pynoddy Documentation

Release

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Contents:

CHAPTER

ONE

PYNODDY

pynoddy is a python package to write, change, and analyse kinematic geological modelling simulations performed with Noddy (see below for more infomration on Noddy).

1.1 How does it work?

At this stage, pynoddy provides wrapper modules for existing Noddy history (.his) and result files (.g00, etc.). It is

1.2 Installation

To install pynoddy simply run:

```
python setup.py install
```

Note:

- sufficient priviledges are required (i.e. run in sudo with MacOSX/ Linux and set permissions on Windows)

Important: the Noddy executable has to be in a directory defined in the PATH variable!!

1.3 Documentation

1.4 Tutorial

A tutorial starting with simple examples for changing the geological history and visualisation of output, as well as the implementation of stochastic simulations and uncertainty visualisation are available as interactive ipython notebooks.

These notebooks are also included in this documentation as non-interactive versions.

1.5 Dependencies

pynoddy depends on several standard Python packages that should be shipped with any standard distribution (and are easy to install, otherwise):

- numpy
- matplotlib

- pickle

The uncertainty anaysis, quantification, and visualisation methods based on information theory are implemented in the python package pygeoinfo. This package is available on github and part of the python package index. It is automatically installed with the setup script provided with this package. For more information, please see:

(todo: include package info!)

In addition, to export model results for full 3-D visualisation with VTK, the pyevtk package is used, available on bitbucket:

https://bitbucket.org/pauloh/pyevtk/src/9c19e3a54d1e?at=v0.1.0

1.6 License

pynoddy is free software and published under a MIT license (see license file included in the repository). Please attribute the work when you use it, feel free to change and adapt it otherwise!

1.7 What is Noddy?

Noddy itself is a kinematic modelling program written by Mark Jessell [1] to simulate the effect of subsequent geological events (folding, unconformities, faulting, etc.) on a primary sedimentary pile. A typical example would be:

1. Create a sedimentary pile with defined thicknesses for multiple formations
2. Add a folding event (for example simple sinoidal folding, but complex methods are possible!)
3. Add an unconformity and, above it, a new sedimentary pile
4. Finally, add a sequence of late faults affecting the entire system.

The result could look something like this:

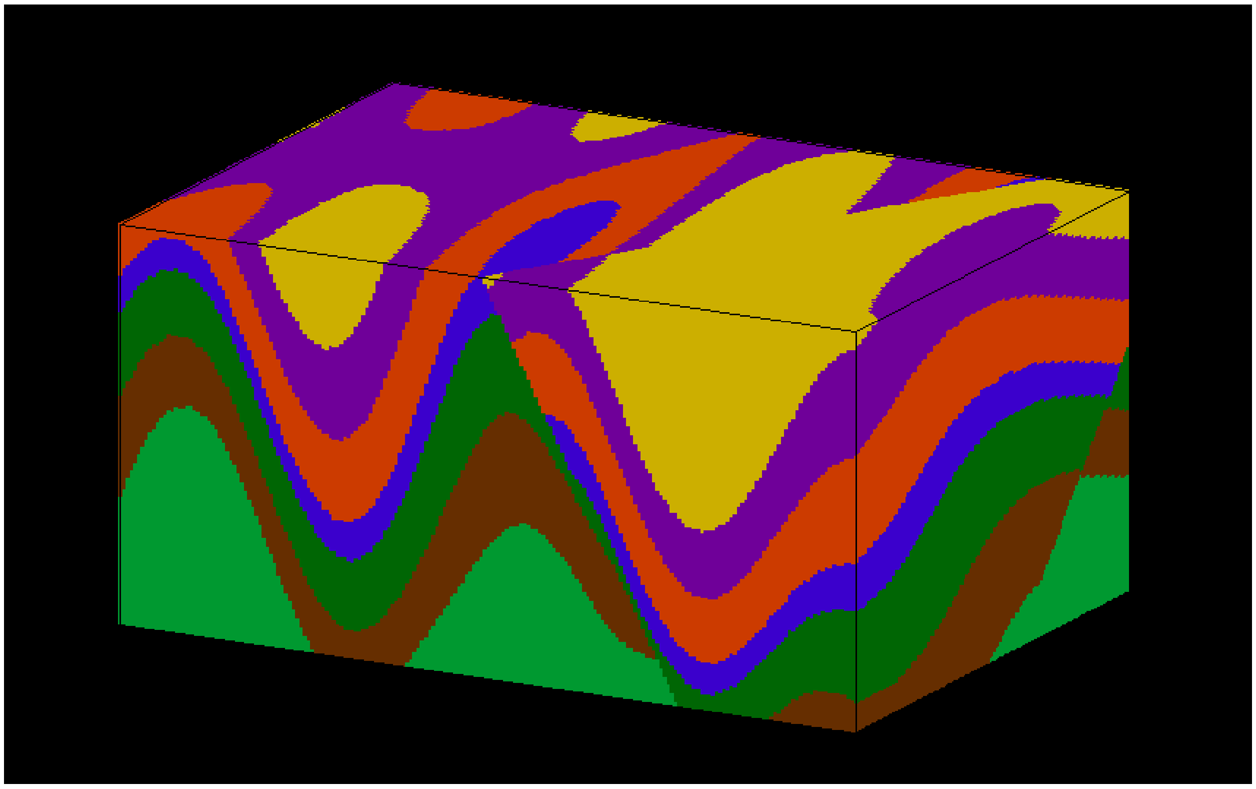
The software runs on Windows only, but the source files (written in C) are available for download to generate a command line version of the modelling step alone:

