Wrapper for Object-Oriented Programming in Erlang

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Dedication: Users and maintainers of the `WOOPER` layer, version 2.0.

Abstract: The role of the `WOOPER` layer is to provide free software object-oriented facilities to the Erlang language.

The latest version of this documentation is to be found at the official WOOPER website (`http://wooper.esperide.org`).

The documentation is also mirrored here.

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Overview

WOOPER, which stands for *Wrapper for Object-Oriented Programming in Erlang*, is a free software lightweight layer on top of the Erlang language that provides constructs dedicated to Object-Oriented Programming (OOP).

This documentation applies to the WOOPER 2.0 version.

WOOPER is a rather autonomous part of the Ceylan project (yet it uses Myriad and is used by Traces).

At least a basic knowledge of Erlang is expected in order to use WOOPER.

Understanding WOOPER in Two Steps

Here is a class definition, and here is an example of code using it. That's it!

Now, let's discuss these subjects a bit more in-depth.

Motivations & Purpose

Some problems may almost only be tackled efficiently thanks to an object-oriented modelling.

The set of code and conventions proposed here allows to benefit from all the main OOP features (including polymorphism, life cycle management, state management, passive or active instances, and multiple inheritance) directly from Erlang (which natively does not rely on the OOP paradigm), so that - in the cases where it makes sense - an object-oriented approach at the implementation level can be easily achieved.

The WOOPER Mode of Operation in a Nutshell

The WOOPER OOP concepts translate into Erlang constructs according to the following mapping:

WOOPER base concept	**Corresponding mapping to Erlang**
class definition	module (typically compiled in a `.beam` file)
active instance	process
active instance reference	process identifier (PID)
passive instance	opaque term
new operators	WOOPER-provided functions, making use of user-defined `construct/N` functions (a.k.a. the constructors)
delete operator	WOOPER-provided function, making use of any user-defined `destruct/1` (a.k.a. the destructor)
member method definition	module function that respects some conventions (request/oneway/static method)

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WOOPER base concept	Corresponding mapping to Erlang
member method invocation	sending of an appropriate inter-process message
method look-up	class-specific virtual table taking into account inheritance transparently
instance state	instance-specific datastructure storing its attributes, and kept by the instance-specific WOOPER tail-recursive infinite loop
instance attributes	key/value pairs stored in the instance state
class (static) method	module function that respects some conventions

In practice, developing a class with WOOPER mostly involves including the wooper.hrl header file and respecting the WOOPER conventions detailed below.

Example

Here is a simple example of how a WOOPER class can be defined and used.

It shows `new/delete` operators, method calling (both request and oneway), and inheritance.

A cat is here a viviparous mammal, as defined below (this is a variation of our more complete class_Cat.erl example):

```
-module(class_Cat).

% Determines what are the mother classes of this class (if any):
-define(superclasses,[class_Mammal,class_ViviparousBeing]).

% Declaration of class-specific attributes:
% (optional, yet recommended for clarity)
-define(class_attributes,[
          {meow_style,style(),const,"the kind of meow to expect"},
          {whisker_color,"the color of this cat's whiskers"}]).

% Allows to define WOOPER base variables and methods for that class:
-include("wooper.hrl").

% No need to export constructors, destructor or methods.
% Type specifications remain optional (yet are recommended).

% Constructs a new Cat.
construct(State,Age,Gender,FurColor,WhiskerColor) ->
   % First the direct mother classes:
   MammalState = class_Mammal:construct(State,Age,Gender,FurColor),
   ViviparousMammalState = class_ViviparousBeing:construct(MammalState),
   % Then the class-specific attributes; returns an updated state:
   setAttribute(ViviparousMammalState,whisker_color,WhiskerColor).
```

```
destruct(State) ->
   io:format( "Deleting cat ~w! (overridden destructor)~n", [self()] ),
   State.

% Member methods.

% A cat-specific request, supposing the developer missed the fact
% that it is a const one (no problem):
getWhiskerColor(State)->
   wooper:return_state_result(State,?getAttr(whisker_color)).

% A (non-const) oneway, with a spec:
-spec setWhiskerColor(wooper:state(),foo:color()) -> oneway_return().
setWhiskerColor(State,NewColor)->
   NewState = setAttribute( State, whisker_color, NewColor ),
   wooper:return_state(NewState).

% Overrides any request method defined in the Mammal class:
% (const request)
canEat(State,soup) ->
   wooper:const_return_result(true);

canEat(State,croquette) ->
   wooper:const_return_result(true);

canEat(State,meat) ->
   wooper:const_return_result(true);

canEat(State,_OtherFood) ->
   wooper:const_return_result(false).

% Static method:
get_default_whisker_color() ->
   wooper:return_static(white).
```

Straightforward, isn't it? We will discuss it in-depth, though.

To test this class (provided that `GNU make` and `Erlang 21.0` or more recent[1] are available in one's environment), one can easily install `Ceylan-WOOPER`, which depends on Ceylan-Myriad, hence is to be installed first:

```
$ git clone https://github.com/Olivier-Boudeville/Ceylan-Myriad.git
$ cd Ceylan-Myriad && make all && cd ..


$ git clone https://github.com/Olivier-Boudeville/Ceylan-WOOPER.git
$ cd Ceylan-WOOPER && make all
```

[1] Note that, in the Ceylan-Myriad repository, we have a script to streamline the installation of Erlang, see install-erlang.sh; use `install-erlang.sh --help` for guidance.

Running the cat-related example just then boils down to:

```
$ cd examples && make class_Cat_run
```

In the `examples` directory, the test defined in class_Cat_test.erl should run against the class defined in class_Cat.erl, and no error should be detected:

```
Running unitary test class_Cat_run (second form)

--> Testing module class_Cat_test.
[..]
Deleting cat <0.80.0>! (overridden destructor)
Deleting mammal <0.80.0>! (overridden destructor)
Actual class from destructor: class_Cat.
Deleting mammal <0.82.0>! (overridden destructor)
This cat could be created and be synchronously deleted, as expected.
--> Successful end of test.
(test finished, interpreter halted)
```

That's it!
Now, more in-depth explanations.

Why Adding Object-Oriented Capabilities To Erlang?

Although applying blindly an OOP approach while using languages based on other paradigms (Erlang ones are functional and concurrent; the language is not specifically targeting OOP) is a common mistake, there are some problems that may be deemed inherently "object-oriented", i.e. that cannot be effectively modelled without encapsulated abstractions sharing behaviours.

Examples of this kind of systems are multi-agent simulations. If they often need massive concurrency, robustness, distribution, etc. (Erlang is particularly suitable for that), the various types of agents have also often to rely on similar kinds of states and behaviours, while still being able to be further specialised on a per-type basis.

The example mentioned through the current guide is an illustration[2] of the interacting lives of numerous animals of various species. Obviously, they have to share behaviours (ex: all ovoviviparous beings may lay eggs, all creatures can live and die, all have an age, etc.), which cannot be mapped easily (read: automatically) to Erlang concepts without adding some generic constructs.

WOOPER, which stands for *Wrapper for OOP in Erlang*, is a lightweight yet effective (performance-wise, but also regarding the user-side developing efforts) means of making these constructs available, notably in terms of state management and multiple inheritance.

The same programs could certainly be implemented *without* such OOP constructs, but at the expense of way too much manually-crafted, specific (per-class) code. This process would be tedious, error-prone, and most often the result could hardly be maintained.

[2]This example is not a *simulation*, it is just a multi-agent system. For real, massive, discrete-time simulations of complex systems in Erlang (using WOOPER), one may refer to Sim-Diasca instead (a free software simulation engine).

How to Use WOOPER: Detailed Description & Concept Mappings

Classes

Classes & Names A class is a blueprint to create objects, a common scheme describing the state and behaviour of its instances, i.e. the attributes and methods that all objects created from that class shall support.

With WOOPER, each class has a unique name, such as `class_Cat`.

To allow for **encapsulation**, a WOOPER class is mapped to an Erlang module, whose name is by convention made from the `class_` prefix followed by the class name, in the so-called CamelCase: all words are spelled in lower-case except their first letter, and there are no separators between words, like in: *ThisIsAnExample*.

So a class modeling, for example, a cat should translate into an Erlang module named `class_Cat`, thus in a file named `class_Cat.erl`. At the top of this file, the corresponding module would be therefore declared with: `-module(class_Cat).`.

Similarly, a pink flamingo class could be declared as `class_PinkFlamingo`, in `class_PinkFlamingo.erl`, which would include a `-module(class_PinkFlamingo).` declaration.

Inheritance & Superclasses A WOOPER class can inherit from other classes, in which case the state and behaviour defined in the mother classes will be readily available to this child class.

Being in a **multiple inheritance** context, a given class can have any number (`[0..n]`) of direct mother classes, which themselves may have their mother classes, and so on. This is to lead to a class hierarchy that forms a direct, acyclic graph.

The direct mother classes (and only them) are to be declared in WOOPER thanks to the `superclasses` define[3]. For example, a class with no mother class should specify, once having declared its module:

```
-define(superclasses,[]).
```

In this particular case, with no mother class to be declared, this `superclasses` define could be omitted as a whole (yet this would be probably less obvious to the reader).

As for our cat, this superb animal could be modelled both as a mammal (itself a specialised creature) and a viviparous being[4]. Hence its direct inheritance could be defined as:

```
-define(superclasses,[class_Mammal,class_ViviparousBeing]).
```

The superclasses (direct mother classes) of a given class can be known thanks to its `get_superclasses/0` static method[5] (automatically defined by WOOPER):

```
> class_Cat:get_superclasses().
[class_Mammal,class_ViviparousBeing]
```

[3] Alternatively, this definition could be done thanks to the `-superclasses([]).` parse attribute, but for the sake of consistency with the class attributes that will be presented next, the define-based form is the one that we recommend.

[4] Neither of them is a subset of the other, these are mostly unrelated concepts, at least in the context of that example! (ex: a platypus is a mammal, but not a viviparous being, right?).

Instances

Instance Mapping With WOOPER, which focuses on multi-agent systems, all **active instances** of a class are mapped to Erlang processes (one WOOPER instance is exactly one Erlang process).

They are therefore, in UML parlance, *active objects* (each has its own thread of execution, they may apparently "live" simultaneously[6]).

Such an instance process simply loops over its state forever, waiting for incoming method calls and processing them one after the other.

Instance State Another common OOP need is to rely on **state management** and **encapsulation**: each instance should be stateful, have its state fully private, and be able to inherit automatically the data members defined by its mother classes.

In WOOPER, this is obtained thanks to a per-instance associative table, whose keys are the names of attributes and whose values are the attribute values. This will be detailed in the state management section.

---

[5] Note that, to anticipate a bit, a static method (i.e. a class method that does not apply to any specific instance of it) of a class `X` is nothing more than an Erlang function, exported by WOOPER from the corresponding `class_X` module and which would return its result `R` as: `wooper:return_static(R)`. So the corresponding type specification would be `-spec get_superclasses() -> static_return([wooper:classname()])`. here.

[6] For some uses, such a concurrent feature (with *active* instances) may not be needed, in which case one may prefer dealing with purely *passive* instances (implemented as mere Erlang *terms* instead of Erlang *processes*).

To anticipate a bit, instead of using `new/N` (returning the PID of a new process instance looping over its state), one may rely on `new_passive/N`, returning to the caller process an opaque term corresponding to the initial state of a new passive instance, a term that can be then stored and interacted upon at will. See the passive instance section for more details. Most of this document concentrates on active instances, so, unless specified otherwise, just mentioning *instance* by itself refers to an active one.

Methods

They can be either:

- **member methods**: they applies to a specific *instance* (of a given class), like in: `MyCatPid ! declareBirthday`
- or **static methods**: they are general to a *class*, not targeting specifically an instance of it, like in: `class_Cat:get_default_mew_duration()`

Unless specified otherwise, just mentioning *method* by itself refers to a *member method*. Static methods are discussed in their specific subsection (see Static Methods).

Member methods can be publicly called by any process (be it WOOPER-based or not) - provided of course it knows the PID of that instance - whether locally or remotely (i.e. on other networked computers, like with RMI or with CORBA, or directly from the same Erlang node), distribution (and parallelism) being seamlessly managed thanks to Erlang.

Member methods (either inherited or defined directly in the class) are mapped to specific Erlang functions that are triggered by Erlang messages.

