object, are summarized in the

following table. They are identically to the OTcl info options on objects.

Options for the info method on objects

<code>objName info args methodName</code>	Returns the arguments of the specified proc (object specific method).
<code>objName info body methodName</code>	Returns the body of the specified proc.
<code>objName info class ?className?</code>	Returns the name of the class of the current object, if <i>className</i> was not specified. Otherwise it returns 1 if <i>className</i> matches the object's class and 0 if not.
<code>objName info commands ?pattern?</code>	Returns all commands defined on the object if <i>pattern</i> was not specified. Otherwise it returns all commands that match the pattern.
<code>objName info default methodName arg var</code>	Returns 1 if the argument <i>arg</i> of the specified proc has a default value, otherwise 0. If the default value exists it is stored in <i>var</i> .
<code>objName info precedence ?pattern?</code>	Returns all classes in the precedence order from which the specified object inherits methods. The returned list of classes contains the mixin and instmixin classes as well as the classes of the superclass chain in linearized order (i.e., duplicate classes are removed). If the <i>pattern</i> is specified, only matching classes are returned.
<code>objName info vars ?pattern?</code>	Returns all variables defined on the object if <i>pattern</i> was not specified, otherwise it returns all variables that match the pattern.

For example on the kitchen object

```
kitchen info procs
```

returns `enter` and `leave` as a Tcl-list since these are the procs defined on the object.

Classes

Creating Classes and deriving Instances

There are different ways to create a class in XOTcl. They have in common that they derive the new class from a meta-class. Initially the `Class` command provides access to the meta-class `Class`, which holds the features common to all classes. It also allows one to derive new meta-classes. The common way to create a new class is:

```
Class className ?args?
```

Similar to the object short form, this is a short form of a call to the `create instance` method of the meta-class `Class`, which is also executed by the standard `unknown` mechanism. This mechanism is always triggered when XOTcl does not know a method called on an object. Supposed that there is no method with the name `className`, defined on the class-object of `Class`, XOTcl looks up the method `unknown` (which is found on the `Class Object`) and executes it. The standard `unknown`-mechanism of XOTcl calls `create` with all arguments stepping one step to the right; in the general case:

```
Class create className ?args?
```

This may also be called directly. Besides the indirection when using `unknown`, in most cases there is no difference in the action performed: Firstly the memory is allocated, using the `alloc` instance method; as the next step the constructor `init` is called on the creating object, which is in this case the class-object of the meta-class `Class`. In seldom cases the programmer may want to suppress the `init` call. To do so the `alloc` instance method may also be called directly:

```
Class alloc className ?args?
```

As seen in the preceding section objects are created in the same way. The difference was, that the command `Object`, which accesses a class, instead of the command `Class`, which accesses a meta-class, was used. The user-defined classes may also be used in the same way to create new objects:

```
className objName ?args?
```

Resembling the creation of classes this creates an object `objName` of type `className` using the `unknown` mechanism. That means the `create` instance method of the class is called. If there is no other instance method defined on the class-path so far (which would mean, an user defined creation process is invoked), the `create` instance method of the class `Object` is invoked. This method is similar to the `create` method of the meta-class `Class`. It firstly calls the `alloc` instance method on its (of the `Class` class) which allocates memory for the object, and makes it an instance of its class. Afterwards a call to the constructor `init` is invoked.

Now we can specify the object for the kitchen by the class to which it belongs. In this case a kitchen is an instance of a room.

```
Class Room
Room kitchen
```

A `set` call on a class creates an instance variable on the class-object. This variable is unique for all instances, therefore, it may be referred to as a class variable.

Methods Defined in Classes

Methods which are defined in classes and which are provided to the instances of these classes are called "instprocs". The syntax for defining an instproc is:

```
className instproc procname args body
```

It is similar to the definition of procs on objects, but uses the keyword `instproc` to distinguish between the methods defined on the class-object and those defined on the class. Since all rooms (in the modeled world) have ceilings, we may want to define a simple convenience instproc, which is able to set the color:

```
Room instproc setCeilingColor color {
  my set ceilingColor $color
}
```

A special instproc, the constructor `init`, was mentioned already. Now we are able to define such an instproc. Defined on a class it is responsible for all initialization tasks, which needed to be performed, when constructing a new instance object of the class. The constructor of the `Room` can initialize a variable for the color, in which the ceiling is painted, to white as default, since this is the color of ceilings without painting.


```
Room instproc init args {
    my setCeilingColor white
    next
}
```

After this definition, all instances derived from the `Room` class have an instance variable `ceilingColor` with the value `white`. The `args` argument used here is a special argument in Tcl which allows us to use a list of arguments which may change its length from call to call.

An `instproc` can be deleted by the method `instproc` as well. If `instproc` is called with an empty argument list and an empty body, the specified method is deleted, as the following example shows:

```
Room instproc setCeilingColor {} {}
```

Information about Classes

Resembling to objects, information on classes may be gained through the `info` instance method of the meta-class `Class`. Note that this instance method does not only support the class `info` options, but also the object `info` options, since the accessing command refers to the class-object, which itself is an object and, therefore, offers its informations. The following table summarizes the additional `info` options available on classes.

Options for the `info` method on classes

<code>className info heritage ?pattern?</code>	Returns a list of all classes in the precedence order of the class hierarchy matching <i>pattern</i> or a list of all classes, if <i>pattern</i> was not specified.
<code>className info instances ?pattern?</code>	Returns a list of the instances of the class matching <i>pattern</i> or of all instances, if <i>pattern</i> was not specified.
<code>className info instargs methodName</code>	Returns the arguments of the specified <code>instproc</code> (method provided to objects).
<code>className info instbody methodName</code>	Returns the body of the specified <code>instproc</code> .
<code>className info instcommands ?pattern?</code>	Returns all commands defined on the class, if <i>pattern</i> was not specified, otherwise it returns all commands provided to objects that match the pattern.
<code>className info instdefault methodName arg var</code>	Returns 1 if the argument <i>arg</i> of the specified <code>instproc</code> has a default value, otherwise 0. If the default value exists it is stored in <i>var</i> .
<code>className info subclass ?className2?</code>	Returns a list of all subclasses of the class, if <i>className2</i> was not specified, otherwise it returns 1 if <i>className2</i> is a subclass and 0 if not.
<code>className info superclass ?className2?</code>	Returns a list of all super-classes of the class, if <i>className2</i> was not specified, otherwise it returns 1 if <i>className2</i> is a superclass and 0 if not.

Inheritance

Besides encapsulation of operations and state in objects, a second central ability of object–orientation is inheritance. XOTcl supports single and multiple inheritance with a directed acyclic class graph. Automatically each new class created by the instance methods `create` and `alloc` of `Class` inherits from `Object`. Therefore, it is ensured that all instances of the new class have access to the common features of objects stored in the class `Object`.

To specify further inheritance relationships the instance methods `superclass` of `Class` is used:

```
className -superclass classList
```

E.g. in the example a kitchen may be seen as a special room:

```
Class Room
Class Kitchen -superclass Room
```

Now all instances of `Kitchen` are able to access the operations stored in the `Room` and in the `Kitchen` class. Note the transition the kitchen was going through: firstly it was a singular object, then it was an object with a user–defined class, and now it is a class. This is possible (and not senseless) because of the per–object specialization ability and the dual shape of a class, which is at the same time object and class. Both lead to a seamless connection of the run–time properties (the object features) and their descriptive properties (the class features). It is possible to avoid the strict distinction between them, known from static typed languages, like C++, Java, etc.

Moreover, since the syntaxes of constructs expressing the same concern are nearly identical, we can re–factor a solution with very few changes to the alternative. We will see similar "ease of refactoring" throughout the XOTcl language. E.g., we can also easily re–factor the class hierarchies or exchange class hierarchies against mixin solutions with only slight changes in the code.

Besides single inheritance, as seen, XOTcl provides also multiple inheritance. This is syntactically solved by giving the `superclass` instance method a list of classes instead of a single class as argument.

```
Class Room
Class 4WallsRoom -superclass Room
Class CookingPlace
Class Kitchen -superclass {4WallsRoom CookingPlace}
```

Now the kitchen class is specialized a bit more. It is a special room which has four walls *and* it is a cooking place. Multiple inheritance, as seen here, is as simple to apply as single inheritance.

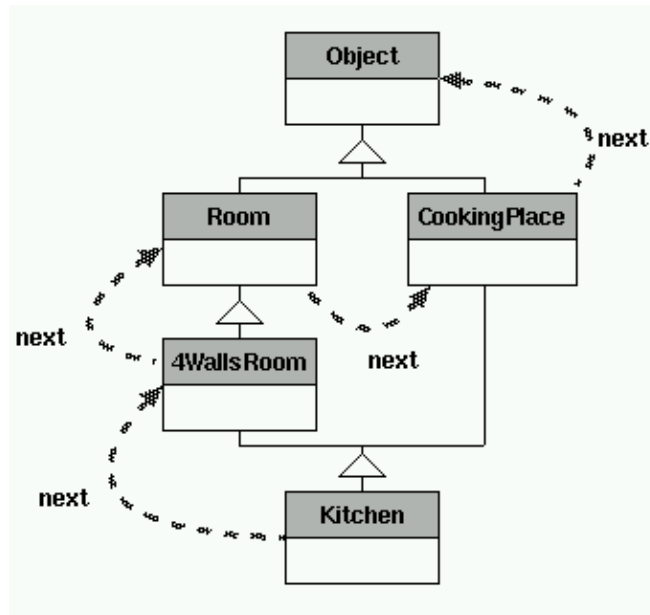
Most often when the disadvantages of multiple inheritance are discussed, the name resolution along the class graph is considered as the biggest problem. The question is, which method is to be chosen and which path through class graph is to be taken, if more then one method of the specified name exist on the class graph.

In the example such questions would arise for an object of the `Kitchen` class, if two same–named methods are defined on `CookingPlace` and `4WallsRoom` or if a method of the class `Object` is called, which is reachable through two paths (along `CookingPlace` or `Room`).

Often – e.g. in the inheritance model of C++ – the path through the graph is not clearly determined and/or the rules are too complicated to be understood on the first glance. The programmer often can only determine by trial which method is found firstly. Than an explicit naming of the class is necessary, which means storage of

non-local information in sub-classes. Often different compilers of one language behave differently. All these issues make code reuse difficult. Moreover understandability and portability are reduced.

Figure 3: The example classes and the following next-path



XOTcl goes an intuitive and unambiguous way to solve this problem. It resolves the precedence order along a `next-path`. Firstly the class of the object is searched, which is `Kitchen` in example. Then the super-classes are searched in definition order, which means at first `4WallsRoom`, then `CookingPlace`. Each branch is searched completely, before changing to the next branch. That means, `Room` is searched, before the `CookingPlace` branch is visited. At last the top of the hierarchy, the class `Object`, is searched.

The usage of `next` in XOTcl is different to OTcl: In OTcl, `next` is defined as a method, in XOTcl it is a primitive command. Furthermore, in OTcl, it is always necessary to provide the full argument list for every invocation explicitly. In XOTcl, a call of `next` without arguments can be used to call the shadowed methods with the same arguments (which is the most common case). When arguments should be changed for the shadowed methods, they must be provided explicitly in XOTcl as well. In the rare case that the shadowed method should receive no argument, the flag `--noArgs` must be used.

Destruction of Classes

Classes are destroyed by the destruction of the class-object using the `destroy` method of the `Object` class. The destruction of super-classes does not destroy the sub-classes. The super-class is simply removed from the sub-classes' super-class lists. All classes have the super-class `Object`, if no super-class is specified. Therefore, if all super-classes are destroyed or removed, the new super-class is `Object`, not: no super-class. The destruction of the class of an object does neither delete the object nor leave it without class. In XOTcl a deleted class leaves its instances with the class `Object`.

So all empty class- and superclass-relationships are automatically reseted to `Object`. Note, that this are differences to OTcl, where the destruction of an class destroys all instances and an empty super-class list remains empty.

Method Chaining

A special feature of XOTcl is the method chaining without explicit naming of the “mix-in”-method. It allows one to mix the same-named superclass methods into the current method (modeled after CLOS). The previously described next-path is the basis for this functionality. At the point marked by a call to the next primitive of XOTcl the next shadowed method on the next path is searched and, when it is found, it is mixed into the execution of the current method. When no method is found, the call of next returns an empty string, otherwise it returns the result of the called method. The syntax is:

```
next ?arguments/--noArgs?
```

As stated earlier the usage of next in XOTcl differs from OTcl, since the next call without arguments in OTcl means per default that no arguments are passed. But most often all arguments are passed through to the shadowed methods (since these will most likely have the same signatures). When all variables should be passed through, in OTcl it is necessary for correct variable substitution to use:

```
eval $self next $args
```

To avoid such difficulties, we made the passing of all arguments the default case; a simple

```
next
```

performs the task of passing all arguments to the shadowed methods. These arguments are called the *standard arguments*. If the standard argument feature should not be used, optionally arguments can be given or the flag `--noArgs` could be set as sole argument, which means that the shadowed method is called with no arguments.