https://github.com/markjessell/functionNoddy

It has been tested and compiled on MacOSX, Windows and Linux.

1.8 References

[1] Mark W. Jessell, Rick K. Valenta, Structural geophysics: Integrated structural and geophysical modelling, In: Declan G. De Paor, Editor(s), Computer Methods in the Geosciences, Pergamon, 1996, Volume 15, Pages 303-324, ISSN 1874-561X, ISBN 9780080424309, http://dx.doi.org/10.1016/S1874-561X(96)80027-7.



CHAPTER

TWO

SIMULATION OF A NODDY HISTORY AND VISUALISATION OF OUTPUT

Examples of how the module can be used to run Noddy simulations and visualise the output.

```
# Basic settings
import sys, os
import subprocess

# Now import pynoddy
import pynoddy

# determine path of repository to set paths corretly below

repo_path = os.path.realpath('../..')
```

2.1 (1) Compute the model

The simplest way to perform the Noddy simulation through Python is simply to call the executable. One way that should be fairly platform independent is to use Python's own subprocess module:

```
# Change to sandbox directory to store results
os.chdir(os.path.join(repo_path, 'sandbox'))

# Path to exmaple directory in this repository
example_directory = os.path.join(repo_path,'examples')
# Compute noddy model for history file
history_file = 'simple_two_faults.his'
history = os.path.join(example_directory, history_file)
output_name = 'noddy_out'
# call Noddy

# NOTE: Make sure that the noddy executable is accessible in the system!!
sys
print subprocess.Popen(['noddy', history, output_name],
                       shell=False, stderr=subprocess.PIPE,
                       stdout=subprocess.PIPE).stdout.read()
#
```

For convenience, the model computation is wrapped into a Python function in pynoddy:

```
pynoddy.compute_model(history, output_name)
```

Note: The Noddy call from Python is, to date, calling Noddy through the subprocess function. In a future implementation, this call could be subsituted with a full wrapper for the C-functions written in Python. Therefore, using the member function compute_model is not only easier, but also the more “future-proof” way to compute the Noddy model.

2.2 (2) Loading Noddy output files

Noddy simulations produce a variety of different output files, depending on the type of simulation. The basic output is the geological model. Additional output files can contain geophysical responses, etc.

Loading the output files is simplified with a class class container that reads all relevant information and provides simple methods for plotting, model analysis, and export. To load the output information into a Python object:

```
N1 = pynoddy.NoddyOutput(output_name)
```

The object contains the calculated geology blocks and some additional information on grid spacing, model extent, etc. For example:

