

Scripting CompuCell3D extension modules in Python

Tutorial

V3.4.2

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The focus of this manual is to teach you how to use Python scripting language to develop CompuCell3D extension modules. First thing first, we will assume that you have a working knowledge of Python. We do not expect you to be a Python guru, rather we assume that you know how to write simple Python scripts that use functions, classes, dictionaries, lists (or sequences). If, however it will be your first attempt to use Python I strongly recommend that you go over basic Python programming literature. My favorite is a book by David Beazley (creator of SWIG) “Python Essential Reference”. In his book he teaches you Python fundamentals in less the 20 pages which saves you plenty of time. And the book is inexpensive either (on Amazon it is less than 30 US \$).

Python extensions to CompuCell3D, Python modules and these tutorials have been developed by Maciej Swat and Christopher Mueller and James Glazier.

OK, let's get started.

CompuCell3D scripting

Once Python scripting became available in CompuCell3D it turned CompuCell3D into fully fledged simulation environment with level of flexibility known from Matlab or Mathematica. Of course, I am not saying that CompuCell3D is as sophisticated as those two commercial products but rather, that it gives you the ability to create simulations with much greater degree of flexibility than it was possible with xml model description files.

If you decide to use Python scripting for CompuCell3D you will be running Python script in which you will call C++ and Python modules. Very first question that comes right now to your mind is “What about the performance, scripting languages are slow, aren't they”? The answer to this question could be easily turned into Computer Science paper but to make long story short, we say that unless you use Python “unwisely” you will not hit any performance barrier for CompuCell3D simulations. Yes, there will be things that should be done in C++ because Python will be way to slow to handle certain tasks, however, throughout our two years experience with CompuCell3D we found that 80 % of times Python will make your life way easier and will not impose ANY noticeable degradation in the performance. What matters here is that with Python scripting you will be able to dramatically increase your productivity and it really does not matter if you know C++ or not. With Python you do not compile anything, just write script and run. If a small change is necessary you edit source code and run again. No time is wasted for dealing with compilation/installation of C/C++ modules. Most professional programmers will tell you that scripting languages are crucial to increase your productivity and frankly based, on our experience with Python all we can say is that it is really true. Without further ado. let's begin CompuCell3D/Python tutorials.

CompuCell3D in Python

Python written simulations still need to be accompanied by xml file. Remember that Python is used to extend CompuCell3D, so the way it works is you start the Player and open up an xml file that contains your simulation description. Now, if you want to use Python extensions for your simulation you go to Python menu and click “Run Python Script”. Then you go to “Python->Configure Python Extensions...” and choose a Python script in which you have coded the simulation. In practice you do need to code entire simulation. What you do is you use a template file and modify it in certain places to

get access to your Python-written extension modules. If it sounds too complicated now, do not worry, we will go step-by-step through several examples and this will show you that it is not that difficult.

Before we go any further one more word of explanation: when you use “pure C++” CompuCell3D the flow of the simulation is hard coded in C++, you do not have any access to it. all you can do is to write plugins or steppables. In Python the flow of the simulation is coded in Python and this gives you the ability to do whatever you want with it. So why it might be tempting to mess around with different settings there, I would recommend that unless you fully understand what you are doing you are better off using Python script with simulation description as a template and modify it inly in certain places as it will be shown. Otherwise you might get cryptic error messages and your simulation will crash. Well, just a word of caution.

To run CompuCell3D simulations written in Python you first need to prepare Python script, or I should say copy and modify existing one.

Our first example will be a very simple one. We will run cell sorting and then we will add a module that will print every 10 MCS a list of cell id cell type and cell volume. It is not very complicated module and not a very useful in this particular context, but it will show you how to access from Python level all the cells, how to iterate over the list of cells and extract certain information.

OK, let's take a look at the template used to describe in Python flow of CompuCell3D simulation.

File: *cellsort 2D.py*

```
import sys
from os import environ
from os import getcwd
import string

sys.path.append(environ["PYTHON_MODULE_PATH"])

import CompuCellSetup
CompuCellSetup.setSimulationXMLFileName("examples_PythonTutorial/cellsort_2D/cellsort_2D.xml")

sim,simthread = CompuCellSetup.getCoreSimulationObjects()

#Create extra player fields here or add attributes

CompuCellSetup.initializeSimulationObjects(sim,simthread)

#Add Python steppables here
steppableRegistry=CompuCellSetup.getSteppableRegistry()

CompuCellSetup.mainLoop(sim,simthread,steppableRegistry)
```

This is a basic template that we will be modifying to customize our simulations. To get the examples working we had to add module search path so that Python knows where to find the modules. Lines:

```
from os import getcwd
and
sys.path.append(environ["PYTHON_MODULE_PATH"])
```

are used to set additional search path to be the one of directory called “examples_PythonTutorial” (this is where all the examples from this tutorial are stored) of the current directory.

For now try running `cellsort_2D.py` accompanied by `cellsort_2D.xml` file to make sure that everything works fine. As you can see the only thing `cellsort_2D.py` does is to run your simulation described in `cellsort_2D.xml` file. However it runs the simulation accessing all the `CompuCell` objects through Python. and this is exactly what we want.

Example 1 – Loop on Cell's List

Now let's develop a simple Python steppable that will print every 10 MCS a list of cell id cell type and cell volume.

Important: The steppables from this tutorial are stored in files `cellsort_2D_steppables_extra_attrib.py`, `cellsort_2D_steppables_info_printer.py` and `cellsort_2D_steppables_neighbor_tracker.py`.

To do this open up editor and type the following script:

File: `cellsort 2D steppables info printer.py`

```
from PySteppables import *
import CompuCell
import sys

class InfoPrinterSteppable(SteppablePy):
    def __init__(self, _simulator, _frequency=10):
        SteppablePy.__init__(self, _frequency)
        self.simulator=_simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)

    def start(self):
        print "This function is called once before simulation"

    def step(self, mcs):
        print "This function is called every 10 MCS"
```

```
for cell in self.cellList:
    print "CELL ID=",cell.id, " CELL TYPE=",cell.type," volume=",cell.volume
```

First three lines are boiler plate for creating new steppable – they include necessary Python files. Next you define a class `InfoPrinterSteppable` which inherits from `SteppablePy` class. What `SteppablePy` inheritance does it assures that your steppable has three mandatory functions that steppables should have:

```
start(self)
step(self,_mcs)
finish(self)
```

Those functions are called by a `steppableRegistry` (see `cellsort_2D.py`) with predefined frequency - i.e. `start` and `finish` are called once at the beginning and at the end of the simulation and `step` is called every user defined number of MCS.

If you do not define a one of the mandatory functions nothing will happen and the default implementation of those function (empty function) defined in `SteppablePy` will be called.

The most important initializing function of the above class is the constructor. There we set references (or pointers if you prefer) to simulator object from C++ code and we get also a reference to cell inventory also from C++ code.

Now, the `start(self)` function has a trivial body - we print there a simple message.

Notice that we have not defined `finish(self)` function.

Now the most important function that does useful work is `step(self, mcs)`. We will copy code of the above function and put comments every other line so that you know what is going on.

File: *cellsort 2D steppables info printer.py*

```
def step(self,mcs):
    print "This function is called every 10 MCS"
    for cell in self.cellList:
        print "CELL ID=",cell.id, " CELL TYPE=",cell.type," volume=",cell.volume
```

We hope you agree that the implementation of this steppable was not too complicated. There were some strange names on the way but you will get used to them and if you forget them there are many examples included with `CompuCell3D` so you may always look it up. The implementation of the above functionality in C++ would be not much more complicated, however, you would need to compile the module, install it in the appropriate directory and would not be able to make changes as efficiently as when you are using Python.

The `self.inventory` and `self.cellList` objects contain most up-to-date list of cells present in the simulation.

The difference between the two is that `self.cellList` wraps the content of `self.inventory` and offers easier way of iterations over all the cells.

In case you wonder what other cell attributes you can print from Python, use `dir(cell)` statement to see what attributes are available in each cell:

```
for cell in self.cellList:
    dir(cell)
```

Now, once you have written this steppable you need to place a reference to it in the main simulation code. This is how you do it: start with `cellsort_2D.py` file that we have just studied and add the following lines (put the lines right after these

File: *cellsort 2D info printer.py*

```
#Add Python steppables here
steppableRegistry=CompuCellSetup.getSteppableRegistry()

from cellsort_2D_steppables_info_printer import InfoPrinterSteppable
infoPrinterSteppable=InfoPrinterSteppable(_simulator=sim,_frequency=10)
steppableRegistry.registerSteppable(infoPrinterSteppable)
```

Notice here that `infoPrinterSteppable` is a name of the variable whereas `InfoPrinterSteppable` is a name of the class. The difference is small one starts with capital letter (name of the class) and one with lower case letter (name of the variable). This distinction is important because Python is case-sensitive.

Full script, now called `cellsort_2D_info_printer.py` appears below (notice we have added few comments):

File: *cellsort 2D info printer.py*

```
import sys
from os import environ
from os import getcwd
import string

sys.path.append(environ["PYTHON_MODULE_PATH"])

import CompuCellSetup

sim,simthread = CompuCellSetup.getCoreSimulationObjects()

#Create extra player fields here or add attributes
```

```

CompuCellSetup.initializeSimulationObjects(sim,simthread)

#Add Python steppables here
steppableRegistry=CompuCellSetup.getSteppableRegistry()

# we import newly written steppable into main script
from cellsort_2D_steppables_info_printer import InfoPrinterSteppable

# this line effectively invokes constructor of our new steppable. Notice that
# we can set frequency for the steppable. Here we duplicate the default
# settings but equally we you may change it to 20, 30, or whatever you want
# notice that here we have created object infoPrinterSteppable which is of
# type InfoPrinterSteppable. It is important that you distinguish objects and
# types
infoPrinterSteppable=InfoPrinterSteppable(_simulator=sim,_frequency=10)

# now we register newly created object infoPrinterSteppable with steppable
# registry. From now on this steppable will be called automatically with
# the frequency that you requested
steppableRegistry.registerSteppable(infoPrinterSteppable)

CompuCellSetup.mainLoop(sim,simthread,steppableRegistry)

```

It really is not too difficult, is it?