E.g. the following next call ignores the standard arguments and sends the arguments 1 and 2 instead:

```
next 1 2
```

As an example all classes involved in the previous example should get a constructor instance method, which simply sets an instance variable on the object:

```
Room instproc init args {
  my set roomNumber 0
  next
}
4WallsRoom instproc init args {
  my set doorPosition 0
  next
}
CookingPlace instproc init args {
  my set stoveType electric
  next
}
Kitchen instproc init args {
  my set cookName -
  next
}
```

After creation an object of class `Kitchen` gets automatically four instance variables `cookName`, `roomNumber`, `doorPosition` and `stoveType` set up with default values in this order (since this is the order of the classes in the next-path). Note, that the order is important, because one missing next call, in one

of the `init` methods, means that succeeding `init` methods will not be executed. This mechanism functions equally on all kinds of `instprocs`, not only on constructors.

The constructors use the `args` argument, which allows us to give a list of variable length as arguments. To ensure reusability of our classes the constructors should use `args` in most cases, since they may pass through arguments for constructors further up the class hierarchy.

If a `proc` with the searched name exists on the object it shadows all `instprocs`. A `next` call in a `proc` leads to the normal `next-paths` search, starting with the object's class.

By the way, an observant reader might notice that the example above can be rewritten without explicit constructors, just by using parameters with default values.

```
Class Room -parameter {{roomNumber 0}}
Class 4WallsRoom -superclass Room -parameter {{doorPosition 0}}
Class CookingPlace -parameter {{stoveType electric}}
Class Kitchen -superclass {4WallsRoom CookingPlace} -parameter {{cookName -}}
```

If an instance of a `Kitchen` is created it will contain instance variables for `doorPosition`, `cookName`, `roomNumber`, and `stoveType`, as the following statements will show.

```
Kitchen k
puts [k info vars]
```

Dynamic Class and Superclass Relationships

Another property of XOTcl that distinguishes it from statically typed languages are dynamics of class relationships. The realization of the definition of `super-classes` as seen above with the `superclass` method suggests already, that it is not only available at the class definition time. In the above example its appended to the class definition with `"-superclass"` as a short syntax for method invocation at definition time (all other available methods can also be called with a preceding dash ("-") appended to definitions).

At any time the class graph may be changed entirely using the `superclass` method. Suppose the rooms and kitchens created in modeling of a house should be displayed to a screen, but it is not determined, whether the user of the system has the possibilities for graphical outputs. Two classes `TextOutput` and `GraphicalOutput` may be defined, which handle the output. Both have an `instproc` `paint` which does the painting of the virtual world on the chosen display type. The common output requirements are handled by a derived class `VirtualWorldOutput` which calls the `paint` method of the superclass using `next`. In statically typed languages it would need more sophisticated constructs to change the output class at run-time. E.g. a delegation to another object handling the intrinsic task of the output object would be introduced solely for the purpose of configuring the output form. With a dynamic class system we can use the `superclass` method to do so easily:

```
Class TextOutput
TextOutput instproc paint args {
  # do the painting ...
}
Class GraphicalOutput
GraphicalOutput instproc paint args {
  # do the painting ...
}

# initially we use textual output
```

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```
Class VirtualWorldOutput -superclass TextOutput
VirtualWorldOutput instproc paint args {
  # do the common computations for painting ...
  next; # and call the actual output
}

# user decides to change to graphical output
VirtualWorldOutput superclass GraphicalOutput
```

Sometimes, such a change to new intrinsic properties should not happen for all instances of a class (or the class hierarchy), but only for one specific object. Then the usage of a dynamic super–class relationship is a too coarse–grained means. A second form of such dynamics is the changing of the relationship between object and class. This means, objects can also change their class dynamically at run–time. This feature may be used to model a life–cycle of an object, without loosing the object's identity, inner state or per–object–specializations through procs. The `class` instance method enables this functionality.

An example would be an agent for the virtual world. Agents may be placeholders for persons, who interactively travel the world, or programs, which act automatically. When a person decides at run–time to give a task it has performed formerly by hand to an automatic agent, the agents nature changes from interactive agent to automatic agent, but the identity and the local state (that means the parts of the task, that are already fulfilled by the person) stay the same. This is a scenario for changing class relationships, e.g.:

```
Class Agent
Class AutomaticAgent -superclass Agent
Class InteractiveAgent -superclass Agent

# create a new agent for a person
InteractiveAgent agent1

# the person does something ...
# and decides the change to an automatic agent
agent1 class AutomaticAgent
```

Meta–Classes

Meta–classes are a special kind of classes. Similar as classes are managing objects (where managing means: control the creation and destruction of instances, know what instances exist, provide methods), meta–classes are managing classes. So, meta–classes are used to define classes. In other words, every `Class` in XOTcl is created by a meta–class, in most cases by the meta–class named `Class`. New user–defined meta–classes can be defined as subclasses of the predefined meta–class `Class`, or by adding an `instmixin class` (see [below](#)) containing `Class` to the precedence chain of the class. By defining `Object instmixin Class` one can even change the object system of XOTcl in a way such that every created `Object` is a meta–class.

Since the concept of a meta–class are sometimes confusing to people of a background of some other programming languages, we explain meta–classes slowly with the analogy of classes and objects.

When a class `Foo` is created via the command

```
Class Foo
```

it has no private variables and no special methods. This is somewhat similar as creating an object via `Object`:

```
Object foo
```

This plain object `foo` can be configured directly, or one can create a class that configures the object. Instead of writing

```
Object foo
foo set x 1
foo proc hi {} {puts "hello"}
```

one can use

```
Class C -superclass Object
C instproc init {} {my set x 1}
C instproc hi {} {puts "hello"}
```

and create an instance and call the method.

```
C c1
c1 hi
```

The same holds for meta-classes and classes as well: Instead of writing

```
Class Foo
Foo set x 1
Foo proc hi {} {puts "hello"}
```

the following can be used:

```
Class MC -superclass Class
MC instproc init {} {my set x 1}
MC instproc hi {} {puts "hello"}
```

The instances of meta-classes are classes which can be defined the usual way:

```
MC Bar
Bar hi
Bar b1
```

Now we have a class names `Bar` which has a class-scoped variable named `x` with the value of 1 (set via the constructor); the class `Bar` has as well a class-method named `hi` which prints, when called, the string "hello". The class `Bar` can be used to create instances of the class like `b1`, `b2` and so on.

Note that the command `Class` is a predefined definition of the most general meta-class in XOTcl. Each time we are creating a class, we use this meta-class. In order to define a specialized meta-class, we can do this the traditional object-oriented way: we subclass. Therefore, in to define a specialized meta-class, we can use:

```
Class myMetaClass -superclass Class
```

This defines a new meta-class `myMetaClass`, which has all the abilities of meta-classes. That means that the programmer is able to specify new class features or override old ones. Later she/he may instantiate these into new classes.

This is a very powerful language feature, since it allows one to give some classes further abilities than the others (or to restrict classes). This way large program structures, like certain design pattern parts, may be instantiated. Meta-classes hold the common abstract parts of the structures. They allow one to form libraries of such structures very easily.

Example 1: Overloading the info method of classes

As a simple example we can derive a new meta-class `NoClassInfo` from `Class`. Later we override the `info` method of `Class`. Thus the classes created with `NoClassInfo`, have an `info` option that only produces an error message. All classes created with `NoClassInfo`, like `Agent` in the example below, are not capable of accessing the class `info` method anymore:

```
Class NoClassInfo -superclass Class
# redefine info ability
NoClassInfo instproc info args {
  error "No class info available"
}
# derive agent class from meta-class, which
# can not access class info
NoClassInfo Agent
```

Now a call like:

```
Agent info superclass
```

triggers the error message.

Example 2: Defining Classes that Count Their Instances

Meta-classes are frequently used to define some bookkeeping about the number of instances on the class level. In the following example we define a meta-class named `CountedClass` which defines classes that count their instances:

```
Class CountedClass -superclass Class -parameter {{counter 0}}
CountedClass instproc create args {
  my incr counter
  next
}
CountedClass instproc instdestroy args {
  my incr counter -1
  next
}
CountedClass Dog

Dog piffie
Dog ideofix
puts "nr of dogs: [Dog counter]"

piffie destroy
puts "nr of dogs: [Dog counter]"
```

Note that the behavior introduced by meta-classes can be orthogonal to the behavior of the classes. One can define `Dog` as a specialization of `Animal` or defines a special kind of dog such as `Poodle` using the method `superclass` as usual.

Example 3: The Singleton Meta-Class

Finally, a small example, which is more practical. Some applications have the requirement that only one instance of a class might be defined at a certain time. Such a behavior is frequently called a "Singleton". In XOTcl we can define a class `singleton` by overloading the `create` method of `Class`: when `create` is

called and there exists already an instance of the singleton it is returned instead of a new instance.

```
Class Singleton -superclass Class
Singleton instproc create args {
  expr {[my exists instance] ? [my set instance] : [my set instance [next]]}
}
```

If someone wants to have a class e.g. `Manager` to be a singleton, you can create it by e.g.

```
Singleton Manager -superclass FOO
```

Create, Destroy, and Recreate Methods

XOTcl allows since version 0.84 for a flexible destroy and recreate scheme. `create` and `alloc` are both Class instprocs handling creation for their instances. I.e.:

```
className alloc [self]
```

and

```
className create [self]
```

are used for creating an instance. A similar method `instdestroy` exists on `Class` that handles physical destruction of an object. The method `destroy` on `Object` which lets an object destroy itself in fact has the following behavior:

```
Object instproc destroy args {
  [my info class] instdestroy [self]
}
```

However, this behavior is not implemented in XOTcl, but in C. `create` distinguishes between the following situations:

- *Create a new object:* `create` calls `alloc` and then `doInitializations`.
- *Recreate an existing object:* When the specified object exists, it is recreated through the `recreate` method:

```
givenClass recreate [self]
```

`recreate` can be customized e.g. by overloading or interception. By default it calls `cleanup` followed by `doInitializations`.

In both cases, the method `doInitializations` is called automatically from C and has the following default behavior:

- Search for parameter default values,
- Call parameter initialization methods,
- Call the constructor `init`.

Each step has a method call that can be changed, intercepted, etc. Of course, `cleanup`, `recreate`, `instdestroy`, etc. can also be overloaded or intercepted.

Consider a typical case for overloading `recreate`: a structure preserving `recreate` that cleans up the class but preserves the existing class hierarchy (subclass and instance relationships):

```
Class StructurePreservingRecreate
StructurePreservingRecreate instproc recreate {cl args} {
  if {[my isclass $cl]} {
    set subclass [$cl info subclass]
    set instances [$cl info instances]
  }
  next
  if {[my isclass $cl]} {
    foreach sc $subclass {
      $sc superclass $cl
    }
    foreach i $instances {
      $i class $cl
    }
  }
}
Object instmixin add StructurePreservingRecreate
```

Now the following code does not change the superclass or instance relationships of C:

```
Class A
Class B
Class C -superclass {A B}
Class D
Class E -superclass {C D}
C c1
C c2

# recreate -> is structure preserving
Class C -superclass {A B}
C c2

# test
puts superclass=[C info superclass]
puts subclass=[C info subclass]
puts instances=[C info instances]
puts class=[c1 info class]
puts class=[c2 info class]
```

Methods with Non-Positional Arguments

So far we have introduced methods only with positional arguments: that is, the position of an argument in the argument list determines to which local variable the argument is bound, when the method is invoked. Sometimes non-positional arguments -- arguments that carry both a name and a value when the method is invoked -- are useful. Before a non-positional argument can be used, it must be defined in the method definition using the following syntax:

```
className instproc methodName ?non-pos-args? args body ?assertions
objName proc methodName ?non-pos-args? args body ?assertions
```

The non-positional arguments are defined with the following syntax:

```
{-name?:checkoption1, checkoption2, ...? default value} \
{-name?:checkoption1, checkoption2, ...? ?default value?} ...
```

Only the name of the non-positional argument is really required, all other parts of this syntax are optional.

Let's consider a simple example, where a method with two non-positional args is defined; one has only a name ("a"), and one has a name and a default value (b):

