pyFormex manual

Release 0.4

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CONTENTS

Preface — Warning

This document is to become the pyFormex manual. As the pyFormex program itself is still under development, this document is by no means final and does not even pretend to be accurate for any version of pyFormex. However, as half documentation is better than none, we decided to make this preliminary version available to the general public. This document may evolve fast, so check back regularly. For the most uptodate info and for topics that are not covered in this manual yet, we refer the user to the pydoc pages[1] that were automatically generated from the pyFormex source.

[1] http://pyformex.berlios.de/doc

CHAPTER

ONE

Introduction

1.1 What is pyFormex?

You probably expect to find here a short definition of what pyFormex is and what it can do for you. I may have to disappoint you: describing the essence of pyFormex in a few lines is not an easy task to do, because the program can be (and is being) used for very different tasks. So I will give you two answers here: a short one and a long one.

The short answer is that pyFormex is a program to *generate large structured sets of coordinates by means of subsequent mathematical transformations gathered in a script.* If you find this definition too dull, incomprehensible or just not descriptive enough, read on through this section and look at some of the examples in this manual and on the pyFormex website[1]. You will then probably have a better idea of what pyFormex is.

The initial intent of pyFormex was the rapid design of three-dimensional structures with a configuration that can easier be obtained through mathematical description than through interactive generation of its subparts and assemblage thereof. While during development of the program we have concentrated mostly on wireframe type structures, surface and solid elements have been part of pyFormex right from the beginning. Still, most of the examples included with pyFormex are of frame type and most of the practical use of the program is in this area.

The stent[2] structure in the figure below is a good illustration of what pyFormex can do and what it was intended for.

This structure is composed of 22032 line segments, each with 2 nodes. Nobody in his right mind would ever even try to input all the 132192 coordinates of all the points describing that structure. With pyFormex, one could define the structure by a sequence of operations like this:

- Create a planar base module of two crossing wires.
- Extend the base module with a mirrored and translated copy.
- Replicate the base module in both directions of the base plane.
- Roll the planar grid into a cylinder.

The procedure is illustrated by the subsequent images in the figure below.

[1] http://pyformex.berlios.de

[2] A stent is a tube-shaped structure that is e.g. used to reopen (and keep open) obstructed blood vessels.

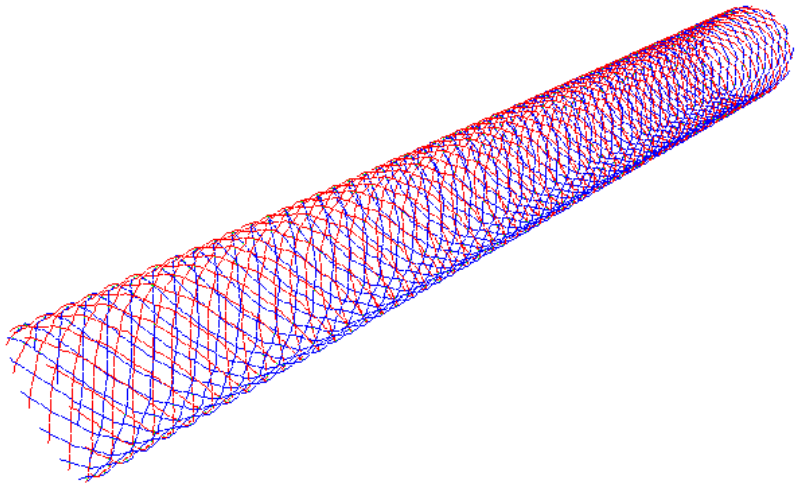


Figure 1.1: WireStent example.

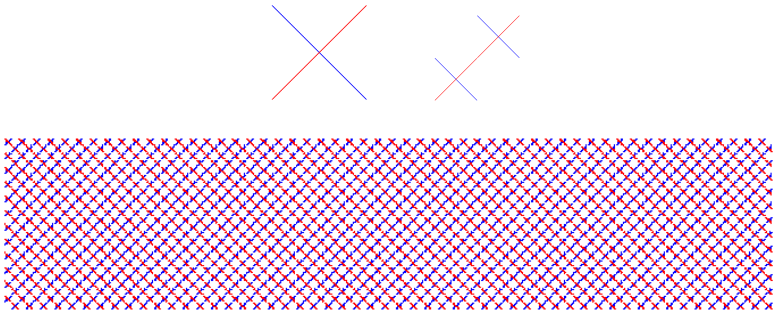


Figure 1.2: WireStent example.

1.2 Rationale

pyFormex does not fit into a single category of traditional (mostly commercial) software packages, because it is not being developed as a program with a specific purpose, but rather as a collection of tools we need is some of our research projects. Many of the tasks for which we now use pyFormex could as well or sometimes even better be done with some other software package, like a CAD program or a matrix calculation package or a solid modeler/renderer or a finite element preprocessor. Each of these is very well suited for the task it was designed for, but none provides all the features of pyFormex in a single consistent packages.

Perhaps the most important feature of pyFormex is that is was primarily intended to be an easy scripting language for creating geometrical models of 3D-structures. The Graphical User Interface was only added as a convenient means to visualize the designed structure. pyFormex can still run without user interface, and this makes it ideal for use in a batch toolchain.

The author of pyFormex, professor in structural engineering and heavy computer user since mainframe times, deeply regrets that computing skills of nowadays engineering students are often limited to using graphical interfaces of mostly commercial packages. This greatly limits their abilities, because in their mind: 'If there is no menu item to do a certain task, then it can not be done!' The hope to get some of them back to coding has been a stimulus in continuing our work on pyFormex.

Finally, pyFormex is, and will always be, free software in both meanings of free: guaranteeing your freedom (see 1.3) and without paying.

1.3 License and Disclaimer

1.4 Installation

1.4.1 Prerequisites

In order to run pyFormex, you need to have the following installed (and working) on your computer.

- Python[4]: Version 2.4 or higher is recommended. Versions 2.3 and 2.2 might work with only a few minor changes. Nearly all Linux distributions come with Python installed, so this should not be no major obstacle.
- NumPy[5]: Version 1.0-rc1 or higher. Earlier versions can be made to work, but will require some changes to be made. NumPy is the package we use for fast numerical array operations in Python and is essential for pyFormex.[6] On Linux systems, installing NumPy from source is usually straightforward. Debian users should install the packages python-numpy, python-numpy-dev and python-numpy-ext. There are binary packages for Windows on the Sourceforge download page[7].

If you only want to use the Formex data model and transformation methods, this will suffice. But most probably you will also want to run the pyFormex Graphical User Interface (GUI) for visualizing your structures. Then you also need the following.

- Qt4[8]: The widget toolkit on which the GUI was built. For Debian users this come in the packages python-qt4 and python-qt4-dev.
- PyQt4[9]: The Python bindings for Qt4. Debian users shoould install the packages python-qt4, python-qt4-dev, python-qt4-gl.
- PyOpenGL[10]: Pytong bindings for OpenGL, used for drawing and manipulating the 3D-structures. For denian users this is in package python-opengl.

[3] http://www.gnu.org/licenses/gpl.html
[4] http://www.python.org
[5] http://numpy.scipy.org/
[6] The `Numarray` package, which was used up until pyFormex 0.3, is no longer supported
[7] http://www.numpy.org/
[8] http://www.trolltech.com/products/qt
[9] http://www.riverbankcomputing.co.uk/pyqt/index.php
[10] http://pyopengl.sourceforge.net/

1.4.2 Downloading

The official releases of pyFormex can be downloaded from the pyFormex website[11]. As of the writing of this manual, the latest release is pyformex 0.4[12]. pyFormex is currently distributed in the form of a `.tar.gz` (tarball) archive. See 1.4.3 for how to proceed further.

Alternatively you can download the tarball releases from our local FTP server[13]. This one is slower, but you occasionally you might find there an interim release or release candidate not (yet) available on the official server.

Finally, you can also get the latest development code from the SVN repository on the pyFormex website[14]. If you have Subversion[15] installed on your system, you can just do
`svn checkout svn://svn.berlios.de/pyformex/trunk pyFormex`
and the whole current pyFormex tree will be copied to a subdirectory `pyformex` on your current path.

Unless you absolutely need some of the latest features or bugfixes, the tarball releases are what you want to go for.

1.4.3 Installation on Linux platforms

Once you have downloaded the pyFormex tarball, unpack it with
`tar xvzf pyformex-version.tar.gz`
Then go to the created pyformex directory:
`cd pyformex-version`
and do
`make install`
This will install pyFormex in `/usr/local/lib/pyformex-version`. If you want to install somewhere else, you need to change the Makefile first.

The installation procedure installs everything into this single directory, but also makes a couple of symlinks: /usr/local/share/doc/pyformex-version is a link to the doc subdirectory of pyformex, ans /usr/local/bin/pyformex is a link to the main executable pyformex.py.

1.4.4 Installation on Windows platforms

There is no installation procedure yet. All the pre-requisite packages are available for Windows, so in theory it is possible to run pyFormex on Windows. We know of some users who are running pyFormex succesfully using the –nogui option, i.e. without the Graphical User Interface (GUI). A few things may need to be changed for running the GUI on Windows. We will have a look at this in the future, but it is not our primary concern. Still, any feedback on (succesful or not succesful) installation attempts on Windows is welcome.

