

Custom Neurons Interface Developer Documentation

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1 Introduction

The NEST Simulator, which stands for Neural Simulation Tool, has been created with the purpose of enabling complex simulations of point-like neurons. There's a wide range of possible models, from the simple integrate and fire model, to the more complex Hodgkin-Huxley one.

These neurons can be connected through weighted connections and their activity recorded using virtual tools (multimeter, spike detector, etc...).

In the NEST code, every model extends from a parent class, implementing only basic functions, such as collecting the incoming spikes. The real model is written in the child classes, so that, using polymorphism, adding new neurons is accomplished relatively easily.

However, each time one wants to add a new neuron, he has to write it in C++ (a difficult language) and recompile the whole project. This makes the tool not so flexible and slows down development time.

That's why the need for a plugin system has arisen. This new feature should enable to easily write neurons, create .so files (shared libraries) and just put them in a special directory, which the NEST will automatically recognize and allow the code inside to be executed. In addition, since C++ is a difficult language, models should be written in a more scientific language such as Python.

The purpose of this Bachelor Project is the creation of a plugin system having these features. This is accomplished using a relatively new technology, Cython. This special tool enables one to write Python code and compile it into C++.

During the next sections, first the NEST structure will be presented, then a global description of the NEST-.so file interface will be depicted. After that, more details are given, beginning with the NEST C++ side, followed by the CyNEST (the Cython) side. The next step will be a very little description of a tool used in order to compile the custom python neuron, *cmpneuron*. Finally, performances and improvements are analyzed.

2 NEST Structure

The aim of this section is to enable the reader understanding the global NEST structure, which is essential in order to grasp the details of the new interface, presented in the next sections.

Basically NEST is composed of three major parts:

- The simulation kernel : this is the core of the system, enabling, among others, simulations, events scheduling, communication of neurons and activity recording. The C++ models are also situated in this part.
- SLI Interface : NEST is a high configurable simulator, therefore a powerful language has been created in order to configure simulation properties, set experiment parameters, create neurons and connexions between them, ect... SLI is loosely based on PostScript, using a stack to put, manipulate and retrieve objects.
- CyNEST Interface : NEST can be used from a Python terminal, configuring it by calling very high functions, which will in turn call corresponding SLI commands. This interface can be accessed by just typing *import cynest* in a Python terminal.

For more information, see the original documentation (http://www.nest-initiative.org/index.php/Software:About_NEST).

3 Global Interface Structure

This section deals with the global structure of the new interface between NEST and custom neurons.

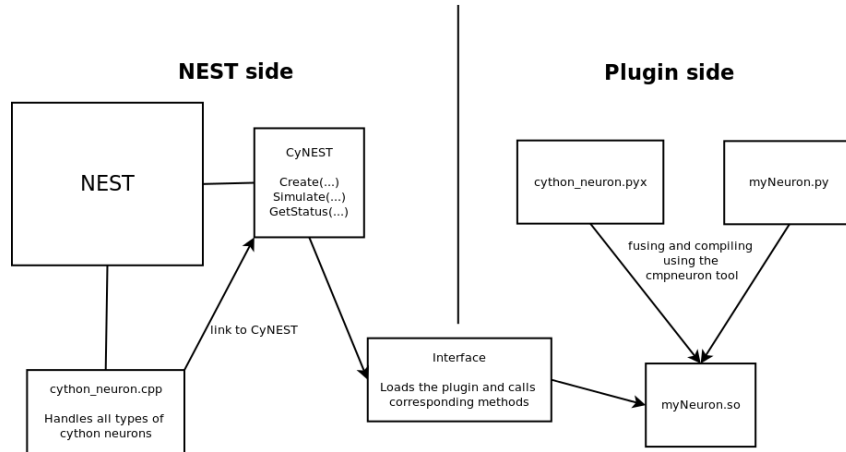


Figure 1: Interface Structure

Figure 1 shows that structure as a diagram. One can see that there's a direct link between `cython_neuron.cpp` and CyNEST (normally the two parts cannot directly communicate, but a link is necessary, that's why it has been added). The interface is placed between CyNEST and the plugin.