```
Object o
o proc someproc {-a {-b {1 2 3}} x y} {
    puts "$a $b $x $y"
}
```

We can invoke this method as follows:

```
o someproc -b {4 5} -a 1 3 4
```

Here, the order of a and b can be changed; hence the name non-positional arguments. As b has a default value, we do not need to provide a value for it. In the following invocation b has the value "1 2 3":

```
o someproc -a 1 3 4
```

The ordinary arguments start after the last non-positional argument (here: "3 4"). We can explicitly end the non-positional arguments by using "--". This is useful if we want to provide arguments that contain dashes ("–"), e.g.:

```
o someproc -a 1 -- -b -c
```

Sometimes we want to check or control the non-positional arguments. For instance, in the above invocation, we might want to check that a is not forgotten, because otherwise the method cannot execute properly. This is the role of the checkoptions. There are three predefined checkoptions: `required`, `boolean` and `switch`. `required` checks whether a non-positional argument is given, `boolean` checks that a non-positional argument is of boolean type. For instance:

```
Class P
P instproc someproc {-a:required {-b:boolean true}} {
    puts "$a $b"
}
P p
```

This method requires a, and b needs to be of type boolean (is has the default value `true`). This invocation is valid:

```
p someproc -a 1 -b 0
```

This invocation is invalid, because a is missing, and b is not a Tcl boolean type:

```
p someproc -b " a b v"
```

The checkoption `switch` is similar to `boolean` except it does not require an additional argument. If the default value is `false`, the switch can be turned on, if the default is `true` it can be switched off.

The checkoptions are extensible. In fact, they are defined in an object `:::xotcl::nonposArgs`. We can extend this object with new methods. A check option method has the following syntax:

```
someobject/someclass proc|instproc methodName {?optional nonpositional arguments? argName arg} {
    ...
}
```

```
}
```

`argName` is here used to denote the name of the argument, and `arg` is the provided value.

Of course, the non-positional arguments can also be introspected. The following `info` options return the non-positional arguments of a method:

```
objName info nonposargs methodName  
className info instnonposargs methodName
```

Message Interception Techniques



Even though object–orientation orders program structures around data, objects are characterized primarily by their behavior. Object–oriented programming style encourages the access of encapsulated data only through the methods of an object, since this enables data abstractions. A method invocation can be interpreted as a message exchange between the calling and the called object. Therefore, objects are at runtime only traceable through their message exchanges. At this point the message interceptors can be applied to catch and manipulate all incoming and outgoing messages of an object.

Generally interceptors can be applied to attach additional or extrinsic concerns to an object or a class or a class hierarchy. For instance roles or aspects can be implemented this way on various levels of scale.

We have already discussed some interception techniques implicitly. E.g., the `unknown` mechanism intercepts messages that have not be found on the object. It can be used as a very useful programming technique, e.g., the define a default behavior for an object. The interceptors presented in this section have a different character: They are applied before/after the original method *even if the method is defined for the target object*. Thus these interception techniques may be applied

We will discuss the message interceptors in this section in detail. The table below gives an impression, when which interceptor may be applied.

Message Interceptors Overview

	<i>Applied When</i>	<i>Primary Target Structure</i>	<i>Coverage</i>
<i>Per–Object Filter</i>	before/after a call	object hierarchies	all methods
<i>Per–Class Filter</i>	before/after a call	class and class hierarchies	all methods
<i>Per–Object Mixin</i>	before/after a call	object	specific methods
<i>Per–Class Mixin</i>	before/after a call	class and class hierarchies	specific methods
<i>Unknown Mechanism</i>	after method was not found	object	all unknown calls

Filter

The filter (see [Neumann and Zdun 1999a] for more details) is a language construct to implement broader extensional concerns either for a single object or for several classes or class hierarchies. This way large program structures at the scale of several classes or class hierarchies can be managed. It is a very general interception mechanism which can be used in various application areas. E.g. a very powerful programming language support for certain design patterns is easily achievable, but there are also several other domains which are covered, like tracing of program structures, self–documentation at run–time, re–interpretation of the running program, etc.

A *per–class filter* is a special instance method that is registered for a class *C*. A *per–object filter* is a special instance method that is registered for an object *o*. Every time an object of class, *C* or the object *o* respectively, receives a message, the *filter* method is invoked automatically.

Usage of Filters

All messages to a filtered object must go through the filter before they reach their destination object. A simple example would be a sole filter on the class of the object. To define such a filter two steps are necessary. Firstly a filter method has to be defined, then the filter has to be registered. The filter method consists of three parts which are all optional. A filter method has the following form:

```
className instproc FilterName args {
  pre-part
  next
  post-part
}
```

When a filter comes to execution at first the actions in the *pre-part* are processed. The filter is free in what it does with the message. Especially it can (a) pass the message, which was perhaps modified in the *pre-part*, to other filters and finally to the object. It can (b) redirect it to another destination. Or it can (c) decide to handle the message on its own. The forward passing of messages is implemented through the `next` primitive of XOTcl. After the filter has passed its *pre-part*, the actual called method is invoked through `next`.

After the call of `next` is processed, the execution returns to the point in the filter, where the `next` call is located and resumes execution with the actions of the *post-part*. These may contain arbitrary statements, but especially may take the result of the actual called method (which is returned by the `next`-call) and modify it. The caller then receives the result of the filter, instead of the result of the actual called method.

The *pre-* and *post-*part may be filled with any ordinary XOTcl-statements. The distinction between the three parts is just a naming convention for explanation purposes.

The filter uses the `args` argument which lets us use a list of variable length as arguments, since it must filter a lot of different calls, which may have different argument lists. Furthermore, it may pass through arguments to other filters and the preceding filters may change the argument list.

Since any `proc/instproc` may be a filter, a registration of the filter is necessary, in order to tell XOTcl, which `instprocs` are filters on which classes. The `filter` and `instfilter` instance methods are able to handle this task for *per-object* filters and *per-class* filters respectively. Similar to the XOTcl language introduced so far, the filter registration is dynamic at run-time. By supplying a new list of filters to `filter/instfilter`, the programmer can change the filters registered on a class at arbitrary times. The filter instance method has the syntax:

```
className instfilter filterList
```

for *per-class* filters and:

```
objName filter filterList
```

for *per-object* filters.

Now a simple example should show the filter's usage. In the preceding examples we have defined several rooms. Every time a room action occurs it is likely that the graphical sub-system has to change something on the output of that particular room. Therefore, at first we need a facility to be informed every time an action on a room happens. This is quite easily done using filters:

```
Class Room
```

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```
Room r1; Room r2;      # just two test objects

Room instproc roomObservationFilter args {
    puts "now a room action begins"
    set result [next]
    puts "now a room action ends - Result: $result"
    return $result
}

Room instfilter roomObservationFilter
```

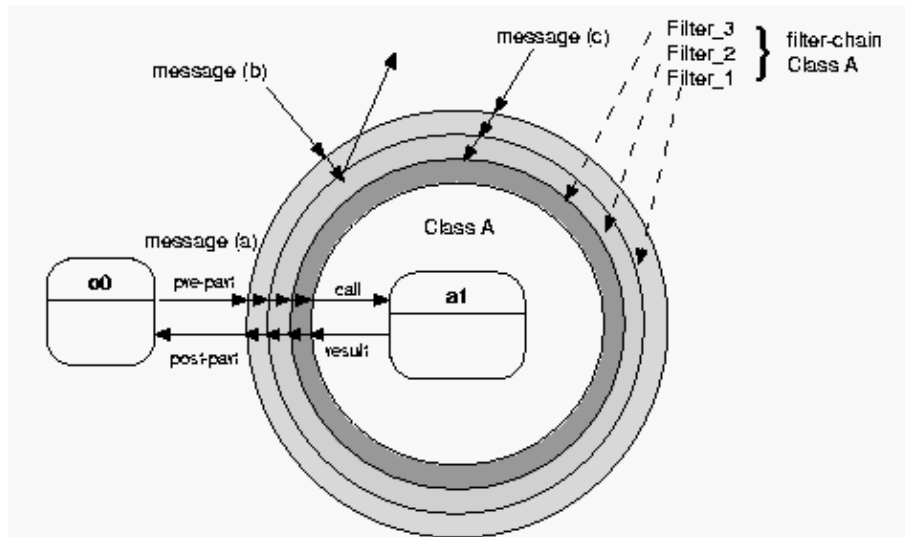
Now every action performed on room objects is notified with a pre- and a post-message to the standard output stream. We return the result of the actual called method, since we don't want to change the program behavior at all. E.g. we can set an instance variable on both of the two room objects:

```
r1 set name "room 1"
r2 set name "room 2"
```

The output would be:

```
now a room action begins
now a room action ends - Result: room 1
now a room action begins
now a room action ends - Result: room 2
```

Figure 4: Cascaded Message Filtering



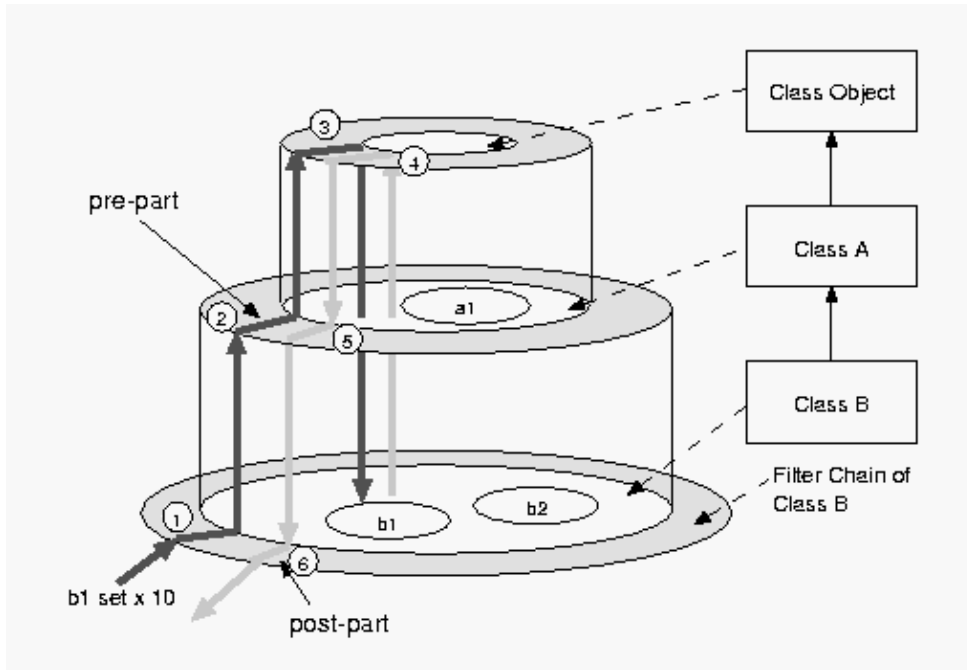
All classes may have more than one filter. In fact they may have a whole filter chain, where the filters are cascaded through `next`. The `next` method is responsible for the forwarding of messages to the remaining filters in the chain one by one till all pre-parts are executed. Then the actual method is executed and then the

post-parts come to turn. If one next-call is omitted the chain ends in this filter method. As an example for an additional filter we may register a filter that just counts the calls to rooms.

```
Room set callCounter 0; # set class variable
Room instproc counterFilter args {
  [self class] instvar callCounter
  incr callCounter
  puts "the call number callCounter to a room object"
  next
}
Room instfilter {roomObservationFilter counterFilter}
```

Filters are invoked in registration order. The order may be changed by removing them and adding them in new order. Filters are inherited by sub-classes. E.g. in the preceding example for the next path, an OvalOffice was derived from the Room class. Without a change to the program each OvalOffice object automatically produces the same filter output as rooms.