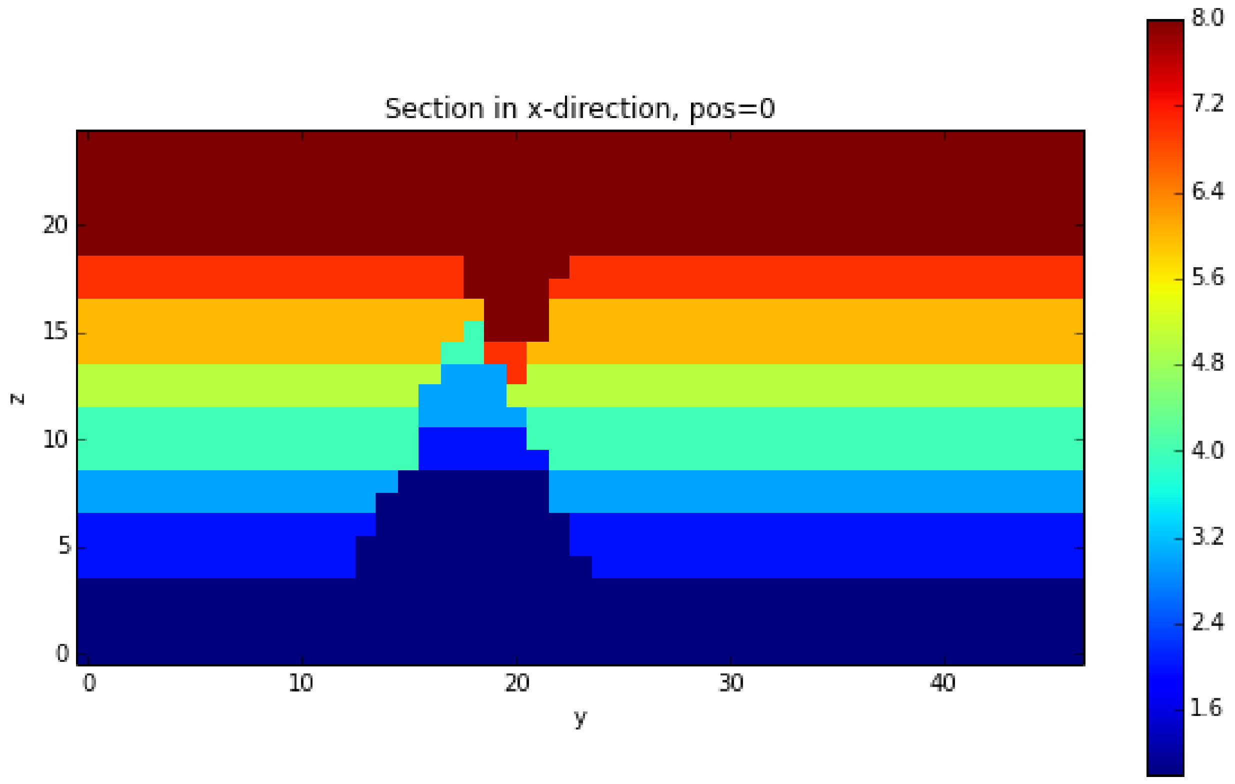
```
print("The model has an extent of %.0f m in x-direction, with %d cells of width %.0f m" %
      (N1.extent_x, N1.nx, N1.delx))
```

```
The model has an extent of 12400 m in x-direction, with 62 cells of width 200 m
```

2.3 (3) Plotting sections through the model

The NoddyOutput class has some basic methods for the visualisation of the generated models. To plot sections through the model:

```
N1.plot_section('x', position = 0)
```



2.4 (4) Export model to VTK

A simple possibility to visualise the modeled results in 3-D is to export the model to a VTK file and then to visualise it with a VTK viewer, for example Paraview. To export the model, simply use:

```
N1.export_to_vtk()
```

CHAPTER

THREE

CHANGE NODDY INPUT FILE AND RECOMPUTE MODEL

Visualising output of a Noddy model is nice, but not terribly helpful as it can be done with the GUI itself. More interesting is it to change aspects of the Noddy input (history) file with the Python module to quickly compare the effect of changes in the geological history.

Implementing these changes in scripts is the first step to a more extensive uncertainty analysis, as we will see in the next section.

```
import sys, os
import matplotlib.pyplot as plt
# adjust some settings for matplotlib
from matplotlib import rcParams
# print rcParams
rcParams['font.size'] = 15
# determine path of repository to set paths corretly below
# os.chdir(r'/Users/flow/git/pynoddy/docs/notebooks/')
repo_path = os.path.realpath('../..')
import pynoddy
```

First step: load the history file into a Python object:

```
# Change to sandbox directory to store results
os.chdir(os.path.join(repo_path, 'sandbox'))

# Path to exmaple directory in this repository
example_directory = os.path.join(repo_path,'examples')
# Compute noddy model for history file
history_file = 'simple_two_faults.his'
history = os.path.join(example_directory, history_file)
output_name = 'noddy_out'
H1 = pynoddy.NoddyHistory(history)
```

```
8
```