Let's admit that during a simulation, the update method of a neuron is called (a very likely situation!) and that this neuron is a custom one. The information flow is the following: NEST calls the update method of `cython_neuron.cpp`, which through the direct link calls the CyNEST update function. This one uses the interface to call the previously loaded neuron update method inside that plugin file. We can actually say the CyNEST update method is somehow already a part of the interface.

During the next sections, the most important regions of the diagram will be covered in much greater detail, so that the reader can have insight into the subtle details and concepts that populate this innovative feature of NEST.

4 C++ Side

The fourth section of this document will describe in greater detail the implementation of the general cython neuron handler class, which is responsible for creating new neurons of a certain custom type, handling general events and calling the corresponding plugin functions (calibrate, update, ect...).

4.1 Neuron Registration

When creating a new neuron object in the Python terminal by typing `cyneest.Create("myneuron")`, NEST will search that particular model among its classes. But how to know if a model has a corresponding class (i.e., if it exists)? The `models/modelsmodule.cpp` class provides the answer. Every new model is registered in the **models dictionary**, so that when the previous method is called, NEST just checks in this dictionary, looks for a particular model and creates the corresponding class object.

In order to register a new model, a code such this has to be written :

```
register_model<iaf_cond_alpha>(net_, "iaf_cond_alpha");
```

Here, the first *iaf_cond_alpha* corresponds to the class name, whereas the second one corresponds to the string pointing to that particular class.

All of that implies that when a new custom neuron is added, it must be dynamically registered. This can be achieved by looking for .so files in the cython models folder. Note that when NEST is installed, in the main location there's a folder named *cython_models* containing the custom created neurons. In fact, after a new neuron has been created, it must be placed there.

Therefore, NEST must check for .so files, retrieve their names (of course without the extension) and register new models giving as class *cython_neuron* and string the .so file name, like this:

```
register_model<cython_neuron>(net_, file.name);
```

For more information, look to the *ModelsModule::addCythonNeurons()* method contained in the *models/modelsmodule.cpp* file.

4.2 General Handler - CyNEST link

In order to make the overall system work, there is no need for a plugin neuron to implement the totality of the normal neuron methods. The only ones for which a redefinition is mandatory are:

- Calibrate()
- Update()
- GetStatus()
- SetStatus()

Event handling, such as spikes or currents incoming, is enough straightforward to be handled in the *cython_neuron* class in a general way. Here's an example :

```
void nest::cython_neuron::handle(CurrentEvent& e)
{
    assert(e.get_delay() > 0);

    const double_t I = e.get_current();
    const double_t w = e.get_weight();

    // add weighted current; HEP 2002-10-04
    B_.currents_.add_value(e.get_rel_delivery_steps(
        network()->get_slice_origin()), w * I);
}
```

However, the previous exposed functions are contained in the plugin neuron and must be called from the C++ class.

When dealing with a plugin system, care must be taken to the portability problem. Even if a .so file has been compiled on a machine, maybe it won't work on another one because of the different architectures.

Even worse is the Python case: the neuron .so file isn't a normal C or C++ shared library, but a mix of compiled Python and C. Therefore many operations have to be performed when loading such a library, because one has to deal with the Global Lock Interpreter and other annoying Python concepts. Luckily, Cython enables to very easily load files like that without taking into account the low level details.

Since NEST already uses Cython for the high level API (CyNEST), the bridge between the general handler and the plugin neuron will be this interface. But how to access functions of CyNEST from this C++ class? The answer is using static function pointers. At the starting of NEST, the high API will fill these pointers with its own functions, but these pointers are also accessible from the

general handler, and since finally the CyNEST is compiled into C++, everything can work. Note that in order everything to work fine, **at least Cython 0.18 must be installed**.

These pointers are situated in the *cynest/buffer.h* file, inside the *CythonEntry* class:

```
static void* cInit;
static void* cCalibrate;
static void* cUpdate;
static void* cSetStatus;
static void* cGetStatus;
static void* cStdVars;
```

In order to get or set one of these, some methods are available (only one pointer is shown) :

```
void putInit(void* value) {
    CythonEntry::cInit = value;
}
void* getInit() {
    return CythonEntry::cInit;
}
```

Note that it is necessary to make the pointer accessible only through methods. In fact, whereas on the C++ side there's no major problem as it can be accessed directly by the variable name, Cython has some restrictions that must be respected.