Figure 5: Filter Inheritance



Filter chains can also be combined through (multiple) inheritance using the next method. When the filter chain of the object's class is passed, the filter chains of the superclasses are invoked using the same precedence order as for inheritance. Since on the subclass there may also be another filter chain, without sophisticated computing in the pre- and post-parts one can produce easily a powerful tracing facility. E.g. if we want to distinguish an OvalOffice from other rooms we may want to add a filter solely for rooms of the type OvalOffice:

```
Class OvalOffice -superclass Room
```


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```
OvalOffice o1; # test object
OvalOffice instproc ovalOfficeObservationFilter args {
    puts "actions in an oval office"
    next
}
OvalOffice instfilter ovalOfficeObservationFilter
```

A simple call to the `o1` object, like:

```
o1 set location "Washington"
```

produces the following output:

```
actions in an oval office
now a room action begins
the call number 3 to a room object
now a room action ends - Result: Washington
```

As seen already, filter registrations can be added dynamically at runtime. But they may also be removed. Perhaps the counting on rooms should stop after a while, then a simple call of the `instfilter` method is sufficient:

```
Room instfilter roomObservationFilter
```

Filters can be removed completely by giving an empty list to the registration method:

```
Room instfilter {}
```

Per-object filters operate on a single object. E.g. if we only want to observe a single `Room` object `room1`, we can use the `filter` method to register the `roomObservationFilter` only for this particular instance:

```
room1 filter roomObservationFilter
```

As a filter we can register any method in the precedence order of the class or object. Thus we can also register procs as per-object filters. Additionally, meta-class methods may be registered as per-class filters. Filters are linearized so that each filter is only executed once, even if it is registered multiple times.

Introspection on Filters

In order to gain information about the currently registered filters on a certain object/class, the object info option `filters` and the class info option `instfilters` may be queried. It returns a list of the currently registered filters:

```
className info instfilter
objName info filter
```

A special call-stack info option for filters is `self filterreg`. It returns the name of the object or class on which the filter is registered. Since the filter may be registered on other objects/classes than the one on which it is defined, this may vary from `self class` in the filter. The command returns a list of the form:

```
objName filter filterName
```

or:

```
className instfilter filterName
```

respectively.

Example: A Simple Trace Filter

The trace example primarily demonstrates the inheritance of filter chains. Since all classes inherit from `Object`, a filter on this class is applied on all messages to objects. The `Trace` object encapsulates methods for managing the tracing:

```
Object Trace
Trace set traceStream stdout

Trace proc openTraceFile name {
  my set traceStream [open $name w]
}

Trace proc closeTraceFile {} {
  close $Trace::traceStream
  my set traceStream stdout
}

Trace proc puts line {
  puts $Trace::traceStream $line
}

Trace proc add className {
  $className instfilter [concat [$className info filter] traceFilter]
}
```

First we define the object and set a variable for the stream to which we send the trace outputs (here: `stdout`). With a method for opening and a method for closing a file we can redirect the trace stream to a file. `puts` is helper method for the filter to print an output to the selected output stream. In `add` the `traceFilter` is appended to the existing filters of a specified class. The actual filter method (see below) displays the calls and exits of methods with an according message. The calls are supplied with the arguments, the exit traces contain the result values. We have to avoid the tracing of the trace methods explicitly.

```
Object instproc traceFilter args {
  # don't trace the Trace object
  if {[string equal [self] ::Trace]} {return [next]}
  set context "[self class]->[self callingproc]"
  set method [self calledproc]
  switch -- $method {
    proc -
      instproc {::set dargs [list [lindex $args 0] [lindex $args 1] ...] }
      default {::set dargs $args }
  }
  Trace::puts "CALL $context> [self]->$method $dargs"
  set result [next]
  Trace::puts "EXIT $context> [self]->$method ($result)"
  return $result
}
```

As trace message we write the callee’s context (class and proc), the invoked method (using `calledproc`), and the given arguments. In the switch statement we avoid to print whole method bodies.

With

```
Trace add Room
```

messages to all rooms, including all instances of `Room`’s sub-classes, are surrounded with a `CALL` and an `EXIT` output. With

```
Trace add Object
```

messages to all objects in an XOTcl environment are surrounded with a `CALL` and an `EXIT` output. In general, it is possible to restrict the trace to instances of certain classes, or to produce trace output for only certain methods. This requires registration methods and a more sophisticated implementation of the filter method.

Mixin Classes

Per-object and per-class mixins (see [\[Neumann and Zdun 1999c\]](#) for more details) are another interception technique of XOTcl to handle complex data-structures dynamically. Here, we use mixin as a short form for mixin class. All methods which are mixed into the execution of the current method, by method chaining or through a mixin class, are called *mixin methods*. Mixin classes resembles the filter presented in the preceding section. While the filters work on all calls to all methods of an object/class hierarchy, the mixin classes are applied on specific methods. The filter is defined in a single method, while the mixin is composed several method in a class.

Supplemental Classes

Mixin classes cover a problem which is not solvable elegantly just by the method chaining, introduced so far. To bring in an addition to a class, the normal XOTcl way is to define a mixin method and chain the methods through `next`, e.g.:

```
Class Basic
Basic instproc someProc {
  # do the basic computations
}
Class Addition
Addition instproc someProc {
  # do the additional computations
  next
}
```

In order to mix-in the additional functionality of the *supplemental* class `Addition` a new helper class (sometimes called intersection class) has to be defined, like:

```
Basic+Addition -superclass Addition Basic
```

This is even applicable in a dynamical manner, every object of the class `Basic` may be changed to class `Basic+Addition` at arbitrary times, e.g.:

```
Basic+Addition basicObj
...
basicObj class Basic+Addition
```

Now consider a situation with two addition classes. Then following set of classes has to be defined to cover all possible combinations:

```
Class Basic
Class Addition1
Class Addition2
Class Basic+Addition1 -superclass Addition1 Basic
Class Basic+Addition2 -superclass Addition2 Basic
Class Basic+Addition1+Addition2 -superclass Addition2 Addition1 Basic
```

The number of necessary helper classes rises exponential. For n additions, $2^n - 1$ (or their permutations if order matters) artificially constructed helper-classes are needed to provide all combinations of additional mix-in functionality. Furthermore it is possible that the number of additions is unlimited, since the additions may produce other additions as side-effects. This demonstrates clearly that the sub-class mechanism provides only a poor mechanism for mix-in of orthogonal functionality. Therefore we provide an extension in the form of object mixin classes, which are added in front of the search precedence of classes.

Per-Object Mixins

The mix-ins methods extend the next-path of shadowed methods. Therefore, per-object mix-in methods use the `next` primitive to access the next shadowed method. Consider the following example:

```
Class Agent
Agent instproc move {x y} {
  # do the movement
}
Class InteractiveAgent -superclass Agent
# Addition-Classes
Class MovementLog
MovementLog instproc move {x y} {
  # movement logging
  next
}
Class MovementTest
MovementTest instproc move {x y} {
  # movement testing
  next
}
```

An agent class is defined, which allows agents to move around. Some of the agents may need logging of the movements, some need a testing of the movements, and some both (perhaps only for a while). These functionalities are achieved through the additional classes, which we will apply through per-object mixins.

Before we can use the per-object mix-ins on a particular object, we must register the mixins on it with the `mixin` instance method. It has the syntax:

```
objName mixin mixinList
```

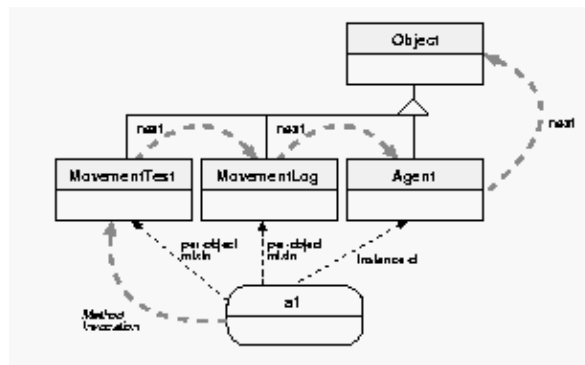
For example we may create two interactive agents, where one is logged and one is tested:

```
InteractiveAgent i1; InteractiveAgent i2
i1 mixin MovementLog
i2 mixin MovementTest
```

At arbitrary times the mixins can be changed dynamically. For example *i2*'s movements can also be logged:

```
i2 mixin MovementTest MovementLog
```

Figure 6: Per-Object Mix-Ins: Next-Path for the Example



The `mixin` option of the `info` instance method allows us to introspect the per-object mix-ins. It has the syntax:

```
objName info mixin ?className?
```

It returns the list of all mix-ins of the object, if `className` is not specified, otherwise it returns 1, if `className` is a mixin of the object, or 0 if not.

Note, that the constructors (`init` methods) of per-object mixins (and per-class mixins) are only called, if the mixin is registered already during object initialization (when `init` is called). For per-object mixins, one can achieve the initialization of a mixin via an idiom like

```
Object o -mixin M -init
```

that registers the mixin before `init` is called. When a mixin is registered after object creation and it needs initializations, it is necessary to define special methods for this. Note, that the behavior described here is introduced in version 0.84 to ensure consistent behavior of intrinsic classes, per-object and per-class mixins, and to achieve predictable behavior for dynamic registration for all kind of mixins, and as well during recreations of objects having mixins registered. Older versions used heuristics for the initialization of per-object mixins.

Per-Class Mixins

Per-class mixins are exactly identical in their behavior to per-object mixins, but they operate on classes. Thus they are the class-specific variant of the per-object mixins, like `instprocs` are a class-specific variant of `procs`. Therefore, in the language the per-class mixins are called `instmixins`.

In general a per-class mixin is a class which is mixed into the precedence order of all instances of the class and all its subclasses it is registered for. It is also searched before the object's class itself is searched, but after per-object mixins.

Per-class mixins are *linearized* according to the precedence order like classes on the superclass hierarchy. I.e. from the full list of per-object mixins, per-class mixins, and intrinsic classes (and all the superclasses of all these classes) always the last occurrence is used.

From the point of view of language expressibility `instmixins` are not required, because they cannot express anything that per-object mixins cannot express already (like `procs` can express any `instproc` feature). As alternative to `instmixins`, we could simply register the per-object mixins in the constructor of the class.

But there at least the following reasons for `instmixins` as an additional language construct:

1. we can at runtime determine with `info mixin` and `info instmixin` whether it is a class- or object-specific mixin. Thus we get a better structuring at runtime.
2. We have not to 'pollute' the constructors with per-class mixin registrations. Therefore, the constructors get more understandable.
3. If it is required to add (and remove) dynamically interceptors to a set of objects, which are instances of a certain type, per-class mixins are much easier to handle (e.g. add an `instmixin` to `Object` to intercept e.g. all calls to certain predefined methods).
4. The language is more 'symmetrical', since any object-specific feature in XOTcl has a class-specific variant.

The mix-ins methods of per-class mixins extend the next-path of shadowed methods in the same way as per-object mixin methods. Before we can use a per-class mix-in on a particular class, we must register the mixin on it with the `instmixin` instance method. It has the syntax:

```
className instmixin mixinList
```

Now consider that in the given per-object mixin example all interactive agents should be tested. We could either build a subclass `TestedInteractiveAgent` or register the per-object mixin in the constructor of the interactive agent class. The subclass solution leads to the same combinatorial explosion of intersection classes as discussed in the previous section, if more supplemental classes are added. The per-object mixin solution pollutes the constructor and does not prevail the structural semantics that the 'tested' property belongs to the interactive agent class at runtime

Here, we can use a per-class mixin:

```
Class Agent
Agent instproc move {x y} {# do the movement}
Class InteractiveAgent -superclass Agent
Class MovementTest
MovementTest instproc move {x y} {
  # movement testing
  next
```

```

}

# now register the instmixin
InteractiveAgent instmixin MovementTest

```

The per-class mixin now operates on all interactive agent including the instances of subclasses. E.g. for interactive agents `i1` and `i2` we automatically have movement testing. `i2` is also logged, since it has the logging class as object-specific mixin:

```

InteractiveAgent i1
InteractiveAgent i2 -mixin MovementLog

i1 move 3 4
i2 move 1 2

```

At arbitrary times the instmixins can be changed dynamically.

The `instmixin` option of the class `info` instance method allows us to introspect the per-class mixins. It has the syntax:

```

className info instmixin ?className2?

```

It returns the list of all instmixins of the the class, if `className2` is not specified, otherwise it returns 1, if `className2` is a mixin of the object, or 0 if not.

Per-class mixins are applied transitively. That means the per-class mixin A of a per-class mixin B is also applied for an object in in B's scope. This is exactly the same as how superclasses are applied for instances. Consider the following example

```

Class X11 \
  -instproc test args {
puts [self class]
next
  }
Class X12 \
  -instproc test args {
puts [self class]
next
  }
Class X \
  -instmixin {X11 X12} \
  -instproc test args {
puts [self class]
next
  }

Class Y \
  -instmixin X

Y create y -test
X create x -test

```

Here the application as a superclass (for `x`) yields the same result as the application as an instmixin (for `y`):