For example, our cat class may define, among others, following member methods (actual arities to be discussed later):

- `canEat`, taking one parameter specifying the type of food, and returning whether the corresponding cat can eat that kind of food; here the implementation should be cat-specific (i.e. specific to cats and also, possibly, specific to this very single cat), whereas the method signature shall be shared by all beings
- `getWhiskersColor`, taking no parameter, returning the color of its whiskers; this is indeed a purely cat-specific method, and different cats may have different whisker colors; as this method, like the previous one, returns a result to the caller, it is a *request* method
- `declareBirthday`, incrementing the age of our cat, not taking any parameter nor returning anything; it will be therefore be implemented as a *oneway* method (i.e. not returning any result to the caller, hence not even needing to know it), whose call is only interesting for its effect on the state of this cat: here, making it one year older
- `setWhiskerColor`, assigning the specified color to the whiskers of that cat instance, not returning anything (another oneway method, then)

Declaring a birthday is not cat-specific, nor mammal-specific: we can consider it being creature-specific. Cat instances should then inherit this method, preferably indirectly from the `class_Creature` class, in all cases without having to specify anything, since the `superclasses` define already implies it (implying one time for all that cats *are* creatures and thus, unless specified otherwise, are and behave as such). Of course this inherited method may be overridden at will anywhere in the class hierarchy.

We will discuss the *definition* of these methods later, but for the moment let's determine their signatures and declarations, and how we are expected to *call* them.

Method Declaration All cat-specific methods (member or static ones) are to be defined in the context of `class_Cat` (defined, as mentioned, in `class_Cat.erl`). Defining a method automatically declares it, so no method should be explicitly exported (knowing WOOPER is to take care of it).

The arity of member methods should be equal to the number of parameters they should be called with, plus one that is automatically managed by WOOPER and that corresponds to the (strictly private, never exported or sent to anyone) state of that instance.

This `State` variable defined by WOOPER can be somehow compared to the `self` parameter of Python, or to the `this` hidden pointer of C++. That state is automatically kept by WOOPER instances in their main loop, and automatically prepended, as first element, to the parameters of incoming method calls.

> **Note**
>
> To respect the principle of least astonishment, WOOPER demands that this first parameter is named exactly `State` (doing otherwise will result in a compile-time WOOPER error being issued).

Method Invocation Let's suppose that the `MyCat` variable designates an (active) instance of `class_Cat`. Then this `MyCat` reference is actually just the PID of the Erlang process hosting this instance; so it may be named `MyCatPid` instead for additional clarity.

All member methods (regardless of whether they are defined directly by the actual class or inherited) are to be called from outside this class thanks to a properly formatted Erlang message, sent to the targeted instance via its PID.

When the method is expected to return a result (i.e. when it is a request), the caller must specify in the corresponding message its own PID, so that the instance knows to whom the result should be sent.

Oneways, as for them, are to be triggered with no caller information[7], since no answer is to be sent back.

Therefore the `self()` parameter in the call tuples for requests below corresponds to the PID *of the caller*, while `MyCat` is bound to the PID *of the target instance*.

The three methods previously discussed would indeed be called that way:

```
% Calling the canEat request of our cat instance:
MyCat ! {canEat,soup,self()},
receive
    {wooper_result,true} ->
      io:format("This cat likes soup!!!");

    {wooper_result,false} ->
      io:format("This cat does not seem omnivorous.")
end,

% A parameter-less request:
MyCat ! {getWhiskersColor,[],self()},
receive
```

[7] Should the caller PID be nevertheless of use for a given oneway (this may happen), this information shall be listed among its expected parameters.

```
        {wooper_result,white} ->
          io:format("This cat has normal whiskers.");

        {wooper_result,blue} ->
          io:format("What a weird cat...")
    end,

    % A parameter-less oneway:
    MyCat ! declareBirthday.
```

Method Name Methods are designated by their name (as an atom), i.e. the one specified when defining them (ex: `canEat`).

We recommend that their name is spelled in CamelCase and remains short and descriptive, and start with a verb, like in: `getColor`, `computeSum`, `registerDefaultSettings`, etc.

Some method names are reserved for WOOPER; notably no user-defined method should have its name prefixed with `wooper` or with `onWOOPER`.

The list of the other reserved names (that shall thus not be defined by a class developer) includes:

- `get_classname` and `get_superclasses`
- `executeRequest` and `executeRequestAs`, `executeConstRequest` and `executeConstRequestAs`
- `executeOneway` and `executeOnewayAs`, `executeConstOneway` and `executeConstOnewayAs`
- `new` and other related construction operators (`new_link`, `synchronous_new`, etc.; see below)
- `delete_any_instance_referenced_in`, `delete_synchronously_any_instance_referen` `delete_synchronously_instances`

They are reserved for all arities.

The method name is always the first information given when calling it (typically in the method call tuple).

Method Parameters All methods are free to change the state of their instance and possibly to trigger any side-effect (ex: sending a message, writing a file, kidnapping Santa Claus, etc.).

As detailed below, there are two kinds of member methods:

- *requests* methods: they shall return a result to the caller (obviously they need to know it, i.e. the caller has to specify its PID)
- *oneway* methods: no specific result are expected from them (hence no caller PID is to be specified)

Both can take any number of parameters, including none. As always, the **marshalling** of these parameters and, if relevant, of any returned value is performed automatically by Erlang.

Parameters are to be specified in a (possibly empty) list, as second element of the call tuple, like in: `{getWhiskersColor,[],self()}`.

If only a single, non-list, parameter is needed, the list can be omitted, and the parameter can be directly specified. So `Alfred ! {setAge,31}.` works just as well as `Alfred ! {setAge,[31]}.`.

> **Note**
>
> This cannot apply if the unique parameter is a list, as this would be ambiguous. For example: `Foods=[meat,soup,croquette], MyCat ! {setFavoriteFoods,Foods}` would result in a call to `setFavoriteFoods/4`, i.e. a call to `setFavoriteFoods(State,meat,soup,croquette)`, whereas the intent of the programmer is probably to call a `setFavoriteFoods/2` method like `setFavoriteFoods(State,Foods) when is_list(Foods) -> [..]` instead.
> The proper call would then be `MyCat ! {setFavoriteFoods,[Foods]}`, i.e. the parameter list should be used, and it would then contain only one element, the food list, whose content would therefore be doubly enclosed.
> Note also that, of course, strings *are* lists. So `Joe ! {setName,"Armstrong"}.` is likely not the call you are looking for. Most probably you should prefer: `Joe ! {setName,["Armstrong"]}.`.

Two Kinds of Member Methods

Request Methods A **request** is a member method that returns a result to the caller.

For an instance to be able to send an answer to a request triggered by a caller, of course that instance needs to know the caller PID.

Therefore requests have to specify, as the third element of the call tuple, an additional information: the PID to which the answer should be sent, which is almost always the caller (hence the `self()` in the actual calls).

So these three potential information (request name, parameters, reference of the sender - i.e. an atom, usually a list, and a PID) are gathered in a triplet (a 3-tuple) sent as a message: `{request_name,[Arg1,Arg2,..],self()}`.

If only one parameter is to be sent, and if that parameter is not a list, then this can become `{request_name,Arg,self()}`.

For example:

```
MyCat ! {getAge,[],self()}.
```

or:

```
Douglas ! {askQuestionWithHint,[{meaning_of,"Life"},{maybe,42}],self()}.
```

or:

```
MyCalculator ! {sum,[[1,2,4]],self()}.
```

The actual result `R`, as determined by the method, is sent back as an Erlang message, which is a `{wooper_result,R}` pair, to help the caller pattern-matching the WOOPER messages in its mailbox.

`receive` should then be used by the caller to retrieve the request result, like in the case of this example of a 2D point instance:

```
MyPoint ! {getCoordinates,[],self()},
receive
   {wooper_result,[X,Y]} ->
       [..]
end,
[..]
```

Oneway Methods A **oneway** is a member method that does not return a result to the caller.

When calling oneway methods, the caller does not have to specify its PID, as no result is expected to be returned back to it.

If ever the caller sends by mistake its PID nevertheless, a warning is sent back to it, the atom `wooper_method_returns_void`, instead of `{wooper_result,Result}`.

The proper way of calling a oneway method is to send to it an Erlang message that is:

- either a pair, i.e. a 2-element tuple (therefore with no PID specified): `{oneway_name,[Arg1,Arg2,..]}` or `{oneway_name,Arg}` if `Arg` is not a list; for example: `MyPoint ! {setCoordinates,[14,6]}` or `MyCat ! {setAge,5}`
- or, if the oneway does not take any parameter, just the atom `oneway_name`. For example: `MyCat ! declareBirthday`

No return should be expected (the called instance does not even know the PID of the caller), so no receive should be attempted on the caller side, unless wanting to wait until the end of time.

Due to the nature of oneways, if an error occurs instance-side during the call, the caller will never be notified of it.

However, to help the debugging, an error message is then logged (using `error_logger:error_msg`) and the actual error message, the one that would be sent back to the caller if the method was a request, is given to `erlang:exit` instead.

Method Results

Execution Success: `{wooper_result,ActualResult}` If the execution of a method succeeded, and if the method is a request, then `{wooper_result,ActualResult}` will be sent back to the caller (precisely: to the process whose PID was specified in the call triplet).

Otherwise one of the following error messages will be emitted[8].

[8] Note, though, that in general terms there is little interest in pattern-matching these messages (defensive programming is not always the best option; linking created active instances to their creator is usually a better approach).

Execution Failures When the execution of a method fails, three main error results can be output (as a message for requests, as a log for oneways).

A summary could be:

Error Result	Interpretation	Likely guilty
`wooper_method_not_found`	No such method exists in the target class.	Caller
`wooper_method_failed`	Method triggered a runtime error (it has a bug).	Called instance
`wooper_method_faulty_return`	Method does not respect the WOOPER return convention.	Called instance

> **Note**
>
> As mentioned above, failure detection may better be done through the use of (Erlang) links, either explicitly set (with `erlang:link/1`) or, preferably (ex: to avoid race conditions), with a linked variation of the `new` operator (ex: `new_link/N`), as discussed later in this document. So a reader in a hurry may want to skip these considerations and directly jump to the Method Definition section.

`wooper_method_not_found`

The corresponding error message is `{wooper_method_not_found,InstancePid,Classname,Method`

For example `{wooper_method_not_found,<0.30.0>,class_Cat,layEggs,2,...}`.

Note that `MethodArity` includes the implied state parameter (that will be discussed later), i.e. here `layEggs/2` might be defined as `layEggs(State,NumberOfNewEggs) -> [..]`.

This error occurs whenever a called method could not be found in the whole inheritance graph of the target class. It means this method is not implemented, at least not with the deduced arity.

More precisely, when a message `{method_name,[Arg1,Arg2,..,ArgN]...}` (request or oneway) is received, `method_name/N+1` has be to called: WOOPER tries to find `method_name(State,Arg1,..,ArgN)`, and the method name and arity must match.

If no method could be found, the `wooper_method_not_found` atom is returned (if the method is a request, otherwise the error is logged), and the object state will not change, nor the instance will crash, as this error is deemed a caller-side one (i.e. the instance has a priori nothing to do with the error).

`wooper_method_failed`

The corresponding error message is `{wooper_method_failed,InstancePid,Classname,MethodNam`

For example, `{wooper_method_failed,<0.30.0>,class_Cat,myCrashingMethod,1,[],{{ba`

If the exit message sent by the method specifies a PID, it is prepended to `ErrorTerm`.

Such a method error means that there is a runtime failure, it is generally deemed an instance-side issue (the caller should not be responsible for it, unless it sent incorrect parameters), thus the instance process logs that error, sends an error term to the caller (if and only if it is a request), and then exits with the same error term.

`wooper_method_faulty_return`

The corresponding error message is `{wooper_method_faulty_return,InstancePid,Classname,Me`
For example, `{wooper_method_faulty_return,<0.30.0>,class_Cat,myFaultyMethod,1,[]`
This error occurs only when being in debug mode.

The main reason for this to happen is when debug mode is set and when a method implementation did not respect the expected method return convention (more on that later).

It means that the method is not implemented correctly (it has a bug), or, possibly, that it was not (re)compiled with the proper debug mode, i.e. the one the caller was compiled with.

This is an instance-side failure (the caller has no responsibility for that), thus the instance process logs that error, sends an error term to the caller (if and only if it is a request), and then exits with the same error term.