Sometimes it is useful to write information not to the screen (as we did above) but to a file. Let's rewrite above steppable so that the output would go to the file called "OutputFile.txt":

File: *cellsort 2D steppables info printer.py*

```

class InfoPrinterSteppable(SteppablePy):
    def __init__(self,_simulator,_frequency=10):
        SteppablePy.__init__(self,_frequency)
        self.simulator=_simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        # this creates an iterable list of cells
        self.cellList=CellList(self.inventory)
        file=open("OutputFile.txt",w)

    def start(self):
        print "This function is called once before simulation"

```

```
def step(self,mcs):
    print "This function is called every 10 MCS"
    for cell in self.cellList:
        file.write("CELL ID=%d CELL TYPE=%d volume=%d\n" %(cell.id,cell.type,cell.volume))
```

Two steps are necessary to write to a file – opening a file and writing to it. We open a file using open statement and write using the following syntax:

```
file.write("formatting string" %(values for formating string))
```

The formatting string contains regular text and formatting characters such as '\n' denoting end of line, %d denoting integer number, %f denoting floating point number and %s denoting strings. For more information on this topic please see any Python manual or see online Python documentation.

The reason we have chosen the example with cell inventory simulation is that this is one of the most frequent tasks with CPM modeling. You usually want to run simulation and then iterate over all the cells and do various tasks. This example gives you a template that you may reuse for your simulations.

Important: In the above example we were printing cell attributes such as cell type, cell id etc. Sometimes in the simulations you will have two cells and you may want to test if they are different. The most straightforward Python construct would look as follows:

```
cell1=cellField.get(pt)
cell2=cellField.get(pt)

if cell1 != cell2 :
    #do something
```

Because cell1 and cell2 point to cell at pt i.e. the same cell then cell1 != cell2 should return false. Alas, written as above the condition is evaluated to true. The reason for this is that what is returned by cellField is a Python object that wraps a C++ pointer to a cell. Nevertheless two Python objects cell1 and cell2 are different objects because they are created by different calls to cellField.get() function. Thus, although logically they point to the same cell, you cannot use != operator to check if they are different or not.

The solution is to use the following function

```
CompuCell.areCellsDifferent(cell1,cell2)
```

or write your own Python function that would do the same:

```
def areCellsDifferent(self,_cell1,_cell2):
```

```

if (_cell1 and _cell2 and _cell1.this!=_cell2.this) or (not _cell1 and _cell2) or (_cell1 and not _cell2):
    return 1
else:
    return 0

```

Example 2 – Add Cell Attributes

In this example we will teach you how to attach extra attribute to the cell from the Python level. For example you want every cell to have a countdown clock that will be recharged once its value reaches zero.

To accomplish this task we will need a steppable that will manage the clock but we also need a way to attach additional attribute that will serve as a clock. One way to do that would be to add line

```
int clock
```

to Cell.h file and recompile entire package. Cell.h is a C++ header file that defines basic properties of the CompuCell3D cells. Well, I do not have to tell you by now that this is extremely inefficient way because in this case you will need to recompile the whole package. And if you want to add another attribute, yes, you will be recompiling again. Most important your simulation will not be portable because it will be only runnable using a particular version of CompuCell3D that has been modified.

Way better approach is to do it from Python level. To be fair, in certain cases adding attribute at C++ level makes sense (that's why we have volume, target volume etc. defined in the C++ code for Cell), however, if you need a “casual” attribute, you better do it from Python.

Let's see how it is done. In the cellsort_2D_extra_attrib.py file insert the following after “#Create extra player fields here or add attributes” line:

```
pyAttributeAdder,listAdder=CompuCellSetup.attachListToCells(sim)
```

It is important that you keep pyAttributeAdder,listAdder on the left hand side of the equation as it prevents those two objects created inside attachListToCells(sim) from being garbage collected.

At this point every time a new cell is created it is going to have a additional list attribute attached to it. This list can be modified from Python level as we will show you in a second. Here is the body of the new steppable that we have just developed. As you can see we declared only step function which is OK as we pointed it out earlier.

File: *cellsort_2D_steppables.py*

```

class ExtraAttributeCellsort(SteppablePy):
    def __init__(self,_simulator,_frequency=10):
        SteppablePy.__init__(self,_frequency)

```

```

self.simulator=_simulator
self.inventory=self.simulator.getPotts().getCellInventory()
self.cellList=CellList(self.inventory)

def step(self,mcs):
    for cell in self.cellList:
        list_attrib=CompuCell.getPyAttrib(cell)
        print "length=",len(list_attrib)
        list_attrib[0:2]=[cell.id*mcs,cell.id*(mcs-1)]
        print "CELL ID modified=",list_attrib[0]," ", list_attrib[1]

```

As you can see the body of the step function is very similar to the previous steppable that we have developed. We simply iterate over inventory of cells, however this time instead of just printing cell information we modify additional cell attribute. Moreover we have also done a nice trick. Namely, when we registered `listAdder` we asked `CompuCell3D` to attach to every cell as additional attribute a list and this list has one empty element (integer number initialized to zero). Now, what we do in line

```
list_attrib[0:2]=[cell.id*mcs,cell.id*(mcs-1)]
```

we replace first two entries of the list with `cell.id*mcs` , `cell.id*(mcs-1)`.

One interesting thing here is the fact that initially we had just one element in the list but using `list_attrib[0:2]` construct we tell Python to replace first two entries of the list with `cell.id*mcs` , `cell.id*(mcs-1)` and if the list does not have enough entries they will be added automatically.

We can also write the following:

```
list_attrib[0:3]=[cell.id*mcs,cell.id*(mcs-1),"Another text attribute"]
```

In this case we added third entry to the list and in this case it is a simple text constant. This demonstrates that lists in Python can group various objects and they do not need to be of the same type. So this is quite powerful technique, you effectively extend one entry list into multiple entry list and this happens in a very simple way at the Python level.

You need to be however careful when you have a simulation in which new cells are created because once a cell has been created during the simulation the content of the additional attribute is initialized to one element list (with zero being the only entry). In such a case you need to account for that fact and if you use additional attribute you first need to make sure that it has been properly initialized (i.e. it is different than the default attribute with which a new cell was created).

One way to do it would be to check either a size of the list or the content of the first element and make sure that they are not the defaults. This is how our steppable's `step(self,mcs)` function would look like with this extra check:

File: *cellsort 2D steppables extra attrib.py*

```
def step(self,mcs):
    for cell in self.cellList:
        list_attrib=CompuCell.getPyAttrib(cell)
        print "length=",len(list_attrib)
        list_attrib[0:2]=[cell.id*mcs,cell.id*(mcs-1)]
        print "CELL ID modified=",list_attrib[0]," ", list_attrib[1]
```

This example demonstrated how you can add additional attributes to cells during run time and how you access them from Python level. With the features that we have just described your simulations can be taken to the next level in terms of what you can accomplish with CompuCell3D.

Note that in many cases you might be better of using PyDictAdder instead of PyListAdder. PyDictAdder will attach a dictionary (hash table) as an additional attribute of the cell. Here is a fragment of example code (for full source code see ExtraAtrib_player_dictionary.py in the main installation directory):

```
pyAttributeAdder,dictAdder=CompuCellSetup.attachDictionaryToCells(sim)
```

Now the steppable that manipulates extra attribute looks as below (see also PySteppablesExamples.py for full listing):

File: *PySteppablesExamples.py*

```
class ModifyDictAttribute(SteppablePy):
    def __init__(self,_simulator,_frequency=1):
        SteppablePy.__init__(self,_frequency)
        self.simulator=_simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)
    def start(self):
        for cell in self.cellList:
            print " MODIFY ATTRIB CELL ID=",cell.id
            dictionary=CompuCell.getPyAttrib(cell)
            dictionary["newID"]=cell.id*2
            print "NewID=",dictionary["newID"]

    def step(self,mcs):
        for cell in self.cellList:
            if not mcs % 20:
```

```
dictionary=CompuCell.getPyAttrib(cell)
print "NewID=",dictionary["newID"]
```

As you can see from the script above the structure of it is essentially the same as the structure of the previous example with PyListAdder. The difference now is that when you access cell attribute (dictionary) you do it by specifying attribute name not a number of the list element (dictionary["newID"]=cell.id*2). This usually makes your program easier to read and maintain.

Adding Python Objects as attributes

The above examples demonstrated how to attach simple attributes to a cell but what if you want to add a more complex attribute , say a class (strictly speaking an object of a given class). In this case the solution is simple. First define a class then create object of this class and attach it to the cell. However there is an **IMPORTANT** detail here - your class **HAS TO** inherit from object which means it has to be “new style” python class. Lets see an example:

```
class CustomClass(object): # notice that we inherit from object
    def __init__(self, _x,y):
        self.x=_x
        self.y=_y
    def calculate(self):
        print "this is a result of calculations: ",x*y
        return x*y

class ModifyDictAttribute(SteppablePy):
    def __init__(self,_simulator,_frequency=1):
        SteppablePy.__init__(self,_frequency)
        self.simulator=_simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)
    def start(self):
        for cell in self.cellList:
            print " MODIFY ATTRIB CELL ID=",cell.id
            dictionary=CompuCell.getPyAttrib(cell)
            dictionary["customClass"]=CustomClass(cell.id,cell.id+1)

def step(self,mcs):
    for cell in self.cellList:
        if not mcs % 20:
            dictionary=CompuCell.getPyAttrib(cell)
```

```
print "CustomClass calculations=",dictionary["customClass"].calculate()
```

If you do not inherit from object and try to use user defined class as an attribute you will get segfault whenever cell is destroyed. The take home message here is that whenever using classes as cell attributes always inherit from object to avoid run time errors

Important: Current implementation allows users to attach list or dictionary to a cell but not both in the way presented above. However, from Python level you may insert a list into a dictionary or insert dictionary to a list so in practice this easy work around allows you to actually have both list and dictionary remembering that you need to one extra step to make things work.