Before a neuron can call one of these functions, the corresponding pointers must be retrieved, calling methods like *getInit()*, which is performed during neuron initialization. The method *cython_neuron::initSharedObjects* does this (here's shown the Calibrate functions) :

```
void* resultCalibrate = cEntry.getCalibrate();
cythonCalibrate = (void (*)(std::string, int, Datum*))resultCalibrate;
```

The neuron will then call the *cythonInit* function, which will initialize the neuron on the Cython side, and the *cythonStdVars* function, which will pass the Standard Parameters use and the exact behaviour of these functions will be explained in later sections.

The only thing to know is that *cythonInit* will return a neuron pointer, which is usefull to identify an exact neuron among others of the same type. Therefore, for each call to the cython functions, the neuron type and the id are mandatory. Here's an example within the Update method:

```

for ( long_t lag = from ; lag < to ; ++lag )
{
    (*state_)[names::in_spikes]=B_.in_spikes_.get_value(lag);
    (*state_)[names::ex_spikes]=B_.ex_spikes_.get_value(lag);
    (*state_)[names::currents]=B_.currents_.get_value(lag);
    (*state_)[names::t_lag]=lag;

    if(cythonUpdate != NULL) {
        cythonUpdate(name, neuronID);    // call shared object
    }
    ...

    // surely exists
    spike_emission = (*state_)[names::spike];

    // threshold crossing
    if (spike_emission)
    {
        ...
    }
    ...
}

```

As one can see, the *cythonUpdate* function only needs the neuron type and the id. The *state_* members contains the totality of neuron parameters and is passed to the *cythonInit* function in order to fill the corresponding cython neuron. In fact, for every neuron on the C++ side, there's a corresponding neuron on the Cython side (identified by the neuron type and id). In this way, when the C++ neuron will call the Cython one, this latter will already have all the needed parameters, without asking for them.

4.3 Standard Parameters

When a neuron calls one of the Cython functions, such as *cythonCalibrate* or *cythonUpdate*, the parameters contained in *status_* have to be passed to the corresponding cython neuron. The naive approach of doing this is by copying them into the cython neuron, calling the corresponding function and retry them back.

This could work for *cythonCalibare*, but not for *cythonUpdate* as it is called many times and this approach would slow down the system.

Furthermore, as one can realize, during a simulation the only important parameters constantly updated by the C++ neuron are :

- currents

- in_spikes
- ex_spikes
- t_lag
- spike

These are called **Standard Parameters** and are the only one worth copying in the Cython neuron before calling the corresponding function.

A good way of speeding up the parameter passing is by giving to the Cython neuron direct pointers to these values, as one can see:

```
IntegerDatum* sI = (IntegerDatum*)(*state_)[names::spike].datum();
...
cythonStdVars(get_name(), neuronID, sI->get_p_val(), isD->get_p_val(),
              esD->get_p_val(), cD->get_p_val(), lI->get_p_val());
```

Therefore, the Cython neuron will change the values pointed by these pointers without making any copy.

However, it is sometimes important to set or retrieve the totality of parameters and this is done during *cythonSetStatus*, *cythonGetStatus* and *cythonCalibrate*. More information is detailed in the following section.

5 CyNEST Side

This section will deal with the Cython side of the project, which has to load the shared file representing the neuron, call all its functions and passing parameters.

5.1 C++ - Cython Interface

Cython has a mechanism that allow one to interface C++ classes with Cython code. This is essential because this side has to fill the pointers previously presented. The file *cynest/classes.pyd* represents this interface and looks like:

```
cdef extern from "buffer.h":
    cdef cppclass CythonEntry:
        CythonEntry()
        void putInit(void* value)
        void* getInit()
        void putCalibrate(void* value)
        ...

    cdef cppclass SpecialFunctions:
        SpecialFunctions()
        double get_ms(int, long, double)
        long get_ticks_or_steps(int, int, long, double)
        unsigned int get_scheduler_value(int, unsigned int)
```

The following step is to create for each one of these classes, a corresponding wrapping class callable from any Cython code.