3.1 (1) Get basic information on the model

The history file contains the entire information on the Noddy model. Some information can be accessed through the NoddyHistory object (and more will be added soon!):

```
# history_file = 'two_faults_fold_unconformity_slice.his'
history = os.path.join(example_directory, history_file)
import pynoddy.history
reload(pynoddy.history)
reload(pynoddy.events)
```

```
H1 = pynoddy.history.NoddyHistory(history)
H1._raw_events
```

```
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[{'line_end': 161, 'line_start': 7, 'num': 1, 'type': ' STRATIGRAPHY'},
 {'line_end': 461, 'line_start': 162, 'num': 2, 'type': ' FAULT'},
 {'line_end': 762, 'line_start': 462, 'num': 3, 'type': ' FAULT'}]
```

```
H1.events
```

```
{1: <pynoddy.events.Stratigraphy instance at 0x104f9b320>,
 2: <pynoddy.events.Fault instance at 0x104f9b368>,
 3: <pynoddy.events.Fault instance at 0x104f9b440>}
```

```
H1.events[2].properties
# print H1.events[5].properties.keys()
```

```
{'Amplitude': 2000.0,
 'Blue': 254.0,
 'Color Name': 'Custom Colour 8',
 'Cyl Index': 0.0,
 'Dip': 60.0,
 'Dip Direction': 90.0,
 'Event #2': 'FAULT',
 'Geometry': 'Translation',
 'Green': 0.0,
 'Movement': 'Hanging Wall',
 'Pitch': 90.0,
 'Profile Pitch': 90.0,
 'Radius': 1000.0,
 'Red': 0.0,
 'Rotation': 30.0,
 'Slip': 1000.0,
 'X': 5500.0,
 'XAxis': 2000.0,
 'Y': 3968.0,
 'YAxis': 2000.0,
 'Z': 0.0,
 'ZAxis': 2000.0}
```

3.2 (2) Change model cube size and recompute model

The Noddy model itself is, once computed, a continuous model in 3-D space. However, for most visualisations and further calculations (e.g. geophysics), a discretised version is suitable. The discretisation (or block size) can be adapted in the history file. The according pynoddy function is change_cube_size.

A simple example to change the cube size and write a new history file:

```
# We will first recompute the model and store results in an output file for comparison
reload(pynoddy)
NH1 = pynoddy.NoddyHistory(history)
pynoddy.compute_model(history, output_name)
NO1 = pynoddy.NoddyOutput(output_name)
```

```
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# Now: change cubsize, write to new file and recompute
NH1.change_cube_size(50)
# Save model to a new history file and recompute (Note: may take a while to compute now)
new_history = "fault_model_changed_cubesize.his"
new_output_name = "noddy_out_changed_cube"
NH1.write_history(new_history)
pynoddy.compute_model(new_history, new_output_name)
NO2 = pynoddy.NoddyOutput(new_output_name)
```

The different cell sizes are also represented in the output files:

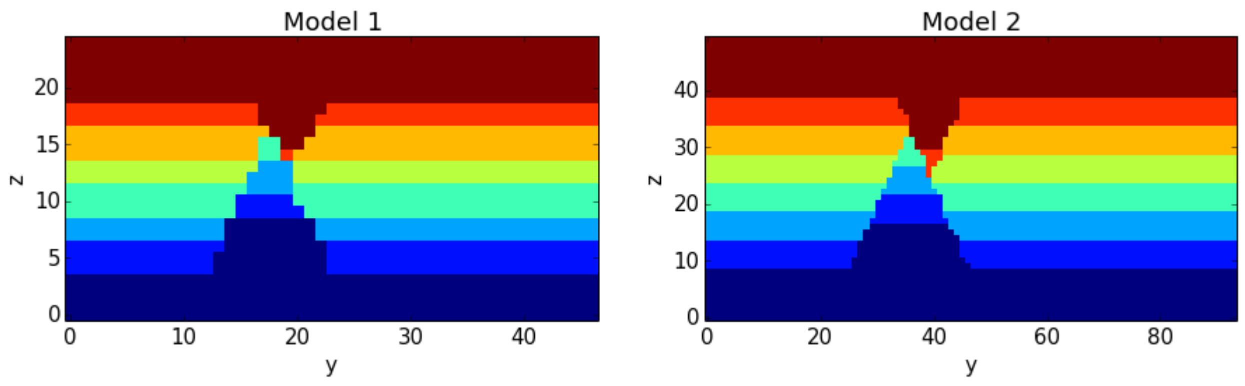
```
print("Model 1 contains a total of %7d cells with a blocksize %.0f m" %
      (NO1.n_total, NO1.delx))
print("Model 2 contains a total of %7d cells with a blocksize %.0f m" %
      (NO2.n_total, NO2.delx))
```

```
Model 1 contains a total of   72850 cells with a blocksize 200 m
Model 2 contains a total of  582800 cells with a blocksize 100 m
```