Caller-Side Error Management

As we can see, errors can be better discriminated if needed, on the caller side. Therefore one could make use of that information, as in:

```
MyPoint ! {getCoordinates,[],self()},
receive
   {wooper_result,[X,Y]}->
       [..];
   {wooper_method_not_found,Pid,Class,Method,Arity,Params}->
       [..];
   {wooper_method_failed,Pid,Class,Method,Arity,Params,ErrorTerm}->
       [..];
   %Errortermcanbeatuple{Pid,Error}aswell,dependingontheexit:
   {wooper_method_failed,Pid,Class,Method,Arity,Params,{Pid,Error}}->
       [..];
   {wooper_method_faulty_return,Pid,Class,Method,Arity,Params,UnexpectedTer
       [..];
   wooper_method_returns_void->
       [..];
     OtherError ->
       % Should never happen:
       [..]
end.
```

However defensive development is not really favoured in Erlang, one may let the caller crash on unexpected return instead. Therefore generally one may rely simply on matching the message sent in case of success[9]:

```
MyPoint ! {getCoordinates,[],self()},
receive
     {wooper_result, [X,Y] } ->
       [..]
end,
[..]
```

[9] In which case, should a failure happen, the method call will become blocking; linking instances can alleviate this potential problem.

Method Definition Here we reverse the point of view: instead of **calling** a method, we are in the process of **implementing** a callable one.

A method signature has always for first parameter the state of the instance, for example: `getAge(State) -> [..]`, or `getCoordinate(State,Index) -> [..]`.

For the sake of clarity, this variable should always be named `State` exactly (implying it shall not be named for example `MyState` or muted as `_State`). This convention is now enforced at compile-time.

A method must always return at least the newer instance state, so that WOOPER can rely on it from now onward.

Note that when a method "returns" the state of the (active) instance, it returns it to the (local, process-wise) private WOOPER-based main loop of that instance: in other words, the state variable is *never* exported/sent/visible outside of its process (unless of course a developer writes specific methods for that).

Encapsulation is ensured, as the instance is the only process able to access its own state. On method ending, the instance then just loops again, with its updated state: that new state will be the base one for the next call, and so on.

One should therefore see each WOOPER instance as primarily a process executing a main loop that keeps the current state of that instance:

- it is waiting idle for any incoming (WOOPER) message
- when such a message is received, based on the actual class of the instance and on the method name specified in the call, the appropriate function defined in the appropriate module is selected by WOOPER, taking into account the inheritance graph (actually a direct per-class mapping, somewhat akin to the C++ virtual table, has already been determined at start-up, for better performances)
- then this function is called with the appropriate parameters (those of the call, in addition to the internally kept current state)
- if the method is a request, the specified result is sent back to the caller
- then the instance loops again, on the state possibly updated by this method call

Thus the caller will only receive the **result** of a method, if it is a request. Otherwise, i.e. with oneways, nothing is sent back (nothing can be, anyway).

More precisely, depending on its returning a specific result, the method signature will correspond either to the one of a request or of a oneway, and will use in its body a corresponding method terminator (typically either, respectively, `wooper:return_state_result/2` or `wooper:return_state/1`) to ensure that a new state *and* a result are returned, or just a new state.

Note that all clauses of a given method must end directly with such a method terminator; this is so not only to be clearer for the reader, but also for WOOPER itself, so that it can determine the type of method at hand.

Finally, a recommended good practice is to add a type specification (see Dialyzer) to each method definition, which allows to indicate even more clearly whether it is a request or a oneway, whether it is a `const` method, etc. Comments are welcome additions as well.

For Requests

Requests in general Requests will use `wooper:return_state_result(NewState,Result)` to terminate their clauses: the new state will be kept by the instance, whereas the result will be sent to the caller. Hence `wooper:return_state_result/2` means that the method returns a state **and** a result.

For example:

```
declareSettings(State,Settings) ->
    NewState = register_settings(Settings,State),
    wooper:return_state_result(NewState,settings_declared).
```

Two remarks there:

- `register_settings/2` is an helper function here; the `State` parameter is intentionally put in last position to help the reader distinguishing it from methods
- returning a constant atom (`settings_declared`) has actually an interest: it allows to make that operation synchronous (i.e. the caller is to wait for that result atom; it is only when the caller will have received it that it will know for sure that the operation was performed; otherwise a oneway shall be used)

All methods are of course called with the parameters that were specified in their call tuple.

For example, if we declare following request:

```
giveBirth(State,NumberOfMaleChildren,NumberOfFemaleChildren) ->
   [..]
```

Then we may call it, in the case of a cat having 2 male kitten and 3 female ones, with:

```
MyCat ! {giveBirth,[_Male=2,_Female=3],self()}.
```

Const Requests Some clauses of a request may return an unchanged state. It is then a `const` clause, and rather than using the `wooper:return_state_result/2` request terminator, it shall use the `wooper:const_return_result/1` one.

A request whose clauses are all `const` is itself a const request.

For example, instead of:

```
getWhiskerColor(State) ->
   wooper:return_state_result(State,?getAttr(whisker_color)).
```

one should prefer writing this const request as (and WOOPER will enforce it):

```
getWhiskerColor(State) ->
   wooper:const_return_result(?getAttr(whisker_color)).
```

Note that `State` can be used as always, and that even here it is not reported as unused (so one should not attempt to mute it, for example as `_State`).

Sender PID Requests can access to one more information than oneways: the PID of the caller that sent the request. As WOOPER takes care automatically of sending back the result to the caller, having the request know explicitly the caller is usually not useful, thus the caller PID does not appear explicitly in request signatures, among the actual parameters.

However WOOPER keeps track of this information, which remains available to requests, and may be useful for some of them.

From a request body, the caller PID can indeed be retrieved by using the `getSender` macro, which is automatically managed by WOOPER:

```
giveBirth(State,NumberOfMaleChildren,NumberOfFemaleChildren) ->
    [..]
    CallerPID = ?getSender(),
    [..]
```

Thus a request has natively access to its caller PID, i.e. with no need to specify it in the parameters as well as in the third element of the call tuple; so, instead of having to define:

```
MyCat ! {giveBirth,[2,3,self()],self()}
```

one can rely on only:

```
MyCat ! {giveBirth,[2,3],self()}
```

while still letting the possibility for the called request (here `giveBirth/3`, for a state and two parameters) to access the caller PID thanks to the `getSender` macro, and maybe store it for a later use or do anything appropriate with it.

Note that:

- having to handle explicitly the caller PID is rather uncommon, as WOOPER takes care automatically of the sending of the result back to the caller
- the `getSender` macro should only be used for requests, as of course the sender PID has no meaning in the case of oneways; if that macro is called nevertheless from a oneway, then it returns the atom `undefined`.

Request Type Specifications Using them is not mandatory, yet is very much recommended, and WOOPER provides suitable constructs for that.

As mentioned, a request is to return a new state and a result. The former is always `wooper:state()`, so it may be made implicit. The latter can be any type `T()`. So a request may be considered as returning the WOOPER `request_return(T())` type.

As for const requests, they shall be considered returning the `const_request_return(T())` type.

Making the previous examples more complete:

```
-spec declareSettings(wooper:state(),settings()) ->
                request_return('settings_declared').
declareSettings(State,Settings) ->
```

```
    NewState = register_settings(Settings,State),
    wooper:return_state_result(NewState,settings_declared).

-spec getWhiskerColor(wooper:state()) ->
                const_request_return(color()).
getWhiskerColor(State) ->
   wooper:const_return_result(?getAttr(whisker_color)).
```

(of course the developer is responsible for the definition of the `settings()` and `color()` types here)

Note that we prefer surrounding atoms in single quotes when specified as a type.

Of course, should type specifications be used, they must be correct; WOOPER will for example raise a compile-time error should `request_return/1` be used on a function that is not detected as a request.

For Oneways After relevant adaptations, most of the conventions for requests apply to oneways.

Oneways in general Oneways will use `wooper:return_state(NewState)` to terminate their clauses: the new state will be kept by the instance, and no result will be returned to the caller (which is not even known - hence no `?getSender` macro applies to oneways either).

For example:

```
setAge(State,NewAge) ->
    wooper:return_state(setAttribute(State,age,NewAge)).
```

This oneway can be called that way:

```
MyCat ! {setAge,4}.
% No result to expect.
```

Const Oneways Even if it is less frequent than for requests, oneways may also be `const`, i.e. may leave the state unchanged, and consequently are only called for side-effects; for example, rather than specifying:

```
displayAge(State) ->
    io:format("My age is ~B~n.",[?getAttr(age)]),
    wooper:return_state(State).
```

WOOPER will ensure that, in this case, `wooper:const_return/0` is preferred to `wooper:return_state/1`:

```
displayAge(State) ->
    io:format("My age is ~B~n.",[?getAttr(age)]),
    wooper:const_return().
```

Oneway Type Specifications The type specification of a oneway should rely, for its return type, either on `oneway_return()` or on `const_oneway_return()`, depending on its constness (no result to account for in either case).

Making the previous examples more complete:

```
-spec setAge(wooper:state,age()) -> oneway_return().
setAge(State,NewAge) ->
    wooper:return_state(setAttribute(State,age,NewAge)).

-spec displayAge(wooper:state) -> const_oneway_return().
displayAge(State) ->
    io:format("My age is ~B~n.",[?getAttr(age)]),
    wooper:const_return().
```

Usefulness Of the Method Terminators The actual definition of the method terminators (ex: `wooper:return_state_result/2`, `wooper:return_state/1`) is actually quite straightforward.

For example `wooper:return_state_result(AState,AResult)` will simply translate into `{AState,AResult}`, and `wooper:return_state(AState)` will translate into `AState`.

Their purpose is just to structure the method implementations, helping the method developer not mixing updated states and results, and helping WOOPER in categorizing appropriately all Erlang-level functions.

More precisely, as mentioned, all clauses of a method must directly end with a call to its corresponding WOOPER method terminator.

For example, the following extract is correct:

```
% Returns the name of this instance.
-spec getName(wooper:state()) -> request_return(name()).
getName(State) ->
  Name = nested_in_request(State),
  wooper:const_return_result(Name).

% (helper)
nested_in_request(State) ->
  ?getAttr(name).
```

Whereas the next one is wrong, as `getName/1` would be identified as a unexported plain function (instead of as a const request), and the other way round for `nested_in_request/1`:

```
% Returns the name of this instance.
-spec getName(wooper:state()) -> request_return(name()).
getName(State) ->
  nested_in_request(State).

% (helper)
nested_in_request(State) ->
  wooper:const_return_result(?getAttr(name)).
```

Defining `nested_in_request/1` as shown below would not help either of course:

```
% (helper)
nested_in_request(State) ->
  ?getAttr(name).
```

So, should a method be reported as unused, most probably that no method terminator was used (hence it was not identified as such, and thus not auto-exported, and thus may be reported as unused).

Self-Invocation: Calling a Method From the Instance Itself When implementing a method of a class, one may want to call other methods **of that same class** (have they been overridden or not).

For example, when developing the `declareBirthday/1` oneway of `class_Mammal` (which, among other things, is expected to increment the mammal age), one may want to perform a call to its `setAge/2` oneway (possibly introduced by an ancestor class like `class_Creature`, or possibly overridden directly in `class_Mammal`) on the current instance.

One *could* refer to this method respectively as a function exported by that ancestor (ex: called as `class_Creature:setAge(...)`) or that is local to the current module (a direct `setAge(...)` local call designating then `class_Mammal:setAge/2`).

However, in the future, child classes of `class_Mammal` may be introduced (ex: `class_Cat`), and they might define their own version of `setAge/2`.

Instead of hardcoding which version of that method shall be called (like in the two previous cases, which establish statically the intended version to call), a developer may desire - if not expect - that, for a cat or for any specialised version thereof, `declareBirthday/1` calls automatically the "right" `setAge/2` method (i.e. the lastly overridden one in the inheritance graph). Possibly any `class_Cat:setAge/2` - not the version of `class_Creature` or `class_Mammal`.

Such an inheritance-aware call could be easily triggered asynchronously: a classical message-based method call directly addressed by an instance to itself could be used, like in `self()!{setAge,10}`, and (thanks to WOOPER) this would lead to executing the "right" version of that method.

If this approach may be useful when not directly needing, from the method, the result of the call and/or not needing to have it executed at once, in the general case one wants to have that possibly overridden method be executed *directly*, synchronously, and to obtain immediately the corresponding updated state and, if relevant, the associated output result.

Inheritance-based Self-Invocation To perform the self-invocation of a method whose actual implementation is automatically determined based on the inheritance of the class at hand, one should call the WOOPER-defined `executeRequest/{2,3}` or `executeOneway/{2,3}` functions (or any variation thereof), depending on the type of the method to call.

These two helper functions behave quite similarly to the actual method calls that are based on the operator `!`, except that no target instance has to be specified (since it is by definition a call made by an instance to itself) and that no message exchange at all is involved: the method look-up is just performed through the inheritance hierarchy,

the correct method is called with the specified parameters and the result is then directly returned.