1.5 Running pyFormex

To start pyFormex, enter the command `pyformex`. This will start the pyFormex Graphical User Interface (GUI), form where you can launch examples or load, edit and run your own pyFormex scripts.

[11] http://pyformex.berlios.de
[12] http://prdownload.berlios.de/pyformex/pyformex-0.4.tar.gz
[13] ftp://bumps.ugent.be/pub/pyformex
[14] http://pyformex.berlios.de
[15] http://subversion.tigris.org/

The installation procedure may have installed pyFormex into your desktop menu or even have created a start button in the desktop panel. These provide convenient shortcuts to start the pyFormex GUI.

The pyFormex program takes some optional command line options, that modify the working of the program.

1.5.1 Command line options

The whole list of possible command line options can be seen by executing the command `pyformex -help`. This will produce the following output.

```
usage: pyformex.py [<options>] [ --  <Qapp-options> ]

options:
  --dri               Force the use of Direct Rendering
  --nodri             Disables the use of Direct Rendering (overrides the --dri
                      options)
  --makecurrent       Call makecurrent on initializing the OpenGL canvas
  --nogui             do not load the GUI
  --config=CONFIG     use file CONFIG for settings
  --nodefaultconfig   skip all default locations of config files
  --redirect          redirect standard output to the message board (only if no
                      --nogui option given)
  --debug             display debugging info to sys.stdout
  --version           show program's version number and exit
  -h, --help          show this help message and exit
```

1.5.2 Running pyFormex without the GUI

If you start pyFormex with the `-nogui` option, no Graphical User Interface is created. This is extremely useful to run automated scripts in batch mode. When run with the `-nogui` option, pyFormex will interprete all arguments remaining after interpreting the options, as filenames of scripts to be run (and possibly arguments to be interpreted by these scripts). Thus, if you want to run a pyFormex script `myscript.py` in batch mode, just give the command `pyformex -nogui myscript.py`.

1.6 Quick tutorial for the pyFormex GUI

In the current version () the GUI mainly serves the following purposes:

- Display a structure in 3D. This includes changing the viewpoint, orientation and viewing distance. Thus you can interactively rotate, translate, zoom.
- Save a view in one of the supported image formats. Most of the images in this manual and on the pyFormex website were created that way.
- Changing pyFormex settings (though there aren't many yet that can be changed through the GUI).
- Running pyFormex scripts, possibly starting other programs and display their results.

The GUI does not (yet) provide a means to interactively design a structure, select parts of a structure or set/show information about (parts of) the structure. Designing a structure is done by writing a small script with the mathematical expressions needed to generate it. Any text editor will be suitable for this purpose. The author uses XEmacs, but this is just a personal preference. A pyFormex editor integrated into the

GUI remains on our TODO list, but it certainly is not our top priority, because general purpose editors are adequate for most of our purposes.

Since Python[16] is the language used in pyFormex scripts, a Python aware editor is preferable. It will highlight the syntax and help you with proper alignment (which is very important in Python).

The best way to learn to use pyFormex is by studying and changing some of the examples. I suggest that you first take a look at the examples included in the pyFormex GUI and select those that display structures that look interesting to you. Then you can study the source code of those examples and see how the structures got built. When starting up, pyFormex reads through the Examples directory (this is normally the 'examples' subdirecty located under the pyformex installation dir). Examples > WireStent

1.6.1 Customizing the GUI

Some parts of the pyFormex GUI can easily be customized by the user. The appearance (widget style and fonts) can be changed from the preferences menu. Custom menus can be added by executing a script. Both are very simple tasks even for beginning users. They are explained shortly hereafter.

Experienced users with a sufficient knowledge of Python and GUI building with Qt can of course use all their skills to tune every single aspect of the pyFormex GUI according to their wishes. If you send us your modifications, we might even include them in the official distribution.

Changing the appearance of the GUI

Adding custom menus

When you start using pyFormex for serious work, you will probably run into complex scripts built from simpler subtasks that are not necessarily always executed in the same order. While the pyFormex scripting language offers enough functions to ask the user which parts of the script should be executed, in some cases it might be better to extend the pyFormex GUI with custom menus to execute some parts of your script.

For this purpose, the gui.widgets module of pyFormex provides a Menu widget class. Its use is illustrated in the example Stl.py.

1.7 Quick Python tutorial

This could be part of the tutorial in chapter 2

1.8 Quick NumPy tutorial

This could be part of the tutorial in chapter 2

[16] http://www.python.org

CHAPTER

TWO

PYFORMEXtutorial

2.1 Introduction

pyFormex is a Python implementation of Formex algebra. Using pyFormex, it is very easy to generate large geometrical models of 3D structures by a sequence of mathematical transformations. It is especially suited for the automated design of spatial frame structures. But it can also be used for other tasks, like finite element preprocessing, or just for creating some nice pictures.

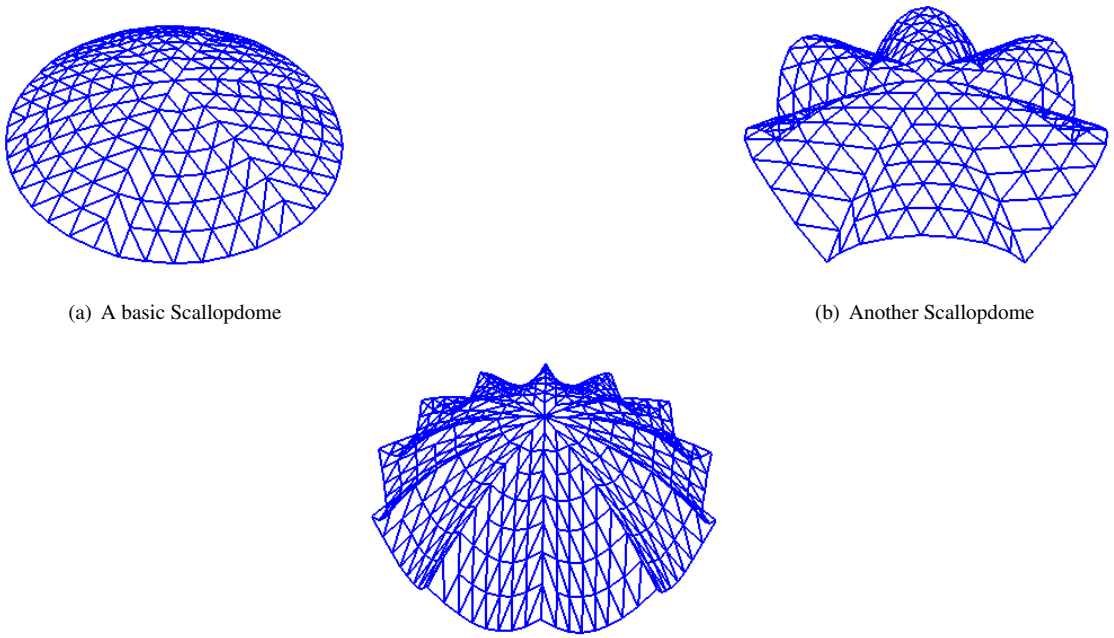
By writing a very simple script, a large geometry can be created by copying, translating, rotating,... Formices. pyFormex will interpret this script and draw what you have created. This is clearly very different than the traditional way of creating a model, like CAD. There are two huge advantages about using pyFormex:

- It is especially suited for the automated design of spatial frame structures. A dome, arc, hypar,... can be rather difficult to draw with CAD, but when using mathematical transformations, it becomes a piece of cake!
- Using a script makes it very easy to apply changes in the geometry: you simply modify the script and let pyFormex play it again. For instance, you can easily change an angle, the radius of a dome, the ratio f/l of an arc,... Using CAD, you would have to make an entirely new drawing! This is also illustrated in fig 2.1: these domes were all created with the same script, but with other values of the parameters.

2.2 Getting started

This section holds some basic information on how to use Python and pyFormex.

- Each script should begin with `#!/usr/bin/env pyformex`
- To start the pyFormex GUI, double click on the file 'pyformex' in the installation directory, or type *pyformex* in the terminal. Using the terminal can be very useful, because errors that are created while running the script will appear in the terminal. This can provide useful information when something goes wrong with your script.
- To create a new pyFormex-script, just open a new file with your favorite text editor and save it as 'myproject.py'.
- To edit a script, you can
  - Open it with your favorite text editor.



(a) A basic Scallopdome

(b) Another Scallopdome

(c) Yet another Scallopdome

Figure 2.1: Same script, different domes

  - File > Open
    At this point, the script will be loaded but nothing will happen.
    File > Edit
    The script will now open in the default text editor. This default editor can be changed in the file '.pyformexrc' in the installation directory.

- To play a script, you can
  - File > Open
    File > Play
  - Type *pyformex myproject.py* in the terminal. This will start the pyFormex GUI and load your script at the same time.
    File > Play
  - To play a script without using the GUI (for example in finite element preprocessing, if you only want to write an output file, without drawing the structure), type *pyformex –nogui myproject.py*

- When writing a script in Python, there are some things you should keep in mind:
  - When using a function that requires arguments, an argument list must have any positional arguments followed by any keyword arguments, where the keywords must be chosen from the formal parameter names. It's not important whether a formal parameter has a default value or not. No argument may receive a value more than once – formal parameter names corresponding to positional arguments cannot be used as keywords in the same calls.