We can compare the effect of the different model discretisations in section plots, created with the plot_section method described before. Let's get a bit more fancy here and use the functionality to pass axes to the plot_section method, and to create one figure as direct comparison:

```
# create basic figure layout
fig = plt.figure(figsize = (15,5))
ax1 = fig.add_subplot(121)
ax2 = fig.add_subplot(122)
NO1.plot_section('x', ax = ax1, colorbar=False, title="Model 1")
NO2.plot_section('x', ax = ax2, colorbar=False, title="Model 2")

plt.show()
```



3.3 (3) Change aspects of geological events

Ok, now from some basic settings to the things that we actually want to change: aspects of the geological history defined in Noddy. This can happen on two hierarchical levels: on the level of each single event (i.e. changing parameters relating to one event) and on the level of the events themselves (i.e. the order of the events).

We will here have a look at the paramteres of the single events:

CHAPTER

FOUR

GEOLOGICAL EVENTS IN PYNODDY: ORGANISATION AND ADPATIATION

We will here describe how the single geological events of a Noddy history are organised within pynoddy. We will then evaluate in some more detail how aspects of events can be adapted and their effect evaluated.

4.1 Loading events from a Noddy history

In the current set-up of pynoddy, we always start with a pre-defined Noddy history loaded from a file, and then change aspects of the history and the single events. The first step is therefore to load the history file and to extract the single geological events. This is done automatically as default when loading the history file into the History object:

```
import sys, os
import matplotlib.pyplot as plt
# adjust some settings for matplotlib
from matplotlib import rcParams
# print rcParams
rcParams['font.size'] = 15
# determine path of repository to set paths corretly below
# os.chdir(r'/Users/flow/git/pynoddy/docs/notebooks/')# some basic module imports
repo_path = os.path.realpath('../..')

import pynoddy

# Change to sandbox directory to store results
os.chdir(os.path.join(repo_path, 'sandbox'))

# Path to exmaple directory in this repository
example_directory = os.path.join(repo_path,'examples')
# Compute noddy model for history file
history_file = 'simple_two_faults.his'
history = os.path.join(example_directory, history_file)
output_name = 'noddy_out'
reload(pynoddy.history)
H1 = pynoddy.history.NoddyHistory(history)
```

```
8
```

Events are stored in the object dictionary "events" (who would have thought), where the key corresponds to the position in the timeline:

```
H1.events
```

```
{1: <pynoddy.events.Stratigraphy instance at 0x10fc90680>,
 2: <pynoddy.events.Fault instance at 0x10fc90098>,
 3: <pynoddy.events.Fault instance at 0x10fc906c8>}
```

We can see here that three events are defined in the history. Events are organised as objects themselves, containing all the relevant properties and information about the events. For example, the second fault event is defined as:

```
H1.events[3].properties
```

```
{'Amplitude': 2000.0,
 'Blue': 0.0,
 'Color Name': 'Custom Colour 5',
 'Cyl Index': 0.0,
 'Dip': 60.0,
 'Dip Direction': 270.0,
 'Event #3': 'FAULT',
 'Geometry': 'Translation',
 'Green': 0.0,
 'Movement': 'Hanging Wall',
 'Pitch': 90.0,
 'Profile Pitch': 90.0,
 'Radius': 1000.0,
 'Red': 254.0,
 'Rotation': 30.0,
 'Slip': 1000.0,
 'X': 5500.0,
 'XAxis': 2000.0,
 'Y': 7000.0,
 'YAxis': 2000.0,
 'Z': 5000.0,
 'ZAxis': 2000.0}
```

4.2 Changing aspects of geological events

So what we now want to do, of course, is to change aspects of these events and to evaluate the effect on the resulting geological model.