Example 3

This example is a task for you to figure out what this steppable does.

File: *cellsort 2D steppables extra attrib.py*

```
class TypeSwitcherSteppable(SteppablePy):
    def __init__(self,_simulator,_frequency=100):
        SteppablePy.__init__(self,_frequency)
        self.simulator=_simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)

    def step(self,mcs):
        for cell in self.cellList:
            if cell.type==1:
                cell.type=2
            elif (cell.type==2):
                cell.type=1
            else:
                print "Unknown type. In cellsort simulation there should only be two types 1 and 2"
```

Try running this example and see what happens.

Example 4 – Cell's Neighbors

This example is a little bit more complicated. We will show you how to iterate over the list of cell neighbors. So for each cell in the cell inventory we will print a list of cell neighbors. A neighbor is a cell that has non-zero common surface area with a given cell. Since we will be using neighbor tracker plugin we need to declare it in the xml file. Check *cellsort_2D_neighbor_tracker.xml* file for details. The Python file to be used with the xml file is *cellsort_2D_neighbor_tracker.py*.

First let's look at how the steppable looks like:

File: *cellsort 2D steppables neighbor tracker.py*

```
class NeighborTrackerPrinterSteppable(SteppablePy):
    def __init__(self,_simulator,_frequency=100):
        SteppablePy.__init__(self,_frequency)
        self.simulator=_simulator
        self.nTrackerPlugin=CompuCell.getNeighborTrackerPlugin()
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)
    def start(self):pass

    def step(self,mcs):
        self.cellList=CellList(self.inventory)
        for cell in self.cellList:
            cellNeighborList=CellNeighborListAuto(self.nTrackerPlugin,cell)
            print "*****NEIGHBORS OF CELL WITH ID ",cell.id," *****"
            for neighborSurfaceData in cellNeighborList:
                if neighborSurfaceData.neighborAddress:
                    print "neighbor.id",neighborSurfaceData.neighborAddress.id,"
commonSurfaceArea=",neighborSurfaceData.commonSurfaceArea
                else:
                    print "Medium commonSurfaceArea=",neighborSurfaceData.commonSurfaceArea
```

As you recognize this is another example of steppable where we iterate over cell inventory. However this time we iterate over the list of neighbors as well. Since it is a new thing let's go over steps necessary to get cell neighbors being accessible from Python. First notice that in the constructor (`__init__`) we initialize a reference to the NeighborTracker plugin:

```
self.nTrackerPlugin=CompuCell.getNeighborTrackerPlugin()
```

This is necessary because this plugins gives us access to data structures that store cell neighbors. The bottom line here is that we need to include this line in the constructor. Now, in step function things get a little bit more complicated (but we assure you, in C++ it would be even more scary). Let us give you some hints how things should be set up.

For each cell we visit we construct a temporary list of cell's neighbors:

```
cellNeighborList=CellNeighborListAuto(self.nTrackerPlugin,cell)
```

In the very next line we walk over all neighbor:

```
for neighborSurfaceData in cellNeighborList:
```

We then check if the neighbor is a Medium (NULL pointer):

```
if neighborSurfaceData.neighborAddress:
```

and if the neighbor cell (neighborSurfaceData.neighborAddress) is different than Medium we print its id (neighborSurfaceData.neighborAddress.id) and common surface area (neighborSurfaceData.commonSurfaceArea) between cell (the one from for cell in self.cellList) and neighbor cell (neighborSurfaceData.neighborAddress).

Example 5 – Concentration Field

In this example we will show you how you may extract values of the concentration field from the simulation. We will use diffusion_2D.xml which is a simple simulation where you only solve diffusion equation. There are no cells there, to make things simple. We will also use diffusion_2D.py file which contains actual code for simulation in Python. in the xml file we declare a concentration field FGF.

Let us show how to develop how to access FGF from Python level. We will develop a steppable that will write values of the concentration field to the file.

File: *diffusion2D steppables.py*

```
class ConcentrationFieldDumperSteppable(SteppablePy):
    def __init__(self, _simulator, _frequency=1):
        SteppablePy.__init__(self, _frequency)
        self.simulator=_simulator
        self.dim=self.simulator.getPotts().getCellFieldG().getDim()

    def setFieldName(self, _fieldName):
        self.fieldName=_fieldName

    def step(self, mcs):
        fileName=self.fieldName+"_"+str(mcs)+".dat"
        self.outputField(self.fieldName, fileName)

    def outputField(self, _fieldName, _fileName):
        field=CompuCell.getConcentrationField(self.simulator, _fieldName)
        pt=CompuCell.Point3D()
        if field:
            try:
                fileHandle=open(_fileName, "w")
            except IOError:
                print "Could not open file ", _fileName, " for writing. Check if you have necessary permissions"
```

```

print "dim.x=",self.dim.x
for i in xrange(self.dim.x):
    for j in xrange(self.dim.y):
        for k in xrange(self.dim.z):
            pt.x=i
            pt.y=j
            pt.z=k
            fileHandle.write("%d\t%d\t%d\t%f\n"%(pt.x,pt.y,pt.z,field.get(pt)))

```

This steppable is not as complicated as the one in Example 4 but, still, we will walk through the code to explain everything.

In the constructor (`__init__`) we set references to simulator object and get dimension of the lattice:

```
self.dim=self.simulator.getPotts().getCellFieldG().getDim()
```

`self.dim` has three components `x`, `y` and `z` (`self.dim.x`, `self.dim.y`, `self.dim.z`) each denoting lattice dimension in the three directions.

Next we have a function that allows us to set field name that we wish to dump to the file. This function is invoked in the following way from the `diffusion_2D.py` file:

```

from diffusion_2D_steppables import ConcentrationFieldDumperSteppable
concentrationFieldDumperSteppable=ConcentrationFieldDumperSteppable\
(_simulator=sim, _frequency=100)
concentrationFieldDumperSteppable.setFieldName("FGF")
steppableRegistry.registerSteppable(concentrationFieldDumperSteppable)

```

So as you can see once you have instantiated `concentrationFieldDumperSteppable` object you set the concentration field name. Pretty straightforward. Now, the `step` function actually outsources all the work to the `outputField` function. In the first two lines of this function we get a reference to the concentration field. This field exists in “C++ space” but is accessible from Python using syntax as shown below. The next line creates a local object `Point3D` which is a C++ class that stores coordinates of the lattice. Again it is accessible from Python.

```

field=CompuCell.getConcentrationField(self.simulator,_fieldName)
pt=CompuCell.Point3D()

```

The next few lines

```
if field:
```

```

try:
    fileHandle=open(_fileName,"w")
except IOError:
    print "Could not open file ", \
        _fileName," for writing. Check if you have necessary permissions"

```

are to check if the reference to the field is non-null (which it would be if you typed something like “dgster44345” as a field name) and then we open a file and a reference to file handle is stored in fileHandle variable. Notice that we use exceptions to signal any error during file open operation.

The actual write to the file is a triple for loop. It is pretty straightforward to follow. Notice that we extract value of the concentration field using field.get(pt) construct. That's why we were creating Point3D object earlier in this function.

This example demonstrates how using Python you may extract information from the running CompuCell3D simulation. Needless to say, following this example you may perform complicated analyses of simulation result and write them to the file while simulation is running.

Note again how our formatting string looks like in the write to file statement:

```
fileHandle.write("%d\t%d\t%d\t%d\t%f\n"%(pt.x,pt.y,pt.z,field.get(pt)))
```

%d denotes integer %t denotes tabulator character and %f denotes floating point number. This will get familiar once you develop your own script that writes to a file.

Example 6 – Extra Player Field

In this example we will show you how to add concentration field to the Player from the Python level. This feature is just a kind of proof of concept thing and the details of implementation may change in the future however it is useful to go over this example to show you that from Python you may also influence what Player is doing and do your own visualizations. We will use *diffusion_2D_extra_player_field.py* file together with *diffusion_2D.xml* (unmodified from the previous examples) file.

To insert additional field to the Player we modify *diffusion_2D_extra_player_field.py* file by inserting the following line (note that we show more lines to show you the exact place where you need to insert the line which adds new concentration field to the Player):

File: *diffusion_2D_extra_player_field.py*

```

sim,simthread = CompuCellSetup.getCoreSimulationObjects()

import CompuCell #notice importing CompuCell to main script has to be done after call to getCoreSimulationObjects()

#Create extra player fields here or add attributes

```

```
CompuCellSetup.initializeSimulationObjects(sim,simthread)
```

```
dim=sim.getPotts().getCellFieldG().getDim()
```

```
extraPlayerField=simthread.createFloatFieldPy(dim,"ExtraField") # initializing pressure Field - this location in the code is important this must be called before preStartInit or otherwise field list will not be initialized properly
```

Now, you have to be aware that the field we inserted exists only in the Player. This means that C++ part CompuCell3D does not know about its existence. nevertheless this field is controllable from Python level.

Now, let's see how we defined our steppable that will be updating values of the “ExtraField” during the simulation run.