    Simply put: you can either set the arguments in the right order and only give their value, or you can give arguments by their name and value. This last option holds some advantages: not only is it easier to check what you did, but sometimes a function has many arguments with default values and you only want to change a few. If this isn't entirely clear yet, just look at the examples later in this tutorial or check the Python tutorial.

– Indentation is essential in Python. Indentation is Python's way of grouping statements. In straight-forward scripts, indentation is not needed (and forbidden!), but when using a for-statement for example, the body of the statement has to be indented. A small example might make this clear. Also notice the ':'

```
print 'properties'
for key, item in properties.iteritems():
    print key, item
```

– If you want to use functions from a seperate module (like `properties`), you add a line on top of the script

```
from properties import *
```

All functions from that module are now available.

– The hash character, "#", is used to start a comment in Python.

– Python is case sensative.

2.3 The geometrical model

2.3.1 Creating a Formex

What is a Formex?

A Formex is a numarray of order 3 (axes 0,1,2) and type Float. A scalar element represents a coordinate (F:uniple).

A row along the axis 2 is a set of coordinates and represents a point (node, vertex, F: signet). For simplicity's sake, the current implementation only deals with points in a 3-dimensional space. This means that the length of axis 2 is always 3. The user can create Formices (plural of Formex) in a 2-D space, but internally these will be stored with 3 coordinates, by adding a third value 0. All operations work with 3-D coordinate sets. However, a method exists to extract only a limited set of coordinates from the results, permitting to return to a 2-D environment.

A plane along the axes 2 and 1 is a set of points (F: cantle). This can be thought of as a geometrical shape (2 points form a line segment, 3 points make a triangle, ...) or as an element in FE terms. But it really is up to the user as to how this set of points is to be interpreted.

Finally, the whole Formex represents a set of such elements.

Additionally, a Formex may have a property set, which is an 1-D array of integers. The length of the array is equal to the length of axis 0 of the Formex data (i.e. the number of elements in the Formex). Thus, a single integer value may be attributed to each element. It is up to the user to define the use of this integer (e.g. it could be an index in a table of element property records). If a property set is defined, it will be copied together with the Formex data whenever copies of the Formex (or parts thereof) are made. Properties can be specified at creation time, and they can be set, modified or deleted at any time. Of course, the properties that are copied in an operation are those that exist at the time of performing the operation.

Simply put: a Formex is a set of elements, and every element can have a property number.

Creating a Formex using coordinates

The first and most useful way to create a Formex is by specifying it's nodes and elements in a 3D-list.

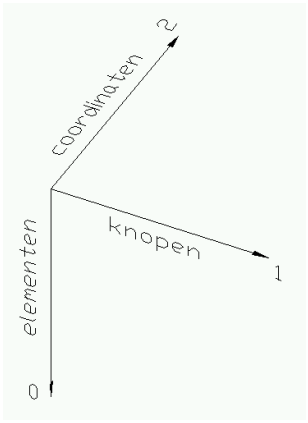


Figure 2.2: The scheme of a Formex

```
F=Formex([[[0,0],[1,0],[1,1],[0,1]]])
```

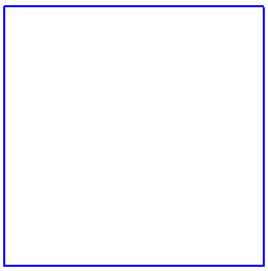


Figure 2.3: A very simple Formex

This creates a Formex F, which has the nodes (0,0), (1,0), (1,1) and (0,1). These nodes are all part of a single element, thus creating a square plane. This element is also the entire Formex. On the other hand, if you would change the position of the square brackets like in the following example, then you'd create a Formex F which is different from the previous. The nodes are the same, but the connection is different. The nodes (0,0) and (1,0) are linked together by an element, and so are the nodes (1,1) and (0,1). The Formex is now a set of 2 parallel bars, instead of a single square plane.

```
F=Formex([[[0,0],[1,0]],[[1,1],[0,1]]])
```

If we want to define a Formex, similar to the square plane, but consisting of the 4 edges instead of the actual plane, we have to define four elements and combine them in a Formex. This is *not* the same Formex as fig 2.3, although it looks exactly the same.

```
F=Formex([[[0,0],[0,1]], [[0,1],[1,1]], [[1,1],[1,0]], [[1,0],[0,0]]])
```

The previous examples were limited to a 2-D environment for simplicity's sake. Of course, we could add a third dimension. For instance, it's no problem defining a pyramid consisting of 8 elements ('bars').

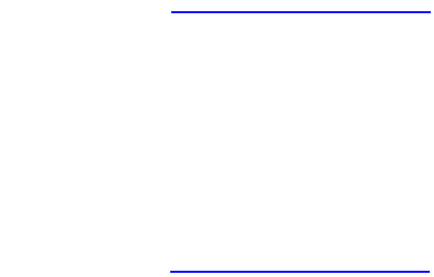


Figure 2.4: Same nodes, different Formex

```
F=Formex([[[0,0,0],[0,1,0]], [[0,1,0],[1,1,0]], [[1,1,0],[1,0,0]], [[1,0,0],
[0,0,0]], [[0,0,0],[0,1,0]], [[0,0,0],[0.5,0.5,1]], [[1,0,0],[0.5,0.5,1]],
[[1,1,0], [0.5,0.5,1]], [[0,1,0],[0.5,0.5,1]]])
```

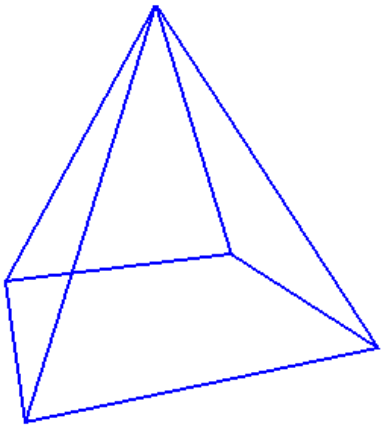


Figure 2.5: A pyramid

However, as you can see, even in this very small example the number of nodes, elements and coordinates you have to declare becomes rather large. Defining large Formices using this method would not be practical. This problem is easily overcome by copying, translating, rotating,... a smaller Formex — as will be explained in 2.3.6 — or by using patterns.

Creating a Formex using patterns

The second way of creating a new Formex, is by defining patterns. In this case, a line segment pattern is created from a string.

The function `pattern(s)` creates a list of line segments where all nodes lie on the gridpoints of a regular grid with unit step. The first point of the list is [0,0,0]. Each character from the given string *s* is interpreted as a code specifying how to move to the next node. Currently defined are the following codes:
0 = goto origin [0,0,0]
1..8 move in the x,y plane
9 remains at the same place
When looking at the plane with the x-axis to the right,

1 = East, 2 = North, 3 = West, 4 = South, 5 = NE, 6 = NW, 7 = SW, 8 = SE.
Adding 16 to the ordinal of the character causes an extra move of +1 in the z-direction. Adding 48 causes an extra move of -1. This means that 'ABCDEFGHI', resp. 'abcdefghi', correspond with '123456789' with an extra z +/-= 1. The special character '\' can be put before any character to make the move without making a connection. The effect of any other character is undefined.

This method has important restrictions, since it can only create lines on a regular grid. However, it can be a much easier and shorter way to define a simple Formex. This is illustrated by the difference in length between the previous creation of a square and the next one, although they define the same Formex (figure 2.3).

```
F=Formex(pattern('1234'))
```

Some simple patterns are defined in `simple.py` and are ready for use. These patterns are stacked in a dictionary called 'Patterns'. Items of this dictionary can be accessed like `Patterns['cube']`.

```
#!/usr/bin/env pyformex
from simple import *
c=Formex(pattern(Pattern['cube']))
clear();draw(c)
```

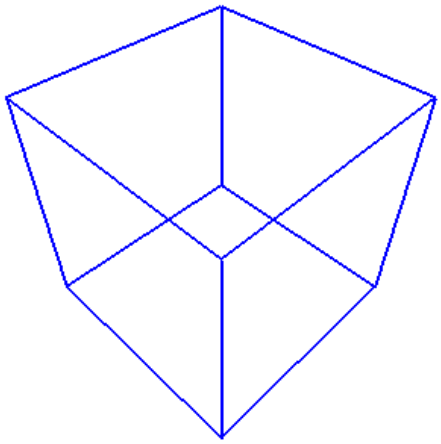


Figure 2.6: A cube

Creating a Formex using coordinates from a file

In some cases, you might want to read coordinates from a file an combine them into a Formex. This is possible with the module `file2formex` and it's function `fileFormex()`. Each point is connected to the following, forming an element (bar).