More precisely, **executeRequest** is `executeRequest/2` or `executeRequest/3`, its parameters being the current state, the name of the request method, and, if needed, the parameters of the called request, either as a list or as a standalone one.

`executeRequest` returns a pair made of the new state and of the result.

For example, for a request taking more than one parameter, or one list parameter:

```
{NewState,Result} = executeRequest(CurrentState,myRequestName,
                                   ["hello",42])
```

For a request taking exactly one, non-list, parameter:

```
{NewState,NewCounter} = executeRequest(CurrentState,
                                       addToCurrentCounter,78)
```

For a request taking no parameter:

```
{NewState,Sentence} = executeRequest(CurrentState,getLastSentence)
```

Const requests can be called[10] as well, like in:

```
Color = executeConstRequest(CurrentState,getColor)
```

Regarding now **executeOneway**, it is either `executeOneway/2` or `executeOneway/3`, depending on whether the oneway takes parameters. If yes, they can be specified as a list (if there are more than one) or, as always, as a standalone non-list parameter.

`executeOneway` returns the new state.

For example, a oneway taking more than one parameter, or one list parameter:

```
NewState = executeOneway(CurrentState,say,[ "hello", 42 ])
```

For a oneway taking exactly one (non-list) parameter:

```
NewState = executeOneway(CurrentState,setAge,78)
```

For a oneway taking no parameter:

```
NewState = executeOneway(CurrentState,declareBirthday)
```

Const oneways can also be called[11] as well, like in:

```
executeConstOneway(CurrentState,displayAge)
```

> **Note**
>
> As discussed previously, there are caller-side errors that are not expected to crash the instance. If such a call is performed directly from that instance (i.e. with one of the `execute*` constructs), then two errors will be output: the first, non-fatal for the instance, due to the method call, then the second, fatal for the instance, due to the failure of the `execute*` call. This is the expected behaviour, as here the instance plays both roles, the caller and the callee.

[10] Note that currently WOOPER will not check that a called request is indeed const, and will silently drop any updated state.

[11] Note that currently WOOPER will not check that a called oneway is indeed const, and will silently drop any updated state.

Self-Invocation of an Explicitly-Designated Method One can specify **explicitly** the class (of course belonging to the inheritance graph of the class at hand) defining the version of the method that one wants to execute, bypassing the inheritance-aware overriding system.

For example, a method needing to call `setAge/2` from its body would be expected to use something like: `AgeState = executeOneway(State,setAge,NewAge).`

If `class_Cat` overrode `setAge/2`, any cat instance would then call the overridden `class_Cat:setAge/2` method instead of the original `class_Creature:setAge/2`.

What if our specific method of `class_Cat` wanted, for any reason, to call the `class_Creature` version of `setAge/2`, now shadowed by an overridden version of it? In this case a `execute*As` function should be used.

These functions, which are `executeRequestAs/{3,4}` and `executeOnewayAs/{3,4}`, behave exactly as the previous `execute*` functions, except that they take an additional parameter (to be specified just after the state) that is the name of the mother class (direct or not) having defined the version of the method that we want to execute.

> **Note**
> This mother class does not have to have specifically defined or overridden that method: this method will just be called in the context of that class, as if it was an instance of the mother class rather than one of the actual child class.

In our example, we should thus use simply:

```
AgeState = executeOnewayAs(State,class_Creature,setAge,NewAge)
```

in order to call the `class_Creature` version of the `setAge/2` oneway.

Finally, as one could expect, these functions have their const counterparts, namely: `executeConstRequestAs/{3,4}` and `executeConstOnewayAs/{3,4}`, whose usage offers no surprise, like in:

```
Color = executeConstRequestAs(MyState,class_Vehicle,getColorOf,[wheels])
```

Static Methods Static methods, as opposed to member methods, do not target specifically an instance, they are defined at the class level.

They thus do not operate on a specified process or PID, they are just to be called thanks to their module name, exactly as any exported standard function.

In order to further separate them from member methods, we recommend that the names of static methods obey the `snake_case` convention (as opposed to `CamelCase` one): a static method may for example be named `get_default_settings` (rather than `getDefaultSettings`).

Being class-level, their actual definition does not involve any specific instance state, and so only a result is to be returned thanks to their method terminator, which is `wooper:return_static/1`.

The same applies to their result type in terms of type specification, which is to be expressed using `static_return(T())`.

Here are a few examples of rather straightforward static methods, with or without type specifications:

```
get_default_whisker_color() ->
    wooper:return_static(black).
```

```
-spec determine_croquette_appeal(cat_name()) ->
           static_return('strong'|'moderate'|'weak').
determine_croquette_appeal(_CatName="Tortilla") ->
    wooper:return_static(strong);

determine_croquette_appeal(_CatName="Abysse") ->
    wooper:return_static(moderate).
```

An example of use:

```
PossibleColor = class_Cat:get_default_whisker_color(),
[..]
```

Finally, having static methods leaves little interest to defining and exporting one's standard, plain functions; when doing so, one should wonder whether a static method could not be a solution at least as good.

State Management

Principles We are discussing here about how an instance is to manage its inner state.

Its state is only directly accessible from inside the instance, i.e. from the body of its methods, whether they are inherited or not: the state of an instance is **private** (local to its process), and the outside can *only* access it through the methods defined by its class.

The state of an instance (corresponding to the one that is given by WOOPER as first parameter of all its methods, thanks to a variable conventionally named `State`) is simply defined as a **set of attributes**.

Each attribute is designated by a name, defined as an atom (we recommend using `camel_case` for them), and is associated to a mutable value, which can be any Erlang term.

The current state of an instance can be thought as a list of `{attribute_name,attribute_value}` pairs, like in:

```
[ {color,black}, {fur_color,sand}, {age,13}, {name,"Tortilla"} ].
```

State Implementation Details

Instance Attributes Declaring them

Class-specific attributes may be **declared**, with some qualifiers.

Attribute declarations are fully optional[12], yet specifying them is nevertheless recommended, at the first place for the developer and for any upcoming maintainer.

To do so, the `class_attributes` define must be set to a list of attribute declarations, like in:

```
-define(class_attributes,[
            ATTR_DECL1,
            ATTR_DECL2,
            [...]
            ATTR_DECLN]).
```

These declarations are to relate only to the **class-specific** attributes, i.e. the ones specifically introduced by the class at hand, regardless of the ones inherited from the mother classes.

The most general form of an **attribute declaration** includes the following four information:

```
{Name,Type,QualifierInfo,Description}
```

where:

- `Name` is the name of that attribute, as an atom (ex: `fur_color`)
- `Type` corresponds to the type specification of that attribute (ex: `[atom()]`, `foo:color_index()`); note that the Erlang parser will not support the `|` (i.e. union) operator, like in `'foo'|integer()`; we recommend to use the `union` pseudo-function instead (with any arity greater or equal to 2), like in: `union('foo',integer())`

[12] Current versions of WOOPER do not specifically use these information, but future versions may.

- `QualifierInfo` is detailed just below
- `Description` is a plain string describing the purpose of this attribute; this is a comment aimed only at humans, which preferably does not start with a capital letter and does not end with a dot (ex: `"describes the color of the fur of this animal (not including whiskers)"` or a shorter `"color of the fur of this animal (not including whiskers)"`)

A **qualifier information** is either a single qualifier, or a list of qualifiers.
A **qualifier** can be:

- a *scope* qualifier: `public`, `protected` or `private`; in future versions, a public attribute will correspond to the union of `settable` and `gettable` and will result in accessor methods being automatically generated; for example, should the `fur_color` attribute be declared public, then:
  - the `getFurColor/1` const request would be added (with its spec): `getFurColor(State) -> wooper:const_return_result(?getAttr(fur_color)).`
  - the `setFurColor/2` oneway would be added (with its spec): `setFurColor(State,FurColor) -> wooper:return_state(setAttribute(State,fur_color,FurColor)).`
- an *initialisation* qualifier: `{initial,18}` would denote that the initial value of the corresponding attribute is `18` (this value would then be set even before entering any constructor)
- a *mutability* qualifier: `{const,24}` would denote that the corresponding attribute is `const` and that its (fixed) value is `24` (thus `const` implies here `initial`, which should not specified in that case); `const` can also be specified just by itself (with no initial value), so that it can be initialised later, in constructors, and, of course, just once (this is useful for non-immediate, yet const, values)
- the *none* qualifier: `none` implies that no specific qualifier is specified, and as a result the defaults apply; this qualifier can only be used by itself (not in a list), as an alternative to specifying an empty qualifier list

The defaults are:

- `protected`
- mutable (i.e. non-`const`)
- no specific initial value enforced (not even `undefined`)

So an example of attribute declaration could be:

```
{age,integer(),{initial,18},"stores the current age of this creature"}
```

Note

Currently, these information are only of use for the developer (i.e. for documentation purpose). No check is made about whether they are used, whether no other attributes are used, whether the type is meaningful and indeed enforced, the default initial value is not set, etc. Some of these information might be handled by future WOOPER versions.

Shorter attribute declarations can also used, then with less than the 4 aforementioned pieces of information mentioned:

- only 3 of them: `{Name,Type,Description}` (implying: qualifier is `none`)
- only 2 of them: `{Name,Description}` (implying: type is `any()`, qualifier is `none`)
- only 1 of them: `Name` (implying: type is `any()`, qualifier is `none`, no description)

(and, of course, any number of attributes may not be specified at all)
Finally, a full example of the declaration of class attributes can be:

```
-define(class_attributes,[
          name,
          {age,integer(),{initial,18},"stores the current age of this creat
          birth_date,
          {weight,"total weight measured"}]).
```

Storing them

The attributes of a class instance can be seen as a series of key/value pairs stored in an associative table, whose type has been chosen for its look-up/update efficiency and scalability.

This is a dynamic datastructure, allowing attributes to be added, removed or modified at any time (the safer conventions that apply will be discussed later).

This table, among other elements, is itself stored in the overall instance state, i.e. in the variable designated by `State` specified at the beginning of each member method (and constructors, and destructor), on which the process corresponding to active instances is looping, and whose type is `wooper:state()`.

We strongly advise to suffix the name of the various state variables used with `State` (ex: `RegisteredState`, `FinalState`, etc.).

Managing the State of an Instance A set of WOOPER-provided functions allows to operate on these state variables, notably to read and write the attributes that they contain.

As seen in the various examples, method implementations will access (read/write) attributes stored in the instance state, whose original version (i.e. the state of the instance at the method beginning) is always specified as their first parameter, conventionally named `State`.

This current state can be then modified in the method, and a final state (usually an updated version of the initial one) will be returned locally to WOOPER, thanks to a method terminator.

Then the code (automatically instantiated by the WOOPER header in the class implementation) will loop again for this instance with this updated state, waiting for the next method call, which will possibly change again the state (and trigger side-effects), and so on.

One may refer to wooper.hrl for the actual definition of most of these WOOPER constructs.

Modifying State The `setAttribute/3` function

Setting an attribute (creating[13] and/or modifying it) should be done with the `setAttribute/3` function:

```
NewState = setAttribute(AState,AttributeName,NewAttributeValue)
```

For example, `AgeState = setAttribute(State,age,3)` will return a new state, bound to `AgeState`, exact copy of `State` (notably with all the attribute pairs equal) but for the `age` attribute, whose value will be set to 3.

Therefore, during the execution of a method, any number of states can be defined (ex: `State`, `InitialisedState`, `AgeState`, etc.) before all, but the one that is returned, are garbage-collected.

Note that the corresponding state duplication remains efficient both in terms of processing and memory, as the different underlying state structures (ex: `State` and `AgeState`) actually **share** all their terms except the one modified - thanks to the immutability of Erlang variables that allows to reference rather than copy, be these datastructures tables, records, or anything else.

In various cases, notably in constructors, one needs to define a series of attributes in a row, but chaining `setAttribute/3` calls with intermediate states that have each to be named is not really convenient.

A better solution is to use the `setAttributes/2` function (note the plural) to set a list of attribute name/attribute value pairs in a row.

For example:

```
ConstructedState = setAttributes(MyState,
          [{age,3},{whisker_color,white}])
```

will return a new state, exact copy of `MyState` but for the listed attributes, set to their respective specified value.

The `removeAttribute/2` function

[13] Attribute creation should (by convention) only be done in constructors (not in methods).

> **Note**
> The `removeAttribute/2` function is now deprecated and should not be used anymore.

This function was used in order to fully remove an attribute entry (i.e. the whole key/value pair).