File: *diffusion 2D steppables player.py*

```
class ExtraFieldVisualizationSteppable(SteppablePy):
    def __init__(self,_simulator,_frequency=10):
        SteppablePy.__init__(self,_frequency)
        self.simulator=_simulator
        self.cellFieldG=self.simulator.getPotts().getCellFieldG()
        self.dim=self.cellFieldG.getDim()

    def setScalarField(self,_field):
        self.scalarField=_field

    def start(self):pass

    def step(self,mcs):
        for x in xrange(self.dim.x):
            for y in xrange(self.dim.y):
                for z in xrange(self.dim.z):
                    pt=CompuCell.Point3D(x,y,z)
                    if (not mcs%20):
                        value=x*y
                        fillScalarValue(self.scalarField,x,y,z,value)
                    else:
                        value=sin(x*y)
                        fillScalarValue(self.scalarField,x,y,z,value)
```

As you may see this steppable is quite easy to understand. In the constructor (`__init__`) we get references to simulator object and we also extract the dimension of the lattice. `setScalarField` function is used to

pass to the steppable a reference to the field that we have just allocated (we will show later). step function is actually very simple iteration over all pixels of the self.scalarField. As you may see if the number of MCS is divisible by 20 we set value of the self.scalarField to a product of x and z coordinates and if it is not divisible by 20 we set it to $\sin(x*y)$. Notice that we need to use fillScalarValue function to set a value of the Player field. In particular, a construct

```
self.scalarField.set(pt,value)
```

would not work because it is valid for fields in the C++ part of the CompuCell3D and fields available in Player have different interface so the conclusion is that you need to use fillScalarValue function.

Notice also that in order to get access to fillScalarValue and sin we need to import PlayerPython and math Python modules.

Now let's look at the way in which we invoke this steppable from main Python program:

```
from diffusion_2D_steppables_player import ExtraFieldVisualizationSteppable
extraFieldVisualizationSteppable=ExtraFieldVisualizationSteppable\ (_simulator=sim,_frequency=10)
extraFieldVisualizationSteppable.setScalarField(extraPlayerField)
steppableRegistry.registerSteppable(extraFieldVisualizationSteppable)
```

You can see that the steppable is called every 10 MCS and that in order to properly initialize it we need to pass reference to just allocated Player field

```
extraFieldVisualizationSteppable.setScalarField(extraPlayerField)
```

This example demonstrates that you have basic tools to extend Player visualization capabilities from Python level. We however anticipate that this feature may look somewhat different in the future and should be more user friendly. This is just to let you know that next version of the Player will have much greater possibilities as far as controlling your visualization from Python level.

At this point you should be able to develop steppables in Python so now let's see what else we can accomplish from the Python level. We will now show you how to develop Python plugins it is the objects that will be called either every spin flip or every spin flip attempt (those will be primarily energy functions). Here however you need to be careful as you might end up producing performance bottle neck. Yes, there are some things for which Python is not the best solution and plugins might be a good example for that. However, as we will show, it is still worth learning how to implement plugins in Python. Also, the slight slowdown might be not a high price to pay for much faster set up of the complex simulation using Python.

Example 7- Mitosis

In developmental simulations we often need to simulate cells which grow and divide. In earlier versions of CompuCell3D we had to write quite complicated plugin to do that which was quite cumbersome and unintuitive (see example 9). The only advantage of the plugin was that exactly after

the pixel copy which had triggered mitosis condition CompuCell3D called cell division function immediately. This guaranteed that any cell which was supposed divide at any instance in the simulation, actually did. However, because state of the simulation is normally observed after completion of full a Monte Carlo Step, and not in the middle of MCS it makes actually more sense to implement Mitosis as a steppable. Let us examine the simplest simulation which involves mitosis. We start with a single cell and grow it. When cell reaches critical (doubling) volume it undergoes Mitosis. We check if the cell has reached doubling volume at the end of each MCS. The folder containing this simulation is `examples_PythonTutorial/steppableBasedMitosis`. The mitosis algorithm is implemented in `examples_PythonTutorial/steppableBasedMitosis/steppableBasedMitosisSteppables.py`

File: `examples_PythonTutorial/steppableBasedMitosis/steppableBasedMitosisSteppables.py`

```

from PySteppables import *
from PySteppablesExamples import MitosisSteppableBase
import CompuCell
import sys

class VolumeParamSteppable(SteppablePy):
    def __init__(self, simulator, _frequency=1):
        SteppablePy.__init__(self, _frequency)
        self.simulator= _simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)
    def start(self):
        for cell in self.cellList:
            cell.targetVolume=25
            cell.lambdaVolume=2.0

    def step(self,mcs):
        for cell in self.cellList:
            cell.targetVolume+=1

class MitosisSteppable(MitosisSteppableBase) :
    def __init__(self, simulator, _frequency=1):
        MitosisSteppableBase.__init__(self, _simulator, _frequency)

    def step(self,mcs):
        cells_to_divide=[]

        for cell in self.cellList:

            if cell.volume>50: # mitosis condition
                cells_to_divide.append(cell)

        for cell in cells_to_divide:
            self.divideCellRandomOrientation(cell)

    def updateAttributes(self):

        parentCell=self.mitosisSteppable.parentCell
        childCell=self.mitosisSteppable.childCell
        childCell.targetVolume=parentCell.targetVolume
        childCell.lambdaVolume=parentCell.lambdaVolume
        if parentCell.type==1:
            childCell.type=2
        else:
            childCell.type=1

```

Two steppables: VolumeParamSteppable and MitosisSteppable are the essence of the above simulation. The first steppable initializes volume constraint for all the cells present at T=0 MCS (only one cell) and then every 10 MCS (see the frequency with which VolumeParamSteppable is initialized to run - examples_PythonTutorial/steppableBasedMitosis/steppableBasedMitosis.py) it increases target volume of cells, effectively causing cells to grow.

The second steppable checks every 10 MCS (we can, of course, run it every MCS) if cell has reached doubling volume of 50. If so such cell is added to the list cells_to_divide which subsequently is iterated and all the cells in it divide.

Remark: It is important to divide cells outside the loop where we iterate over entire cell inventory. If we keep dividing cells in the this loop we are adding elements to the list over which we iterate over and this might have unwanted side effects. The solution is to use list of cells to divide as we did in the example.

Notice that we call self.divideCellRandomOrientation(cell) function to divide cells. Other modes of division are available as well and they are shown in examples_PythonTutorial/steppableBasedMitosis/steppableBasedMitosisSteppables.py as commented line with appropriate explanation.

Notice MitosisSteppable inherits MitosisSteppableBase class (defined in PySteppablesExamples.py). It is the base class which ensures that after we call any of the cell dividing function (e.g. divideCellRandomOrientation) CompuCell3D will automatically call updateAttributes function as well. updateAttributes function is very important and we must call it in order to ensure integrity and sanity of the simulation. During mitosis new cell is created (accessed in Python as childCell – defined in MitosisSteppableBase - self.mitosisSteppable.childCell) and as such this cell is uninitialized. It does have default attributes of a cell such as volume, surface (if we decide to use surface constraint or SurfaceTracker plugin) but all other parameters of such cell are set to default values. In our simulation we have been setting targetVolum and lambdaVolume individually for each cell. After mitosis childCell will need those parameters to be set as well. To make things more interesting, in our simulation we decided to change type of cell to be different than type of parent cell. In more complex simulations where cells have more attributes which are used in the simulation, we have to make sure that in the updateAttributes function childCell and its attributes get properly initialized. It is also very common practice to change attributes of parentCell after mitosis as well to account for the fact that parentCell is not the original parentCell from before the mitosis.

Important: the name of the function where we update attributes after mitosis has to be exactly updateAttributes. If it is called differently CC3D will not call it automatically. We can of course call such function by hand, immediately we do the mitosis but this is not very elegant solution.

Example 8 – Energy Functions

First let's take a look how to develop an energy function that calculates a change in volume energy. With the knowledge you already have it should be easy to follow this example.

First, let's modify cellsort_2D.xml and save changes as cellsort_2D_py_plugin.xml. The most notable change is that we are not using VolumePlugin but VolumeTracker. The latter plugin tracks changes in volume but does not calculate energy change. In other words it keeps cell volume up to date.

This is the line you need to replace VolumeEnergy entry with:

```
<Plugin Name="VolumeTracker"/>
```

Now let us show the implementation of the the volume plugin in Python. We will store it in *cellsort_2D_plugins_with_py_plugin.py* file. The Python simulation file will be *cellsort_2D_with_py_plugin.py*.

The implementation of the plugin looks as follows:

File: *cellsort 2D plugins with py plugin.py*

```

from PyPlugins import *

class VolumeEnergyFunctionPlugin(EnergyFunctionPy):

    def __init__(self,_energyWrapper):
        EnergyFunctionPy.__init__(self)
        self.energyWrapper=_energyWrapper
        self.vt=0.0
        self.lambda_v=0.0

    def setParams(self,_lambda,_targetVolume):
        self.lambda_v=_lambda;
        self.vt=_targetVolume

    def changeEnergy(self):
        energy=0.0
        if(self.energyWrapper.newCell):
            energy+=self.lambda_v*(1+2*(self.energyWrapper.newCell.volume-self.vt))
        if(self.energyWrapper.oldCell):
            energy+=self.lambda_v*(1-2*(self.energyWrapper.oldCell.volume-self.vt))
        return energy

```

The most important here is changeEnergy function. This is where the calculation takes place. Of course when we create the plugin object in the Python main script we will need to make a call to setParams function because, that is how we set parameters for this plugin. The changeEnergy function calculates the difference in the volume energy for oldCell and newCell. The volume energy is given by the formula:

$$E_{volume} = \lambda (V - V_{target})^2$$

Consequently the change in the volume energy for newCell (the one whose volume will increase due to spin flip) is:

$$\Delta E_{newCell} = \lambda (V_{newCell} + 1 - V_{target})^2 - \lambda (V_{newCell} - V_{target})^2 = \lambda (1 + 2(V_{newCell} - V_{target}))$$

for the old cell (the one whose volume will decrease after spin flip) the corresponding formula is:

$$\Delta E_{oldCell} = \lambda(V_{oldCell} - 1 - V_{target})^2 - \lambda(V_{oldCell} - V_{target})^2 = \lambda(1 - 2(V_{oldCell} - V_{target}))$$

And overall change of energy is:

$$\Delta E = \Delta E_{newCell} + \Delta E_{oldCell}$$

So as you can see this changeEnergy function just implements the formulas that we have just described. notice that sometimes oldCell or newCell might be a medium cells so that's why we are doing checks for cell being non-null to avoid segmentation faults.:

```
if(self.energyWrapper.newCell):
```

Notice also that references to newCell and oldCell are accessible through energyWrapper object. This is a C++ object that stores pointers to oldCell and newCell every spin flip attempt. It also stores Point3D object that contains coordinates of the lattice location at which a given spin flip attempt takes place.