```

::X11
::X12

```

::X

Precedence Order

The precedence order is composed by the precedence order of the superclass hierarchy (as explained earlier) and the message interceptors. In general, filters precede mixins and the superclass hierarchy. They are applied in the order of the next path of the object. Thus per-object filters are ordered before per-class filters.

Mixins are processed after the filters. Again, they are applied in the order of the next path of the object. Thus per-object mixins are ordered before per-class mixins.

Finally, the object's own heritage order comes in the order: object, class, superclasses.

The three precedence order lists (filters, mixins, and classes) are pre-calculated and cached.

Filters as well as classes (mixins and ordinary classes) are linearized. That means, each filter and each class can be only once on a precedence order list. If a filter or class can be reached more than once, than the last occurrence is used.

For instance, consider a class A is superclass, per-class mixin, and per-object mixin. On the precedence order lists only the last occurrence as a superclass is used after linearization.

Guards for Filters and Mixins

Message interceptors, such as filters and mixins, are applied for potentially huge number of messages. In many cases it is possible to reduce the effective number of cases in which interceptors are applied. Interceptor guards offer this functionality: they are boolean conditions with which you can specify in which cases a registered interceptor should be applied.

Filter Guards

A filter guard is a set of conditions that determine whether a filter is to be executed upon a certain invocation or not. Syntactically we can append a filter guard to the filter registration, or it can be registered using the methods `filterguard` for filters and `instfilterguard` for `instfilters`.

Each filter guard is an ordinary condition. A filter guard is executed in the call frame of the filter to be executed, if the filter guard returns 1. Thus, the call-stack information are already set to the values of the targeted filter – and these values can be used in the filter guard.

Let us consider a simple program:

```
Class Room
Room instproc enter {name} {puts [self proc]}
Room instproc leave {name} {puts [self proc]}
Room instproc loggingFilter args {
  puts [self calledproc]
  next
}
Room instfilter loggingFilter
```


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Now consider we only want to apply the logging filter for enter and leave, not for any other message sent to Room instances. In the following example, for instance, we do not want to log the `set` message:

```
Room r
r enter Uwe
r leave Uwe
r set roomName "Office"
```

In this example a `filterguard` can be applied to restrict the application of the filter to those two methods:

```
Room instfilterguard loggingFilter {
  [self calledproc] == "enter" ||
  [self calledproc] == "leave"}
```

Here we limit the filter application of the logging filter on rooms to calls to enter and leave. All other calls are not filtered at all. Note that the same syntax can also be applied for `filterguard`. Also, there is a short form to register filter guards directly during filter registration. The following code has the same semantics as the filter and filter guard definitions above:

```
Room instfilter {{loggingFilter -guard {
  [self calledproc] == "enter" ||
  [self calledproc] == "leave"}}}
```

The filter guard language construct is registration centric. It only applies for the class or object on which a filter is registered, not for all applications of the filter method. That is, if we use `loggingFilter` on another class we may give no or completely different filter guards.

If no filter guard is given for a filter, we assume that it is to be applied on all methods (equivalent to the filter guard '1' which is always true).

There are introspection options for filter guards. In particular, we can use `info filterguard` and `info instfilterguard` for getting the filter guards for a particular filter or `instfilter` respectively. For instance:

```
puts [Room info instfilterguard loggingFilter]
```

This prints out the content of the above guard definition. We can also append `-guard` to `info filter` or `info instfilter` to obtain a filter definition with guards:

```
puts [Room info instfilter -guards]
```

If we call a method from within a filter guard, as for instance `callsMethod`, we might require some parameters from the guard's context, such as `calledproc`. These parameters can be passed as references, as in the following example:

```
Room instfilter loggingFilter
Room instfilterguard loggingFilter {[my callsMethod openURL [self calledproc]]}
```

This example works because the `filterguard` is already set to the scope of the guard. Now we can use this dynamic `calledproc` context in the called method:

```
Room instproc callsMethod {method calledproc} {
  return[string match $calledproc $method]
}
```

We simply check whether the called method matches the given method name or not.

Mixin Guards

Similar to filters, there are mixin guards, defined with `mixinguard` and `instmixinguard`, or with `-guard` during mixin registration. Consider a simple example: there are a number of birds who have two mixins: Fly and Sing. For Fly there are limitations: a bird can only fly if it is at least two years old and is not a Penguin. Such problems are solved with mixin guards:

```
Class Fly
Fly instproc fly {} {puts "[my signature]: yippee, fly like an eagle!"}

Class Sing
Sing instproc sing {} {puts "[my signature]: what a difference a day makes"}
```

```
Class Animal -parameter age
Animal instproc unknown args { puts "[my signature]: how should I $args?"}
Animal instproc signature {} {
  return "[self] [my info class] ([my age] years)"
}

Class Bird -superclass Animal
Class Penguin -superclass Bird
Class Parrot -superclass Bird
Class Duck -superclass Bird

Parrot tweedy -age 1
Penguin pingo -age 5
Duck donald -age 4
Parrot lora -age 6

Bird instmixin {{Fly -guard {[my age] > 2 && ![my istype Penguin]}} Sing}
```

An invocation like:

```
foreach bird {tweedy pingo donald lora} { $bird fly }
```

yields the following result:

```
::tweedy ::Parrot (1 years): how should I fly?
::pingo ::Penguin (5 years): how should I fly?
::donald ::Duck (4 years): yippee, fly like an eagle!
::lora ::Parrot (6 years): yippee, fly like an eagle!
```

There are similar introspection options for mixin guards as those for filter guards. In particular, we can use `info mixinguard` and `info instmixinguard` for getting the mixin guards for a particular mixin or `instmixin` respectively.

Querying, Setting, Altering Filter and Mixin Lists

The methods `mixin`, `instmixin`, `filter` and `instfilter` are system slots having the same query and update interface.

- If one of those methods is called without argument, it returns the current setting.

- If it is called with one argument, the argument is used to set the specified list as indicated in the above examples.
- If these methods are called with more than one argument, the first argument is used to specify the action. Possible values for the action are `set`, `get`, `add` and `delete`. See below for commonly used examples.

<code>obj mixin</code>	same as: <code>obj info mixin</code>
<code>obj mixin {C1 C2}</code>	same as: <code>obj mixin assign {C1 C2}</code>
<code>obj mixin assign {C1 C2}</code>	sets the mixins for <code>obj</code>
<code>obj mixin add C3</code>	adds the mixin C3 on front of the mixin list
<code>obj mixin add C3 end</code>	adds the mixin C3 at the end the mixin list
<code>obj mixin add C3 3</code>	adds the mixin C3 at the 3rd position
<code>obj mixin delete ::C3</code>	removes the mixin C3 from the mixin list. Use absolute class names. <code>delete</code> supports an optional flag <code>-nocomplain</code> that does not produce an error, when the specified class is not in the list.

Note, that the list of possible actions can be extended by extending the class `::xotcl::Relations`.

Querying Call-stack Information

Since the presented interceptors are normal XOTcl instprocs they can access all XOTcl introspection abilities introduced so far. In instprocs all recent information is accessible within their scope. But the interceptors are mechanisms, which cover more then their sole scope. The meaningful usage of the meta-programming abilities often requires to go further and to get information from the caller's and the callee's scope (e.g for delegation decisions). Therefore, we introduced rich call-stack informations for the interceptors. Note, that these are also available for ordinary methods, but the "called..." info options return empty strings.

All call-stack information are packed compactly into the `self` primitive as additional options. Note, before XOTcl version 0.84 these were implemented as a part of the `info` method. They are part of the `self` command for conceptual integrity: introspection options in `info` can be expected to produce the same result, when they are not explicitly changed. In contrast, all information provided by `self` are call-stack dependent.

Querying Call-stack Information via self

<code>self activelevel</code>	Returns the stack level from where the current command was invoked from, or where the last next was called (whatever is closer to the invocation). If the current command was invoked from an XOTcl method the absolute level is returned (e.g. #4) which can be used in the <code>uplevel</code> or <code>upvar Tcl</code> command or XOTcl method. If the current command was not invoked from an XOTcl method, the value 1 is returned.
<code>self calledproc</code>	Returns the name of the method which was invoked in the original call.
<code>self calledclass</code>	Returns the name of the class which presumably (if no dynamic class change occurs afterwards) is invoked in the original call.
<code>self callingclass</code>	Returns the name of the class from which the call was invoked (if one exists, otherwise an empty string).
<code>self callinglevel</code>	Returns the stack level from where the current command was invoked from. In contrary to <code>activelevel</code> next-calls are ignored in the computation. If the

	current command was invoked from an XOTcl method the absolute level is returned (e.g. #4) which can be used in the <code>uplevel</code> or <code>upvar</code> Tcl command or XOTcl method. If the current command was not invoked from an XOTcl method, the value 1 is returned.
<code>self callingproc</code>	Returns the name of the method from which the call was invoked (if one exists, otherwise an empty string).
<code>self callingobject</code>	Returns the name of the object from which the call was invoked (if one exists, otherwise an empty string).
<code>self filterreg</code>	In a filter: returns the name of the object/class on which the filter is registered. Returns either ' <i>objName filter filterName</i> ' or ' <i>className instfilter filterName</i> '.
<code>self isnextcall</code>	Return 1 if this method was invoked via next, otherwise 0
<code>self next</code>	Return the "next" method on the path as a string, i.e. the method which will be called by [next].

Note, that three options with the prefix `calling` represent the values of `self`, `self proc`, and `self class` in the scope where the original call was invoked. In the following section we will show a simple program in which all of the `info` options have different values.

Filter Call–stack Information Example

Now we discuss a simple example that shows that all filter introspection options may have different values:

```

Class InfoTrace
InfoTrace instproc infoTraceFilter args {
  puts "SELF:                [self]"
  puts "SELF PROC:           [self proc]"
  puts "SELF CLASS:           [self class]"
  puts "INFO CLASS:           [my info class]"
  puts "CALLED PROC:           [self calledproc]"
  puts "CALLING PROC:         [self callingproc]"
  puts "CALLING OBJECT:       [self callingobject]"
  puts "CALLING CLASS:        [self callingclass]"
  puts "REGISTRATION CLASS:   [self filterreg]"
  puts "CALLING LEVEL:        [self callinglevel]"
  puts "ACTIVE LEVEL:         [self activelevel]"
  next
}

Class CallingObjectsClass
CallingObjectsClass callingObject

Class FilterRegClass -superclass InfoTrace
Class FilteredObjectsClass -superclass FilterRegClass
FilteredObjectsClass filteredObject

CallingObjectsClass instproc callingProc args {
  filteredObject set someVar 0
}
FilterRegClass instfilter infoTraceFilter

```

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The invocation of `callingObject callingProc` produces the following output:

```
SELF:                ::filteredObject
SELF PROC:           infoTraceFilter
SELF CLASS:         ::InfoTrace
INFO CLASS:         ::FilteredObjectsClass
CALLED PROC:        set
CALLING PROC:       callingProc
CALLING OBJECT:     ::callingObject
CALLING CLASS:     ::CallingObjectsClass
REGISTRATION CLASS: ::FilterRegClass instfilter infoTraceFilter
CALLING LEVEL:     #1
ACTIVE LEVEL:      #1
```

The filter reports for `self` the value `filteredObject`, since this is the object on which the `set` call is invoked; `infoTraceFilter` is the method of the filter, and therefore, the actual proc, while the actual class is `InfoTrace`, the filter's class. The class of the actual object is `FilteredObjectsClass`.

The called procedure is `set`. While the program stays in a `XOTcl-instproc` all `calling-info`-options are set, the calling procedure is `callingProc`, the calling class is the class, where the method is defined (namely `CallingObjectsClass`), and the object from which the call invoked is `callingObject`.

In this example, the calling level is equal to the active level, both are `#1`.

Slots



A slot is a meta-object that manages property-changes of objects. A property is either an attribute or a role in an relation. In a nutshell, a slot has among other attributes:

- a *name* (which it used to access it),
- a *domain* (object or class on which it can be used) , and
- can be *multivalued* or not.

We distinguish between *system slots* (predefined slots like `class`, `superclass`, `mixin`, `instmixin`, `filter`, `instfilter`) and *attribute slots* (e.g. attributes of classes).

System Slots

System slots are predefined slots defining e.g. some relations between classes, or between objects and classes. The predefined system slots are:

- `superclass`: every class in XOTcl has one or more superclasses. The name of this slot is `superclass`, the domain is `::xotcl::Class`, the slot is multivalued, since one object might have multiple superclasses.
- `class`: every object has a class; therefore, the domain of the slot is `::xotcl::Class`, the property is not multivalued.
- `mixin`: every object in XOTcl can have one or more mixin classes. The name of this slot is `mixin`, the domain is `::xotcl::Object` , the slot is multivalued.
- `instmixin`: same as above, but the domain is `::xotcl::Class`.
- `filter`, `instfilter`: similar to `mixin` and `instmixin`.

The system slots were introduced earlier with their semantics. Here we just point out, that they have all the same interfaces for querying, setting, adding and removing of slot values.

Every slot can be used set and query the property from its domain. The syntax for setting values is

```
object property newValue
```

and for getting its values is

```
set x [object property]
```

where *property* denotes the slot name. Every multivalued slot provides the methods `add` and `delete`. Here are a few examples for using the system slot `mixin` which we have introduced already in the section of the [mixins](#)

```
Object o; Class M; Class N
o mixin ::M      ;# replacing the per-object mixins of o with M
o mixin reset ::M ;# same as before
o mixin add ::N  ;# add N to the front of the mixin list
o mixin delete ::M ;# delete M from the mixin list
puts [o mixin]  ;# query the current mixin list
```

Every system slot (e.g. `superclass`) has the exact same interface.

Attribute Slots

Attribute slots are used to manage the setting and querying of instance variables. We define now a person with three attributes `name`, `salary` and `projects`.