This function is deprecated now, as we prefer defining all attributes once for all, at construction time, and never adding or removing them dynamically: the good practice is just to operate on their value, which can by example be set to `undefined`, without having to deal with the fact that, depending on the context, a given attribute may or may not be defined (kids: don't do that).

For example `NewState = removeAttribute(State,an_attribute)` could be used, for a resulting state having no key corresponding to `an_attribute`.

Neither the `setAttribute*` variants nor `removeAttribute/2` can fail, regardless of the attribute being already existing or not.

Reading State The `hasAttribute/2` function

> **Note**
> The `hasAttribute/2` function is now deprecated and should not be used anymore, as no attribute is expected to be removed anymore either.

To test whether an attribute is defined, one could use the `hasAttribute/2` function: `hasAttribute(AState,AttributeName)`, which returns either `true` or `false`, and cannot fail.

For example, `true = hasAttribute(State,whisker_color)` matches if and only if the attribute `whisker_color` is defined in state `State`.

Note that generally, as already mentioned, it is a bad practice to define attributes outside of the constructor of an instance, as the availability of an attribute could then depend on the actual state, which is an eventuality generally difficult to manage reliably.

A better approach is instead to define all possible attributes directly from the constructor. They would then be assigned to their initial value and, if none is appropriate, they should be set to the atom `undefined` (instead of not being defined at all).

The `getAttribute/2` function

Getting the value of an attribute is to be done with the `getAttribute/2` function:

```
AttributeValue = getAttribute(AState,AttributeName)
```

For example, `MyColor = getAttribute(State,whisker_color)` returns the value of the attribute `whisker_color` from state `State`.

The requested attribute may not exist in the specified state. In this case, a runtime error is issued.

Requesting a non-existing attribute triggers a bad match. In the previous example, should the attribute `whisker_color` not have been defined, `getAttribute/2` would return:

```
{key_not_found,whisker_color}
```

The `getAttr/2` macro

Quite often, when having to retrieve the value of an attribute from a state variable, that variable will be named `State`, notably when using directly the original state specified in the method declaration.

Indeed, when a method needs a specific value, generally either this value was already available in the state it began with (then we can read it from `State`), or is computed in the course of the method, in which case that value is most often already bound to a variable, which can then be re-used directly rather than be fetched from a state.

In this case, the `getAttr/2` macro can be used: `?getAttr(whisker_color)` expands (literally) as `getAttribute(State,whisker_color)`, and is a tad shorter.

This is implemented as a macro so that the user remains aware that an implicit variable named `State` is then used.

The less usual cases where a value must be read from a state variable that is *not* the initial `State` one occur mostly when wanting to read a value from the updated state returned by a `execute*` function call. In this case the `getAttribute/2` function should be used.

Read-Modify-Write Operations Some additional helper functions are provided for the most common operations, to keep the syntax as lightweight as possible.

The `addToAttribute/3` function

When having a numerical attribute, `addToAttribute/3` adds the specified number to the attribute.

To be used like in:

```
NewState = addToAttribute(State,AttributeName,Value)
```

For example:

```
MyState = addToAttribute(FirstState,a_numerical_attribute,6)
```

In `MyState`, the value of attribute `a_numerical_attribute` is increased of 6, compared to the one in `FirstState`.

Calling `addToAttribute/3` on a non-existing attribute will trigger a runtime error (`{key_not_found,AttributeName}`).

If the attribute exists, but no addition can be performed on it (i.e. if it is meaningless for the type of the current value), a `badarith` runtime error will be issued.

The `subtractFromAttribute/3` function

When having a numerical attribute, `subtractFromAttribute/3` subtracts the specified number from the attribute.

To be used like in:

```
NewState = subtractFromAttribute(State,AttributeName,Value)
```

For example:

```
MyState = subtractFromAttribute(FirstState,a_numerical_attribute,7)
```

In MyState, the value of attribute a_numerical_attribute is decreased of 7, compared to the one in FirstState.

Calling subtractFromAttribute/3 on a non-existing attribute will trigger a runtime error ({key_not_found,AttributeName}). If the attribute exists, but no subtraction can be performed on it (meaningless for the type of the current value), a badarith runtime error will be issued.

The `toggleAttribute/2` function

Flips the value of the specified (supposedly boolean) attribute: when having a boolean attribute, whose value is either true or false, sets the opposite logical value to the current one.

To be used like in:

```
NewState = toggleAttribute(State,BooleanAttributeName)
```

For example:

```
NewState = toggleAttribute(State,a_boolean_attribute)
```

Calling toggleAttribute/2 on a non-existing attribute will trigger a runtime error ({key_not_found,AttributeName}). If the attribute exists, but has not a boolean value, a badarith runtime error will be issued.

The `appendToAttribute/3` function

The corresponding signature is NewState = appendToAttribute(State,AttributeName,Element when having a list attribute, appends specified element to the attribute list, in first position.

For example, if a_list_attribute was already set to [see_you,goodbye] in State, then after NewState = appendToAttribute(State,a_list_attribute,hello), the a_list_attribute attribute defined in NewState will be equal to [hello,see_you,goodbye].

Calling appendToAttribute/3 on a non-existing attribute will trigger a a badmatch runtime error. If the attribute exists, but is not a list, an ill-formed list will be created (ex: [8|false] when appending 8 to false, which is not a list).

The `deleteFromAttribute/3` function

The corresponding signature is NewState = deleteFromAttribute(State,AttributeName,Eleme when having a list attribute, deletes first match of specified element from the attribute list.

For example: NewState = deleteFromAttribute(State,a_list_attribute,hello), with the value corresponding to the a_list_attribute attribute in State variable being [goodbye,hello,cheers,hello,see_you] should return a state whose a_list_attribute attribute would be equal to [goodbye,cheers,hello,see_you], all other attributes being unchanged.

If no element in the list matches the specified one, no error will be triggered and the list will be kept as is.

Calling deleteFromAttribute/3 on a non-existing attribute will trigger a badmatch runtime error. If the attribute exists, but is not a list, a function_clause runtime error will be issued.

The `popFromAttribute/2` function

The corresponding signature is {NewState,Head} = popFromAttribute(State,AttributeName): when having an attribute of type list, this function removes the head from the list and

returns a pair made of the updated state (same state except that the corresponding list attribute has lost its head, it is equal to the list tail now) and of that head.

For example: `{NewState,Head} = popFromAttribute(State,a_list_attribute).` If the value of the attribute `a_list_attribute` was `[5,8,3]`, its new value (in `NewState`) will be `[8,3]` and `Head` will be bound to `5`.

The `addKeyValueToAttribute/4` function

The corresponding signature is `NewState = addKeyValueToAttribute(State,AttributeName,Ke` when having an attribute whose value is a table (a Myriad `table:table()` pseudo-type), adds specified key/value pair to that table attribute.

For example: `TableState = setAttribute(State,my_table,table:new()),` `NewState = addKeyValueToAttribute(TableState,my_table,my_key,my_value)` will result in having the attribute `my_table` in state variable `TableState` being a table with only one entry, whose key is `my_key` and whose value is `my_value`.

Multiple Inheritance & Polymorphism

The General Case Both multiple inheritance and polymorphism are automatically managed by WOOPER: even if our cat class does not define a `getAge/1` request, it can nevertheless readily be called on a cat instance, as it is inherited from its mother classes (here from `class_Creature`, an indirect mother class).

Therefore all creature instances can be handled the same, regardless of their actual classes:

```
% Inherited methods work exactly the same as methods defined
% directly in the class:
MyCat ! {getAge,[],self()},
receive
  {wooper_result,Age} ->
    io:format( "This is a ~B year old cat.", [Age] )
end,

% Polymorphism is immediate:
% (class_Platypus inheriting too from class_Mammal,
% hence from class_Creature).
MyPetList = [MyCat,MyPlatypus],
[ begin
    PetPid ! {getAge,[],self()},
    receive
      {wooper_result,Age} ->
        io:format("This is a ~B year old creature.",[Age])
    end
  end || PetPid <- MyPetList ].
```

Running this code should output something like:

```
This is a 4 year old cat.
This is a 4 year old creature.
This is a 9 year old creature.
```

The point here is that the implementer does not have to know what are the actual classes of the instances that are interacted with, provided that they share a common ancestor; polymorphism allows to handle them transparently.

The Special Case of Diamond-Shaped Inheritance In the case of a diamond-shaped inheritance, as the method table is constructed in the order specified in the declaration of the superclasses, like in:

```
-define(superclasses,[class_X,class_Y,...]).
```

and as child classes override mother ones, when an incoming WOOPER message arrives the selected **method** should be the one defined in the last inheritance branch of the last child (if any), otherwise the one defined in the next to last branch of the last child, etc.

Generally speaking, overriding in that case the relevant methods that were initially defined in the child class at the base of the diamond, in order that they perform explicitly a direct call to the wanted module, is by far the most reasonable solution, in terms of clarity and maintainability, compared to trying to guess which version of the method in the inheritance graph should be called.

Regarding the instance state, the **attributes** are set by the constructors, and the developer can select in which order the direct mother classes should be constructed.

However, in such a diamond-shaped inheritance scheme, the constructor of the class that sits at the top of a given diamond will be called more than once.

Any side-effect that it would induce would then occur as many times as this class is a common ancestor of the actual class; it may be advisable to create idempotent constructors in that case.

> **Note**
>
> More generally speaking, diamond-shaped inheritance is seldom necessary. More often than not, it is the consequence of a less-than-ideal OOP design, and should be avoided anyway.

Life-Cycle

Basically, creation and destruction of instances are managed respectively thanks to the new/new_link and the delete operators (all these operators are WOOPER-reserved function names, for all arities, and are automatically generated), like in:

```
MyCat = class_Cat:new(Age,Gender,FurColor,WhiskerColor),
MyCat ! delete.
```

Instance Creation: new/new_link and construct

Role of a new /construct Pair Whereas the purpose of the new / new_link operators is to *create* a working (active) instance on the user's behalf, the role of construct is to *initialise* an instance of that class (regardless of how it was created, i.e. of which new variation was triggered), while being able to be chained for inheritance, as explained later.

Such an initialisation is of course part of the instance creation: all calls to any of the new operators result in an underlying call to the corresponding constructor (construct operator).

For example, both creations stemming from MyCat = class_Cat:new(A,B,C,D) and MyCat = class_Cat:new_link(A,B,C,D) will rely on class_Cat:construct/5 to set up a proper initial state for the MyCat instance; the same class_Cat:construct(State,A,B,C,D) will be called for all creation cases (one may note that, because of its first parameter, which accounts for the WOOPER-provided initial State parameter, the arity of construct is equal to the one of new / new_link plus one).

The new_link operator behaves exactly as the new operator, except that it creates an instance that is Erlang-linked with the process that called that operator, exactly like spawn_link behaves compared to spawn[14].

The new and new_link operators are automatically defined by WOOPER (thanks to a relevant parse transform), but they rely on their corresponding, class-specific, user-defined construct operator (only WOOPER is expected to make use of it). More precisely, for each of the construct/N+1 operator defined by the class developer, WOOPER creates a full set of corresponding new variations, including new/N and new_link/N.

At least one construct operator must be defined by the class developer (otherwise WOOPER will raise a compile-time error), knowing that any number of them can then be defined, each with its own arity (ex: construct/1, construct/2, construct/3, etc.), and each with possibly multiple clauses that will be, as usual, selected at runtime based on pattern-matching.

construct operators may not be exported explicitly by the class developer, as WOOPER will automatically take care of that if necessary.

For example:

```
% If having defined class_Dog:construct/{1,3}:
MyFirstDog  = class_Dog:new(),
MySecondDog = class_Dog:new(_Weight=4.4,_Colors=[sand,white]).
```

[14]For example it induces no race condition between linking and termination in the case of a very short-lived spawned process.

The Various Ways of Creating an Instance As shown with the `new_link` operator, even for a given set of construction parameters, many variations of `new` can be of use: linked or not, synchronous or not, with a time-out or not, on current node or on a user-specified one, etc.

For a class whose instances can be constructed from `N` actual parameters (hence having a `construct/N+1` defined), the following new operator variations, detailed in the next section, are built-in:

- if an **active** instance is to be created on the **local** node:
  - non-blocking creation: `new/N` and `new_link/N`
  - blocking creation: `synchronous_new/N` and `synchronous_new_link/N`
  - blocking creation with time-out: `synchronous_timed_new/N` and `synchronous_timed_new_link/N`
- if an **active** instance is to be created on any specified **remote** node:
  - non-blocking creation: `remote_new/N+1` and `remote_new_link/N+1`
  - blocking creation: `remote_synchronous_new/N+1` and `remote_synchronous_new_link/N`
  - blocking creation with time-out: `remote_synchronous_timed_new/N+1` and `remote_synchronous_timed_new_link/N+1`
- if a **passive** instance is to be created by the current **process**: `new_passive/N`

> **Note**
> All `remote_*` variations require one additional parameter (that shall be specified first), since the remote node on which the instance should be created has of course to be specified.