The next file ('square.txt') would create the same square as before(figure 2.3).

```
0,0,0
0,1,0
1,1,0
1,0,0
```

```
#!/usr/bin/env pyformex
from file2formex import *
F=fileFormex('square.text', closed='yes')
```

2.3.2 Adding property numbers

Each Formex element can have a property number. Each property number is represented by a different color when the Formex is drawn. This is the first reason why you could use property numbers: to make your drawing more transparent or just more beautiful. However, these numbers can also be used as an entry in a dictionary of properties - thus linking the element with a property. This property can be about anything, but in finite element processing this would be the element section, material, loads,... The use of properties in this way will be futher explained in 2.4. Property numbers can be specified at creation time, and they can be set, modified or deleted at any time.

```
>>> #!/usr/bin/env pyformex
>>> F=Formex(pattern('1234'),[5])
>>> print F.prop()
>>> G=Formex(pattern('1234'),[6,8,2,4])
>>> print G.prop()
>>> F.setProp([6,7])
>>> print F.prop()
>>> G.setProp([6,7,8,9])
>>> print G.prop()

[5 5 5 5]
[6 8 2 4]
[6 7 6 7]
[6 7 8 9]
```

2.3.3 Drawing a Formex

Of course, you'd want to see what you have created. This is accomplished by the function `draw()`. The next example creates figure 2.5.

```
F=Formex([[[0,0,0],[0,1,0]], [[0,1,0],[1,1,0]], [[1,1,0],[1,0,0]], [[1,0,0],
[0,0,0]], [[0,0,0],[0,1,0]], [[0,0,0],[0.5,0.5,1]], [[1,0,0],[0.5,0.5,1]],
[[1,1,0], [0.5,0.5,1]], [[0,1,0],[0.5,0.5,1]]])
draw(F)
```

It also possible to draw multiple Formices at the same time.

```
from simple import *
F=Formex([[[0,0,0],[0,1,0]], [[0,1,0],[1,1,0]], [[1,1,0],[1,0,0]], [[1,0,0],
[0,0,0]], [[0,0,0],[0,1,0]], [[0,0,0],[0.5,0.5,1]], [[1,0,0],[0.5,0.5,1]],
[[1,1,0],[0.5,0.5,1]], [[0,1,0],[0.5,0.5,1]]]).setProp(1)
G=Formex(pattern(Pattern['cube'])).setProp(3)
draw(F+G)
```

It might be important to realize that even if you don't draw a particular Formex, that doesn't mean you didn't create it!

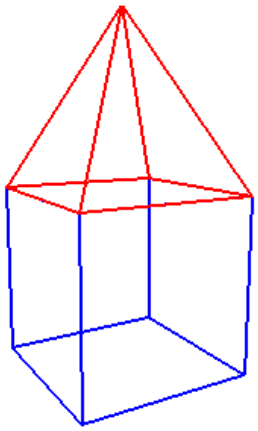


Figure 2.7: Drawing multiple Formices

Now, when you are creating a large geometry, you might be interested in seeing the different steps in the creation. To remove all previously drawn Formices, you can use `clear()` what sweepes the screen clean. If you want to see a certain step in the creation longer than the default time, use `sleep(t)`, with t the delay (in seconds) before executing the next command.

```
F=Formex(pattern('164'))
draw(F)
G=F.replic(5,1,0)
clear()
draw(G)
```

2.3.4 Saving images

After drawing the Formex, you might want to save the image. This is very easy to do:
File > Save Image
The filetype should be 'bmp', 'jpg', 'pbm', 'png', 'ppm', 'xbm', 'xpm', 'eps', 'ps', 'pdf' or 'tex'.
To create a better looking picture, several settings can be changed:

- Change the background color Settings > Background Color
- Use a different (bigger) linewidth Settings > Linewidth
- Change the canvas size. This prevents having to cut and rescale the figure with an image manipulation program (and loosing quality by doing so). Settings > Canvas Size

It is also possible to save a series of images. This can be especially useful when playing a script which creates several images, and you would like to save them all. For example, figure 1.1, which shows the different steps in the creation of the WireStent model, was created this way.
File > Toggle MultiSave

2.3.5 Information about a Formex

There are a number of functions available that return information about a Formex. Especially when using pyFormex as finite element preprocessor, the most useful functions are:

Function	Description
`F.nelems()`	Return the number of elements in the Formex.
`F.nnodes()`	Return the number of nodes in the Formex.
`F.prop()`	Return the properties as a numpy array.
`F.bbox()`	Return the bounding box of the Formex.
`F.center()`	Return the center of the Formex.
`F.feModel()`	Return a tuple of nodal coordinates and element connectivity.

`feModel()` is very important in finite element processing. It returns all nodes and all elements of the Formex in a format useful for FE processing. A tuple of two arrays is returned. The first is float array with the coordinates of the unique nodes of the Formex. The second is an integer array with the node numbers connected by each element.

```
>>> #!/usr/bin/env pyformex
>>> from simple import *

>>> c = Formex(pattern(Pattern['cube']))
>>> draw(c)
>>> nodes,elems = c.feModel()
>>> print 'Nodes'
>>> print nodes
>>> print 'Elements'
>>> print elems

Nodes
[[ 0.  0. -1.]
 [ 1.  0. -1.]
 [ 0.  1. -1.]
 [ 1.  1. -1.]
 [ 0.  0.  0.]
 [ 1.  0.  0.]
 [ 0.  1.  0.]
 [ 1.  1.  0.]]
Elements
[[4 5]
 [5 7]
 [7 6]
 [6 4]
 [4 0]
 [5 1]
 [7 3]
 [6 2]
 [0 1]
 [1 3]
 [3 2]
 [2 0]]
```

2.3.6 Changing the Formex

Until now, we've only created simple Formices. The strength of pyFormex however is that it is very easy to generate large geometrical models by a sequence of mathematical transformations. After initiating a basic Formex, it's possible to transform it by using copies, translations, rotations, projections,...

There are many transformations available, but this is not the right place to describe them all. This is what the reference manual in chapter 3 is for. A summary of all possible transformations and functions can be found there.

To illustrate some of these transformations and the recommended way of writing a script, we will analyse some of the examples. More of these interesting examples are found in 'installdir/examples'. Let's begin with the example 'Spiral.py'.

```
#!/usr/bin/env pyformex
# $Id$
##
## This file is part of pyFormex 0.3 Release Mon Feb 20 21:04:03 2006
## pyFormex is a python implementation of Formex algebra
## Homepage: http://pyformex.berlios.de/
## Distributed under the GNU General Public License, see file COPYING
## Copyright (C) Benedict Verhegghe except where stated otherwise
##
#
"""Spiral"""

m = 36 # number of cells along torus big circle
n = 10 # number of cells along torus small circle

def drawit(F,view='front'):
    clear()
    draw(F,view)

F = Formex(pattern("164"),[1,2,3]); drawit(F)
F = F.replic(m,1,0); drawit(F)
F = F.replic(n,1,1); drawit(F)
F = F.translate1(2,1); drawit(F,'iso')
F = F.cylindrical([2,1,0],[1.,360./n,1.]); drawit(F,'iso')
F = F.replic(5,m,2); drawit(F,'iso')
F = F.rotate(-10,0); drawit(F,'iso')
F = F.translate1(0,5); drawit(F,'iso')
F = F.cylindrical([0,2,1],[1.,360./m,1.]); drawit(F,'iso')
drawit(F,'right')
```

During this first read-through, you will have noticed that every step is drawn. Of course, this is not necessary, but it can be useful. And above all, it is very educational for use in a tutorial...

The next important thing is that parameters were used. It's recommended to always do this, especially when you want to do a parametric study of course, but it can also be very convenient if at some point you want to change the geometry (for example when you want to re-use the script for another application).

A simple function `drawit()` is defined for use in this script only. This function only provides a shorter way of drawing Formices, since it combines `clear()` and `draw`.

Now, let's dissect the script.

```
def drawit(F,view='front'):
    clear()
    draw(F,view)
```

This is a small function that is only defined in this script. It clears the screen and draws the Formex at the same time.

```
m = 36 # number of cells along torus big circle
n = 10 # number of cells along torus small circle
```

These are the parameters. They can easily be changed, and a whole new spiral will be created without any extra effort. The first step is to create a basic Formex. In this case, it's a triangle which has a different property number for every edge.

```
F = Formex(pattern("164"),[1,2,3]); drawit(F)
```

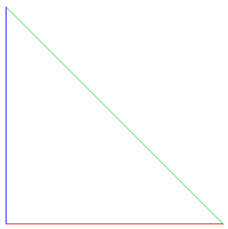


Figure 2.8: The basic Formex

This basic Formex is copied 'm' times in the 0-direction with a translation step of '1' (the length of an edge of the triangle). After that, the new Formex is copied 'n' times in the 1-direction with a translation step of '1'. Because of the recursive definition (F=F.replic), the original Formex F is overwritten by the transformed one.

```
F = F.replic(m,1,0); drawit(F)
F = F.replic(n,1,1); drawit(F)
```

Now a copy of this last Formex is translated in direction '2' with a translation step of '1'. This necessary for the transformation into a cilinder. The result of all previous steps is a rectangular pattern with the desired dimensions, in a plane z=1.

```
F = F.translate(2,1); drawit(F,'iso')
```

This pattern is rolled up into a cilinder around the 2-axis.

```
F = F.cylindrical([2,1,0],[1.,360./n,1.]); drawit(F,'iso')
```