Now if you look into *cellsort_2D_with_py_plugin.py* you will see how we use Python plugins in the simulation:

File: *cellsort_2D_with_py_plugin.py*

```
sim,simthread = CompuCellSetup.getCoreSimulationObjects()

import CompuCell #notice importing CompuCell to main script has to be done after call to getCoreSimulationObjects()

#Create extra player fields here or add attributes or plugins
energyFunctionRegistry=CompuCellSetup.getEnergyFunctionRegistry(sim)

from cellsort_2D_plugins_with_py_plugin import VolumeEnergyFunctionPlugin
volumeEnergy=VolumeEnergyFunctionPlugin(energyFunctionRegistry)
volumeEnergy.setParams(2.0,25.0)

energyFunctionRegistry.registerPyEnergyFunction(volumeEnergy)
```

After a call to getCoreSimulationObjects() we create special object called energyFunctionRegistry that is responsible for calling Python plugins that calculate energy every spin flip attempt. Then we create volume energy plugin that we have just developed and initialize its parameters. Subsequently we register the plugin with EenergyFunctionRegistr:

```
energyFunctionRegistry.registerPyEnergyFunction(volumeEnergy)
```

Let's run our simulation now. As you may have noticed the use of this simple plugin slowed down CompuCell3D more than 10 times. So clearly energy functions is not what you should be implementing in Python too often, although there are situations (e.g. testing the simulation) when speed of implementing the actual plugin matters more than actual speed of run and that's when Python comes handy.

Example 9 – Plugins

In this example we will show you how to build a plugin that will be called every spin flip, as opposed to every spin flip attempt. This plugin will invoke a `changeField3D` function (implemented in C++) from Mitosis plugin. After this call we will set a new cell types for the two cells that we got after mitosis but we will do it from Python level. This technique is quite useful because you are still calling C++ function to do real work (in this case C++ function will run mitosis algorithm) and at the Python level we do only finishing tasks, such as type reassignment, and setting `targetVolume` which usually does not take too much time. So performance-wise we should be OK, although some speed penalty is unavoidable. OK, let's see how this is implemented. We will be using `growingcells_fast.py`, `growingcells_fast.xml` and `growingcells.pif` simulation files.

In `growingcells_fast.xml` we are using `VolumeLocalFlex` plugin. This plugin calculates change of energy based on `targetVolume` and `lambdaVolume` which are attributes of the cell (i.e. it might be different for different cells). For this reason first, we need to initialize `volumeTarget` and `lambdaVolume` for every cell before we start the actual simulation and second, after the mitosis happens we need to set `targetVolume` for the `childCell` and we will set it to match `targetVolume` of the `parentCell`. Every 10 MCS we will be increasing by 1 `targetVolume` of every cell. This task as well as setting up initial `targetVolume` will be managed by `VolumeParamSteppable`:

File: `growingcells_fast_steppables.py`

```
class VolumeParamSteppable(SteppablePy):
    def __init__(self, _simulator, _frequency=1):
        SteppablePy.__init__(self, _frequency)
        self.simulator=_simulator
        self.inventory=self.simulator.getPotts().getCellInventory()
        self.cellList=CellList(self.inventory)
    def start(self):
        for cell in self.cellList:
            cell.targetVolume=25
            cell.lambdaVolume=2.0
    def step(self, mcs):
        for cell in self.cellList:
            cell.targetVolume+=1
```

We hope you are able to decipher this steppable without any problems. Now, let's go to the implementation of the mitosis plugin in Python. This task will be very easy. All we are required to do is

to implement updateAttributes member functions where we assign parent and daughter cell properties after mitosis took place:

File: *growingcells_fast_plugins.py*

```
from PyPluginsExamples import MitosisPyPluginBase
class MitosisPyPlugin(MitosisPyPluginBase):
    def __init__(self, _simulator, _changeWatcherRegistry, _stepperRegistry):
        MitosisPyPluginBase.__init__(self, _simulator, _changeWatcherRegistry, _stepperRegistry)
    def updateAttributes(self):
        self.childCell.targetVolume=self.parentCell.targetVolume
        self.childCell.lambdaVolume=self.parentCell.lambdaVolume

        if self.parentCell.type==1:
            self.childCell.type=2
        else:
            self.childCell.type=1
```

This function is run after mitosis happened in the step function. As you can see, first we set targetVolume of the childCell to targetVolume of the parentCell. Next we do type switching so that child cell has different cell than parent cell. Of course, we are using only two cell types here (1 and 2).

The actual MitosisPyPlugin class is derived from MitosisPyPluginBase class which resides in PyPluginsExamples module and that's why we use import statement:

```
from PyPluginsExamples import MitosisPyPluginBase
```

Finally let's look at how you set up this plugin in the main Python simulation file (see comments in the code snippet below):

File: *growingcells_fast.py*

```
import sys
from os import environ
from os import getcwd
import string

sys.path.append(environ["PYTHON_MODULE_PATH"])

import CompuCellSetup
CompuCellSetup.setSimulationXMLFileName("examples_PythonTutorial/growingcells_fast/growingcells_fast.xml")

sim,simthread = CompuCellSetup.getCoreSimulationObjects()
CompuCellSetup.initializeSimulationObjects(sim,simthread)
```

```

import CompuCell #notice importing CompuCell to main script has to be done after call to getCoreSimulationObjects()

from growingcells_fast_plugins import MitosisPyPlugin

changeWatcherRegistry=CompuCellSetup.getChangeWatcherRegistry(sim)

stepperRegistry=CompuCellSetup.getStepperRegistry(sim)

mitPy=MitosisPyPlugin(sim,changeWatcherRegistry,stepperRegistry)
mitPy.setDoublingVolume(50)

#Add Python steppables here
from PySteppablesExamples import SteppableRegistry
steppableRegistry=SteppableRegistry()

from growingcells_fast_steppables import VolumeParamSteppable
volumeParamSteppable=VolumeParamSteppable(sim,10)
steppableRegistry.registerSteppable(volumeParamSteppable)

CompuCellSetup.mainLoop(sim,simthread,steppableRegistry)

```

If you try running this simulation you will notice that the slowdown in the speed of run is not as dramatic as in the case of simulation with VolumePlugin implemented in Python. This is due to the fact that there are much less actual spin flip than spin flip attempts, and also that in mitosis plugin most of the work is done by a C++ function. Python written Mitosis plugin serves as a wrapper for a C++ counterpart. This suggests that plugins that “react” to the spin flip are a decent candidates for being implemented in Python. However one needs to be careful about the details of implementation. In this case all the most of the work has been done indirectly in C++ anyway.

Important: Objects like changeWatcherRegistry, stepperRegistry, energyFunctionRegistry that we have encountered before serve two purposes:

- 1) They store references to change watchers, steppers, energy functions and run them at appropriate times
- 2) They provide change watchers, steppers, energy functions all the information from C++ code that is necessary for those objects to function properly

After studying all of the above examples you should be able to gain enough information to develop your own modules that will make your simulations be more complex. At the same time you will avoid the hassle of coding in C++ so you will be able to set up your simulations much faster.

Changing cluster id of a cell.

Quite often when working with mitosis you may want to reassign cell's cluster id i.e. to make a given

cell belong to a different cluster than it currently does. You might think that statement like this

```
cell.clusterId=550
```

is a good way of accomplishing it. This could have worked with CC3D versions prior to 3.4.2 However, this is not the case anymore and in fact this is an easy recipe for hard to find bugs that will crash your simulation with very enigmatic messages. So what is wrong here? First of all you need to realize that all the cells (strictly speaking pointers to cell objects) in the CompuCell3D are stored in a sorted container called inventory. The ordering of the cells in the inventory is based on cluster id and cell id. Thus when a cell is created it is inserted to inventory and positioned according to cluster id and cell id. When you iterate inventory cells with lowest cluster id will be listed first. Within cells of the same cluster id cells with lowest cell id will be listed first. In any case if the cell is in the inventory and you do brute force cluster id reassignment the position of the cell in the inventory will not be changed. Why should it be? However when this cell is deleted CompuCell3D will first try to remove the cell from inventory based on cell id and cluster id and it will not find the cell because you have altered cluster id so it will ignore the request however it will delete underlying cell object so the net outcome is that you will end up with an entry in the inventory which has pointer to a cell that has been deleted. Next time you iterate through inventory and try go perform any operation on the cell the CC3D will crash because it will try to perform something with a cell that has been deleted. To avoid such situations always use the following construct to change clusterId of the cell:

```
inventory=self.simulator.getPotts().getCellInventory()  
reassignIdFlag=inventory.reassignClusterId(cell,550)
```

We will introduce Better error checking in the next releases of CC3D to make sure that errors like this one is clearly communicated to the user when it occurs.

Exercises

In this section you will find few exercises that might improve your CompuCell3D Python scripting skills.

Exercise 1

Set up cell sorting simulation using xml (simply use cellsort_2D.xml example included with CompuCell3D package). In the BlobInitializer steppable remove CellSortInit tag so that you begin with a blob of cells each of the same type.