All supported `new` variations are detailed below.

Asynchronous new

This corresponds to the plain `new`, `new_link` operators discussed earlier, relying internally on the usual `spawn*` primitives . These basic operators are **asynchronous** (non-blocking): they trigger the creation of a new instance, and return immediately, without waiting for it to complete and succeed, and the execution of the calling process continues while (hopefully, i.e. with no guarantee - the corresponding process may immediately crash) the instance is being created and executed.

Synchronous new

As mentioned, with the previous asynchronous forms, the caller has no way of knowing when the spawned instance is up and running (if it ever happens), unless triggering a later request on it.

Thus two counterpart operators, `synchronous_new/synchronous_new_link` are also automatically generated.

They behave like `new/new_link` except that they will return only when (and if) the created instance is up and running: they are blocking, synchronous, operators.

For example, once (if) `MyMammal = class_Mammal:synchronous_new(...)` returns, one knows that the `MyMammal` instance is fully created and waiting for incoming messages.

The implementation of these synchronous operations relies on a message (precisely: `{spawn_successful,InstancePid}`) being automatically sent by the created instance to the WOOPER code on the caller side, so that the `synchronous_new` operator will return to the user code only once successfully constructed and ready to handle messages.

Timed Synchronous new

Note that, should the instance creation fail, the caller of a synchronous new would then be blocked for ever, as the awaited message would actually never be sent by the failed new instance. In some cases a time-out may be useful, so that the caller may be unblocked and may react appropriately.

This is why the `synchronous_timed_new*` operators have been introduced: if the caller-side time-out[15] expires while waiting for the created instance to answer, then they will throw an appropriate exception:

- either `{synchronous_time_out,Classname}` if it was a node-local creation (where `Classname` is the name of the class corresponding to the instance to create; ex: `class_Cat`)
- or `{remote_synchronous_time_out,Node,Classname}`, where `Node` is the name of the node (as an atom) on which the instance was to be created

Then the caller may or may not catch this exception.

Remote new

Exactly like a process might be spawned on another Erlang node, a WOOPER (active) instance can be created on any user-specified available Erlang node.

To do so, the `remote_*new*` variations shall be used. They behave exactly like their local counterparts, except that they take an additional information, as first parameter: the node on which the specified instance must be created.

For example:

```
MyCat = class_Cat:remote_new(TargetNode, Age, Gender,
                             FurColor, WhiskerColor).
```

Of course:

- the remote node must be already existing
- the current node must be able to connect to it (shared cookie)
- all modules that the instance will make use of must be available on the remote node, including the ones of all relevant classes (i.e. the class of the instance but also its whole class hierarchy)

All variations of the `new` operator are always defined automatically by WOOPER: nothing special is to be done for them, provided of course that a corresponding constructor has been defined indeed.

[15] Depending on whether or not the class to instantiate was compiled in debug mode, the time-out is to last by default for, respectively, 5 seconds (shorter, to ease debugging) or for 30 minutes (longer, to favor robustness).

Some Examples of Instance Creation Knowing that a cat can be created here out of four parameters (`Age`, `Gender`, `FurColor`, `WhiskerColor`), various cat (active) instances could be created thanks to:

```
% Local asynchronous creation:
MyFirstCat = class_Cat:new(_Age=1,male,brown,white),

% The same, but a crash of this cat will crash the current process too:
MySecondCat = class_Cat:new_link(2,female,black,white),

% This cat will be created on OtherNode, and the call will return only
% once it is up and running or once the creation failed. As moreover the
% cat instance is linked to the instance process, it may crash this
% calling process (unless it traps EXIT signals):
MyThirdCat = class_Cat:remote_synchronous_timed_new_link(OtherNode,3,
  male,grey,black),
[..]
```

Definition of the `construct` Operator Each class must define at least one `construct` operator, whose role is to fully initialise, based on the specified construction parameters, the state of new instances in compliance with the class inheritance - regardless of the `new` variation being used.

The type specification of a constructor relying on `N` construction parameters (hence `construct/N+1`) is:

```
-spec construct(wooper:state(),P1,P2,..,PN) -> wooper:state().
```

In the context of class inheritance, the `construct` operators are expected to be chained: they must be designed to be called by the ones of their child classes, and in turn they must call themselves the constructors of their direct mother classes, if any (should there be multiple direct mother classes, usually their constructors are to be called in the same order as their declaration order in the `superclasses` define).

Hence they always take the current state of the instance being created as a starting base, and returns it once updated, first from the direct mother classes, then by this class itself.

For example, let's suppose `class_Cat` inherits directly both from `class_Mammal` and from `class_ViviparousBeing`, has only one attribute (`whisker_color`) of its own, and that a new cat is to be created out of four pieces of information:

```
-define(superclasses,[class_Mammal,class_ViviparousBeing]).

-define(class_attributes,[whisker_color]).

% Constructs a new Cat.
construct(State,Age,Gender,FurColor,WhiskerColor) ->
  % First the (chained) direct mother classes:
  MammalState = class_Mammal:construct(State,Age,Gender,FurColor),
  ViviparousMammalState = class_ViviparousBeing:construct(MammalState),
  % Then the class-specific attributes:
  setAttribute(ViviparousMammalState,whisker_color,WhiskerColor).
```

The fact that the `Mammal` class itself inherits from the `Creature` class does not have to appear here: it is to be managed directly by `class_Mammal:construct/4` (at any given inheritance level, only direct mother classes must be taken into account).

One should ensure that, in constructors, the successive states are always built from the last updated one, unlike this case (where no mother class has been declared):

```
% WRONG, the age update is lost:
construct(State,Age,Gender) ->
  AgeState = setAttribute(State,age,Age),
  % AgeState should be used here, not State:
  setAttribute(State,gender,Gender),
```

This would be correct:

```
% RIGHT but a bit clumsy:
construct(State,Age,Gender) ->
  AgeState = setAttribute(State,age,Age),
  setAttribute(AgeState,gender,Gender).
```

Recommended form:

```
% BEST:
construct(State,Age,Gender) ->
  setAttributes(State,[{age,Age},{gender,Gender}]).
```

The WOOPER defaults would imply that, in the first case, at compilation time the `AgeState` variable would be reported as unused, and this warning would be considered as a fatal error.

> **Note**
> There is no strict relationship between *construction parameters* and *instance attributes*, neither in terms of cardinality, type nor value.
> For example, attributes could be set to default values, a point could be created from an angle and a distance but its actual state may consist on two cartesian coordinates instead, etc.
> Therefore both have to be defined by the class developer, and, in the general case, attributes cannot be inferred from construction parameters.

Finally, a class can define multiple clauses for any of its constructors: the proper one will be called based on the pattern-matching performed on these parameters.

Instance Deletion

Automatic Chaining Of Destructors We saw that, when implementing a constructor (`construct/N`), like in all other OOP approaches the constructors of the direct mother classes have to be explicitly called, so that they can be given the proper parameters, as determined by the class developer.

Conversely, with WOOPER, when defining a destructor for a class (`destruct/1`), one only has to specify what are the *specific* operations and state changes (if any) that

are required so that an instance of that class is deleted: the proper calling of the destructors of mother classes across the inheritance graph is automatically taken in charge by WOOPER.

Once the user-specified actions have been processed by the destructor (ex: releasing a resource, unsubscribing from a registry, deleting other instances, closing properly a file, etc.), it is expected to return an updated state, which will be given in turn to the destructors of the instance direct mother classes.

WOOPER will automatically make use of any user-defined destructor, otherwise the default one will be used, doing nothing (i.e. returning the exact same state that it was given).

Note also that, as always, there is a single destructor associated to a given class.

As constructors, destructors should not be exported, as WOOPER is to automatically take care of that.

Asynchronous Destruction: using `destruct/1` The type specification of a destructor (`destruct/1`) is:

```
-spec destruct(wooper:state()) -> wooper:state().
```

More precisely, either the class implementer does not define at all a `destruct/1` operator (and therefore uses the default do-nothing destructor), or it defines it explicitly, like in:

```
destruct(State) ->
    io:format("An instance of class ~w is being deleted now!",[?MODULE]),
    % Quite often the destructor does not need to modify the state of
    % the instance:
    State.
```

In both cases (default or user-defined destructor), when the instance will be deleted (ex: `MyInstance ! delete` is issued), WOOPER will take care of:

- calling any user-defined destructor for that class
- then calling the ones of the direct mother classes, which will in turn call the ones of their mother classes, and so on

Note that the destructors for direct mother classes will be called in the reverse order of the one according to the constructors ought to have been called: if a class `class_X` declares `class_A` and `class_B` as mother classes (in that order), then in the `class_X:construct` definition the implementer is expected to call `class_A:construct` and then `class_B:construct`, whereas on deletion the WOOPER-enforced order of execution will be: `class_X:destruct/1`, then `class_B:destruct/1`, then `class_A:destruct/1`, for the sake of symmetry.

Synchronous Destruction: using `synchronous_delete/1` WOOPER automatically defines as well a way of deleting *synchronously* a given instance: a caller can request a synchronous (blocking) deletion of that instance so that, once notified of the deletion, it knows for sure the instance does not exist anymore, like in:

```
InstanceToDelete ! {synchronous_delete,self()},
% Then the caller can block as long as the deletion did not occur:
receive
  {deleted,InstanceToDelete} ->
      doSomething()
end.
```

The class implementer does not have to do anything to support this feature, as the synchronous deletion is automatically built by WOOPER on top of the usual asynchronous one (both thus rely on `destruct/1`).

For a more concise way of doing the same, see also:

- `wooper:delete_synchronously_instance/1` (for a single instance)
- `wooper:delete_synchronously_instances/1` (for multiple ones)

Passive Instances

A passive instance is an instance of a WOOPER class that is not powered by a dedicated (Erlang) process: it is just a mere (opaque) term, a pure data-structure that holds the state[16] of that instance, and that is returned to the process having created that instance (which can then do whatever it wants with it).

As a consequence, such a passive instance will not be able to perform any spontaneous behaviour or to have its member methods be triggered by other processes. However most operations that can be done on "standard" (active) WOOPER instances can also be done on passive ones: like their active counterparts, they are constructed thanks to, well, one of the constructors defined by their class, they are destructed thanks to, well, their destructor, and in-between they will retain their inner state and be able to execute any request or oneway triggered by the process holding that term (and of course any underlying multiple inheritance will be respected).

Triggering a method onto a passive instance will result in a relevant function to be evaluated, not involving any message.

To create a passive instance, the `new_passive` operator shall be used, like in:

```
MyPassiveCat = class_Cat:new_passive(_Age=2,female,_Fur=brown,_Whiskers=whi
```

Then methods can be triggered on it, like in:

```
{WhiskerCat,white} = wooper:execute_request(MyPassiveCat,getWhiskerColor),
OlderCat = wooper:execute_oneway(WhiskerCat,declareBirthday),
RedCat = wooper:execute_oneway(OlderCat,setFurColor,red),
[...]
```

Until, finally:

```
wooper:delete_passive(RedCat).
```

See the `passive_instance_test` module for more details.

[16] This term is mostly the same state term as the one on which the process dedicated to an active instance is looping. So one could even imagine a WOOPER instance going back and forth between an active and a passive mode of operation.

Miscellaneous Technical Points

`delete_any_instance_referenced_in/2`

When an attribute contains either a single instance reference (i.e. the PID of the corresponding process) or a list of instance references, this WOOPER-defined helper function will automatically delete (asynchronously) these instances, and will return an updated state in which this attribute is set to `undefined`.

This function is especially useful in destructors.

For example, if `State` contains:

- an attribute named `my_pid` whose value is the PID of an instance
- and also an attribute named `my_pids` containing a list of PID instances

and if the instance at hand that shall be deleted took ownership of these instances, then:

```
delete(State) ->
    TempState = wooper:delete_any_instance_referenced_in(State,my_pid),
    wooper:delete_any_instance_referenced_in(TempState,my_pids).
```

will automatically delete all these instances (if any) and return an updated state.

Then the destructors of the mother classes can be chained by WOOPER.

See also the various other helpers defined in `wooper.erl`.

`EXIT` Signals / Messages

A class instance may (if trapping EXIT signals) receive EXIT messages from other processes.