This cilinder is copied 5 times in the 2-direction with a translation step of 'm' (the lenght of the cilinder).

```
F = F.replic(5,m,2); drawit(F,'iso')
```

The next step is to rotate this cilinder -10 degrees around the 0-axis. This will determine the pitch angle of

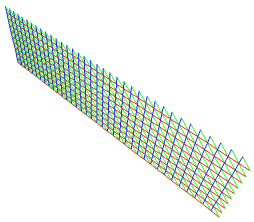


Figure 2.9: The rectangular pattern

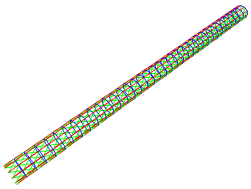


Figure 2.10: The cylinder

the spiral.

```
F = F.rotate(-10,0); drawit(F,'iso')
```

Figure 2.11: The new cylinder

This last Formex is now translated in direction '0' with a translation step of '5'.

```
F = F.translate(0,5); drawit(F,'iso')
```

Finally, the Formex is rolled up, but around a different axis then before. Due to the pitch angle, a spiral is created. If the pitch angle would be 0 (no rotation of -10 degrees around the 0-axis), the resulting Formex would be a torus.

```
F = F.cylindrical([0,2,1],[1.,360./m,1.]); drawit(F,'iso')
drawit(F,'right')
```

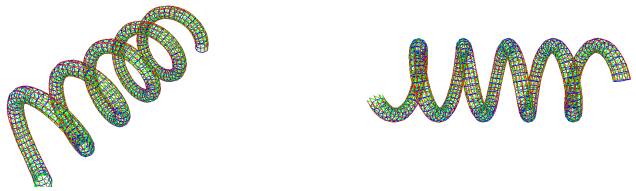


Figure 2.12: The spiral

2.4 Adding properties

Each element of a Formex can hold a property number. This number can be used as an entry in a database, which holds some sort of property. The module `properties` delivers such databases. The Formex and the database are seperate entities, only linked by the property numbers.

2.4.1 The class Property

The first kind of database is called `Property`. This is the base class, and can hold any kind of property.

```
>>> Stick = Property(1, {'colour':'green', 'name':'Stick', 'weight': 25,
'comment':'This could be anything: a gum, a frog, a usb-stick,...'})
>>> author = Property(5,{'Name':'Tim Neels', 'Address': CascadingDict
{'street':'Krijgslaan','city':'Gent','country':'Belgium'})})
```

Data can be accessed in two ways: through the Property-instance itself, or through a dict 'properties'.

```
>>> print Stick
>>> print properties[1]

  comment = This could be anything: a gum, a frog, a usb-stick,...
  colour = green
  name = Stick
  weight = 25

  comment = This could be anything: a gum, a frog, a usb-stick,...
  colour = green
  name = Stick
  weight = 25
```

Adding and changing properties is very easy.

```
>>> Stick.weight=30
>>> Stick.length=10
>>> print properties[1]

  comment = This could be anything: a gum, a frog, a usb-stick,...
  length = 10
  colour = green
  name = Stick
  weight = 30
```

2.4.2 The class NodeProperty

The class NodeProperty can hold properties of nodes in finite element processing. The data is stored in a Dict called 'nodeproperties'. A NodeProperty can hold following sub-properties:

cload A concentrated load. This is a list of 6 items `[F_0, F_1, F_2, M_0, M_1, M_2]`.

bound A boundary condition. This can be defined in 2 ways:

- as a list of 6 items `[ R_0, R_1, R_2, M_0, M_1, M_2 ]`. These items have 2 possible values:

  0 The degree of freedom is not restrained.

  1 The degree of freedom is restrained.

- as a string. This string is a standard boundary type. In Abaqus several types are available:
  - PINNED
  - ENCASTRE
  - XSYMM
  - YSYMM
  - ZSYMM
  - XASYMM
  - YASYMM
  - ZASYMM

displacement The prescribed displacement.

coords The coordinate system which is used for the definition of cload and bound. There are three options: cartesian, spherical and cylindrical.

coordset A list of 6 coordinates of the 2 points that specify the transformation: `[x_1, y_1, z_1, x_2, y_2, z_2]`.

```
>>> top = NodeProperty(1,cload=[5,0,-75,0,0,0])
>>> foot = NodeProperty(2,bound='pinned')
>>> print 'nodeproperties'
>>> for key, item in nodeproperties.iteritems():
>>>     print key, item

nodeproperties
1
  cload = [5, 0, -75, 0, 0, 0]
  coords = cartesian
  displacement = None
  bound = None
  coordset = []
2
  cload = None
  coords = cartesian
  displacement = None
  bound = pinned
  coordset = []
```

2.4.3 The class ElemProperty

The class ElemProperty holds properties related to a single element. The data is stored in a Dict called 'elemproperties'. An element property can hold the following sub-properties:

elemsection The section properties of the element. This is an ElemSection instance.

elemload The loading of the element. This is a list of ElemLoad instances.

elemtype The type of element that is to be used in the analysis.

An elemsection can hold the following sub-properties:

section The section properties of the element. This can be a dictionary or a string. The required data in this dict depends on the sectiontype.

material The element material properties. This can be a dictionary which holds these properties or a string which can be used to search a material database.

sectiontype The sectiontype of the element.

orientation A list [First direction cosine, second direction cosine, third direction cosine] of the first beam section axis. This allows to change the orientation of the cross-section.

An element load can hold the following sub-properties:

magnitude The magnitude of the distibuted load.

loadlabel The distributed load type label.

The general structure of the element properties database looks like this:

- Property
- NodeProperty
    - cload
    - bound
    - displacement
    - coords
    - coordset
- ElemProperty
    - elemsection
        - section
        - material
        - sectiontype
        - orientation
    - elemload
        - magnitude
        - loadlabel
    - elemtype

```
>>> vert = ElemSection('IPEA100', 'steel')
>>> hor = ElemSection({'name':'IPEM800','A':951247,'I':CascadingDict(
{'Ix':1542,'Iy':6251,'Ixy':352})}, {'name':'S400','E':210,'fy':400})
>>> q = ElemLoad(magnitude=2.5, loadlabel='PZ')
>>> top = ElemProperty(1,hor,[q],'B22')
>>> column = ElemProperty(2,vert, elemtype='B22')
>>> diagonal = ElemProperty(4,hor,elemtype='B22')

>>> print 'elemproperties'
>>> for key, item in elemproperties.iteritems():
>>>     print key, item

elemproperties
1
  elemtype = B22
  elemload = [CascadingDict({'magnitude': 2.5, 'loadlabel': 'PZ'})]
  elemsection =
    section =
      A = 951247
      I =
        Iy = 6251
        Ix = 1542
        Ixy = 352
      name = IPEM800
    material =
      fy = 400
      E = 210
      name = S400
    orientation = None
    sectiontype = general
2
  elemtype = B22
  elemload = None
  elemsection =
    section =
      torsional_rigidity = 1542
      name = IPEA100
      moment_inertia_22 = 1140000
      cross_section = 878
      moment_inertia_11 = 1412000
      moment_inertia_12 = 1254
    material =
      shear_modulus = 25
      young_modulus = 210
      name = steel
    orientation = None
    sectiontype = general
4
  elemtype = B22
  elemload = None
  elemsection =
    section =
      A = 951247
      I =
        Iy = 6251
        Ix = 1542
        Ixy = 352
      name = IPEM800
    material =
      fy = 400
      E = 210
      name = S400
```

2.5 Exporting to finite element programs

CHAPTER

THREE

PYFORMEX— reference manual

3.1 formex — the base module

This module contains all the basic functionality for creating, structuring and transforming sets of coordinates. All the definitions in this module are available in your scripts without the need to import the module.

class `Formex`(*data=[[[]]],prop=None*)

A class to hold a structured set of coordinates. A `Formex` is a three dimensional array of float values. The array has a shape `(nelems,nplex,3)`. Each slice `[i,j]` of the array contains the three coordinates of a point in space. Each slice `[i]` of the array contains a connected set of *nplex* points: we will refer to it as an *element*. The number of points in an element is also called the *plexitude* of the element.

It is up to the user on how to interprete the grouping of some points into an element. An element with two points will usually represent a line segment between its two points. But these could just as well be the two opposite corners of a rectangle. A element with plexitude 3 (in short: plex-3 element) could be interpreted as a triangle or as a polygonal or curved line. And if it is a triangle, it could be either the circumference of the triangle or the part of the plane inside that circumference. As far as the Formex class concerns, each element is just a set of points.

All elements in a `Formex` must have the same number of points, but you can construct `Formex` instances with any (positive) number of nodes per element. A plex-1 `Formex` is just a collection of unconnected nodes (each element is a single point).

One way of attaching other data to the `Formex`, is by the use of the 'property' attribute. The property is an array holding one integer value for each of the elements of the Formex. The use of this property value is completely defined by the user. It could be a code for the type of element, or for the color to draw this element with. Most often it will be used as an index into some other (possibly complex) data structure holding all the characteristics of that element.

By including this property index into the Formex class, we make sure that when new elements are constructed from existing ones, the element properties are automatically propagated.