Changes can be performed directly on the level of the Fault.properties dictionary:

```
# get the original dip of the fault
dip_ori = H1.events[3].properties['Dip']
# add 10 degrees to dip
dip_new = dip_ori + 10
# and assign back to properties dictionary:
H1.events[3].properties['Dip'] = dip_new
```

What is left now is to write the model back to a new history file, to recompute the model, and then visualise the output, as before, to compare the results:

```
H1.write_history(new_history)
pynoddy.compute_model(new_history, new_output)
```

```
H1.all_events_end
```

```
761
```

```
n_lines = 0
for ev in H1.events.values:
    ev.

  File "<ipython-input-96-da469714939a>", line 3
    ev.
       ^
SyntaxError: invalid syntax
```

```
print H1.history_lines[H1.all_events_begin]
print H1.history_lines[H1.all_events_end]
```

```
Event #1     = STRATIGRAPHY

    Name     = Fault1
```

```
a = [2,3]
b = [4,5]
c = []
c.append([a1 for a1 in a])
c.append(b[:])
c
```

```
[[2, 3], [4, 5]]
```

```
a.pop()
```

```
3
```

4.3 Changing the order of geological events

The geological history is parameterised as single events in a timeline. Changing the order of events can be performed with two basic methods:

1. Swapping two events with a simple command
2. Adjusting the entire timeline with a complete remapping of events

The first method is probably the most useful to test how a simple change in the order of events will effect the final geological model. We will use it here with our example to test how the model would change if the timing of the faults is swapped.

The method to swap two geological events is defined on the level of the history object:

```
reload(pynoddy.history)
reload(pynoddy.events)
H1 = pynoddy.history.NoddyHistory(history)
```

```
8
```

```
# The names of the two fault events defined in the history file are:
print H1.events[2].name
print H1.events[3].name
print H1.events[2].event_lines[-4:]
print H1.events[3].event_lines[-4:]
```

```
Fault1
```

```
Fault2
['tSurface XDimt= 0.000000rn', 'tSurface YDimt= 0.000000rn', 'tSurface ZDimt= 0.000000rn',
['tSurface XDimt= 0.000000rn', 'tSurface YDimt= 0.000000rn', 'tSurface ZDimt= 0.000000rn',
```

```
# Now: swap the events:
H1.swap_events(2,3)

# And let's check if this is correctly relfected in the events order now:
print H1.events[2].name
print H1.events[3].name
print H1.events[2].event_lines[-4:]
print H1.events[3].event_lines[-4:]
```

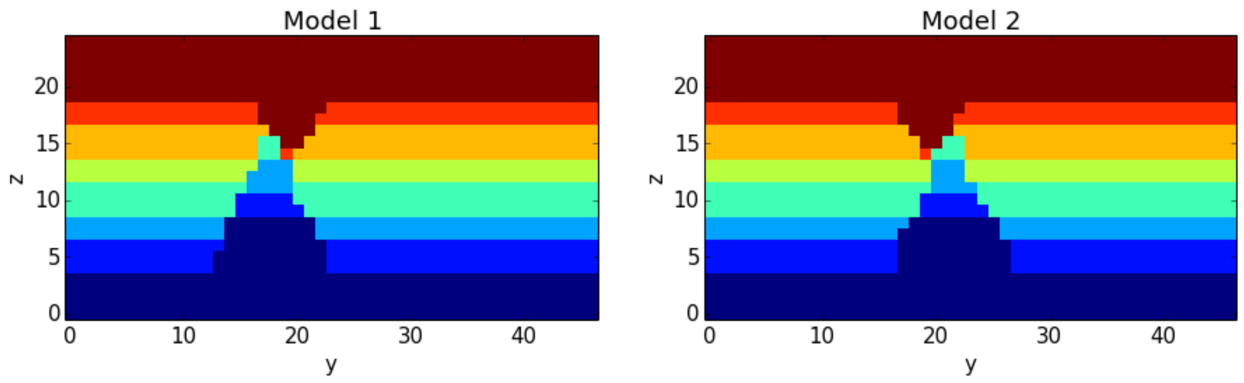
```
Fault1
Fault2
['tSurface XDimt= 0.000000rn', 'tSurface YDimt= 0.000000rn', 'tSurface ZDimt= 0.000000rn',
['tSurface XDimt= 0.000000rn', 'tSurface YDimt= 0.000000rn', 'tSurface ZDimt= 0.000000rn',
```