A given class can process these EXIT notifications:

- either by defining and exporting the `onWOOPERExitReceived/3` oneway
- or by inheriting it

For example:

```
-spec onWOOPERExitReceived(wooper:state(),basic_utils:pid_or_port(),
            basic_utils:exit_reason()) -> const_oneway_return().
onWOOPERExitReceived(State,PidOrPort,ExitReason) ->
      io:format("MyClass EXIT handler ignored signal '~p' "
                "from ~w.~n", [ExitReason,PidOrPort]),
      wooper:const_return().
```

may result in an output like:

```
MyClass EXIT handler ignored signal 'normal' from <0.40.0>.
```

If no class-level `onWOOPERExitReceived/3` oneway is available, the default WOOPER EXIT handler (namely `wooper:default_exit_handler/3`) will be used (it just performs console-based notification).

It will just notify the signal to the user, by displaying a message like:

```
WOOPER default EXIT handler for instance <0.36.0> of class class_Cat
  ignored signal 'normal' from <0.40.0>.
```

`DOWN` Messages for Process Monitors

A class instance may receive DOWN messages from other (monitored) processes.

A given class can process these DOWN notifications:

- either by defining and exporting the `onWOOPERDownNotified/5` oneway
- or by inheriting it

If no class-level `onWOOPERDownNotified/5` oneway is available, the default WOOPER DOWN handler (namely `wooper:default_down_handler/5`) will be used (it just performs console-based notification).

Note that `DOWN` messages shall not be mixed up with the `nodedown` messages of the next section.

Node Monitors

Quite similarly to `EXIT` messages, node monitors and `nodeup` / `nodedown` messages are also managed by WOOPER, see the `onWOOPERNodeConnection/3` and `onWOOPERNodeDisconnection/3` oneways.

Should these oneways be not available for the class at hand, the default WOOPER node handlers (namely `wooper:default_node_up_handler/3` and `default_node_down_handler/3` respectively) will be used (they just perform console-based notifications).

Note that `nodedown` messages shall not be mixed up with the `DOWN` messages of the previous section.

Guidelines

All WOOPER classes must include wooper.hrl:

```
-include("wooper.hrl").
```

> **Note**
> This include should come, in the source file of a class, *after* all WOOPER-related defines (such as `superclasses`, `class_attributes`, etc.).

To help declaring the right defines in the right order, using the WOOPER template is recommended.

One may also have a look at the full test examples, as a source of inspiration.

For examples of re-use of WOOPER by upper layers, one may refer to Ceylan-Traces or to the Sim-Diasca simulation engine.

Class Developer Cheat Sheet

When specifying a **class**: `-module(class_Foobar).`

When specifying its **superclasses**: `-define(superclasses,[A,B]).`

When specifying its **class attributes**: `-define(class_attributes,[ATTR1,ATTR2,...])`

A given `ATTRn` may be one of:

- `{Name,Type,QualifierInfo,Description}`
- `{Name,Type,Description}`

- `{Name,Description}`
- `Name`

`QualifierInfo` can be, for example, `public`, or `[private,const]`.

All member methods have `State` for initial parameter, and are expected to return at least a (possibly const) state.

When defining a **request**:

- its **spec** should rely, for its return type, either on `request_return(T())` or on `const_request_return(T())`
- each of its clause should terminate with either `wooper:return_state_result(S,R)` or `wooper:const_return_result(R)`

When defining a **oneway**:

- its **spec** should rely, for its return type, either on `oneway_return()` or on `const_oneway_return()`
- each of its clause should terminate with either `wooper:return_state(S)` or `wooper:const_return()`

When defining a **static method**:

- its **spec** should rely, for its return type, on `static_return(T())`
- each of its clause should terminate with `wooper:return_static(R)`

Source Editors

We use `Emacs` but of course any editor will be fine.

For Nedit users, a WOOPER-aware nedit.rc configuration file for syntax highlighting (on black backgrounds), inspired from Daniel Solaz's Erlang Nedit mode, is available.

Similarity With other Languages

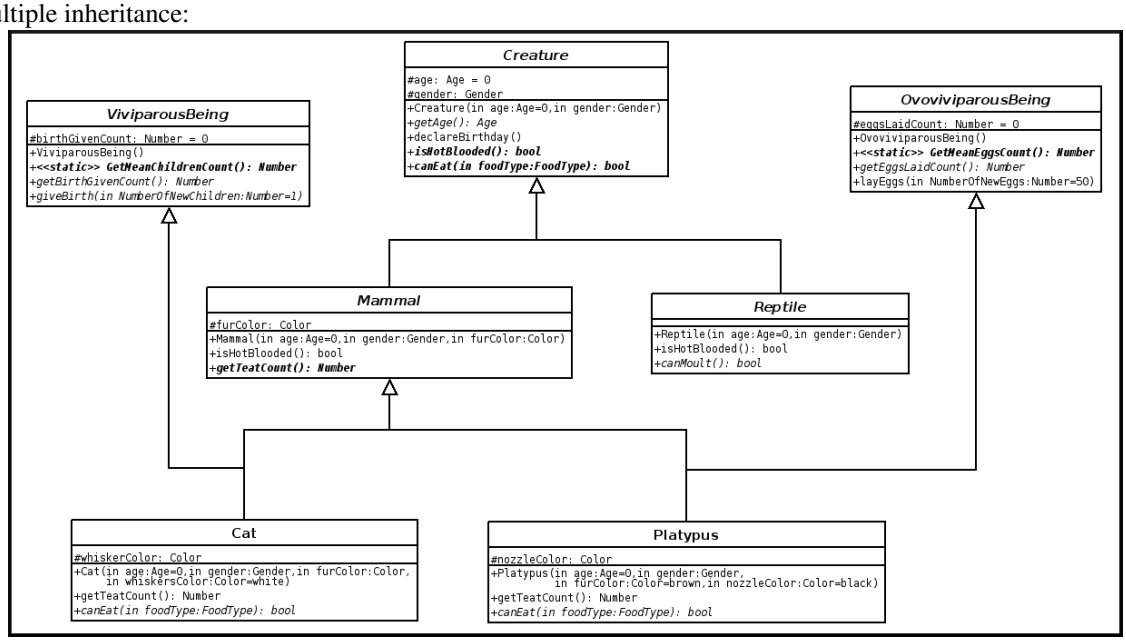
WOOPER is in some ways adding features quite similar to the ones available with other languages, including Python (simple multiple inheritance, implied `self/State` parameter, attribute dictionaries/associative tables, etc.) while still offering the major strengths of Erlang (concurrency, distribution, functional paradigm) and not hurting too much the overall performances (mainly thanks to the prebuilt attribute and method tables).

Actually the main implementation shortcomings that remain are:

- the per-instance memory footprint could be reduced by sharing the "virtual table" of a given class between all its instances

WOOPER Example

We defined a small set of classes in order to serve as an example and demonstrate multiple inheritance:



Class implementations

- class_Creature.erl
- class_ViviparousBeing.erl
- class_OvoviviparousBeing.erl
- class_Mammal.erl
- class_Reptile.erl
- class_Cat.erl
- class_Platypus.erl

Tests

- class_Creature_test.erl
- class_ViviparousBeing_test.erl
- class_OvoviviparousBeing_test.erl
- class_Mammal_test.erl
- class_Reptile_test.erl
- class_Cat_test.erl
- class_Platypus_test.erl

To run a test (ex: `class_Cat_test.erl`), when WOOPER has already been compiled, one just has to enter: `make class_Cat_run`.

Good Practises

When using WOOPER, the following conventions are deemed useful to respect (even if they are not mandatory).

No **warning** should be tolerated in code using WOOPER, as we *never* found useless notifications.

All **attributes** of an instance should better be defined **from the constructor**, instead of being dynamically added during the life of the instance; otherwise the methods would have to deal with some attributes that may, or may not, be defined; if no proper value exists for an attribute at the creation of an instance, then its value should just be set to the atom `undefined`; its type should then go from `T()` to `maybe(T())`.

Class-specific attributes should be specified (using the `class_attributes` define), as doing so brings up much useful information to the developer/maintainer.

Type specifications should be used for at least most non-internal functions (such as constructors, methods, etc.).

The **naming conventions** (ex: `CamelCase` / `snake_case`) shall be respected; notably, helper functions and static methods (which, from an Erlang point of view, are mostly just exported functions) should be named like C functions, in `snake_case` (ex: `compute_sum`) rather than being written in CamelCase (ex: no helper function should be named `computeSum`), to avoid mixing up these different kinds of code.

To further separate helper functions from instance methods, an helper function taking a `State` parameter should better place it at the end of its parameter list rather than in first position (ex: `compute_sum(X,Y,State)` rather than `compute_sum(State,X,Y)`).

In a method body, the various state variables being introduced should be properly named, i.e. their name should start with a self-documenting prefix followed by the `State` suffix, like in: `SeededState=setAttribute(State,seed,{1,7,11})`.

Some more general (mostly unrelated) **Erlang-level conventions** that we like:

- when, in code, more than one parameter is specified in a function signature, parameter names can be surrounded by spaces (ex: `f( Color )`, or `g( Age, Height )`)
- functions should be separated by (at least) three newlines, whereas clauses for a given function should be separated by one or two newlines, depending on their size
- to auto-document parameters, a "mute" variable is preferably to be used: for example, instead of `f( Color, true )` use `f( Color, _Dither=true )`; however note that (unfortunately) these mute variables are still bound and thus pattern-matched: for example, if multiple `_Dither` mute variables are bound in the same scope to different values, a bad match will be triggered at runtime.

Troubleshooting

Debug Mode

We recommend that, as a WOOPER user, one enables its debug mode when developing (ensure in `GNUmakevars.inc` that `ENABLE_DEBUG` has been set to true - which is the case by default), as it may catch various user errors more easily (not only WOOPER-internal errors, but also, and most importantly, any user-originating mistake).

Then only, once one's code is mature enough, this debug mode may be disabled in order to obtain best performances.

General Case

Compilation Warnings A basic rule of thumb in all languages is to enable all warnings and eradicate them before even trying to test a program.

This is still more valid when using WOOPER, whose proper use should never result in any warning being issued by the compiler.

Notably warnings about unused variables are precious in order to catch mistakes when state variables are not being properly taken care of (ex: when a state is defined but never re-used later).

Runtime Errors Most errors while using WOOPER should result in relatively clear messages (ex: `wooper_method_failed` or `wooper_method_faulty_return`), associated with all relevant runtime information that was available to WOOPER, including context and stacktrace.

Another way of overcoming WOOPER issues is to activate the debug mode for all WOOPER-enabled compiled modules (ex: uncomment `-define(wooper_debug,).` in `wooper.hrl` or, preferably, ensure in `GNUmakevars.inc` that `ENABLE_DEBUG` has been set to true), and recompile your classes.

The debug mode tries to perform extensive checking on all WOOPER entry points, from incoming messages to the user class itself, catching mistakes from the class developer as well as from the class user.

For example, the validity of states returned by a constructor, by each method and by the destructor is checked, as the one of states specified to the `execute*` constructs.

If it is not enough to clear things up, an additional step can be to add, on a per-class basis (ex: in `class_Cat.erl`), before the WOOPER include, `-define(wooper_log_wanted,)`.

Then all incoming method calls will be traced, for easier debugging. It is seldom necessary to go till this level of detail.

As there are a few common WOOPER gotchas though, the main ones are listed below.

Mismatches In Method Call Oneway Versus Request Calls

One of these gotchas - experienced even by the WOOPER author - is to define a two-parameter oneway, whose second parameter is a PID, and to call this method wrongly as a request, instead of as a oneway.

For example, let's suppose the `class_Dog` class defines the oneway method `startBarkingAt/3` as:

```
startBarkingAt(State,Duration,ListenerPID) -> ...
```

The correct approach to call this **oneway** would be:

```
MyDogPid ! {startBarkingAt,[MyDuration,self()]}
```

An absent-minded developer could have written instead:

```
MyDogPid ! {startBarkingAt,MyDuration,self()}
```

This would have called a `request` method `startBarkingAt/2` (which could have been for example `startBarkingAt(State,TerminationOffset) -> ...`, the PID being interpreted by WOOPER as the request sender PID), a method that most probably does not even exist.

This would result in a bit obscure error message like `Error in process <0.43.0> on node 'XXXX' with exit value: {badarg,[{class_Dog,wooper_main_loop,1}]}`.

List Parameter Incorrectly Specified In Call

As explained in the Method Parameters section, if a method takes only one parameter and if this parameter is a list, then in a call this parameter cannot be specified as a standalone one: a parameter list with only one element, this parameter, should be used instead.