3.1.1 Formex class members

`f`

A three dimensional array of float values. The array always has a shape with three components (nelems,nplex,3), even if the Formex is empty. An empty Formex has shape[0] == 0.

`p`

Either an integer array with shape (nelems,), or None. If not None, an integer value is attributed to each element of the Formex. There is no provision to attribute different values to the separate nodes

of an element. If you need such functionality, use the *p* array as a pointer into a data structure that has different values per node.

The *p* is called property number or property for short. If it is not None, it will take part in the Formex transformations and its values will propagate to all copies created from the Formex elements.

3.1.2 Basic access methods

__getitem__(*i*)
This is equivalent to `self.f.__getitem__(i)`. It allows to access the data in the coordinate array *f* of the Formex with all the index methods of numpy. The result is an float array or a single float. Thus: `F[1]` returns the second element of *F*, `F[1,0]` the first point of that element and `F[1,0,2]` the z-coordinate of that point. `F[:,1]` is an array with the second point of all elements. `F[:,:,1]` is the y-coordinate of all points of all elements in the Formex.

__setitem__(*i,val*)
This is equivalent to `self.f.__getitem__(i)`. It allows to change individual elements, points or coordinates using the item selection syntax. Thus: `F[1:5,1,2] = 1.0` sets the z-coordinate of the second points of the elements 1, 2, 3 and 4 to the value 1.0.

element(*i*)
Returns the element *i*. `F.element[i]` is currently equivalent with `F[i]`.

point(*i,j*)
Returns the point *j* of the element *i*. `F.point[i,j]` is equivalent with `F[i,j]`.

coord(*i,j,k*)
Returns the coordinate *k* of the point *j* of the element *i*. `F.coord[i,j,k]` is equivalent with `F[i,j,k]`.

3.1.3 Methods returning information

nelems()
Returns the number of elements in the Formex.

nplex()
Returns the number of points in each element.

ndim(*self*)
Returns the number of dimensions. This is the number of coordinates for each point.

In the current implementation this is always 3, though you can define 2D Formices by given only two coordinates: the third will automatically be set to zero.

npoints()
Return the number of points in the Formex.

This is the product of the *nelems()* and *nplex()*.

shape()
Return the shape of the Formex.

The shape of a Formex is the shape of its data array, i.e. a tuple (nelems, nplex, ndim).

data()
Return the Formex as a numpy array.

x()
Return the x-plane.

y()
Return the y-plane.

z()
Return the z-plane.

prop()
Return the properties as a numpy array, or None if the Formex has no properties.

maxprop()
Return the highest property used, or None if the Formex has no properties.

propSet()
Return a list with the unique property values on this Formex, or None if the Formex has no properties.

bbox()
Return the bounding box of the Formex.

The bounding box is the smallest rectangular volume in global coordinates, such that no points of the Formex are outside the box. It is returned as a [2,3] array: the first row holds the minimal coordinates and the second one the maximal.

center()
Return the center of the Formex. This is the center of its `bbox()`.

sizes()
Returns an array with shape (3,) holding the length of the bbox along the 3 axes.

size()
Return the size of the Formex. This is defined as the length of the diagonal of the bbox().

bsphere()
Return the diameter of the bounding sphere of the Formex.

The bounding sphere is the smallest sphere with center in the `center()` of the Formex, and such that no points of the Formex are lying outside the sphere. It is not necessarily the smallest sphere surrounding all points of the Formex.

feModel(*nodesperbox=1,repeat=True,rtol=1.e-5,atol=1.e-5*)
Return a tuple of nodal coordinates and element connectivity.

A tuple of two arrays is returned. The first is a float array with the coordinates of the unique nodes of the Formex. The second is an integer array with the node numbers connected by each element. The elements come in the same order as they are in the Formex, but the order of the nodes is unspecified. By the way, the reverse operation of `coords,elems = feModel(F)` is accomplished by `F = Formex(coords[elems])`. There is a (very small) probability that two very close nodes are not equivalenced by this procedure. Use it multiple times with different parameters to check.

rtol and *atol* are the relative, resp. absolute tolerances used to decide whether any nodal coordinates are considered to be equal.

3.1.4 Methods returning string representations

point2str(*point*)
Return a string representation of a point. The string holds the three coordinates, separated by a comma. *This is a class method, not an instance method.*

elem2str(*elem*)
Return a string representation of an element. The string contains the string representations of all the element's nodes, separated by a semicolon. *This is a class method, not an instance method.*

asFormex()
Return a string representation of a Formex.

Coordinates are separated by commas, points are separated by semicolons and grouped between brackets, elements are separated by commas and grouped between braces. Thus a Formex `F = Formex([[[1,0],[0,1]],[[0,1],[1,2]]])` is formatted as '{[1.0,0.0,0.0; 0.0,1.0,0.0], [0.0,1.0,0.0; 1.0,2.0,0.0]}'.

asFormexWithProp()
Return string representation as Formex with properties. The string representation as done by asFormex() is followed by the words "with prop" and a list of the properties.

asArray()
Return a string representation of the Formex as a numpy array.

setPrintFunction(*func*)
This sets how a Formex will be formatted by the print statement or by a `"%s"` formatting string. *func* can be any of the above functions *asFormex*, *asFormexWithProp* or *asArray*, or a user-defined function.

*This is a class method, not an instance method.*Use it as follows: `Formex.setPrintFunction(Formex.asArray)`.

fprint(*fmt="%10.3e %10.3e %10.3e"*)
Prints all the points of the formex with the specified format. The format should hod three formatting codes, for the three coordinates of the point.

3.1.5 Methods changing the instance data

These are the only methods that change the data of the Formex object. All other transformation methodes return and operate on copies, leaving the original object unchanged.

setProp(*p*)
Create a property array for the Formex.

A property array is a rank-1 integer array with dimension equal to the number of elements in the Formex (first dimension of data). You can specify a single value or a list/array of integer values.

If the number of passed values is less than the number of elements, they wil be repeated. If you give more, they will be ignored.

Specifying a value `None` results in a Formex without properties.

append(*F*)
Appends all the elements of a Formex F to the current one. Use the *__add__* function or the + operator to concatenate two Formices without changing either of the onjects.

Only Formices having the same plexitude as the current one can be appended. If one of the Formices has properties and the other not, the elements with missing properties will be assigned property 0.

3.1.6 Methods returning copies

copy()
Return a deep copy of itself.

__add__(*other*)
Return a Formex with all elements of self and other. This allows the user to write simple expressions as F+G to concatenate the Formices F and G. As with the append() method, both Formices should have the same plexitude.

concatenate(*Flist*)
Return the concatenation of all formices in Flist. All formices should have the same plexitude. *This is a class method, not an instance method.*

select(*idx*)
Return a Formex which holds only elements with numbers in *idx*. *idx* can be a single element number or a list of numbers.

selectNodes(*idx*)
Return a Formex which holds only some nodes of the parent. *idx* is a list of node numbers to select. Thus, if F is a grade 3 Formex representing triangles, the sides of the triangles are given by
```
F.selectNodes([0,1]) + F.selectNodes([1,2]) + F.selectNodes([2,0])
```
The returned Formex inherits the property of its parent.

nodes()
Return a Formex containing only the nodes.

This is obviously a Formex with plexitude 1. It holds the same data as the original Formex, but in another shape: the number of nodes per element is 1, and the number of elements is equal to the total number of nodes. The properties are not copied over, since they will usually not make any sense.

remove(*F*)
Return a Formex where the elements in *F* have been removed.

This is also the subtraction of the current Formex with *F*. Elements are only removed if they have the same nodes in the same order. This is a slow operation: for large structures, you should avoid it where possible.

withProp(*val*)
Return a Formex which holds only the elements with property val.

If the Formex has no properties, a copy is returned. The returned Formex is always without properties.

elbbox()
Return a Formex where each element is replaced by its bbox.

The returned Formex has two points for each element: two corners of the bbox.

unique(*self,rtol=1.e-4,atol=1.e-6*)
Return a Formex which holds only the unique elements.

Two elements are considered equal when all its nodal coordinates are close. Two values are close if they are both small compared to atol or their difference divided by the second value is small compared to rtol. Two elements are not considered equal if one's elements are a permutation of the other's.

Warning: this operation is slow when performed on large Formices.

reverseElements()
Return a Formex where all elements have been reversed.

Reversing an element means reversing the order of its points.

3.1.7 Clipping methods

These methods can be use to make a selection of elements based on their nodal coordinates. The heart is the function

test(*nodes='all',dir=0,min=None,max=None*)
Flag elements having nodal coordinates between min and max.

This function is very convenient in clipping a Formex in one of the coordinate directions. It returns a 1D integer array flagging (with a value 1) the elements having nodal coordinates in the specified

range. Use `where(result)` to get a list of element numbers passing the test. Or directly use the `clip()` or `cclip()` methods to create the clipped Formex.

xmin,xmax are there minimum and maximum values required for the coordinates in direction dir (default is the x or 0 direction). nodes specifies which nodes are taken into account in the comparisons. It should be one of the following:

- a single (integer) node number (< the number of nodes)
- a list of node numbers
- one of the special strings: 'all', 'any', 'none'

The default ('all') will flag all the elements that have all their nodes between the planes x=min and x=max, i.e. the elements that fall completely between these planes. One of the two clipping planes may be left unspecified.