Tasks for you:

- 1) Write Python steppable that initializes cell types so that they are random (with type id either 1 or 2)
- 2) Write Python steppable that initializes cell types so that bottom half is of type 1 and upper half is of type 2. Make the steppable flexible so that users can define coordinate range for cells of type 1 and type 2.
- 3) Write Python steppable that initializes cell types so that different quarters of the blob have alternating cell type ids (1 or 2)

Exercise 2

Open up foam simulation (Foam_try.xml). In one of the exercises that dealt with foams you were asked to find average area of n-sided bubble and produce a histogram of $\langle A_n \rangle$ as a function of n . You did this exercise by taking advantage of a CompuCell3D module that did this analysis for you. All you had to do was to use steppable FoamDataOutput (see Foam_try.xml). Now, your task would be to:

- 1) Write a Python steppable that writes a file where each line (one line per each cell) consists of
cell id its surface number of neighbors
- 2) Modify the steppable so that in addition to writing the file it outputs values of the histogram to a text file. The file format would be as follows:

$n \langle A_n \rangle$

for example

3 23.1
4 34.2
5 50.1

...

Exercise 3

In this, slightly longer exercise, you will build a flowing foam simulation from, almost, scratch.

Open up an editor and start typing “regular” xml file for CompuCell3D simulation (call it e.g. foamair.xml). Make your lattice longer in x-direction so that foam bubbles will flow from left to right. For now let's assume that your lattice will be 100x50x1. After you get your simulation working we will increase the lattice size. Prepare “regular” Python script for CompuCell3D simulation (simply copy existing Python script, modify it and call it foamair.py). Here are the tasks for you:

- 1) Go to PySteppablesExamples.py and find BubbleNucleator steppable (class). Try to understand what it does. Now, use this steppable in the main Python script (foamair.py). Make sure you set up all its options like initial cell type, initial volume, initial lambda volume etc... In foamair.xml include `<Plugin Name="VolumeLocalFlex"/>` tag so that volume energy will be calculated based on local cell parameters. This is why you need to make sure that initial target volume and initial lambda volume are set in the bubble nucleator. You will also need Contact plugin. Copy the syntax from one of existing example xml files.

Try running the simulation.

- 2) As you will notice cells are created on the left side of the lattice and as more and more cells gets created cells foam starts flowing from left to right. Simply cells on the left exert pressure on rightmost cells. Now, at some point you will notice that there is more and more cells and cells become squashed. We need to create sink for the rightmost cells. Get familiar with BubbleCellRemover and make sure you know how to use it. Put BubbleCellRemover into foamair.py, properly initialize it and run the simulation. Did you manage prevent cells from touching right wall of the lattice (occasional touching is OK).
- 3) Now you are ready to start injecting air to some of the bubbles. Read AirInjector class and see what is going on there. Add object of type AirInjector to foamair.py.
- 4) Increase the lattice size and watch the “full size” simulation.

Using Python to Replace XML Configuration File

In the material presented above we required that in order to run the CompuCell3D simulation one needs to supply XML configuration file which will list C++ plugins, steppables and properties of the overall simulation such as lattice dimension, temperature *etc...*

Most recent version of CompuCell3D allows users to script entire simulation using Python only. This way your main simulation script requires only one file instead of two. Of course you still may need other file if you defined Python steppables in separate file but the “main” simulation Python script will now allow users to store all the information that previously were stored in the XML configuration file.

The syntax of the Python replacement was based on actual XML syntax and many Python function names for parameter input have the same names as XML tags making it very easy for users to switch.

In general, to pass information from Python to CompuCell3D you need to instantiate (create) ParseData type objects in Python, fill out their values and register them with CompuCell3D kernel. Once registered, those objects are analyzed by CompuCell3D and appropriate CompuCell3D modules (plugins, steppables or kernel) are being initialized (also created if necessary) and simulation is then ready to run.

Perhaps the best way to show benefits of using CompuCell3D with just one Python configuration file is to show the example:

File: *cellsort-2D-player-new-syntax.py*

```
def configureSimulation(sim):
    import CompuCellSetup
    from XMLUtils import ElementCC3D

    cc3d=ElementCC3D("CompuCell3D")
    potts=cc3d.ElementCC3D("Potts")
    potts.ElementCC3D("Dimensions",{"x":100,"y":100,"z":1})
    potts.ElementCC3D("Steps",{},10000)
    potts.ElementCC3D("Temperature",{},5)
    potts.ElementCC3D("NeighborOrder",{},2)
    potts.ElementCC3D("Boundary_x",{},"Periodic")

    cellType=cc3d.ElementCC3D("Plugin",{"Name":"CellType"})
    cellType.ElementCC3D("CellType", {"TypeName":"Medium", "TypeId":"0"})
    cellType.ElementCC3D("CellType", {"TypeName":"Body1", "TypeId":"1"})
    cellType.ElementCC3D("CellType", {"TypeName":"Body2", "TypeId":"2"})
    cellType.ElementCC3D("CellType", {"TypeName":"Body3", "TypeId":"3"})
```

```

volume=cc3d.ElementCC3D("Plugin",{ "Name": "Volume"})
volume.ElementCC3D("TargetVolume",{},25)
volume.ElementCC3D("LambdaVolume",{},4.0)

contact=cc3d.ElementCC3D("Plugin",{ "Name": "Contact"})
contact.ElementCC3D("Energy", {"Type1": "Medium", "Type2": "Medium"},0)
contact.ElementCC3D("Energy", {"Type1": "Body1", "Type2": "Body1"},16)
contact.ElementCC3D("Energy", {"Type1": "Body1", "Type2": "Medium"},4)
contact.ElementCC3D("Energy",{ "Type1": "Body2", "Type2": "Body2"},16)
contact.ElementCC3D("Energy", {"Type1": "Body2", "Type2": "Medium"},4)
contact.ElementCC3D("Energy", {"Type1": "Body3", "Type2": "Body3"},16)
contact.ElementCC3D("Energy", {"Type1": "Body3", "Type2": "Medium"},4)
contact.ElementCC3D("Energy", {"Type1": "Body1", "Type2": "Body2"},16)
contact.ElementCC3D("Energy", {"Type1": "Body1", "Type2": "Body3"},16)
contact.ElementCC3D("Energy", {"Type1": "Body2", "Type2": "Body3"},16)
contact.ElementCC3D("neighborOrder" , {}, 2)

centerOfMass=cc3d.ElementCC3D("Plugin",{ "Name": "CenterOfMass"})

plasticityTracker=cc3d.ElementCC3D("Plugin",{ "Name": "PlasticityTracker"})
plasticityTracker.ElementCC3D("IncludeType",{ "Body1"})
plasticityTracker.ElementCC3D("IncludeType",{ "Body2"})
plasticityTracker.ElementCC3D("IncludeType",{ "Body3"})

plasticityEnergy=cc3d.ElementCC3D("Plugin",{ "Name": "PlasticityEnergy"})
plasticityEnergy.ElementCC3D("LambdaPlasticity",{},200.0)
plasticityEnergy.ElementCC3D("TargetLengthPlasticity",{},6)

externalPotential=cc3d.ElementCC3D("Plugin",{ "Name": "ExternalPotential"})
externalPotential.ElementCC3D("Lambda",{ "x": -10, "y": 0, "z": 0})

pifInitializer=cc3d.ElementCC3D("Steppable",{ "Type": "PIFInitializer"})
pifInitializer.ElementCC3D("PIFName",{ "Demos/PythonOnlySimulationsExamples/plasticitytest.pif"})

CompuCellSetup.setSimulationXMLDescription(cc3d)

import sys
from os import environ
import string
sys.path.append(environ["PYTHON_MODULE_PATH"])

```

```

import CompuCellSetup

sim,simthread = CompuCellSetup.getCoreSimulationObjects()

configureSimulation(sim)

CompuCellSetup.initializeSimulationObjects(sim,simthread)

from PySteppables import SteppableRegistry
steppableRegistry=SteppableRegistry()

from plasticitytestSteppables import PlasticityLocalSteppable
plasticitySteppable=PlasticityLocalSteppable(_simulator=sim,_frequency=50)
steppableRegistry.registerSteppable(plasticitySteppable)

CompuCellSetup.mainLoop(sim,simthread,steppableRegistry)

```

Notice that `configureSimulation` function is the one which replaces XML configuration file. Notice also how closely names of the function calls for the `ParseData` type objects resemble names of tags used in the XML file. The pattern here, as you may have already noticed it is that every plugin, steppable and Potts section has its own `ParseData` object responsible for passing parameters from Python to the `CompuCell3D` kernel. Once you have initialized `ParseData` objects all you need to do is to register them with `CompuCell3D` kernel using `CompuCellSetup.setSimulationXMLDescription(cc3d)`.

Once is complete you use Python script introduced earlier and put a call to **`configureSimulation`** right after line that initializes `sim` and `simthread` objects - `sim,simthread = CompuCellSetup.getCoreSimulationObjects()`. One thing to be aware of is that if you are using new style of Python scripting does not prohibit you from using XML. As a matter of fact you can even mix where you initialize plugins – some of them may be handled directly through Python as above and some of them might be handled through XML. However, if you decide you want to mix the two styles, be prepared that strange errors may occur with cryptic messages. Therefore we strongly recommend that you pick Python scripting style and avoid strange mixes.