```
Class Person -slots {
  Attribute name
  Attribute salary -default 0
  Attribute projects -default {} -multivalued true
}
```

These attributes might have a default value or they might be multivalued. When an instance of class `Person` is created, the slot names can be used for specifying values for the slots.

```
Person p1 -name "Joe"
```

Object `p1` has three instance variables, namely `name`, `salary` and `projects`. Since slot `projects` is multivalued, we can add a value to the list of values the `add` subcommand.

```
Project project1 -name XOTcl \
  -description "A highly flexible OO scripting language"

p1 projects add ::project1
p1 projects add some-other-value
```

The value of the instance variable `project` of `Person p1` is now the list `{some-other-value ::project1}`.

Attribute slots are implemented via dynamic object aggregations (see [below](#)), where the Class objects contain the slot objects with the information like default etc. In order to prevent name clashes between the slot objects and the methods of a class (like e.g. `create`), an intermediary object named `slot` is used as a container of the slot objects. In the example above we create an object structure of the following form:

```
Person
Person slot name
Person slot salary
Person slot projects
```

This object structure can be used to query and modify the slot properties or to add additional methods to the slot objects. One application is for example to use slot-specific methods for checking slot values, as shown in the next section.

```
Person info vars ;# results in the list of variables of ::Person
Person slot name info vars ;# list of variables of the slot object ::Person::slot::name
```

Since slot objects are ordinary XOTcl objects, they can have their own slots as well (such as `default`, `name` etc.). The following example sets and queries the default of the slot `name` of `Person`:

```
Person slot name default "gustaf"
? {Person slot name default} gustaf
```

However, due to the current implementation, it is necessary to re-init the slot object when the slot properties (such as e.g. `default`) are changed. This can be achieved by calling the method `init` of the slot object.

Note that a statement for creating a slot object like

```
... {
  Attribute name
  ...
}
```

is a short hand notation for

```
... {
  Attribute create name
  ...
}
```

This is exactly the same situation like every where else in XOTcl, when an object/class is created. One has to use `create` explicitly, when a name of a slot object conflicts with a method of the class (e.g. one has to use "Attribute create class" if a slot named `class` is created).

One cannot define on a meta-class an attribute named `slot` or `slots` and use then "... MetaClass Foo -slots { ::xotcl::Attribute x}..." to create the slot objects. To handle this naming conflict, one has to create the slot objects outside of the aggregation and to provide the values for the properties of `Attribute` (domain, manager,) by hand.

Setter and Getter Methods for Slots

When a slot is called via its name, the call is delegated to the slot object. Per default, the slot value is read via the `get` method of the slot and it is set the `assign` method. By redefining these methods, it is possible to provide custom setter and getter methods. The following example redefines the setter methods `assign` to check, whether an attribute value is within the range between 1 and 99.

```
Class create A -slots {
  Attribute foo -default 1 -proc assign {domain var value} {
    if {$value <0 || $value > 99} {
      error "$value is not in the range of 0 .. 99"
    }
    $domain set $var $value
  }
}

A create a1
? {a1 foo 10} 10
? {a1 foo} 10
? {catch {a1 foo -1}} 1
```

For the most common simple cases with single valued attributes, where neither setter or getter are redefined, XOTcl optimizes the slot access function and replaces the delegation to the slot object by the the C-level implementation of `instparametercmd`.

Note that it is possible to subclass `Attribute` (e.g. in order to store more properties for attributes, like when attributes are stored in a relational database) or to register mixin-classes or filters.

Backward-compatible Short-Hand Notation for Attribute Slots

XOTcl provides a short-hand notation for creating attribute slots, which is backward compatible for the most important options of XOTcl version prior to 1.5.0. Instead of writing

```
Class Car -slots {
  Attribute owner
  Attribute doors -default 4
}
```

one can use as well

```
Class Car -parameter {
  owner
  {doors 4}
}
```

The various features of the prior implementation of `parameter` are deprecated and will be removed in future versions.

Experimental Slot Features

Value Checking

Attribute slots can have types assigned which are tested whenever the instance variable is altered. The slot `salary` is defined as `integer` whereas `projects` is defined to be a list of instances of the class `::Project` (a list of instances, since `projects` is defined as multivalued).

```
Class Person -slots {
  Attribute name
  Attribute salary -default 0 -type integer
  Attribute projects -default {} -multivalued true -type ::Project
  ...
}

Person p2 -name "Sue" -salary 1000
```

It is as well possible to define custom value checkers and to normalize the input values. We extend the previous example and define "my sex" as value for `type`. If the value checker consists of multiple words, the type check compiler assumes that the value is a Tcl command, to which the actual value is appended as additional argument before invocation. `my` refers to the slot object. In the example below, we define for the slot object an object specific method that returns 1 or 0 depending on the success of the check. This method (a) checks the values via `switch` and (b) normalizes and resets the value via `uplevel`.

```
Class Person -slots {
  ...
  Attribute sex -type "my sex" -proc sex {value} {
    switch -glob $value {
      m* {my uplevel {$obj set $var m}; return 1}
      f* {my uplevel {$obj set $var f}; return 1}
      default {return 0}
    }
  }
}
```

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The slot values are actually checked via Tcl variable traces whenever the associated variable gets a new value assigned. This means that the values are enforced now matter how the variables are set. Therefore, the checks are performed in the following two commands as well, although the slot values are not accessed via the slot names. The checks will throw an error in the second command, since 1100x is not an integer.

```
p2 incr salary 100
p2 append salary x
```

Similarly the second command below will throw an error, since some-other-value is not an instance of ::Project.

```
p2 projects add ::project1
p2 projects add some-other-value
```

When a check throws an error, the instance variables are reset to the previous value. To restore the original value, an associative array __oldvalue() is kept as instance variable in the object.

In general, checking of variables can be turned off globally by

```
::xotcl::Slot instmixin add ::xotcl::Slot::Nocheck
```

This mixin replaces the methods check and checkall as well as mk_type_checker by no-ops. When the mixin is active and the Attribute definitions are loaded, the specified type has no effect.

Value checking can be turned off also selectively for each slot via using ::xotcl::Slot::Nocheck as per-object-mixin; if attributes are subclassed, it is possible to register the Nocheck mixin on a subclass of Attribute.

Init Commands and Value Commands for Slot Values

An init command (initcmd) of a slot is similar to a default and is a command to be executed when the value of the associated variable is read the first time. That means that when an object is created the associated variable has no value. On the contrary, when a default is used, the variable is set to the default value, when the object is created.

The primary advantage of slot init commands is *Lazy initialization*: When an object has many slots and the initialization of all slots is costly (e.g. the value of each slot is fetched from a relational database), and not all of the values are needed for each instance, only the relevant variables of the object are initialized on demand.

```
Class C -slots {
  Attribute x -initcmd {puts {init}; set _ 101}
}

C c1
c1 info vars ;# ==> returns ""
c1 set x ;# ==> puts init, returns 101
c1 info vars ;# ==> returns "x"
```

The initcmd is executed only once, when the variable is read the first time. For later reads of the variable contents, the values are returned.

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A value command (`valuecmd`) of a slot is similar to a `init` command, except that it is executed whenever the value of the variable is read. A value command can be used e.g. to implement live updates for variables or for abstracting from sql sequences or the like.

Finally the value changed command (`valuechangedcmd`) can be used to specify the behavior, whenever the value of the variable is altered. This option is used to implement the value checking described in the last section.

The slot parameters `default`, `initcmd` and `valuecmd` have to be used mutually exclusively.

Nested Classes and Dynamic Object Aggregations



Most object-oriented analysis and design methods are based on the concepts of generalization and aggregation. Generalization is achieved through class hierarchies and inheritance, while static aggregation is provided through embedding. Since version 8.0 Tcl offers a namespace concept which can be used as a mechanism to provide dynamic aggregations.

A *namespace* provides an encapsulation of variable and procedure names in order to prevent unwanted name collisions with other system components. Each namespace has a unique identifier which becomes part of the fully qualified variable and procedure names. Namespaces are therefore already object-based in the terminology of Wegner. OTcl is object-oriented since it offers classes and class inheritance. Its objects are also namespaces, but an object is more than only a namespace. Therefore, two incompatible namespace concepts have existed in OTcl in parallel.

In XOTcl every object and every class is logically implemented as a separate Tcl namespace. The biggest benefit of this design decision aside from performance advantages is the ability to aggregate objects and nest classes. Contrary in OTcl every object has a global identifier. Through the introspection abilities of namespaces nested classes are also traceable at runtime and can be changed dynamically. In XOTcl objects are allowed to contain nested objects, which are dynamically changeable aggregates of the containing object.

Nested Classes

The notation for nested classes follows the syntax of Tcl namespaces by using ``::" as a delimiter. For example the description of a oval carpet and a desk can nest inside of the `OvalOffice` class:

```
Class OvalOffice
# general carpet
Class Carpet
Class OvalOffice::Desk
# special oval carpet - no name collision
Class OvalOffice::Carpet -superclass ::Carpet
```

Nested classes can be used exactly like ordinary classes, a user can sub-class it, derive instances, etc. The information about the nesting structure of classes is available through the `info` instance method:

```
className info classchildren ?pattern?
className info classparent
```

The `classchildren` option returns a list of children, if one or more exist, otherwise it returns an empty string. `classparent` results in the name of the parent class, if the class is nested. Since nested classes are realized through namespaces, all functionality offered by Tcl's `namespace` command is usable from XOTcl as well.

Dynamic Object Aggregations

The nested classes only provide an aggregation of the descriptive not of the runtime properties of an object. We have pointed out the difference of object and class in XOTcl. Because of the splitting of a class into class and class-object it is possible to give each object its own namespace. The internal implementation of objects enable them to contain nested objects, which are aggregates of the containing object. In XOTcl these can be changed dynamically and introspected through the language support of dynamic object aggregations

[Neumann and Zdun 2000b]. Suppose an object of the class `Agent` should aggregate some property objects of an agent, such as head and body:

```
ClassAgent
Agent myAgent

Class Agent::Head
Class Agent::Body

Agent::Head ::myAgent::myHead
Agent::Body ::myAgent::myBody
```

Now the objects `myHead` and `myBody` are part of the `myAgent` object and they are accessible through a qualification using ```::` (or through Tcl's namespace command). But in the common case they will be accessed, as introduced so far: the explicit full qualification is not necessary when such variables are being accessed from within XOTcl methods, since the object changes to its namespace.

The information about the part-of relationship of objects can be obtained exactly the same way as for classes through the `info` interface:

```
objName info children ?pattern?
objName info parent
```

Relationship between Class Nesting and Object Aggregation

The classes `Head` and `Body` are children of the `Agent` class. It is likely that all agents, interactive or not, have properties for head and body. This implies a static or predetermined relationship between class nesting and object aggregation. Such predetermination do not exist in XOTcl, but are simply build, when specifying the relationship in the constructor, e.g.:

```
Agent instproc init args {
    ::Agent::Head [self]::myHead
    ::Agent::Body [self]::myBody
}
```

Now all agents derived from the class have the two property objects aggregated after creation. But still they are changeable in a dynamical manner, e.g. with:

```
Agent myAgent
myAgent::myHead destroy
```

The agent turns into a headless agent. In companion of the introspection mechanisms such constructions could be very useful. Suppose, that in the virtual world the agents heads may be slashed from their bodies. The graphical system simply needs to ask with `info children` on the agent's object, whether it has a head or not and can choose the appropriate graphical representation.

Simplified Syntax for Creating Nested Object Structures

To ease the generation of nested structures, one can use the predefined method `contains`. In essence, `contains` changes the namespace, where objects are created to the object, on which it is executed. In the example below, we create three nested rectangles, where two of these contain two more points. The outer rectangle is `r0` containing rectangle `r1` and `r2`.

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```
Class Point -parameter {{x 100} {y 300}}
Class Rectangle -parameter {color}

Rectangle r0 -color pink -contains {
  Rectangle r1 -color red -contains {
    Point x1 -x 1 -y 2
    Point x2 -x 1 -y 2
  }
  Rectangle r2 -color green -contains {
    Point x1
    Point x2
  }
}

? {r0 color} pink
? {r0 r1 color} red
? {r0 r1 x1 x} 1
? {r0 r1 x2 y} 2
? {r0 r2 color} green
```

Every object in XOTcl is realized as a Tcl command. If nested objects are created, these commands are available as object specific methods. So, instead of calling the contained rectangle `r1` via the fully qualified name `::r0::r1`, one can use `r0 r1`. This is exactly the same situation as it arises, when e.g. a global Tcl `proc proc o1 {} {...}` and an XOTcl object `o1` (created via `Object o1`) is created. Both commands cannot coexist in the same namespace.