5.2 Filling the pointers

The wrapper class for *CythonEntry* is situated in the *cynest/dynamicneuronsync.pyx* file and looks like :

```
cdef class CythonEntry:
    cdef classes.CythonEntry *thisptr
    def __cinit__(self):
        self.thisptr= new classes.CythonEntry()

    def __dealloc__(self):
        del self.thisptr

    cdef void putInit(self, void* value):
        self.thisptr.putInit(value)

    cdef void* getInit(self):
        return self.thisptr.getInit()

    cdef void putCalibrate(self, void* value):
        self.thisptr.putCalibrate(value)
    ...
```

In order to fill the function pointers, one just has to call *putInit*), *putCalibrate* and so on. This is accomplished by the file *cynest/kernel.pyx*, by just creating a new *CyrrthonEntry* object, calling one of these methods and giving to the pointer another Cython method and is done during the initialization of CyNEST.

5.3 Neurons creation

When a user uses CyNEST within a Python terminal and writes *cynest.Create("myneuron")*, the software must check if the neuron exists and if it's one of the special cython neurons. This is the purpose of the *processNeuronCreation* function, found in the *cynest/dynamicneuronsync.pyx* file. It's mission is to check if a shared file corresponding to that neuron is present and load it:

```
def processNeuronCreation(cmd):
    n = returnNeuronName(cmd)
    if n is not "":
        nList = getDynamicNeuronsName()
        if n in nList and not loadedNeurons.has_key(n):
            libc = PyDLL(spFct.getModelsFolder() + "/" + n + ".so")
            exec("libc.init" + n + "()")
            loadedNeurons[n] = libc
    ...
```


A very important point to realize is that, differently from Python, since Cython is a compiled code it cannot dynamically load another file, for instance using *import myneuron*. This is a huge drawback that will limit performances and coding style. The only way of dynamically loading a file is by using the *ctypes* library included in Python.

This is what has been done in the previous code by calling... = *PyDLL(...)*. The picture depicting the structure of the project shows that on the plugin side, a file named *cython_neuron.pyx* is mixed with the user written neuron. This is true and the final output becomes a shared file. This latter will contain interface functions callable from other code (in this case the Cython side of the project).

However, since *ctypes* has been created for Python, it cannot be used in a proper way with Cython, mostly when dealing with pointers. As an example, Cython code cannot direct pass a pointer to a shared file function, but must make a copy of the pointed value in a special *ctypes* object, create a corresponding *ctypes* pointer, make all the necessary computations and retrieve that value from the *ctypes* pointer.

This makes the Standard Parameters approach very limitative, losing a lot of its original benefits.

5.4 Neuron basic functions

This section will explain the behaviour of the neuron functions callable from the C++ side of the project. These are:

- *cInit*: this function, called by *cythonInit*, will initialize the neuron. The steps are: call the *createNeuorn()* method of the plugin file, append a new entry in a special table created to store the Standard Parameters and synchronize the neuron. This is done by calling the *setNeuronMembers* and *retrieveNeuronMembers* functions, therefore enabling the two neurons (one on the C++ side and the other on the Cython side) to have exactly the same number of parameters. Finally, the function returns the neuron id.
- *cCalibrate*: this function will give to the Cython neuron the C++ neuron parameters, then call the corresponding function (*calibrate*) and retrieve the updated parameters.
- *cSetStatus*: this function will give to the Cython neuron the C++ neuron parameters, then call the corresponding function (*setStatus*) and retrieve the updated parameters. In fact, a neuron could adjust some of them relatively to other ones.
- *cGetStatus*: this will call the corresponding function (*getStatus*) and retrieve the updated parameters. During an execution, the only time the non Standard Parameters are used is when the user calls the *cynest.GetStatus(...)* command on the Python terminal. That's why it is important to retrieve them.