Error With Exit Value: `{undef,[{map_hashtable,new,[..]}..` You most probably forgot to build the `Ceylan-Myriad` directory that contains, among other modules, the `map_hashtable.erl` source file.

Check that you have a `map_hashtable.beam` file indeed, and that it can be found from the paths specified to the virtual machine.

Note that the WOOPER code designates this module as the `table` one (ex: `table:new()`), for a better substituability (this is obtained thanks to a parse-transform provided by `Ceylan-Myriad`).

Current Stable Version & Download

Using Stable Release Archive

Currently no source archive is specifically distributed, please refer to the following section.

Using Cutting-Edge GIT

We try to ensure that the main line (in the `master` branch) always stays functional (sorry for the pun). Evolutions are to be take place in feature branches.

This layer, `Ceylan-WOOPER`, relies (only) on:

- Erlang, version 21.0 or higher
- the Ceylan-Myriad base layer

We prefer using GNU/Linux, sticking to the latest stable release of Erlang, and building it from sources, thanks to GNU `make`.

For that we devised the install-erlang.sh script; a simple use of it is:

```
$ ./install-erlang.sh --doc-install --generate-plt
```

One may execute `./install-erlang.sh --help` for more details about how to configure it, notably in order to enable all modules of interest (`crypto`, `wx`, etc.) even if they are optional in the context of WOOPER.

As a result, once a proper Erlang version is available, the Ceylan-Myriad repository should be cloned and built, before doing the same with the Ceylan-WOOPER repository, like in:

```
$ git clone https://github.com/Olivier-Boudeville/Ceylan-Myriad
$ cd Ceylan-Myriad && make all && cd ..
$ git clone https://github.com/Olivier-Boudeville/Ceylan-WOOPER
$ cd Ceylan-WOOPER && make all
```

Version History & Changes

Version 2.0 [current stable]

Many improvements, notably:

- multiple different-arity constructors per class supported
- no more `wooper_construct_parameters`, longer `wooper_construct_export` or `wooper_construct_export` defines
- automatic detection and export of constructors, any destructor and methods
- WOOPER method terminators introduced (ex: `wooper:return_state_result/2`, instead of the `?wooper_return_state_result` macro)
- the `class_attributes` optional parse attribute define introduced (`-define(class_attributes,[..`
- `execute*With` renamed as `execute*As` (clearer)
- convenience method wrappers such as `wooper:execute_request/3` have their parameters reordered (target - either a PID or a passive instance - comes first now)
- passive instances supported (still a bit experimental, not used a lot, yet working)

More generally, many macros and definitions in the WOOPER header files moved to code generated thanks to a parse-transform.

Version 1.x

Many minor improvements, API enriched in a backward compatible manner.

Version 1.0 [current stable]

Countless improvements have been integrated in the course of the use of WOOPER, which has been now been stable for years.

Since 2016 we switched back to a "rolling release", not defining specific versions.

The main change since the 0.4 version is the use of the newly-introduced `map` Erlang datatype, resulting in the `hashtable` module being replaced by the `map_hashtable`. They obey to the same API and the `table` pseudo-type abstracts out the actual choice in that matter (it is transparently parse-transformed into the currently-retained datatype).

Version 0.4

It is mainly a BFO (*Bug Fixes Only*) version, as functional coverage is pretty complete already.

Main changes are:

- debug mode enhanced a lot: many checkings are made at all fronteers between WOOPER and either the user code (messages) or the class code (constructors, methods, destructor, execute requests); user-friendly explicit error messages are displayed instead of raw errors in most cases; `is_record` used to better detect when an expected state is not properly returned

- `wooper_result` not appended any more to method returns in debug mode
- release mode tested and fixed
- `exit` replaced by `throw`, use of newer and better `try/catch` instead of mere `catch`
- destructor chained calls properly fixed this time
- `delete_any_instance_referenced_in/2` added, `wooper:return_state_*` macros simplified, `remote_*` bug fixed

Version 0.3

Released on Wednesday, March 25, 2009.
Main changes are:

- destructors are automatically chained as appropriate, and they can be overridden at will
- incoming EXIT messages are caught by a default WOOPER handler which can be overridden on a per-class basis by the user-specified `onWOOPERExitReceived/3` method
- direct method invocation supported, thanks to the `executeRequest` and `executeOneway` constructs, and `wooper_result` no more appended to the result tuple
- synchronous spawn operations added or improved: `synchronous_new/synchronous_new_link` and al; corresponding template updated
- state management enriched: `popFromAttribute` added
- all new variations on remote nodes improved or added
- major update of the documentation

Version 0.2

Released on Friday, December 21, 2007. Still fully functional!
Main changes are:

- the sender PID is made available to requests in the instance state variable (see `request_sender` member, used automatically by the `getSender` macro)
- runtime errors better identified and notified
- macros for attribute management added, existing ones more robust and faster
- fixed a potential race condition when two callers request nearly at the same time the WOOPER class manager (previous mechanism worked, class manager was a singleton indeed, but second caller was not notified)
- improved build (Emakefile generated), comments, error output
- test template added
- documentation updated

Version 0.1

Released on Sunday, July 22, 2007. Already fully functional!

WOOPER Inner Workings

General Principles

Understanding Compilation WOOPER is the second level of a software stack beginning with Erlang and then Myriad.

If the initial versions of WOOPER were mostly based on macros and headers, newer ones rely on the Erlang way of doing metaprogramming, namely parse-transforms.

More precisely, the sources of a user-defined class are transformed by the standard Erlang toolchain (`erlc` compiler) into an AST (*Abstract Syntax Tree*), which is first transformed by WOOPER (ex: to generate the new operators, to export any destructor, etc.) and then Myriad (ex: to support newer types such as `void/0`, `maybe/1` or `table/2`).

Understanding the Mode of Operation of a WOOPER Instance Each instance runs a main loop (`wooper_main_loop/1`, defined in wooper.hrl) that keeps its internal state and, through a blocking `receive`, serves the methods as specified by incoming messages, quite similarly to a classical server that loops on an updated state, like in:

```
my_server(State) ->
  receive
    {command,{M,P}} ->
      NewState = execute_command(State,M,P),
      my_server(NewState)
  end.
```

In each instance, WOOPER manages the tail-recursive infinite surrounding loop, `State` corresponding to the (private) state of the instance, and `execute_command(State,M,P)` corresponding to the WOOPER logic that triggers the user-defined method `M` with the current state (`State`) and the specified parameters (`P`), and that may return a result.

The per-instance kept state is twofold, in the sense that it contains two associative tables, one to route method calls and one to store the instance attributes, as explained below.

Method Virtual Table

General Principle This associative table allows, for a given class, to determine which module implements actually each supported method.

For example, all instances of `class_Cat` have to know that their `getWhiskerColor/1` method is defined directly in that class, as opposed to their `setAge/2` method whose actual implementation is to be found, say, in `class_Mammal`, should this class have overridden it from `class_Creature`.

As performing a method look-up through the entire inheritance graph at each call would waste resources, the look-up is precomputed for each class.

Indeed a per-class table is built at runtime, on the first creation of an instance of this class, and stored by the unique (singleton) WOOPER class manager that shares it to all the class instances.

This manager is itself spawned the first time it is needed, and stays ready for all instances of various classes being created (it uses a table to associate to each class its specific virtual table).

This per-class method table has for keys the known method names (atoms) for this class, associated to the values being the most specialised module, in the inheritance graph, that defines that method.

Hence each instance has a reference to a shared table that allows for a direct method look-up.

As the table is built only once and is theoritically shared by all instances of that class[17], it adds very little overhead, space-wise and time-wise. Thanks to the table, method look-up is expected to be quite efficient too (constant-time).

Attribute Table

This is another associative table, this time necessarily per-instance.

Keys are attribute names of that instance, values are the corresponding attribute values.

It allows a simple, seamless yet efficient access to all data members, including inherited ones.

[17] Provided that Erlang does not copy these shared immutable structures, which unfortunately does not seem to be currently the case with the vanilla virtual machine. In a later version of WOOPER, the per-class table will be precompiled and shared as a module, thus fully removing that per-instance overhead.

Issues & Planned Enhancements

- test the impact of using HiPE by default
- integrate automatic persistent storage of instance states, for example in Mnesia databases
- integrate specific constructs for code reflection
- check that a class specified in `execute*As` is indeed a (direct or not) mother class of this one, at least in debug mode
- check that referenced attributes are legit (existing, not reserved, etc.) and their acess as well (ex: regarding constness)
- support qualifier-based declarations of methods and attributes (`public`, `protected`, `private`, `final`, `const`, `pure`, etc.)
- generate a graphical class diagram out of a set of sources (ex: using PlantUML)
- ensure that all instances of a given class *reference* the same table dedicated to the method look-ups, and do not have each their own private *copy* of it (mere referencing is expected to result from single-assignment); storing a per-class direct method mapping could also be done with prebuilt modules: `class_Cat` would rely on an automatically generated `class_Cat_mt` (for "method table") module, which would just be used in order to convert a method name in the name of the module that should be called in the context of that class, inheritance-wise; or, preferably, this information could be added directly to `class_Cat`

Licence

WOOPER is licensed by its author (Olivier Boudeville) under a disjunctive tri-license giving you the choice of one of the three following sets of free software/open source licensing terms:

- Mozilla Public License (MPL), version 1.1 or later (very close to the former Erlang Public License, except aspects regarding Ericsson and/or the Swedish law)
- GNU General Public License (GPL), version 3.0 or later
- GNU Lesser General Public License (LGPL), version 3.0 or later

This allows the use of the WOOPER code in as wide a variety of software projects as possible, while still maintaining copyleft on this code.

Being triple-licensed means that someone (the licensee) who modifies and/or distributes it can choose which of the available sets of licence terms he is operating under.

We hope that enhancements will be back-contributed (ex: thanks to merge requests), so that everyone will be able to benefit from them.

Sources, Inspirations & Alternate Solutions

- **Concurrent Programming in Erlang**, Joe Armstrong, Robert Virding, Claes Wikström et Mike Williams. Chapter 18, page 299: Object-oriented Programming. This book describes a simple way of implementing multiple inheritance, without virtual table, at the expense of a (probably slow) systematic method look-up (at each method call). No specific state management is supported
- Chris Rathman's approach to life cycle management and polymorphism. Inheritance not supported
- ECT, an Object-Oriented Extension to Erlang, very promising yet apparently not maintained anymore
- As Burkhard Neppert suggested, an alternative way of implementing OOP here could be to use Erlang behaviours. This is the way OTP handles generic functionalities that can be specialised (e.g. `gen_server`). One approach could be to map each object-oriented base class to an Erlang **behaviour**. See some guidelines about defining your own behaviours and making them cascade
- As mentioned by Niclas Eklund, despite relying on quite different operating modes, WOOPER and Orber, an Erlang implementation of a **CORBA ORB** (*Object Request Broker*) offer similar OOP features, as CORBA IDL implies an object-oriented approach (see their OMG IDL to Erlang Mapping)

WOOPER and Orber are rather different beasts, though: WOOPER is quite lightweight (less than 20 000 lines of code, including blank lines, numerous comments, tests and examples), does not involve a specific (IDL) compiler generating several stub/skeleton Erlang files, nor depends on OTP or on Mnesia (but depends on Myriad), whereas Orber offers a full, standard, CORBA implementation, including IDL language mapping, CosNaming, IIOP, Interface Repository, etc.

Since Orber respects the OMG standard, integrating a new language (C/C++, Java, Smalltalk, Ada, Lisp, Python etc.) should be rather easy. On the other hand, if a full-blown CORBA-compliant middleware is not needed, if simplicity and ease of understanding is a key point, then WOOPER could be preferred. If unsure, give a try to both!

See also another IDL-based approach (otherwise not connected to CORBA), the Generic Server Back-end (wrapper around `gen_server`).

The WOOPER name is also a tribute to the vastly underrated Wargames movie (remember the WOPR, the NORAD central computer?) that the author enjoyed a lot. It is as well a second-order tribute to the *Double Whopper King Size*, which is a great hamburger indeed[18].

[18] Provided of course one is fine with eating other animals (this is another topic).

Support

Bugs, questions, remarks, patches, requests for enhancements, etc. are to be sent to the project interface, or directly at the mail address mentioned at the beginning of this longer document.

Please React!

If you have information more detailed or more recent than those presented in this document, if you noticed errors, neglects or points insufficiently discussed, drop us a line! (for that, follow the Support guidelines).

Ending Word

Have fun with WOOPER!