The reminder of this section is devoted to presenting specific examples of how to replace XML for various plugins and steppables available in the `CompuCell3D`

CellType Plugin:

```

cellType=cc3d.ElementCC3D("Plugin",{"Name":"CellType"})
cellType.ElementCC3D("CellType", {"TypeName":"Medium", "TypeId":"0"})
cellType.ElementCC3D("CellType", {"TypeName":"Body1", "TypeId":"1"})
cellType.ElementCC3D("CellType", {"TypeName":"Body2", "TypeId":"2"})
cellType.ElementCC3D("CellType", {"TypeName":"Body3", "TypeId":"3"})

```

the format is as CellType is as follows CellType(type name, type id, Freeze or not (default False))

Contact Plugin:

```
contact=cc3d.ElementCC3D("Plugin",{ "Name":"Contact"})
contact.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"Medium"},0)
contact.ElementCC3D("Energy", {"Type1":"Body1", "Type2":"Body1"},16)
contact.ElementCC3D("Energy", {"Type1":"Body1", "Type2":"Medium"},4)
contact.ElementCC3D("Energy",{ "Type1":"Body2", "Type2":"Body2"},16)
contact.ElementCC3D("Energy", {"Type1":"Body2", "Type2":"Medium"},4)
contact.ElementCC3D("Energy", {"Type1":"Body3", "Type2":"Body3"},16)
contact.ElementCC3D("Energy", {"Type1":"Body3", "Type2":"Medium"},4)
contact.ElementCC3D("Energy", {"Type1":"Body1", "Type2":"Body2"},16)
contact.ElementCC3D("Energy", {"Type1":"Body1", "Type2":"Body3"},16)
contact.ElementCC3D("Energy", {"Type1":"Body2", "Type2":"Body3"},16)
contact.ElementCC3D("neighborOrder" , {} , 2)
```

You may also specify how many neighbors to include in the calculations by using NeighborOrder function.

Volume Plugin:

```
volume=cc3d.ElementCC3D("Plugin",{ "Name":"Volume"})
volume.ElementCC3D("TargetVolume", {},25)
volume.ElementCC3D("LambdaVolume" , {},4.0)
```

VolumeTracker Plugin:

```
volumeTracker=cc3d.ElementCC3D("Plugin",{ "Name":"VolumeTracker"})
```

The syntax of the ParseData object for this plugin mirrors XML syntax.

Surface Plugin:

```
surface=cc3d.ElementCC3D("Plugin",{ "Name":"Surface"})
surface.ElementCC3D("TargetVolume", {},25.0)
surface.ElementCC3D("LambdaVolume" , {},1.0)
```

The syntax of the ParseData object for this plugin mirrors XML syntax.

CenterOfMass Plugin:

```
centerOfMass=cc3d.ElementCC3D("Plugin",{ "Name":"CenterOfMass"})
```

This is all that is required if you want to use this plugin.

PlasticityTracker Plugin:

```
plasticityTracker=cc3d.ElementCC3D("Plugin",{ "Name":"PlasticityTracker"})
plasticityTracker.ElementCC3D("IncludeType", {}, "Body1")
```

```
plasticityTracker.ElementCC3D("IncludeType",{,"Body2")
plasticityTracker.ElementCC3D("IncludeType",{,"Body3")
```

Similarly as in XML you use IncludeType function in place of the actual XML tag.

Plasticity Plugin:

```
plasticityEnergy=cc3d.ElementCC3D("Plugin",{ "Name": "PlasticityEnergy"})
plasticityEnergy.ElementCC3D("LambdaPlasticity",{},200.0)
plasticityEnergy.ElementCC3D("TargetLengthPlasticity",{},6)
```

The syntax of this plugin closely follows XML format.

ExternalPotential Plugin:

```
externalPotential=cc3d.ElementCC3D("Plugin",{ "Name": "ExternalPotential"})
externalPotential.ElementCC3D("Lambda",{ "x": -10, "y": 0, "z": 0})
```

The syntax of this plugin closely follows XML format.

LengthConstraintLocalFlex Plugin:

```
lengthConstraint=cc3d.ElementCC3D("Plugin",{ "Name": "LengthConstraintLocalFlex"})
```

Connectivity Plugin:

```
connectivity=cc3d.ElementCC3D("Plugin",{ "Name": "LengthConstraintLocalFlex"})
connectivity.ElementCC3D("Penalty",{}, 10000000)
```

LengthConstraint Plugin:

```
lengthConstraint=cc3d.ElementCC3D("Plugin",{ "Name": "LengthConstraint"})
lengthConstraint.ElementCC3D("LengthEnergyParameters",{ "CellType": "Body1", "TargetLength": 30, "LambdaLength": 5})
```

ConnectivityLocalFlex Plugin:

```
connectLocal=cc3d.ElementCC3D("Plugin",{ "Name": "ConnectivityLocalFlex"})
```

SimpleClock Plugin:

```
simpleClock=cc3d.ElementCC3D("Plugin",{ "Name": "SimpleClock"})
```

SimpleArray Plugin:

```
simpleArray=cc3d.ElementCC3D("Plugin",{ "Name": "SimpleArray"})
simpleArray.ElementCC3D("Values", {}, 10)
```

ChemotaxisDicty Plugin:

```
chemDicty=cc3d.ElementCC3D("Plugin",{ "Name": "ChemotaxisDicty"})
chemDicty.ElementCC3D("Lambda", {}, 200)
chemDicty.ElementCC3D("ChemicalField", {"Source": "ReactionDiffusionSolverFE_SavHog"}, cAMP)
```

The Source refers to name of the PDE solver (ReactionDiffusionSolverFE_SavHog) and value for the ChemicalField is the actual field causing chemotaxis (cAMP).

Chemotaxis Plugin:

```
chemotaxis=cc3d.ElementCC3D("Plugin",{Name:"Chemotaxis"})
chemField=chemotaxis.ElementCC3D("ChemicalField", {"Source":"FlexibleDiffusionSolverFE", "Name":"ATTR"})
chemField.ElementCC3D("ChemotaxisByType", {"Type":"Macrophage", "Lambda":200})
```

Notice that to create the object chemField corresponding to the XML tag ChemicalField which is the child node to the Plugin tag all you need to do is just to call the method chemotaxis.ElementCC3D("ChemicalField", {"Source":"FlexibleDiffusionSolverFE", "Name":"ATTR"}).

PDESolverCaller Plugin:

```
pdesolver=cc3d.ElementCC3D("Plugin",{Name:"PDESolverCaller"})
pdesolver.ElementCC3D("CallPDE", {"PDESolverName":"FlexibleDiffusionSolverFE", "ExtraTimesPerMC":"8"})
```

KernelDiffusionSolver Plugin:

```
kds=cc3d.ElementCC3D("Steppable",{Type:"KernelDiffusionSolver"})
kernel=kds.ElementCC3D("Kernel",{},4)
diffusionField=kds.ElementCC3D("DiffusionField")
diffusionData=diffusionField.ElementCC3D("DiffusionData")
diffusionData.ElementCC3D("FieldName",{}, "FGF")
diffusionData.ElementCC3D("DiffusionConstant",{}, 1.0)
diffusionData.ElementCC3D("DecayConstant",{},0.0)
diffusionData.ElementCC3D("ConcentrationFileName",{}, "Demos/diffusion/diffusion_2D.pulse.txt")
```

The syntax of this plugin closely follows XML format.

Compartment Plugin:

```
compartment=cc3d.ElementCC3D("Plugin",{Name:"Compartment"})
compartment.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"Medium"},0)
compartment.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"NonCondensing"},16)
compartment.ElementCC3D("Energy", {"Type1":"Condensing", "Type2":"Condensing"},2)
compartment.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"Condensing"},11)
compartment.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"Medium"},16)
compartment.ElementCC3D("Energy", {"Type1":"Condensing", "Type2":"Medium"},16)
compartment.ElementCC3D("InternalEnergy", {"Type1":"Medium", "Type2":"Medium"},0)
compartment.ElementCC3D("InternalEnergy", {"Type1":"NonCondensing", "Type2":"NonCondensing"},23)
compartment.ElementCC3D("InternalEnergy", {"Type1":"Condensing", "Type2":"Condensing"},20)
compartment.ElementCC3D("InternalEnergy", {"Type1":"NonCondensing", "Type2":"Condensing"},22)
compartment.ElementCC3D("InternalEnergy", {"Type1":"NonCondensing", "Type2":"Medium"},33)
```

```
compartment.ElementCC3D("InternalEnergy", {"Type1":"Condensing", "Type2":"Medium"},50)
compartment.ElementCC3D("neighborOrder" , {}, 2)
```

You may also specify how many neighbors to include in the calculations by using NeighborOrder name. The InternalEnergy is used to enter internal energies following XML syntax. The order of argument is the same as in the case of Energy function.

OrientedContact Plugin:

```
orientContact=cc3d.ElementCC3D("Plugin",{"Name":"OrientedContact"})
orientContact.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"Medium"},0)
orientContact.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"NonCondensing"},16)
orientContact.ElementCC3D("Energy", {"Type1":"Condensing", "Type2":"Condensing"},2)
orientContact.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"Condensing"},11)
orientContact.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"Medium"},16)
orientContact.ElementCC3D("Energy", {"Type1":"Condensing", "Type2":"Medium"},16)
orientContact.ElementCC3D("neighborOrder" , {}, 2)
```

Rearrangement Plugin:

```
rearrange=cc3d.ElementCC3D("Plugin",{"Name":"Rearrangement"})
rearrange.ElementCC3D("FRearrangement", {},10)
rearrange.ElementCC3D("LambdaRearrangement", {},20)
rearrange.ElementCC3D("PercentageLossThreshold", {},0.50)
rearrange.ElementCC3D("DefaultPenalty", {},100000000000)
```

The syntax of this plugin closely follows XML format.

Mitosis Plugin:

```
mitosis=cc3d.ElementCC3D("Plugin",{"Name":"Mitosis"})
mitosis.ElementCC3D("DoublingVolume", {},50)
```

The syntax of this plugin closely follows XML format.