Copy/Move

Often an object has to be copied/moved. This is a very useful functionality when XOTcl should be used as a prototyping language. The XOTcl method `move` provides this functionality. Another common behavior is implemented by the `copy` method which clones the actual object to a destination object via a deep copy operation. The two methods have the syntax:

```
objName move destination
objName copy destination
```

Copy and move operations work with all object/class information, i.e., information on filters, mixins, parameters, etc. are automatically copied. Copy and move are integrated with class nesting and object aggregations. All copy/move operations are deep copy operations: all nested objects/classes are automatically copied/moved, too. E.g. if we want to reuse an imperial march object of star wars for star wars 2, we can just copy the object:

```
starWars::imperialMarch copy starWars2::imperialMarch
```

Note that `move` is implemented in current versions of `xotcl` as a `copy` plus subsequent `destroy` operation.

Method Forwarding



As you have seen from many previous examples, XOTcl's primary command for method forwarding is the `next` primitive. `next` calls the same-named method of the current object, usually with the same argument list. However, frequently method forwarding is required between different objects as well, commonly referred to as *delegation*.

In general, delegation can be achieved in XOTcl without any special construct using simple methods containing a few lines. However, in several situations, forwarding is as well needed to plain Tcl commands, for example, if object oriented stubs are implemented on base of non-oo function calls. These functions might access instance variables of the objects. XOTcl uses this functionality in various situations, such as for instance in the implementation of the `set`, `unset`, `append`, `array` methods among others.

The forwarding functionality is supported by XOTcl by the methods `forward` and `instforward` that address these requirements and provide an efficient implementation for these tasks.

The forwarding command specifies that whenever *methodName* is called, this invocation is delegated to *callee*, where the actual argument list (from the invocation) is appended to the argument list specified in the forwarding command. Like for `procs` and `instprocs`, we can distinguish between `forward` and `instforward`, depending on we want to the method available for a single object or for the instances of a class.

The general form of the forwarding commands is:

```
obj forward methodName ?options? callee ?arglist?
cls instforward methodName ?options? callee ?arglist?
```

where valid options are `-objscope`, `-methodprefix`, `-earlybinding` and `-default`. The option `-objscope` is used to specify that the command should be executed in the scope of the calling object (i.e. instance variables appear as local variables), `-methodprefix` means that the called method should be prefixed with the specified string (to avoid name clashes), `-earlybinding` means that the function pointer of the specified command (callee) is taken at invocation time (should only be done for (builtin) commands implemented in C), and `-default` provides a means for providing default methods when none are specified.

Each of the arguments after the method name (including `callee`) can be substituted at invocation time, or they are taken literally. The arguments to be substituted are starting always with a percent sign. These arguments can be `%self`, `%proc`, `%l`, `%argclindex`, or `%` followed by a Tcl command, and it can be prefixed with a positional prefix `%@`. We will introduce the usage of these options and argument substitutions based on examples.

In our first example we define an object `dog` and an object `tail`. If the `dog` receives the call `wag` it delegates this call to the `tail` and returns its result. In this introductory example, the method `tail` simply returns its arguments.

In this example, forwarding is achieved through the method `forward` that creates a forwarder command. This method receives as first argument the name, under which the forwarder is registered, followed by the object that receives the delegation (the "callee"), followed by the (optional) method name and optional arguments. More about this later. Here we register the forwarder under the name `wag`, the callee is `tail`, and the method is defined to have the name of the forwarder. We could have written here `dog forward wag tail wag` as well, but we use `%proc` which refers to the name of the forwarder. Using `%proc` is slightly

more general in cases the forwarder is renamed.

```
#####
# trivial object delegation
#####
Object dog
Object tail
tail proc wag args { return $args }
dog forward wag tail %proc
```

With these definitions a call to "dog wag 100" calls actually "tail wag 100" which returns the result of 100.

The following command shows the delegation to a Tcl command (instead of delegation to an object). We define a simple forwarder that forwards a call to the Tcl command `expr` with some arguments.

```
#####
# adding
#####
Object obj
obj forward addOne expr 1 +
```

The invocation `obj addOne 5` returns 6 as value.

In our next example we want additionally that the Tcl command should to be evaluated in the context of the current object. This means that the method can easily access instance variables of the delegating object. We define a forwarder for the class `X` with the name `Incr` (to avoid confusion with the already defined method `incr`), we use the `-objscope` option and specify `incr` as the callee. Since the forwarder is defined via `instforward` the forwarder is available to all instances of the class.

```
#####
# evaluating in scope
#####
Class X -parameter {{x 1}}
X instforward Incr -objscope incr

X x1 -x 100
x1 Incr x
x1 Incr x
x1 Incr x
```

After the three calls to `Incr` the call `x1 x` returns the value 103.

In our next example, we show the usage of the `%-` substitution more advanced argument handling. This example sketches the implementation of the `mixin add`, `mixin set` methods as shown above. In order to obtain extensible subcommands (such as `mixin add`, `mixin delete`, etc.), we define an object for which the subcommands are defined as methods. We will use this object as callee for the appropriate methods. So, we define an object named `mixin` and define a forwarder with the name `Mixin` (again we capitalize `Mixin` to avoid name clashes with the already defined method `mixin`).

```
#####
# mixin example
#####
Object create mixin
mixin proc unknown {m args} {return [concat [self] $m $args]}
obj forward Mixin mixin %l %self
```


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We define here the method `unknown` to see what arguments are passed. The following invocation will lead to the call in noted in the comment.

```
obj Mixin add M1          ;# calls ::mixin add ::obj M1
```

You see that `%1` was substituted by the first argument of the invocation (here `add`) and `%self` was substituted by the name of the current object (here `::obj`). The second argument of the invocation (here `M1`) was appended as usual. However, in calls like

```
obj Mixin
```

we have to deal with cases, where the used argument (`%1`) is not given at the invocation. In this case we get either an error message, or we can specify a default argument via the option `-default`:

```
obj forward Mixin -default {getter setter} mixin %1 %self
```

This definition means that if no argument is specified in the invocation we call the method `getter`, if one argument is given the method `setter`, in other cases we use the specified arguments. Therefore the following three invocations are delegated as indicated in the comments.

```
obj Mixin          ;# calls ::mixin getter ::obj
obj Mixin M1       ;# calls ::mixin setter ::obj M1
obj Mixin add M1   ;# calls ::mixin add ::obj M1
```

When we implement subcommands by delegating to other commands (as shown in the last example), there can be situations where naming conflicts might arise. For example, if we want to implement a subcommand method `class` we might not want to implement a new method `class` on the callee, since this would overwrite the standard definition of `class`. To overcome such difficulties, we provide the option `-methodprefix`. The following example shows how to prefix every called method with the prefix `@`.

```
#####
# sketching extensible info
#####
Object Info
Info proc @mixin {o} {
    $o info mixin
}
Info proc @class {o} { ;# without prefix, doing here a [Info class] would be wrong
    $o info class
}
Info proc @help {o} { ;# define a new subcommand for info
    foreach c [my info procs] {lappend result [string range $c 1 end]}
    return $result
}
Object instforward Info -methodprefix @ Info %1 %self
```

With this definitions, the following call is rewritten as indicated in the comment.

```
x1 Info class          ;# ::Info @class ::x1
```

When a forwarder is defined, the callee (the target command) can be omitted. When the callee is not specified, the method-name is used instead. When the method-name has a namespace prefix, the method name is the tail and the callee is the fully qualified name.

```
#####
```

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```
# optional callee
#####
obj set x 2
obj forward append -objscope
Object n; Object n::x
obj forward ::n::x
```

With this definitions of the forwarder `append` and `x`, the following calls are rewritten as indicated in the comment.

```
obj append x y z          ;# ::append x y z ... returning 2yz
obj x self                ;# ::n::x self ... returning ::n::x
```

The forwarder `append` forwards the call to the Tcl command `append`, which accesses the instance variable `x` and appends the specified values.

The list of tokens executed by the forwarder might contain Tcl commands executed during every invocations. This makes it for instance possible to pass instances variables to the callee. In the next example the object has the instvar named `x` which is multiplied by a factor of 10 when the method `x*` is invoked.

```
#####
# command substitution
#####
obj set x 10
obj forward x* expr {%my set x} *
```

With this definitions, the following call is rewritten as indicated in the comment.

```
obj x* 10                  ;# expr 10 * 10 ... returning 100
```

In certain situations it is necessary to insert arguments always at the same position (e.g. at the second to last position). The positional addressing can be achieved by prefixing the arguments of the forward specification by `%@POS`, where `POS` is either a positive (argument positing from the beginning) or negative integer (argument counting from the end) or the constant `end` (denoting the last position). After `POS` a single space is used as a delimiter for the rest of the argument, which might be some other `%`-substitution or a constant. The positional arguments are evaluated from left to right and should be used in ascending order.

The following examples show a few usages of the positional arguments in the forwarder. The forwarders `f1` to `f5` are created, followed by one or more usages. The first argument of the usage is the call to to forewarder, the second argument is the result.

```
#####
# forwarding with positional arguments
#####
Object obj
obj forward f1 list {%@end 13}
? {obj f1 1 2 3 } [list 1 2 3 13]

obj forward f2 list {%@-1 13}
? {obj f2 1 2 3 } [list 1 2 13 3]

obj forward f3 list {%@1 13}
? {obj f3 1 2 3 } [list 13 1 2 3]
? {obj f3} [list 13]

obj forward f4 list {%@2 13}
```

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```
? {obj f4 1 2 3 } [list 1 13 2 3]

obj forward f5 {%end 99} {%0 list} 10
? {obj f5} [list 10 99]
? {obj f5 a b c} [list 10 a b c 99]
```

The construct `%argclindex LIST` can be used to substitute an argument depending on the number of arguments when the forwarder is invoked. For example, it is possible to call forward to a different method depending on how many arguments are specified. The number of arguments is used as an index in the specified list. When the number of arguments is larger than the number of elements in the specified list, an error is generated.

```
#####
# substitution depending on number of arguments
#####
obj forward f %self [list %argclindex [list a b c]]
obj proc a args {return [list [self proc] $args]}
obj proc b args {return [list [self proc] $args]}
obj proc c args {return [list [self proc] $args]}
? {obj f} [list a {}]
? {obj f 1 } [list b 1]
? {obj f 1 2} [list c {1 2}]
? {catch {obj f 1 2 3}} 1
```

Finally, the concluding example defines a class `chan` to use the I/O-commands in an OO-manner. The `proc open` is used to create a `chan` instance. For the channel object we provide the method `close` (to close a channel and to destroy the channel object), `puts` (to write on a stream), `blocked` (to check whether last command exhausted all input), and `fconfigure` (to configure the stream). Note that for `puts` we specified that the actual stream should be inserted as the second to last argument.

```
Class chan -parameter stream
# create stream and object
chan proc open args {
    set stream [eval open $args]
    my create $stream -stream $stream ;# make an object
}
# close stream and destroy object
chan instproc close {} {
    close [my stream]
    [self] destroy
}
# handle other subcommands (methods) via unknown
chan instproc unknown {m args} {
    set valid [lsort [chan info instcommands]]
    stderr puts "unknown chan method '$m' $args called;
        defined methods: $valid"
}
chan create stdout -stream stdout ;# define standard stream
chan create stderr -stream stderr ;# define standard stream

chan instforward puts puts {%@-1 %my stream}
chan instforward blocked fblocked {%my stream}
chan instforward fconfigure fconfigure {%my stream}

set c [chan open /tmp/junk w]
$c puts -nonewline "hello"
$c puts -nonewline " world"
$c puts ""
$c xxx ;# trigger unknown
```

```
# The stream instances denote the currently open streams
stderr puts "currently open streams: [chan info instances]"
$c close
stderr puts "currently open streams: [chan info instances]"
```

Assertions



In order to improve reliability and self documentation we added assertions to XOTcl. The implemented assertions are modeled after the "design by contract" concept of Bertrand Meyer. In XOTcl assertions can be specified in form of formal and informal pre- and post-conditions for each method. The conditions are defined as a list of and-combined constraints. The formal conditions have the form of normal Tcl conditions, while the informal conditions are defined as comments (specified with a starting "#"). The lists containing the pre- and post-conditions are appended to the method definition (see example below).