- `cStdVars`: this function will save the Standard Parameters pointers in a special double array object of type *StandardParams*.
- `cUpdate`: this is the most important function. Here's the implementation:

```
cdef void cUpdate(string nName, int neuronID) with gil:
    ...
    cdef StandardParams sp = stdParams[neuronName][neuronID]
    loadedNeurons[neuronName].setStdVars(neuronID, sp.spike[0],
        sp.in_spikes[0], sp.ex_spikes[0], sp.currents[0], sp.lag[0])

    loadedNeurons[neuronName].update(neuronID)

    loadedNeurons[neuronName].getStdVars(neuronID, sIR, isDR,
        esDR, cDR, lIR)
    sp.spike[0] = sI.value
    sp.in_spikes[0] = isD.value
    ...
```

The logic of the function is very simple : first the Standard Parameters are passed to the shared file, by value and not by pointer, then the *update* function is called. However, the dealing with the retrieving, the special ctypes objects are used. Finally, when every computation has been performed, the ctypes objects values are copied in the pointed values. As previously said, this is a huge limitation of the mechanism.

5.5 Parameters passing

As explained in the last subsection, two possible modes of parameter passing are possible: Standard Parameters and nn Standard Parameters. Let's see how they work:

- Standard Parameters:
This is done by calling the *setStdVars* and *getStdVars* in the *cUpdate* function, as previously said. But where are these functions? These are situated in the *cmpneuron/cython _neuron.pyx* file and are very straightforward (the way this file is compiled is discussed in the following section):

```
cdef public void setStdVars(int neuronID, long spike, double in_spikes,
    double ex_spikes, double currents, long lag) with gil:
    neurons[neuronID].spike = spike
    neurons[neuronID].in_spikes = in_spikes
    neurons[neuronID].ex_spikes = ex_spikes
    neurons[neuronID].currents = currents
    neurons[neuronID].t_lag = lag
```

```

cdef public void getStdVars(int neuronID, long* spike, double* in_spikes,
    double* ex_spikes, double* currents, long* lag) with gil:
    spike[0] = neurons[neuronID].spike
    in_spikes[0] = neurons[neuronID].in_spikes
    ex_spikes[0] = neurons[neuronID].ex_spikes
    currents[0] = neurons[neuronID].currents
    lag[0] = neurons[neuronID].t_lag

```

The first one just copies the arguments to a special array. This array represents the counterpart neurons of the C++ ones.

The second function just copies to Standard parameters contained in the neuron to the pointed values.

- Non Standard Parameters:

This exchange mechanism is a little more tricky. It's implemented through the functions *setNeuronMembers* and *retrieveNeuronMembers*. Here's the code for the first one:

```

cdef void setNeuronMembers(bytes neuronName, int neuronID, classes.Datum* parameters) w
    cdef dict members = <dict>converter.datumToObject(parameters)
    loadedNeurons[neuronName].setNeuronParams.argtypes = [c_int, py_object]
    loadedNeurons[neuronName].setNeuronParams(neuronID, py_object(members))

```

The first line of the function is a conversion. As one can see, the function arguments contain a special *Datum* object. This comes from the C++ side and represents an SLI object (can contain integers, doubles, booleans, lists, dictionaries and every other builtin type). In this case it is a *DictionaryDatum* representing the totality of neuron parameters.

The *converter* is a wrapper object of type *DataConverter* and its role is to transform a *Datum* into a Python object, in this case a dictionary. The converters this object wrap are CyNEST parts, therefore for more information see the CyNEST doc.

Once the dictionary is ready, this is passed to the *setneuronParams* function contained in tghe *cmpneuron/cython_neuron.pyx* file, which will simply loop over the dictionary and add the corresponding values to the neuron fields.

The retrieving of the neuron parameters works quite similarly:

```

cdef void retrieveNeuronMembers(bytes neuronName, int neuronID,
    classes.Datum* parameters) with gil:
    ...
    cdef classes.Datum* members = converter.objectToDatum
        (loadedNeurons[neuronName].getNeuronParams(neuronID))
    converter.updateDictionary(members, parameters)
    ...

```

The converter transforms the retrieved object (which is just a dictionary containing all the neuron parameters on the plugin side, except for those beginning with '_'). See next section for more explanations) into a *Datum* pointer. This latter will then update the real *Datum* object used on the C++ side.

5.6 Special Functions

6 Compiling the Plugin Neuron

7 Performances

8 Limitations and Improvements

9 Conclusion