NeighborTracker Plugin:

```
neighborTrack=cc3d.ElementCC3D("Plugin",{"Name":"NeighborTracker"})
```

PolarizationVector Plugin:

```
polarVector=cc3d.ElementCC3D("Plugin",{"Name":"PolarizationVector"})
```

ContactMultiCad Plugin:

```
multiCad=cc3d.ElementCC3D("Plugin",{"Name":"ContactMultiCad"})
multiCad.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"Medium"},0)
multiCad.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"CadExpLevel1"},0)
multiCad.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"CadExpLevel2"},0)
```

```

multiCad.ElementCC3D("Energy", {"Type1":"CadExpLevel1", "Type2":"CadExpLevel1"},0)
multiCad.ElementCC3D("Energy", {"Type1":"CadExpLevel1", "Type2":"CadExpLevel2"},0)
multiCad.ElementCC3D("Energy", {"Type1":"CadExpLevel2", "Type2":"CadExpLevel2"},0)
specCad=multiCad.ElementCC3D("SpecificityCadherin")
specCad.ElementCC3D("Specificity", {"Cadherin1":"NCad", "Cadherin2":"NCad"},-1)
specCad.ElementCC3D("Specificity", {"Cadherin1":"NCam", "Cadherin2":"NCam"},-1)
specCad.ElementCC3D("Specificity", {"Cadherin1":"NCad", "Cadherin2":"NCam"},-1)
multiCad.ElementCC3D("EnergyOffset", {},0.0)
multiCad.ElementCC3D("Depth", {},1.75)

```

The syntax of this plugin closely follows XML format.

ContactLocalProduct Plugin:

```

localProduct=cc3d.ElementCC3D("Plugin",{"Name":"ContactLocalProduct"})
localProduct.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"Medium"},0)
localProduct.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"CadExpLevel1"},-16)
localProduct.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"CadExpLevel2"},-16)
localProduct.ElementCC3D("Energy", {"Type1":"CadExpLevel1", "Type2":"CadExpLevel1"},-2)
localProduct.ElementCC3D("Energy", {"Type1":"CadExpLevel1", "Type2":"CadExpLevel2"},-2.75)
localProduct.ElementCC3D("Energy", {"Type1":"CadExpLevel2", "Type2":"CadExpLevel2"},-1)
multiCad.ElementCC3D("EnergyOffset", {},0.0)
multiCad.ElementCC3D("Depth", {},1.75)

```

The syntax of this plugin closely follows XML format.

Notice that for the last two plugins you need to use Python scripting to initialize appropriate cells' expression levels.

ContactLocalFlex Plugin:

```

localFlex=cc3d.ElementCC3D("Plugin",{"Name":"ContactLocalFlex"})
localFlex.ElementCC3D("Energy", {"Type1":"Medium", "Type2":"Medium"},0)
localFlex.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"NonCondensing"},16)
localFlex.ElementCC3D("Energy", {"Type1":"Condensing", "Type2":"Condensing"},2)
localFlex.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"Condensing"},11)
localFlex.ElementCC3D("Energy", {"Type1":"NonCondensing", "Type2":"Medium"},16)
localFlex.ElementCC3D("Energy", {"Type1":"Condensing", "Type2":"Medium"},16)
localFlex.ElementCC3D("neighborOrder" , {} , 2)
localFlex.ElementCC3D("Depth" , {} , 1.75)

```

The syntax of this plugin closely follows XML format.

BlobInitializer Steppable:

```

bloblnit=cc3d.ElementCC3D("Plugin",{"Name":"BlobInitializer"})

```

```
bloblNit.ElementCC3D("Gap", {},0)
bloblNit.ElementCC3D("Width", {},5)
bloblNit.ElementCC3D("CellSortlNit", {}, "yes")
bloblNit.ElementCC3D("Radius", {},40)
```

UniformInitializer Steppable:

```
uniformlNit=cc3d.ElementCC3D("Plugin",{"Name":"uniformInitializer"})
region=uniformlNit.ElementCC3D("Region")
region.ElementCC3D("BoxMin", {"x":20,"y":20,"z":0})
region.ElementCC3D("BoxMax", {"x":80,"y":80,"z":0})
region.ElementCC3D("Types", {}, "Condensing")
region.ElementCC3D("Types", {}, "NonCondensing")
region.ElementCC3D("Width", {}, 5)
```

Similarly as in the XML you can include many regions. Each time you call `uipd.Region()` a reference to the new region is returned. Using this reference (region) you describe the region in the very similar way you would describe it in the XML.

PIFInitializer Steppable:

```
piflNit=cc3d.ElementCC3D("Plugin",{"Name":"PIFInitializer"})
piflNit.ElementCC3D("PIFName", {}, "plasticitytest.pif")
```

PIFDumper Steppable:

```
pifDump=cc3d.ElementCC3D("Plugin",{"Name":"PIFDumper"})
pifDump.ElementCC3D("PIFName", {}, "output")
```

The syntax of this steppable closely follows XML format.

BoxWatcher Steppable:

```
boxWatch=cc3d.ElementCC3D("Plugin",{"Name":"BoxWatcher"})
boxWatch.ElementCC3D("XMargin", {}, 1)
boxWatch.ElementCC3D("YMargin", {}, 1)
boxWatch.ElementCC3D("ZMargin", {}, 1)
```

The syntax of this steppable closely follows XML format.

DictyFieldInitializer Steppable:

```
dictylNit=cc3d.ElementCC3D("Plugin",{"Name":"DictyFieldInitializer"})
dictylNit.ElementCC3D("ZonePoint", {"x":14,"y":14,"z":3}, 10)
dictylNit.ElementCC3D("PresporeRatio", {}, 0.8)
dictylNit.ElementCC3D("Gap", {}, 1)
dictylNit.ElementCC3D("Width", {}, 4)
```

The syntax of this steppable closely follows XML format.

DictyChemotaxis Steppable:

```
dictyChem=cc3d.ElementCC3D("Plugin",{ "Name":"DictyChemotaxis"})
dictyChem.ElementCC3D("ClockReloadValue", {}, 850)
dictyChem.ElementCC3D("ChemotactUntil", {}, 750)
dictyChem.ElementCC3D("IgnoreFirstSteps", {}, 500)
dictyChem.ElementCC3D("ChemotaxisActivationThreshold", {}, 0.2)
dictyChem.ElementCC3D("ChemicalField", {"Source":"ReactionDiffusionSolverFE_SavHog"}, "cAMP")
```

The syntax of this steppable closely follows XML format.

ReactionDiffusionSolverFE_SavHog Steppable:

```
reactionDiff=cc3d.ElementCC3D("Plugin",{ "Name":"ReactionDiffusionSolverFE_SavHog"})
reactionDiff.ElementCC3D("NumberOfFields", {}, 3)
reactionDiff.ElementCC3D("FieldName", {}, "cAMP")
reactionDiff.ElementCC3D("FieldName", {}, "Refractoriness")
reactionDiff.ElementCC3D("DeltaX", {}, 0.37)
reactionDiff.ElementCC3D("DeltaT", {}, 0.01)
reactionDiff.ElementCC3D("DiffusionConstant", {}, 1.0)
reactionDiff.ElementCC3D("DecayConstant", {}, 0.0)
reactionDiff.ElementCC3D("MaxDiffusionZ", {}, 8)
reactionDiff.ElementCC3D("IntervalParameters", {"c1":0.0065,"c2":0.841})
reactionDiff.ElementCC3D("fFunctionParameters", {"C1":20,"C2":3, "C3":15, "a":0.15})
reactionDiff.ElementCC3D("epsFunctionParameters", {"eps1":0.5,"eps2":0.0589, "eps3":0.5})
reactionDiff.ElementCC3D("RefractorinessParameters", {"k":3.5,"b":0.35})
reactionDiff.ElementCC3D("MinDiffusionBoxCorner", {"x":0,"y":0, "z":0})
reactionDiff.ElementCC3D("MaxDiffusionBoxCorner", {"x":40,"y":40, "z":40})
```

The syntax of this steppable follows XML format.

FastDiffusionSolver2DFE Steppable:

```
fastDiff=cc3d.ElementCC3D("Plugin",{ "Name":"FastDiffusionSolver2DFE"})
diffField=fastDiff.ElementCC3D("DiffusionField")
diffData=diffField.ElementCC3D("DiffusionData")
secreData=diffField.ElementCC3D("SecretionData")
diffData.ElementCC3D("UseBoxWatcher", {}, "True")
diffData.ElementCC3D("DiffusionConstant", {}, 0.1)
diffData.ElementCC3D("FieldName", {}, "FGF")
diffData.ElementCC3D("ConcentrationFileName", {}, "diffusion_2D_fast_box.pulse.txt")
```

Again, the syntax follows that of the XML file. Notice that the following calls:

```
diffField=fastDiff.ElementCC3D("DiffusionField")
diffData=diffField.ElementCC3D("DiffusionData")
secrData=diffField.ElementCC3D("SecretionData")
```

return equivalents of DiffusionField, DiffusionData and SecretionData sections of the XML. Once you have these you feel the rest of the steppable parameters following XML pattern. The function names are analogous to the XML tags.

FlexibleDiffusionSolver3DFE Steppable:

```
flexDiffSolver=cc3d.ElementCC3D("Steppable",{ "Type":"FlexibleDiffusionSolver3DFE"})
diffField=flexDiffSolver.ElementCC3D("DiffusionField")
diffData=diffField.ElementCC3D("DiffusionData")
secrData=diffField.ElementCC3D("SecretionData")
diffData.ElementCC3D("FieldName",{ "ATTR"})
diffData.ElementCC3D("DiffusionConstant",{ "0.10"})
diffData.ElementCC3D("DecayConstant",{ "0.0"})
diffData.ElementCC3D("DoNotDiffuseTo",{ "Wall"})
secrData.ElementCC3D("Secretion", { "Type":"Bacterium"},200)
```

The syntax is very similar to that of FastDiffusionSolver2DFE. Notice how Secretion function is implemented:

```
secrData.ElementCC3D("Secretion", { "Type":"Bacterium"},200)
```

The argument order is the following Secreting type name (Bacterium), secretion constant