Since XOTcl offers per-object specialization it is desirable to specify conditions within objects as well (this is different to the concept of Meyer). Furthermore there may be conditions which must be valid for the whole class or object at any visible state (that means in every pre- and post-condition). These are called invariants and may be defined with following syntax for class invariants:

```
className instinvar invariantList
```

or for objects invariants:

```
objName invar invariantList
```

Logically all invariants are appended to the pre- and post-conditions with a logical "and". All assertions can be introspected.

Since assertions are contracts they need not to be tested if one can be sure that the contracts are fulfilled by the partners. But for example when a component has changed or a new one is developed the assertions could be checked on demand. For this purpose the `check` method can be used either to test the pre- or the post-conditions. The syntax is:

```
objName check ?all? ?instinvar? ?invar? ?pre? ?post?
```

Per default all options are turned off. `check all` turns all assertion options for an object on, an arbitrary list (maybe empty) can be used for the selection of certain options. Assertion options are introspected by the `info check` option. The following class is equipped with assertions:

```
Class Sensor -parameter {{value 1}}
Sensor instinvar {
  {[regexp {^[0-9]$} [my value]] == 1}
}
Sensor instproc incrValue {} {
  my incr value
} {
  {# pre-condition:}
  {[my value] > 0}
} {
  {# post-condition:}
  {[my value] > 1}
}
```

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The `parameter` instance method defines an instance variable `value` with value 1. The invariant expresses the condition (using the Tcl command `regexp`), that the value must be a single decimal digit. The method definition expresses the formal contract between the class and its clients that the method `incrValue` only gets input-states in which the value of the variable `value` is positive. If this contract is fulfilled by the client, the class commits itself to supply a post-condition where the variable's value is larger than 1. The formal conditions are ordinary Tcl conditions. If checking is turned on for sensor `s`:

```
s check all
```

the pre-conditions and invariants are tested at the beginning and the post-condition and invariants are tested at the end of the method execution automatically. A broken assertion, like calling `incrValue` 9 times (would break the invariant of being a single digit) results in an error message.

In assertions we do not check methods that modify or introspect assertions. These are `check`, `info`, `proc`, `instproc`, `invar`, and `instinvar`. The reason for this is that we want to be able to recover a malicious action in a `catch` error handler, like:

```
...
if {[catch {my assertionBreakingAction} errMsg]} {
    puts "CATCHED ERROR: $errMsg"
    # remember checking options, for turning them on later again
    set check [my info check]
    my check {}
    # recover from broken assertion
    ...
    # turning checking on again
    $fb check $check
}
```

Meta–Data and Automatic Documentation



To enhance the understandability and the consistency between documentation and program it is useful to have a facility to make the documentation a part of the program. There are several kinds of meta–data which are interesting for a class, e.g. the author, a description, the version, etc.

Older versions of XOTcl have contained a special meta–data command `metadata`. This command is now (from version 0.83) deprecated and replaced by an integrated solution with XOTcl's API documentation functionality. The object `@` is used for documentation and metadata issues. Per default it is not evaluated at all. Everything that is send to `@` is simply ignored. That way we do not waste memory/performance at runtime, if we do not require to parse the metadata/documentation.

If we have to know the meta–data/documentation, as for instance in the `xoDoc` component and the `makeDoc` tool, that handle XOTcl's internal documentation, we have to re–define the documentation object. Alternatively, we can partially parse the source code for `@` commands.

With `@` the meta–data/documentation is handled by first class XOTcl objects. By defining alternate `@` implementations – as in `xoDoc/makeDoc` – we can evaluate the meta–data/documentation arbitrarily. `xoDoc/makeDoc` are only an HTML back–end, but the basic idea is to provide support for several other usages as well (e.g. XML, RDF, on–line help, documentation of dynamic structures, etc).

The object `@` handles comments via its `unknown` method. `xoDoc` adds the appropriate `instprocs` to `t@` to produce HTML output. The appropriate command is:

```
tclsh src/lib/makeDoc.xotcl DOCDIR DOCFILES
```

The source of a documentation is structurally very similar to the XOTcl constructs being commented. E.g. one can copy an `instproc` and add comments at the right places, like:

```
Class C
C instproc m {a1 a2} {
    return [expr {$a1+$a2}]
}
```

can be commented as follows

```
@ Class C { description { "my sample class" } }
@ C instproc m {a1 "first number" a2 "second number"} {
    description "add two numbers"
    return "sum of a1 and a2"
}
```

One can do essentially a copy+paste of the source and add the comments via attribute value pairs. Every basic language construct can have a "description". If you want to include other properties to the description, you can add them like:

```
@ C instproc m {a1 "first number" a2 "second number"} {
    author "GN+UZ"
    date "Feb 31"
    description "add two numbers"
    return "sum of a1 and a2"
}
```

This way, author and date are added automatically to the generated HTML file. In addition, there is a `@File` hook for a per file description, like:

```
@ @File {
  description {
    This is a file which provides a regression test
    for the features of the XOTcl - Language.
  }
}
```

Additional Functionalities



Abstract Classes

In XOTcl a class is defined abstract if at least one method of this class is abstract. The instance method `abstract` defines an abstract method and specifies its interface. Direct calls to abstract methods produce an error message. E.g. a `Storage` class provides an abstract interface for access to different storage forms:

```
Class Storage
Storage abstract instproc open {name}
Storage abstract instproc store {key value}
Storage abstract instproc list {}
Storage abstract instproc fetch key
Storage abstract instproc close {}
Storage abstract instproc delete {k}
```

All kinds of storage have to implement every method from the interface. E.g. a GNU Database Access, a relational database access, and several other storage forms may be derived by sub-classing (therefore, all conform to the same storage access interface).

Checking Commands for being Objects, Classes, or Meta-Classes

Since XOTcl is a hybrid language containing several Tcl commands, sometimes its necessary for applications to distinguish between Tcl commands and object commands for XOTcl. method of the `Object` class looks up an `objName` and returns 1 if it is an object and 0 if not:

```
objName1 isobject objName2
```

If one can be sure that a command represents an object, it might be unsure if the command is only an object or also class or even meta-class. The two instance methods `isclass` and `ismetaclass` check in the same manner, whether a class or meta-class is given (since ever XOTcl class is an object, they also return 0, when `objName` is not an XOTcl object).

```
objName1 isclass objName2
objName1 ismetaclass objName2
```

Exit Handler

A task for a programming language, sometimes of similar importance as object creation, is the object destruction. XOTcl ensures that all objects are destroyed and their destructors are invoked when XOTcl

applications terminate. For that reason objects and classes are destroyed in the order objects, classes, meta-classes. Sometimes further destruction order is of importance. For these cases, the XOTcl language provides an exit handler, which is a user-defined proc, which invokes user-defined exit handling just before the destruction of objects, classes, meta-classes is invoked. For instance, the exit handler lets the user specify objects which have to be destroyed before all other objects.

The exit handler is defined as a proc of `Object`, which is per default empty:

```
::xotcl::Object proc __exitHandler {} {
    # clients should append exit handlers to this proc body
    ;
}
```

There are some procs of the `Object` class pre-defined, which let us specify an exit handler conveniently:

```
Object setExitHandler body
Object getExitHandler
Object unsetExitHandler
```

`setExitHandler` lets us specify a proc body that actually contains the user-defined exit handling:

```
Object setExitHandler {
    aObj destroy
    puts "exiting"
}
```

destroys the object `aObj` before all other objects and prints the message existing to the screen. With `getExitHandler` the exit handler can be introspected. E.g. if we just want to append the destruction of object `bObj` to an existing exit handler, we use `getExitHandler`:

```
Object setExitHandler "[Object getExitHandler]; bObj destroy"
```

`unsetExitHandler` deletes the exit handler.

Automatic Name Creation

The XOTcl `autoname` instance method provides an simple way to take the task of automatically creating names out of the responsibility of the programmer. The example below shows how to create on each invocation of method `new` an agent with a fresh name (prefixed with `agent`):

```
Agent proc new args {
    eval my [my autoname agent] $args
}
```

Autonames may have format strings as in the Tcl 'format' command. E.g.:

```
objName autoname a%06d
```

produces

```
a000000, a000001, a000002, ...
```


Integrating XOTcl Programs with C Extensions (such as TK)



Because all XOTcl commands are in the `::xotcl` namespace, it is usually no problem to integrate XOTcl with other Tcl extensions. Most often it works to import the XOTcl commands (like `Object`, `Class`) into the current namespace because there are no name-clashes with the commands defined by other extensions.

Consider you want to perform a deeper integration of an other extension and XOTcl because you want to benefit from XOTcl's object system. For instance, you might want to introduce composite TK widgets (sometimes called mega-widgets) as classes and inherit from these classes. Here, you have two options: you can change or extend the C code of that other extension to provide XOTcl classes or objects, or you can write an XOTcl wrapper in Tcl. For the first alternative, there are some examples provided in the XOTcl distribution. `XOTclGdbm` provides an OO Tcl interface to the GDBM database, for instance. `XOTclSdbm` does the same for SDBM, and the `TclExpat` wrapper provides a class-based interface to the `TclExpat` XML parser.

Consider you do not want to change the C code of a Tcl extension. Then you can write an OO wrapper in XOTcl for the commands of the other extension. For stateless commands, you can simply write forwarder methods. If the extension maintains some state, you typically associate the state handle with an XOTcl parameter, acquire the state in the XOTcl constructor, and align the XOTcl destructor with the stateful instance.

Consider you want to wrap the Tk button widget. You can acquire the widget in the constructor, and maintain the widget ID in a parameter. You now can forward invocations to this widget ID (e.g. when using "pack"), or register command callbacks (like `buttonPressed`). Note that we let the "self" command be replaced in the scope of the current method so that TK receives the correct object ID for the callback. In the destructor we destroy the widget as well (we use "catch" because sometimes widgets can be destroyed by other means as well (e.g. by their parent widget, when a widget/object hierarchy is destroyed at once)).

```

Class MyButton -parameter {button}
MyButton instproc buttonPressed args {
    puts "pressed [my button]"
}
MyButton instproc init args {
    set ID [namespace tail [self]]
    my instvar button
    set button [button .$ID \
        -text "My Button $ID" \
        -command [list [self] buttonPressed]]
    pack $button
    next
}
MyButton instproc destroy args {
    catch {destroy [my button]}
    next
}

# a test -> 3 buttons, destroy one of them
foreach b {a b c} {
    MyButton $b
}
b destroy

```

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The "trick" to substitute "self" within the current method scope works for all kinds of command callbacks. Extensions such as TK, however, often work with bindings to (global) variables as well. Using global variables is frowned upon in the OO community. Instead you should use instance variables of objects. As Tcl can only bind to existing namespace variables (and XOTcl acquires the namespace of an object on demand), you have to make sure that the namespace of an object exists before binding a variable. That can be done with "requireNamespace":

```
GUIClass instproc buildEntry win {
  my requireNamespace
  entry $win -textvariable [self]::entryValue
  my set entryValue {Init Value}
}
```

Note that in the above example we have used to tail of the object ID as ID for the widget. Usually, it is a good idea to the object name, if possible, for TK (and other extensions) IDs as well. Another option is to use a autoname to get a unique name for the ID.

Sometimes you want to simply send all invocations, not implemented by XOTcl, to the wrapped command. Here, it is tedious to write a wrapper for each of these methods. Instead you can use "unknown" to handle automatic forwarding. Consider you want to wrap TK commands like pack and replace XOTcl object names with their TK widget ID, so that you can use both IDs synonymously. You can rename the respective TK commands in the following way:

```
foreach tkCommand {bell bind bindtags clipboard event
  focus font grid image lower option pack place raise
  selection send tk tkwait winfo wm} {
  rename ::$tkCommand __tk_$tkCommand
  TkCommand ::$tkCommand
  ::$tkCommand set wrapped __tk_$tkCommand
}
```

The XOTcl class handling the ID substitution for the TK command might look as follows:

```
Class TkCommand -parameter wrapped
TkCommand instproc unknown args {
  my instvar wrapped
  set args [Widget replaceWithWidgetIDs $args]
  # now call the command
  eval $wrapped $args
}
```

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