Now let's create a new history file and evaluate the effect of the changed order in a cross section view:

```
new_history = "faults_changed_order.his"
new_output = "faults_out"
H1.write_history(new_history)
pynoddy.compute_model(new_history, new_output)

# Load and compare both models
NO2 = pynoddy.NoddyOutput(output_name)
NO2 = pynoddy.NoddyOutput(new_output)
# create basic figure layout
fig = plt.figure(figsize = (15,5))
ax1 = fig.add_subplot(121)
ax2 = fig.add_subplot(122)
NO1.plot_section('x', ax = ax1, colorbar=False, title="Model 1")
NO2.plot_section('x', ax = ax2, colorbar=False, title="Model 2")

plt.show()
```



CHAPTER FIVE

STOCHASTIC EVENTS

The parameters defining the geological events are, by their very nature, highly uncertain. In addition to these uncertainties, the kinematic approach by itself is only a limiting approximation. The picture that we obtain from the kinematic forword model is therefore a very overconfident repsresentation of reality - an aspect that (hopefully) everyone using Noddy is aware of...

In order to respect the vast nature of these uncertainties, we introduce here an adapted version of the standard geological events defined in Noddy: the definition of a stochastic event:

A stochastic event is geological event in the Noddy history that has an uncertainty associated to it in such a way that, recomputing the geolgoical history will result in a different result each time (note: the definition is borrowed from the notion of stochastic events in probabilistic programming, see for example pymc).

5.1 Definition of stochastic events

We start, as before, with a pre-defined geological noddy history for simplicity:

CHAPTER

SIX

PYNODDY PACKAGE

6.1 Submodules

6.2 pynoddy.history module

Noddy history file wrapper Created on 24/03/2014

@author: Florian Wellmann

class `pynoddy.history.`**`NoddyHistory`**(*history*)

Class container for Noddy history files

`change_cube_size`(*cube_size*)

Change the model cube size (isotropic)

Arguments:

- *cube_size* = float : new model cube size

`determine_events`()

Determine events and save line numbers

Note: Parsing of the history file is based on a fixed Noddy output order. If this is, for some reason (e.g. in a changed version of Noddy) not the case, then this parsing might fail!

`load_history`(*history*)

Load Noddy history

Arguments:

- *history* = string : Name of Noddy history file

`swap_events`(*event_num_1*, *event_num_2*)

Swap two geological events in the timeline

Arguments:

- *event_num_1/2* = int : number of events to be swapped ("order")

`write_history`(*filename*)

Write history to new file

Arguments:

- *filename* = string : filename of new history file

Hint: Just love it how easy it is to 'write history' with Noddy ;-)

6.3 pynoddy.output module

Noddy output file analysis Created on 24/03/2014

@author: Florian Wellmann

class `pynoddy.output.`**`NoddyOutput`**(*output_name*)
Class definition for Noddy output analysis

`export_to_vtk`(***kwds*)
Export model to VTK

Export the geology blocks to VTK for visualisation of the entire 3-D model in an external VTK viewer, e.g. Paraview.

..Note:: Requires pyevtk, available for free on: https://github.com/firedrakeproject/firedrake/tree/master/python/evtk

Optional keywords:

- *vtk_filename* = string : filename of VTK file (default: output_name)

`load_geology`()
Load block geology ids from .g12 output file

`load_model_info`()
Load information about model discretisation from .g00 file

`plot_section`(*direction='y'*, *position='center'*, ***kwds*)
Create a section block through the model

Arguments:

- *direction* = 'x', 'y', 'z' : coordinate direction of section plot (default: 'y')
- ***position* = int or 'center'** [cell position of section as integer value] or identifier (default: 'center')

Optional Keywords:

- *ax* = matplotlib.axis : append plot to axis (default: create new plot)
- *figsize* = (x,y) : matplotlib figsize
- *colorbar* = bool : plot colorbar (default: True)
- *title* = string : plot title
- *savefig* = bool : save figure to file (default: show directly on screen)
- *cmap* = matplotlib.cmap : colormap
- *fig_filename* = string : figure filename

`test`()

6.4 Module contents

Package initialization file for pynoddy

`pynoddy.`**`compute_model`**`(`*history*, *output_name*`)`

CHAPTER

SEVEN

INDICES AND TABLES

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- *modindex*
- *search*

PYTHON MODULE INDEX