If you want to have a list of the element numbers that satisfy the specified conditions, you can use numpy's where function on the result. Thus `where(F.where(min=1.0))` returns a list with all elements lying right of the plane `x=1.0`.

clip(*t*)

Returns a Formex with all the elements where t>0.

t should be a 1-D integer array with length equal to the number of elements of the formex. The resulting Formex will contain all elements where t > 0. This is a convenience function for the user, equivalent to `F.select(t>0)`.

cclip(*t*)

This is the complement of clip, returning a Formex where t<=0.

3.1.8 Affine transformations

scale(*scale*)

Returns a copy scaled with `scale[i]` in direction `i`.

The *scale* should be a list of 3 numbers, or a single number. In the latter case, the scaling is homothetic.

translate(*dir,distance=None*)

Returns a copy translated over *distance* in direction *dir*.

dir is either an axis number (0,1,2) or a direction vector.

If a distance is given, the translation is over the specified distance in the specified direction. If no distance is given, and *dir* is specified as an axis number, translation is over a distance 1. If no distance is given, and *dir* is specified as a vector, translation is over the specified vector.

Thus, the following are all equivalent: `F.translate(1)`; `F.translate(1,1)`; `F.translate([0,1,0])`; `F.translate([0,2,0],1)`

rotate(*angle,axis=2*)

Returns a copy rotated over *angle* around *axis*.

The angle is specified in degrees. Default rotation is around z-axis.

rotateAround(*vector,angle*)

Returns a copy rotated over *angle* around *vector*.

The angle is specified in degrees. The rotation axis is specified by a vector of three values. It is an axis through the center.

shear(*dir,dir1,skew*)

Returns a copy skewed in the direction *dir* of plane *(dir,dir1)*.

The coordinate *dir* is replaced with `(dir + skew * dir1)`.

reflect (*dir,pos=0*)
Returns a Formex mirrored in direction *dir* against plane at *pos*.

Default position of the plane is through the origin.

affine (*mat,vec=None*)
Returns a general affine transform of the Formex.

The returned Formex has coordinates given by `mat * xorig + vec`, where *mat* is a 3x3 matrix and *vec* a length 3 list.

3.1.9 Non-affine transformations

cylindrical (*dir=[0,1,2],scale=[1.,1.,1.]*)
Converts from cylindrical to cartesian after scaling.

dir specifies which coordinates are interpreted as resp. distance(r), angle(theta) and height(z). Default order is [r,theta,z].
scale will scale the coordinate values prior to the transformation. (scale is given in order r,theta,z). The resulting angle is interpreted in degrees.

toCylindrical (*dir=[0,1,2]*)
Converts from cartesian to cylindrical coordinates.

dir specifies which coordinates axes are parallel to respectively the cylindrical axes distance(r), angle(theta) and height(z). Default order is [x,y,z]. The angle value is given in degrees.

spherical (*dir=[0,1,2],scale=[1.,1.,1.],colat=False*)
Converts from spherical to cartesian after scaling.

dir specifies which coordinates are interpreted as longitude(theta), latitude(phi) and distance(r).
scale will scale the coordinate values prior to the transformation.
Angles are then interpreted in degrees.
Latitude, i.e. the elevation angle, is measured from equator in direction of north pole(90). South pole is -90. If colat=True, the third coordinate is the colatitude (90-lat) instead. That choice may facilitate the creation of spherical domes.

toSpherical (*dir=[0,1,2]*)
Converts from cartesian to spherical coordinates.

dir specifies which coordinates axes are parallel to respectively the spherical axes distance(r), longitude(theta) and colatitude(phi). Colatitude is 90 degrees - latitude, i.e. the elevation angle measured from north pole(0) to south pole(180). Default order is [0,1,2], thus the equator plane is the (x,y)-plane. The returned angle values are given in degrees.

bump1 (*dir,a,func,dist*)
Return a Formex with a one-dimensional bump.

dir specifies the axis of the modified coordinates.
a is the point that forces the bumping.
dist specifies the direction in which the distance is measured.
func is a function that calculates the bump intensity from distance. `func(0)` should be different from 0.

bump2 (*dir,a,func*)
Return a Formex with a two-dimensional bump.

dir specifies the axis of the modified coordinates.
a is the point that forces the bumping.
func is a function that calculates the bump intensity from distance. `func(0)` should be different from 0.

bump (*dir,a,func,dist=None*)

Return a Formex with a bump.

A bump is a modification of a set of coordinates by a non-matching point. It can produce various effects, but one of the most common uses is to force a surface to be indented by some point.

dir specifies the axis of the modified coordinates.
a is the point that forces the bumping.
func is a function that calculates the bump intensity from distance. `func(0)` should be different from 0.
dist is the direction in which the distance is measured : this can be one of the axes, or a list of one or more axes. If only 1 axis is specified, the effect is like function `bump1()`. If 2 axes are specified, the effect is like `bump2`. This function can take 3 axes however. Default value is the set of 3 axes minus the direction of modification. This function is then equivalent to `bump2()`.

map (*func*)

Return a Formex mapped by a 3-D function.

This is one of the versatile mapping functions.
func is a numerical function which takes three arguments and produces a list of three output values. The coordinates [x,y,z] will be replaced by func(x,y,z). The function must be applicable to arrays, so it should only include numerical operations and functions understood by the numpy module.

This method is one of several mapping methods. See also `map1()` and `mapd()`.
Example: `E.map(lambda x,y,z: [2*x,3*y,4*z])` is equivalent with `E.scale([2,3,4])`.

map1 (*dir,func*)

Return a Formex where coordinate *i* is mapped by a 1-D function.

func is a numerical function which takes one argument and produces one result. The coordinate *dir* will be replaced by func(coord[dir]). The function must be applicable on arrays, so it should only include numerical operations and functions understood by the numpy module. This method is one of several mapping methods. See also `map()` and `mapd()`.

mapd (*dir,func,point,dist=None*)

Maps one coordinate by a function of the distance to a point.

func is a numerical function which takes one argument and produces one result. The coordinate *dir* will be replaced by `func(d)`, where `d` is calculated as the distance to *point*. The function must be applicable on arrays, so it should only include numerical operations and functions understood by the numpy module. By default, the distance `d` is calculated in 3-D, but one can specify a limited set of axes to calculate a 2-D or 1-D distance.

This method is one of several mapping methods. See also `map()` and `map1()`.
Example: `E.mapd(2,lambda d:sqrt(10**2-d**2),f.center(),[0,1])` maps E on a sphere with radius 10.

replace (*i,j,other=None*)

Replace the coordinates along the axes *i* by those along *j*.

i and *j* are lists of axis numbers.
`replace ([0,1,2],[1,2,0])` will roll the axes by 1.
`replace ([0,1],[1,0])` will swap axes 0 and 1.
An optionally third argument may specify another Formex to take the coordinates from. It should have the same dimensions.

swapaxes (*i,j*)

Swap coordinate axes *i* and *j*.

circulize (*angle*)

Transform a linear sector into a circular one.

A sector of the (0,1) plane with given angle, starting from the 0 axis, is transformed as follows: points on the sector borders remain in place. Points inside the sector are projected from the center on the circle through the intersection points of the sector border axes and the line through the point and perpendicular to the bisector of the angle.

circulize1()
Transforms the first octant of the 0-1 plane into 1/6 of a circle.

Points on the 0-axis keep their position. Lines parallel to the 1-axis are transformed into circular arcs. The bisector of the first quadrant is transformed in a straight line at an angle Pi/6. This function is especially suited to create circular domains where all bars have nearly same length. See the Diamatic example.

shrink(*factor*)
Shrinks each element with respect to its own center.

Each element is scaled with the given factor in a local coordinate system with origin at the element center. The element center is the mean of all its nodes. The shrink operation is typically used (with a factor around 0.9) in wireframe draw mode to show all elements disconnected. A factor above 1.0 will grow the elements.

3.1.10 Topology changing transformations

replic(*n,step,dir=0*)
Return a Formex with *n* replications in direction *dir* with *step*.

The original Formex is the first of the n replicas.

replic2(*n1,n2,t1,t2,d1=0,d2=1,bias=0,taper=0*)
Replicate in two directions.

n1,n2 : number of replications with steps *t1,t2* in directions *d1,d2*.
bias, taper : extra step and extra number of generations in direction *d1* for each generation in direction *d2*.

rosette(*n,angle,axis=2,point=[0.,0.,0.]*)
Return a Formex with *n* rotational replications with angular step *angle* around an axis parallel with one of the coordinate axes going through the given point. *axis* is the number of the axis (0,1,2). *point* must be given as a list (or array) of three coordinates. The original Formex is the first of the n replicas.

translatem(**args*)
Multiple subsequent translations in axis directions.

The argument *list* is a sequence of tuples *(axis, step)*. Thus `translatem((0,x),(2,z),(1,y))` is equivalent to `translate([x,y,z])`. This function is especially conveniant to translate in calculated directions.

3.1.11 Non-member functions

The following functions operate on or return Formex objects, but are not part of the Formex class.

connect(*Flist,nodid=None,bias=None,loop=False*)
Return a Formex which connects the formices in *Flist*.

Flist is a list of formices, *nodid* is an optional list of nod ids and *bias* is an optional list of element bias values. All lists should have the same length. The returned Formex has a plexitude equal to the number of formices in *Flist*. Each element of the Formex consist of a node from the corresponding element of each of the Formices in *Flist*. By default this will be the first node of that element, but a

nodid list may be given to specify the node ids to be used for each of the formices. Finally, a list of bias values may be given to specify an offset in element number for the subsequent Formices.

If *loop* is False, the length of the Formex will be the minimum length of the formices in *Flist*, each minus its respective bias. By setting *loop* True however, each Formex will loop around when its end is encountered, and the length of the resulting Formex is the maximum length in *Flist*.

interpolate(*F,G,div*)

Create interpolations between two formices.

F and *G* are two Formices with the same shape. *v* is a list of floating point values. The result is the concatenation of the interpolations of *F* and *G* at all the values in *div*.

An interpolation of *F* and *G* at value *v* is a Formex *H* where each coordinate *Hijk* is obtained from `Hijk = Fijk + v * (Gijk-Fijk)`. Thus, a Formex `interpolate(F,G,[0.,0.5,1.0])` will contain all elements of *F* and *G* and all elements with mean coordinates between those of *F* and *G*.

As a convenience, if an integer is specified for *div*, it is taken as a number of division for the interval [0..1]. Thus, `interpolate(F,G,n)` is equivalent with `interpolate(F,G,arange(0,n+1)/float(n))`

divide(*F,div*)

Divide a plex-2 Formex at the values in div.

Replaces each member of the Formex *F* by a sequence of members obtained by dividing the Formex at the relative values specified in *div*. The values should normally range from 0.0 to 1.0.

As a convenience, if an integer is specified for *div*, it is taken as a number of divisions for the interval [0..1].

This function only works on plex-2 Formices (line segments).

readfile(*file,sep=',',plexitude=1,dimension=3*)

Read a Formex from file.

This convenience function uses the numpy fromfile function to read the coordinates of a Formex from file.

file is either an open file object or a string with the name of the file to be read. *sep* is the separator string between subsequent coordinates. There can be extra blanks around the separator, and the separator can be omitted at the end of line. If an empty string is specified, the file is read in binary mode.

The file is read as a single stream of coordinates; the arguments *plexitude* and *dimension* determine how these are structured into a Formex. *plexitude* is the number of points that make up an element. The default is to return a plex-1 Formex (unconnected points). *dimension* is the number of coordinates that make up a point (2 or 3). As always, the resulting Formex will be 3D. The total number of coordinates on the file should be a multiple of `plexitude * dimension`.

bbox(*formexlist*)

Computes the overall bounding box of a list of Formices.

The result has the same format as Formex class `bbox()` method, but the resulting box encloses all the Formices in the list.

3.1.12 Other functions

The following functions are defined in the file formex.py, but do not depend on the Formex class. They are defined here because they are mainly supporting functions for the Formex class itself.

sind(*arg*)

Return the sin of an angle in degrees.

cosd(*arg*)
Return the cos of an angle in degrees.

tand(*arg*)
Return the tan of an angle in degrees.

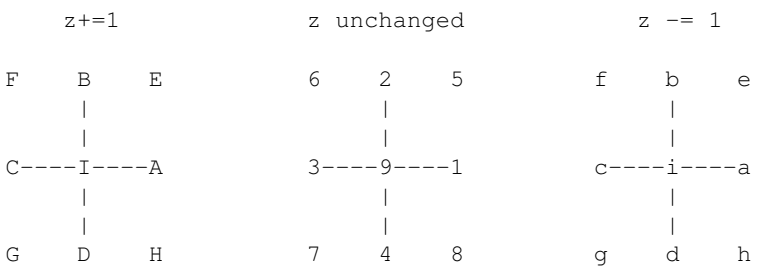
length(*arg*)
Return the quadratic norm of a vector with all elements of arg.

inside(*p,mi,ma*)
Return true if point p is inside bbox defined by points mi and ma

unique(*a*)
Return the unique elements in an integer array.

pattern(*s*)
Return a line segment pattern created from a string.

This function creates a list of line segments where all nodes lie on the gridpoints of a regular grid with unit step. The first point of the list is [0,0,0]. Each character from the given string is interpreted as a code specifying how to move to the next node.
Currently defined are the following codes:
0 = goto origin [0,0,0]
1..8 move in the x,y plane
9 remains at the same place
When looking at the plane with the x-axis to the right,
1 = East, 2 = North, 3 = West, 4 = South, 5 = NE, 6 = NW, 7 = SW, 8 = SE.
Adding 16 to the ordinal of the character causes an extra move of +1 in the z-direction. Adding 48 causes an extra move of -1. This means that 'ABCDEFGHI', resp. 'abcdefghi', correspond with '123456789' with an extra z +/-= 1. This gives the following schema:



The special character '\' can be put before any character to make the move without making a connection. The effect of any other character is undefined. The resulting list is directly suited to initialize a Formex.

translationVector(*dir,dist*)
Return a translation vector in direction dir over distance dist

rotationMatrix(*angle,axis=None*)
Return a rotation matrix over angle, optionally around axis.

The angle is specified in degrees. If axis==None (default), a 2x2 rotation matrix is returned. Else, axis should be one of [0,1,2] and specifies the rotation axis in a 3D world. A 3x3 rotation matrix is returned.

rotationAboutMatrix(*angle,axis*)
Return a rotation matrix over angle around an axis thru the origin.

The angle is specified in degrees. Axis is a list of three components specifying the axis. The result is a 3x3 rotation matrix in list format. Note that: rotationAboutMatrix(angle,[1,0,0]) == rotationMatrix(angle,0) rotationAboutMatrix(angle,[0,1,0]) == rotationMatrix(angle,1) rotationAboutMatrix(angle,[0,0,1]) == rotationMatrix(angle,2) but the latter functions are more efficient.

equivalence (*x,nodesperbox=1,shift=0.5,rtol=1.e-5,atol=1.e-5*)

Finds (almost) identical nodes and returns a compressed list.

The input x is an (nnod,3) array of nodal coordinates. This functions finds the nodes that are very close and replaces them with a single node. The return value is a tuple of two arrays: the remaining (nunique,3) nodal coordinates, and an integer (nnod) array holding an index in the unique coordinates array for each of the original nodes.

The procedure works by first dividing the 3D space in a number of equally sized boxes, with a mean population of nodesperbox. The boxes are numbered in the 3 directions and a unique integer scalar is computed, that is then used to sort the nodes. Then only nodes inside the same box are compared on almost equal coordinates, using the numpy allclose() function. Two coordinates are considered close if they are within a relative tolerance rtol or absolute tolerance atol. See numpy for detail. The default atol is set larger than in numpy, because pyformex typically runs with single precision. Close nodes are replaced by a single one.

Currently the procedure does not guarantee to find all close nodes: two close nodes might be in adjacent boxes. The performance hit for testing adjacent boxes is rather high, and the probability of separating two close nodes with the computed box limits is very small. Nevertheless we intend to access this problem by repeating the procedure with the boxes shifted in space.

distanceFromPlane (*f,p,n*)

Return the distance of points f from the plane (p,n).

f is an [...,3] array of coordinates. p is a point specified by 3 coordinates. n is the normal vector to a plane, specified by 3 components.

The return value is a [...] shaped array with the distance of each point to the plane through p and having normal n. Distance values are positive if the point is on the side of the plane indicated by the positive normal.

distanceFromLine (*f,p,q*)

Return the distance of points f from the line (p,q).

f is an [...,3] array of coordinates. p and q are two points specified by 3 coordinates.

The return value is a [...] shaped array with the distance of each point to the line through p and q. All distance values are positive or zero.

distanceFromPoint (*f,p*)

Return the distance of points f from the point p.

f is an [...,3] array of coordinates. p is a point specified by 3 coordinates.

The return value is a [...] shaped array with the distance of each point to the line through p and q. All distance values are positive or zero.

3.2 simple — simple geometries

This module contains some functions, data and classes for generating Formices with simple geometries.

circle (*a1=1.,a2=2.,a3=360.*)

Creates a Formex which is a polygonal approximation to a circle or arc.

All points generated by this function lie on a circle with unit radius at the origin in the x-y-plane.

a1 (the dash angle) is the angle enclosed by the begin and end point of each line segment.
a2 (the module angle) is the angle enclosed between the start points of two subsequent line segments.
a3 (the arc angle) is the total angle enclosed between the first point of the first segment and the en point of the last segment.

All angles are given in degrees and are measured in the direction from x to y-axis. The first point of the first segment is always on the x-axis.

Remark that a1 == a2 produces a continues line, a1 < a2 gives a dashed line. The default a3=360. produces a full circle; for a3 < 360, the result is an arc. Large angle values result in polygones: circle(120,120) is an equilateral triangle and circle(60,60) is regular hexagone. The default values produces a dashed (near-)circle.

APPENDIX

A

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Version 2, June 1991

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